K S INSTITUTE OF TECHNOLOGY

Kanakapura Main Road, Raghuvanahalli, Bengaluru-560109
Department of Mechanical Engineering

NAME: MANJUNATHA.B.R

SUBJECT CODE/NAME:15ME82/ADDITIVE MANUFACTURING

SEMESTER/YEAR:VIII SEM/2019-20

ACADEMIC YEAR: 2019-20

BRANCH:MECHANICAL ENGINEERING

Signature of HOD

Head of the Department
Dept. of Mechanical Engg.
K.S. Institute of Technology
Bengaluru - 560 109

Course In-charge

Principal

K S INSTITUTE OF TECHNOLOGY

Kanakapura Main Road, Raghuvanahalli, Bengaluru-560109

Department of Mechanical Engineering

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K. S. INSTITUTE OF TECHNOLOGY

VISION

“To impart quality technical education with ethical values, employable skills and research to achieve excellence”

MISSION

- To attract and retain highly qualified, experienced & committed faculty.
- To create relevant infrastructure
- Network with industry & premier institutions to encourage emergence of new ideas by providing research & development facilities to strive for academic excellence
- To inculcate the professional & ethical values among young students with employable skills & knowledge acquired to transform the society

DEPARTMENT OF MECHANICAL ENGINEERING

VISION

“To groom incumbents to compete with their professional peers in mechanical engineering that brings recognition”

MISSION

- To impart sound fundamentals in mechanical engineering
- To expose students to new frontiers
- To achieve engineering excellence through experiential learning and team work.

PROGRAM EDUCATIONAL OBJECTIVES (PEO'S)

- To produce graduates who would have developed a strong background in basic science and mathematics and ability to use these tools in Mechanical Engineering.
- To prepare graduates who have the ability to demonstrate technical competence in their fields of Mechanical Engineering and develop solutions to the problems.
- To equip graduates to function effectively in a multi-disciplinary environment individually, within a global, societal, and environmental context.

PROGRAM SPECIFIC OUTCOMES (PSO's)

- It is expected that a student in mechanical engineering will possess an:
- **PSO1:**Ability to apply concept of mechanical engineering to design a system, a component or a process/system to address a real-worldchallenges
- **PSO2:** Ability to develop effective communication, team work, entrepreneurial and computational skills

PROGRAM OUTCOMES (PO's)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineeringfundamentals, and an engineering specialization to the solution of complex engineering problems.

2. **Problem analysis**: Identify, formulate, review research literature, and analyze complexengineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

3. **Design/development of solutions**: Design solutions for complex engineering problems anddesign system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

4. **Conduct investigations of complex problems**: Use research-based knowledge and researchmethods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modernengineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assesssocietal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

7. **Environment and sustainability**: Understand the impact of the professional engineering solutionsin societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms ofthe engineering practice.

9. **Individual and team work**: Function effectively as an individual, and as a member or leader indiverse teams, and in multidisciplinary settings.

10. **Communication**: Communicate effectively on complex engineering activities with the engineeringcommunity and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. **Project management and finance**: Demonstrate knowledge and understanding of theengineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage inindependent and life-long learning in the broadest context of technological change.

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#14, Raghuvanahalli, Kanakapura Main Road, Bengaluru-5600109

DEPARTMENT OF MECHANICAL ENGINEERING

Course: Additive Manufacturing			
Type: **Core**		**Course Code:**15ME82	
No of Hours per week			
Theory (Lecture Class)	Practical/Field Work/Allied Activities	Total/Week	Total teaching hours
3Hrs/week	0	4	50
Marks			
Internal Assessment	Examination	Total	Credits
40	60	100	3

Aim/Objective of the Course: Students will be able to

1. Understand the additive manufacturing process, polymerization and powder metallurgy process
2. Understand characterisation techniques in additive manufacturing.
3. Acquire knowledge on CNC and Automation.

Course Outcomes:

After studying this course, the students will be able to,

15ME82.1	Understanding the Additive Manufacturing process, Systems drives and actuators used in it	K2 (Understanding)
15ME82.2	Discussing the Polymerization and Powder Metallurgy process and the importance of Nanotechnology	K2 (Understanding)
15ME82.3	Summarizing the characterisation techniques used in Powder Metallurgy process	K2 (Understanding)
15ME82.4	Explaining the characterisation techniques used on Nanomaterials	K2 (Understanding)
15ME82.5	Acquiring Knowledge on CNC and Automation	K2 (Understanding)

SYLLABUS CONTENT	
Module 1 Introduction to Additive Manufacturing: Introduction to AM, AM evolution, Distinction between AM & CNC machining, Advantages of AM, AM process chain: Conceptualization, CAD, conversion to STL, Transfer to AM, STL file manipulation, Machine setup, build, removal and clean up, post processing. Classification of AM processes: Liquid polymer system, Discrete particle system, Molten material systems and Solid sheet system. Post processing of AM parts: Support material removal, surface texture improvement, Accuracy improvement, aesthetic improvement, preparation for use as a pattern, property Enhancements using non-thermal and thermal techniques. Guidelines for process selection: Introduction, selection methods for a part, challenges of selection AM Applications: Functional models, Pattern for investment and vacuum casting, Medical models, art models, Engineering analysis models, Rapid tooling, new materials Development, Bi-metallic parts, Re-manufacturing. Application examples for Aerospace, Defence, automobile, Bio-medical and general engineering industries System Drives and devices: Hydraulic and pneumatic motors and their features, Electrical motors AC/DC and their features Actuators: Electrical Actuators; Solenoids, Relays, Diodes, Thrusters, Triacs, Hydraulic and Pneumatic actuators, Design of Hydraulic and Pneumatic circuits, Piezoelectric actuators, Shape memory alloys LO: At the end of this session the student will be able to, 1. Defining the Additive Manufacturing ,distinction between AM and CNC Machining process and Sequence to be followed in AM 2. Classifying the AM Processes and forming the Guide lines to select the process and application of AM in different Models 3. To use right system drives, devices and actuators in additive manufacturing process	CO1 10HRS POI-3 PO2-2 PO3-1 PO4-1 PSO1-2 PSO2-3

MODULE:2 POLYMERS & POWDER METALLURGY Basic Concepts: Introduction to Polymers used for additive manufacturing: polyamide, PF resin, polyesters etc. Classification of polymers, Concept of functionality, Polydispersity and Molecular weight [MW], Molecular Weight Distribution [MWD] Polymer Processing: Methods of spinning for additive manufacturing: Wet spinning, Dry spinning. Biopolymers, Compatibility issues with polymers. Moulding and casting of Polymers, Polymer processing techniques General Concepts: Introduction and History of Powder Metallurgy (PM), Present and Future Trends of PM Powder Production Techniques: Different Mechanical and Chemical methods, Atomisation of Powder, other emerging processes and Application of Powder Metallurgy: Filters, Tungsten Filaments, Self-Lubricating Bearings, Porous Materials, Biomaterials Importance of Nano-technology, Emergence of Nanotechnology, Bottom up and Top-down approaches, challenges in Nanotechnology LO: At the end of this session the student will be able to, 1. Know the importance of polymers in additive manufacturing process and the basis For classifying the polymers. 2. Understand the different methods used for processing the Polymers 3. Apply the Powder metallurgy concepts and the importance of Nano materials	CO2 8HRS POI-3 PO2-3 PO3-1 PO4-2 PSO1-2 PSO2-3

MODILE-3 Characterization Techniques: Particle Size & Shape Distribution, Electron Microscopy of Powder, Interparticle Friction, Compression ability, Powder Structure, Chemical Characterization Microstructure Control in Powder: Importance of Microstructure Study, Microstructures of Powder by Different techniques. Powder Shaping: Particle Packing Modifications, Lubricants & Binders, Powder Compaction & Process Variables, Pressure & Density Distribution during Compaction, Isotactic Pressing, Injection Moulding, Powder Extrusion, Slip Casting, Tape Casting. Sintering: Theory of Sintering, Sintering of Single & Mixed Phase Powder, Liquid Phase Sintering Modern Sintering Techniques, Physical & Mechanical Properties Evaluation, Structure-Property Correlation Study, Modern Sintering techniques, Defects Analysis of Sintered Components Application of Powder Metallurgy: Filters, Tungsten Filaments, Self-Lubricating Bearings, Porous Materials, Biomaterials etc LO: At the end of this session the student will be able to, 1.know the different Characterization Techniques 2.Apply the different powder shaping techniques 3.Importace of sintering techniques and application of Powder Metallurgy	CO3 10HRS POI-3 PO2-2 PO3-1 PSO1-2 PSO2-3
Module 4 NANO MATERIALS & CHARACTERIZATION TECHNIQUES: Introduction: Importance of Nano-technology, Emergence of Nanotechnology, Bottomup and Top-down approaches, challenges in Nanotechnology Nano-materials Synthesis and Processing: Methods for creating Nanostructures; Processes for producing ultrafine powders- Mechanical grinding; Wet Chemical Synthesis of Nano-materials- sol-gel process; Gas Phase synthesis of Nano-materials- Furnace, Flame assisted ultrasonic spray pyrolysis; Gas Condensation Processing (GPC), Chemical Vapour Condensation(CVC) Optical Microscopy - principles, Imaging Modes, Applications, Limitations. Scanning Electron Microscopy (SEM) - principles, Imaging Modes, Applications, Limitations. Transmission Electron Microscopy (TEM) - principles, Imaging Modes, Applications, Limitations.X- Ray Diffraction (XRD) - principles, Imaging Modes, Applications, Limitations.Scanning Probe Microscopy (SPM) - principles, Imaging Modes, Applications, Limitations.Atomic Force Microscopy (AFM) - basic principles, instrumentation, operational modes, Applications, Limitations. Electron Probe Micro Analyzer (EPMA) - Introduction, Sample preparation, Working procedure, Applications, Limitations. LO: At the end of this session the student will be able to, 1.Know the importance of Nano materials and methods for creating Nano structures	CO4 10HRS POI-3 PO2-3 PO3-1 PSO1-2 PSO2-3

2.Understand the different methods used for processing it 3.Able to use different microscopes for different applications **Module-5** Manufacturing control and Automation Classification of NC /CNC machine tools, Advantage, disadvantages of NC /CNC machine tools, Application of NC/CNC Part programming: CNC programming and introduction, Manual part programming: Basic (Drilling, milling, turning etc.), Special part programming, Advanced part programming, Computer aided part programming (APT) Introduction: Automation in production system principles and strategies of automation, basic Elements of an automated system. Advanced Automation functions. Levels of Automations, introduction to automation productivity Control Technologies in Automation: Industrial control system. Process industry vs discrete manufacturing industries. Continuous vs discrete control. Continuous process and its forms. Other control system components LO At the end of this session the student will be able to, 1) Classify the NC and CNC machine tools, their merits, demerits and applications 2) Discuss the effectiveness of different part programming techniques. 3) Compare the automation in production system with Non automation system 4) Relating the control technologies used in automation system for different types of industries	12HRS POI-3 PO2-3 PO3-1 PO3-1.5 PSO1-2 PSO2-3

TEXT BOOKS

1. Chua Chee Kai, Leong Kah Fai, “Rapid Prototyping: Principles & Applications”, World Scientific, 2003.
2. G Odian Principles of Polymerization, Wiley Inerscience John Wiley and Sons, 4th edition, 2005
3. Mark James Jackson, Microfabrication and Nanomanufacturing, CRC Press, 2005.
4. Powder Metallurgy Technology, Cambridge International Science Publishing, 2002.
5. P. C. Angelo and R. Subramanian: Powder Metallurgy- Science, Technology and Applications, PHI, New Delhi, 2008.
6. Mikell P Groover, Automation, Production Systems and Computer Integrated Manufacturing, 3rd Edition, Prentice Hall Inc., New Delhi, 2007.

REFERENCE BOOKS:

1. Wohler's Report 2000 - Terry Wohlers - Wohler's Association -2000
2. Computer Aided Manufacturing - P.N. Rao, N.K. Tewari and T.K. Kundra Tata McGraw Hill 1999
3. Ray F. Egerton , Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM , Springer, 2005.
4. P. C. Angelo and R. Subramanian: Powder Metallurgy- Science, Technology and Applications, PHI, New Delhi, 2008.

Website:

1) https://alanefcrandall.blogspot.com/2018/10/download-additive-manufacturing.html
2) https://www.slideshare.net › StephinAbrahamSabu › additive-manufacturin..
3) https://www.nist.gov › document › murrish-boeing-intro-ampdf
4) https://www.youtube.com › watch

CO - PO MAPPING

PO1: Science and engineering Knowledge **PO2:** Problem Analysis **PO3:** Design & Development **PO4:**Investigations of Complex Problems **PO5:** Modern Tool Usage **PO6:** Engineer & Society	**PO7:**Environment and Sustainability **PO8:**Ethics **PO9:**Individual & Team Work **PO10:** Communication **PO11:**Project Management & Finance **PO12:**Life long Learning

CO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
15ME82.1	3	2	1	1	-	-	-	-	-	-	-	-	3	2
15ME82.2	3	2	1	2	-	-	-	-	--	--	-	-	3	2
15ME82.3	3	2	1	-	-	-	-	-	-	-	-	-	3	2
15ME82.4	3	2	1	-	-	-	-	-	-	-	-	-	3	2
15ME82.5	3	2	1	1.5	-	-	-	-	-	-	-	-	3	2
AVERAGE	3	2	1	1.5	-	-	-	-	-	-	-	-	3	2

CO -PO mapping for the events conducted after gap identification

Sl. No.	Gap Identification	CO	Relevant PO Mapping
1 2	Assignments and group discussion Case studies	PO6,PO9and P12 PO5,PO7,PO8,PO10 and PO11	PO6,PO9 and PO12 Mapped to 0 as students will learn about responsibility of engineers in society, as a team member and Individually executing the work throughout his life time Case studies

Mungu.BR
Course In-charge

Signature of HOD

Head of the Department
Dept. of Mechanical Engg.
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Bengaluru - 560 109

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TENTATIVE CALENDAR OF EVENTS: EVEN SEMESTER (2019-2020)

SESSION: FEB 2020 – JUNE 2020

Week No.	Month	Day						Days	Activities
		Mon	Tue	Wed	Thu	Fri	Sat		
1	Feb	10 *	11	12	13	14	15	6	10-commencement of higher semester 15-Monday Time Table
2	Feb	17	18	19	20	21 H	22	5	21 - Maha Shivarathri 22- Friday time table 22 - ISTE State Level convention 23- Graduation Day
3	Feb	24	25	26	27	28	29 DH	5	
4	Mar	2	3	4	5	6 TA	7*	6	* Sports Day
5	Mar	9 T1	10 T1	11 T1	12	13	14	6	14 -Wednesday time table
6	Mar	16	17	18 BV	19 ASD	20	21 DH	5	
7	Mar	23	24	25 H	26	27	28*	5	25-Ugadhi 28- * Ananya
8	Mar/Apr	30	31	1	2	3	4 DH	5	
9	Apr	6 H	7	8	9	10 H	11	4	6- Mahaveera Jayanthi 10- Good Friday 11 - Wednesday time table
10	Apr	13 TA	14 H	15 T2	16 T2	17 T2	18 DH	4	14- Ambedkar Jayanthi
11	Apr	20	21	22	23	24 BV	25 ASD	6	25-Tuesday time table
12	Apr/May	27	28	29	30	1 H	2 DH	4	1-May Day
13	May	4	5	6	7	8	9	6	9-Friday time table
14	May	11	12	13	14 *	15 * TA	16 DH	5	14- National Conference 15-Project Exhibition
15	May	18 T3	19 T3	20 T3	21 LT	22 LT	23 LT	6	
16	May	25	26	27	28	29	30 DH	4	25 - Ramzan
17	Jun	1 *						1	* Last Working Day
Total No of Working Days : 83									

Total Number of working days (Excluding holidays and Tests)=71

H	Holiday
BV	Blue Book Verification
T1,T2, T3	Tests 1,2, 3
ASD	Attendance & Sessional Display
DH	Declared Holiday
LT	Lab Test
TA	Test attendance

Monday	14
Tuesday	14
Wednesday	14
Thursday	14
Friday	13
Total	**69**

20.1.2020

K.S.INSTITUTE OF TECHNOLOGY
LIST OF STUDENTS FOR THE ACADEMIC YEAR 2019-20(EVEN SEM)
MECHANICAL ENGINEERING

VIII SEM ASEC

ADDITIVE MANUFACTURING (15 ME82)

Name	USN	Student Mobile	Email	Father Mobile	Mother Mobile
MANISH N	1KS14ME046	8123752991	manishgowdan@gmail.com	9008055558	
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K. S. INSTITUTE OF TECHNOLOGY, BENGALURU - 560109
DEPARTMENT OF MECHANICAL ENGINEERING
EVEN SEMESTER - JAN to JUNE 2020

Class Teacher : Mr. Manjunath B R

SECTION: VIII A

NEW BUILDING LH - 203

W.E.F: 10/02/2020

PERIOD	1	2	10:20 - 10.35	3	4	12:25 - 1:15	5	6	7
TIME/DAY	8:30 - 9:25	9:25 - 10:20		10:35 - 11:30	11:30 - 12:25		1:15 - 2:10	2:10 - 3:05	3:05- 4:00
MON	AM (15ME82)	PLCM (15ME835)	TEA BREAK	AM (15ME82)	OR (15ME81)	LUNCH TIME	Internship (15ME84)A2/Project (15ME85)A1/ Seminar(15MES86) A3		
TUE	OR (15ME81)	OR (15ME81)		AM (15ME82)	PLCM (15ME835)		Internship (15ME84)A3/Project (15ME85)A2/ Seminar(15MES86)A1		
WED	PLCM (15ME835)	OR (15ME81)		PLCM (15ME835)	AM (15ME82)		Internship (15ME84)A1/Project (15ME85)A3/ Seminar(15MES86)A2		
THU	-	-		-	-		-	-	-
FRI	-	-		-	-		-	-	-
SAT	-	-		-	-		-	-	-

Subject Code	Subject Name	Faculty Name
15ME81	Operations Research	Mr.Harish.U
15ME82	Additive Manufacturing	Mr. Manjunath B R
15ME835	Product life cycle management	Mr.Naresha K
15ME84	Internship / Professional Practice	Mr. Murulidhar K S, Mr. Ranganath N, Mr. Bharath Kumar K R, Mr. Madhu G, Mr. Gautham S, Mr. Ganesh Arjun Bhargav, Mr. Amruth K, Mr. Saleem Khan
15ME85	Project Phase – II	Dr. Nirmala L / Mr. Naresha K, Prof. Umashankar M, Dr. Ajas Kumar S, Mr. Prasad K, Dr. Girish T R, Mr. Harish U
15MES86	Seminar	Mr. Anilkumar A, Dr. Ajay Kumar S, Mr. Prasad K, Mr. Manjunath B R, Mr. Parashuram A K, Mrs. N. Sreesudha, Mr. Madhu G, Mrs. Tejashwini M L, Mr. Rajesh L

CO- ORDINATOR
04/02/2020

4/2/2020
HEAD OF THE DEPARTMENT
Dept. of Mechanical Engg.
K.S. Institute of Technology
Bengaluru - 560 109.

PRINCIPAL
K.S. INSTITUTE OF TECHNOLOGY
BENGALURU - 560 109.

ADDITIVE MANUFACTURING

Course	Code	Credits	L-T-P	Assessment		Exam Duration
				SEE	CIA	
Additive Manufacturing	15ME82	4	4-0-0	80	20	3 Hrs

Course Objectives:

Students will be able to

1. Understand the additive manufacturing process, polymerization and powder metallurgy process
2. Understand characterisation techniques in additive manufacturing.
3. Acquire knowledge on CNC and Automation.

Module 1		
	Introduction to Additive Manufacturing: Introduction to AM, AM evolution, Distinction between AM & CNC machining, Advantages of AM, **AM process chain:** Conceptualization, CAD, conversion to STL, Transfer to AM, STL file manipulation, Machine setup, build , removal and clean up, post processing. **Classification of AM processes:** Liquid polymer system, Discrete particle system, Molten material systems and Solid sheet system. **Post processing of AM parts:** Support material removal, surface texture improvement, accuracy improvement, aesthetic improvement, preparation for use as a pattern, property enhancements using non-thermal and thermal techniques. **Guidelines for process selection**: Introduction, selection methods for a part, challenges of selection **AM Applications:** Functional models, Pattern for investment and vacuum casting, Medical models, art models, Engineering analysis models, Rapid tooling, new materials development, Bi-metallic parts, Re-manufacturing. Application examples for Aerospace, defence, automobile, Bio-medical and general engineering industries	**10 Hours**
Module 2		
	System Drives and devices: Hydraulic and pneumatic motors and their features, Electrical motors AC/DC and their features **Actuators:** Electrical Actuators; Solenoids, Relays, Diodes, Thyristors, Triacs, Hydraulic and Pneumatic actuators, Design of Hydraulic and Pneumatic circuits, Piezoelectric actuators, Shape memory alloys.	**8 Hours**
Module 3		
	POLYMERS & POWDER METALLURGY **Basic Concepts:** Introduction to Polymers used for additive manufacturing: polyamide, PF resin, polyesters etc. Classification of polymers, Concept of functionality,	**12 Hours**

	Polydispersity and Molecular weight [MW], Molecular Weight Distribution [MWD] **Polymer Processing:** Methods of spinning for additive manufacturing: Wet spinning, Dry spinning. Biopolymers, Compatibility issues with polymers. Moulding and casting of polymers, Polymer processing techniques **General Concepts:** Introduction and History of Powder Metallurgy (PM), Present and Future Trends of PM **Powder Production Techniques:** Different Mechanical and Chemical methods, Atomisation of Powder, other emerging processes.**Characterization Techniques**: Particle Size & Shape Distribution, Electron Microscopy of Powder, Interparticle Friction, Compression ability, Powder Structure, Chemical Characterization **Microstructure Control in Powder:** Importance of Microstructure Study, Microstructures of Powder by Different techniques **Powder Shaping:** Particle Packing Modifications, Lubricants & Binders, Powder Compaction & Process Variables, Pressure & Density Distribution during Compaction, Isotactic Pressing, Injection Moulding, Powder Extrusion, Slip Casting, Tape Casting. **Sintering:** Theory of Sintering, Sintering of Single & Mixed Phase Powder, Liquid Phase Sintering Modern Sintering Techniques, Physical & Mechanical Properties Evaluation, Structure-Property Correlation Study, Modern Sintering techniques, Defects Analysis of Sintered Components **Application of Powder Metallurgy:** Filters, Tungsten Filaments, Self-Lubricating Bearings, Porous Materials, Biomaterials etc.	
	Module 4	
	NANO MATERIALS & CHARACTERIZATION TECHNIQUES: **Introduction:** Importance of Nano-technology, Emergence of Nanotechnology, Bottom-up and Top-down approaches, challenges in Nanotechnology **Nano-materials Synthesis and Processing:** Methods for creating Nanostructures; Processes for producing ultrafine powders- Mechanical grinding; Wet Chemical Synthesis of Nano-materials- sol-gel process; Gas Phase synthesis of Nano-materials- Furnace, Flame assisted ultrasonic spray pyrolysis; Gas Condensation Processing (GPC), Chemical Vapour Condensation(CVC). **Optical Microscopy** - principles, Imaging Modes, Applications, Limitations. **Scanning Electron Microscopy (SEM)** - principles, Imaging Modes, Applications, Limitations. **Transmission Electron Microscopy (TEM)** - principles, Imaging Modes, Applications, Limitations.**X- Ray Diffraction (XRD)** - principles, Imaging Modes, Applications, Limitations.**Scanning Probe Microscopy (SPM)** - principles, Imaging Modes, Applications, Limitations.**Atomic Force Microscopy (AFM)** - basic principles, instrumentation, operational modes, Applications, Limitations. **Electron Probe Micro Analyzer (EPMA)** - Introduction, Sample preparation, Working procedure, Applications, Limitations.	**10 Hours**
	Module 5	
	MANUFACTURING CONTROL AND AUTOMATION **CNC technology - An overview:** Introduction to NC/CNC/DNC machine tools,	**10 Hours**

	Module 5	
	MANUFACTURING CONTROL AND AUTOMATION **CNC technology - An overview:** Introduction to NC/CNC/DNC machine tools, Classification of NC /CNC machine tools, Advantage, disadvantages of NC /CNC machine tools, Application of NC/CNC **Part programming:** CNC programming and introduction, Manual part programming: Basic (Drilling, milling, turning etc.), Special part programming, Advanced part programming, Computer aided part programming (APT) **Introduction:** Automation in production system principles and strategies of automation, basic Elements of an automated system. Advanced Automation functions. Levels of Automations, introduction to automation productivity **Control Technologies in Automation:** Industrial control system. Process industry vs discrete manufacturing industries. Continuous vs discrete control. Continuous process and its forms. Other control system components.	**10 Hours**

Course Outcomes

1. Understand the different process of Additive Manufacturing. using Polymer, Powder and Nano materials manufacturing.
2. Analyse the different characterization techniques.
3. Describe the various NC, CNC machine programing and Automation techniques.

TEXT BOOKS:

1. Chua Chee Kai, Leong Kah Fai, "Rapid Prototyping: Principles & Applications", World Scientific, 2003.
2. G Odian Principles of Polymerization, Wiley Inerscience John Wiley and Sons, 4th edition, 2005
3. Mark James Jackson, Microfabrication and Nanomanufacturing, CRC Press, 2005.

KS INSTITUTE OF TECHNOLOGY BANGALORE

DEPARTMENT OF MECHANICAL ENGINEERING

NAME OF THE STAFF : MANJUNATHA.B.R

SUBJECT CODE/NAME : 15ME82/Additive Manufacturing

SEMESTER/YEAR : VIII SEM

ACADEMIC YEAR : 2019-2020

Sl. No.	Topic to be covered	Mode of Delivery	Teaching Aid	No. of Periods	Cumulative No. of Periods	Proposed Date
Module-1.						
1	Introduction to AM, AM evolution, Distinction between AM & CNC machining, Advantages of AM	L+ D	BB	1	1	10/2/2020
2	**AM process chain:** Conceptualization, CAD, conversion to STL, Transfer to AM, STL file.	L+ D	BB	1	2	10/2/2020
3	Manipulation, Machine setup, build, removal and clean up, post processing	L+ D	BB	1	3	11/2/2020
4	**Classification of AM processes:** Liquid polymer system, Discrete particle system, Molten material systems and Solid sheet system.	L+D	BB	1	4	12/2/2020
5	**Post processing of AM parts:** Support material removal, surface texture improvement, Accuracy improvement, aesthetic improvement	L+ D	BB	1	5	17/2/2020
6	Preparation for use as a pattern, property, Enhancements using non-thermal and thermal techniques	L+ D	BB	1	6	17/2/2020

7	**Guidelines for process selection**: Introduction, selection methods for a part, challenges of process selection	L+D	BB	1	7	18/2/2020
8	**AM Applications:** Functional models, Pattern for investment and vacuum casting, Medical models, art models, Engineering analysis models	L+D	BB	1	8	19/2/2020
9	Rapid tooling, new materials, Development, Bi-metallic parts, Re-manufacturing.	L+ D	BB	1	9	24/2/2020
10	Application examples for Aerospace, Defense, automobile, Bio-medical and general engineering industries	L+D	BB	1	10	24/2/2020
Module-2						
11	Hydraulic System drives and their features	L+ D	BB	1	11	25/2/2020
12	Electrical motors AC/DC and their features	L+D	BB	1	12	2/3/2020
13	**Actuators:** Electrical Actuators; Solenoids, Relays, Diodes, Thrusters, Triacs	L+D	BB	1	13	2/3/2020
14	Hydraulic actuators and their features	L+ D	BB	1	14	3/3/2020
15	Pneumatic actuators and their features	L+D	LCD	1	15	16/3/2020
16	Design of Hydraulic and Pneumatic circuits	L+D	BB	1	16	16/3/2020
17	Piezoelectric actuators and their features	L+ D	BB	1	17	16/3/2020
18	Shape memory alloys and their Characteristics’	L+D	BB	1	18	17/3/2020
Module-3						
19	**General concepts:** Introduction and History of Powder metallurgy	L+D	BB+LCD	1	19	18/3/2020
20	**Powder Production Techniques** Different Mechanical and Chemical methods, Atomization of Powder, other emerging processes	L+D	BB+LCD	1	20	23/3/2020
21	Filters, Tungsten Filaments, Self-Lubricating Bearings, Porous Materials,	L+ D	BB	1	21	23/3/2020

22	Importance of Nano-technology, Emergence of Nanotechnology, Bottom up and Top-down approaches, challenges in Nanotechnology	L+ D	BB	1	22	24/3/2020
23	**POLYMERS: Basic Concepts:** Introduction to Polymers used for additive manufacturing: polyamide, PF resin, polyesters etc. Classification of polymers, Concept of functionality, Polydispersity and Molecular weight [MW], Molecular Weight Distribution [MWD]	L+D	LCD	1	23	24/3/2020
24	**Polymer Processing:** Methods of spinning for additive manufacturing: Wet spinning, Dry spinning. Biopolymers, Compatibility issues with polymers. Moulding and casting of Polymers, Polymer processing techniques	L+D	LCD	1	24	30//3/2020
25	Video on different Polymer Processing Techniques	L+D	LCD	1	25	31//3/2020
26	**Microstructure Control in Powder:** Importance of Microstructure Study, Microstructures of Powder by Different techniques	L+D	BB	1	26	1/04/2020
27	**Powder Shaping:** Particle Packing Modifications, Lubricants & Binders, Powder Compaction & Process Variables	L+D	BB	1	27	7/04/2020
28	Pressure & Density Distribution during Compaction, Isotactic Pressing, Injection Molding, Powder Extrusion, Slip Casting, Tape Casting	L+D	BB	1	28	8/04/2020
29	**Sintering:** Theory of Sintering, Sintering of Single & Mixed Phase Powder, Liquid Phase Sintering	L+D	BB	1	29	13/04/2020
30	Modern Sintering Techniques, Physical & Mechanical Properties Evaluation, Structure-Property Correlation Study	L+D	BB	1	30	13/04/2020
31	Modern Sintering techniques, Defects Analysis of Sintered Components	L+D	BB	1	31	20/04/2020
32	**Application of Powder Metallurgy:** Filters, Tungsten Filaments, Self-Lubricating Bearings, Porous Materials, Biomaterials etc.	L+D	LCD	1	32	20/04/2020

Module-4						
33	**NANO MATERIALS & CHARACTERIZATION TECHNIQUES:** **Introduction:** Importance of Nano-technology, Emergence of Nanotechnology, Bottom up and Top-down approaches, challenges in Nanotechnology	L+D	BB	1	33	21/04/2020
34	Synthesis of Nano-materials sol-gel process; Gas Phase synthesis of Nano-materials- Flame assisted ultrasonic spray pyrolysis	L+D	BB	1	34	22/04/2020
35	GasCondensationProcessing(GPC),ChemicalVapourCondensation(CVC) **Optical Microscopy -** principles, Imaging Modes, Applications, Limitations	L+D	BB	1	35	27/04/2020
36	**Scanning Electron Microscopy (SEM) -** principles, Imaging Modes, Applications, Limitations. **Transmission Electron Microscopy (TEM) -** principles, Imaging Modes, Applications, Limitations	L+D	BB	1	36	27/04/2020
37	.**X- Ray Diffraction (XRD) -** principles, Imaging Modes, Applications, Limitations. **Scanning Probe Microscopy (SPM) -** principles, Imaging Modes, Applications, Limitations	L+D	LCD	1	37	28/04/2020
38	**Atomic Force Microscopy (AFM) -** basic principles, instrumentation, operational modes, Applications, Limitations	L+D	LCD	1	38	29/04/2020
39	**Electron Probe Micro Analyzer (EPMA) -** Introduction, Sample preparation, Working procedure, Applications, Limitations.	L+D	BB	1	39	4/05/2020

Module-5						
40	Introduction to NC/CNC/DNC machine tools	L+ D	BB	1	40	4/05/2020
41	Classification of NC /CNC machine tools, Advantage, disadvantages of NC	L+D	BB	1	41	5/05/2020
42	Application of NC/CNC Part programming**:** CNC programming and introduction,	L+D	BB	1	42	6/05/2020

43	Manual part programming: Basic (Drilling, milling, turning etc.)	L+ D	BB	1	43	11/05/2020
44	Manual part programming: Basic (Drilling, milling, turning etc.)	L+ D	BB	1	43	11/05/2020
44	Special part programming, Advanced part programming, Computer aided part programming (APT)of automation,	L+D	LCD	1	44	12/05/2020
45	Basic Elements of an automated system. Advanced Automation	L+D	BB	1	45	13/05/2020
46	Levels of Automations, introduction to automation productivity	L+ D	BB	1	46	26/05/2020
47	Industrial control system. Process industry vs discrete manufacturing industries.	L+D	BB	1	47	27/05/2020
48	Continuous and Discrete Control processes and its forms	L+D	BB	1	48	27/05/2020
49	Non Continuous and Discrete System components	L+D	BB	1	49	1/06/2020
50	Video on working of 3D Printer, AM Processes	L+D	LCD	1	50	1/06/2020

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Course In-charge

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DEPARTMENT OF MECHANICAL ENGINEERING
ASSIGNMENT QUESTIONS

Academic Year	2019-2020		
Batch	2015		
Year/Semester/section	IV/VIII/A+B		
Subject Code-Title	15ME82:ADDITIVE MANUFACTURING		
Name of the Instructor	Dr.B.S.Ajaykumar+ B.R.Manjunath	Dept	ME

Assignment 1 **Total marks:20**
Date of Issue:02-03-2020 **Date of Submission: 01-04-2020**

Sl. No	Assignment Questions	K Level	CO	Marks
1	**Explain** in detail about Additive manufacturing and Briefly describe its evolution	Understanding	CO1	2
2	**Enumerate** difference between additive manufacturing and CNC machining process	Understanding	CO1	2
3	**Define** System devices and **explain** actuators in the additive manufactur process	Understanding	CO2	2
4	With a neat sketch, **Briefly** explain the function of a balanced motor	Understanding	CO2	2
5	**Briefly** explain the classification of Polymers	Understanding	CO3	2
6	**Summarise** the chemical and Thermal properties of Polyester?	Understanding	CO3	2
7	With a neat sketch, **briefly** explain X-ray power diffraction	Understanding	CO4	2
8	**Discuss** the principles, image modes, applications and limitations of microscopy	Understanding	CO4	2
9	**Classify** the CNC machine tools based on control loops with a neat block diagram.	Understanding	CO5	2
10	**Explain** in detail the components of an NC system	Understanding	CO5	2

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ASSGNMENT QUESTIONS 2019 – 2020 EVEN SEMESTER

SCHEME AND SOLUTION

Degree : **B.E** **Semester** : **VIII**
Branch : **Mechanical** **Course Code** : **15ME82**
Course Title : **Additive manufacturing** **Max Marks** : **20**

Q.NO.	POINTS	MARKS
1	Concept of additive manufacturing and brief note on its evolution	1+1
2	Important five differences between **AM** and **CNC** machines	2
3	Defn of system devices,Actuators,types and their functions in precise form	0.5+1.5
4	Sketch and Brief note on Functions of Balanced Motor	1+1
5	Seven classification.1) By Origin.2) By Monomer.3) By Thermal Response	
	4) By Mode of Formation. 5) By Structure. 6) By Application and Physical Properties. 7) Tactility and Brief note on each	0.5+1.5
6	Brief note on Chemical and Thermal properties of Polyester.	1+1
7	Sketch of X-Ray Diffraction unit and brief note on it.	1+1
8	Brief discussion on principles and modes and applications and limitations	1+0.5+0.5
9	Four Classification, Sketch with brief note on it Sketch of Components of NC System and brief note on functions of NC System.	0.5+1.5

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KSIT Bangalore

DEPARTMENT OF MECHANICAL ENGINEERING

ASSIGNMENT QUESTIONS

Academic Year	**2019-2020**		
Batch	**2015**		
Year/Semester/section	**IV/VIII/A+B**		
Subject Code-Title	**15ME82:ADDITIVE MANUFACTURING**		
Name of the Instructor	**Dr.B.S.Ajaykumar+ B.R.Manjunath**	**Dept**	**ME**

Assignment 2 **Total marks:20**

Date of Issue:23-05-2020 **Date of Submission: 01-06-2020**

Sl no	Assignment Questions	K-Level	CO	Marks
1.	**Briefly** explain challenges in Nanotechnology	**Understanding**	**CO1**	2
2.	**With** a neat sketch, briefly describe a Flame assisted ultrasonic spray Pyrolysi and Chemical vapour Condensation process	**Understanding**	**CO1**	2
3.	**Explain** the working principle of scanning Electron microscope	**Understanding**	**CO2**	2
4.	**Differentiate** between “XRD” and “TEM” Analysis	**Understanding**	**CO2**	2
5.	**Write a note on** application and limitation of “ Electron probe micro analyser	**Understanding**	**CO3**	2
6.	Briefly **discuss** the Classification of Polymers	**Understanding**	**CO3**	2
7.	**Distinguish between** NC, CNC and DNC System	**Understanding**	**CO4**	2
8.	**Explain** various numerically controlled part programming Languages	**Understanding**	**CO4**	2
9.	**Summarise** various advanced automation functions	**Understanding**	**CO5**	2
10.	**Explain** in detail the components of an NC system.	**Understanding**	**CO5**	2

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ASSGNMENT QUESTIONS 2019 – 2020 EVEN SEMESTER

SCHEME AND SOLUTION

Degree	**:**	**B.E**	**Semester**	**:**	**VIII**
Branch	**:**	**Mechanical**	**Course Code**	**:**	**15ME82**
Course Title	**:**	**Additive manufacturing**	**Max Marks**	**:**	**20**

Q.NO.	POINTS	MARKS
1	challenges in Nanotechnology	1+1
2	Flame assisted ultrasonic spray Pyrolysi Sand Chemical vapour Condensation process	1+1
3	working principle of scanning Electron microscope and sketch	0.5+1.5
4	**Differentiate** between "XRD" and "TEM" Analysis	1+1
5	application and limitation of " Electron probe micro analyser	0.5+1.5
6	Briefly **discuss** the Classification of Polymers	2
7	**Distinguish between** NC, CNC and DNC System	1+1+1
8	**Explain** various numerically controlled part programming Languages.	2
9	**Summarise** various advanced automation functions.	2
10	Continuous and Discrete control systems	

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I SESSIONAL TEST QUESTION PAPER 2019 – 20 ODD SEMESTER

SET-A

USN | | | | | | | | | | |

Degree	: **BE**	**Semester**	: **VIII(A&B)**
Branch	: **Mechanical**	**Subject Code**	: **15ME82**
Subject Title	: **Additive Manufacturing**	**Date**	:**12-03-2020**
Duration	: **90 minutes**	**Max Marks**	:**30M**

Note: Answer ONE full question from each part.

Q No.	Question	Marks	K Level	CO mapping
	PART-A			
1(a)	**Explain** in detail about evolution of additive manufacturing	6	K2 (Understanding)	CO1
(b)	With Flow Chart **discuss** AM Process Chain	6	K2 (Understanding	CO1
(c)	Briefly **discuss** Stereo "Lithography Technique"	6	K2 (Understanding	CO1
	OR			
2(a)	**Summarize** the Merits and Demerits of Liquid polymer system	6	K2 (Understanding	CO1
(b)	Briefly **discuss "**Discrete particle System	6	K2 (Understanding	CO1
(c)	**Summarize** the Merits and Demerits of Laminated object manufacturing process	6	K2 (Understanding	CO1
	PART-B			
3(a)	Briefly **discuss** the History of Powder Metallurgy	6	K2 (Understanding)	CO2
(b)	**Write a note** on Process and Metallurgical advantages of Powder Metallurgy process	6	K2 (Understanding	CO2
	OR			
4(a)	**Explain** "Ball milling method" and "Water Atomization" method to manufacture Powders	6	K2 (Understanding)	CO2
(b)	Briefly **discuss** the Chemical powder production Techniques	6	K2 (Understanding	CO2

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I SESSIONAL TEST QUESTION PAPER 2019 – 20 ODD SEMESTERS

SET-B

USN										

Degree	:	**BE**	**Semester**	**:VIII(A&B)**
Branch	:	**Mechanical**	**Subject Code**	**:15ME82**
Subject Title	:	**Additive Manufacturing**	**Date**	**:12-03-2020**
Duration	:	**90 minutes**	**Max Marks**	**:30**

Note: Answer ONE full question from each part.

Q No.	Question	Marks	K Level	CO mapping
	PART-A			
1(a)	With Flow Chart **discuss** AM Process Chain	6	**K2 (Understanding)**	**CO1**
(b)	**Compare** Additive and CNC machining process	6	**K2 (Understanding)**	**CO1**
(c)	Briefly **discuss** Stereo "Lithography Technique	6	**K2 (Understanding)**	**CO1**
	OR			
2(a)	Briefly **discuss "**Discrete particle System	6	**K2 (Understanding**	**CO1**
(b)	**Summarize** the Merits and Demerits of Liquid polymer system	6	**K2 (Understanding**	**CO1**
(c)	Briefly **discuss "**Solid sheet System	6	**K2 (Understanding**	**CO1**
	PART-B			
3(a)	**Explain** "Ball milling method" and "Water Atomization" method to manufacture Powders	**6**	**K2 (Understanding)**	**CO2**
(b)	**Write a note** on Process and Commercial advantages of Powder Metallurgy process	**6**	**K2 (Understanding**	**CO2**
	OR			
4(a)	**Explain** Chemical powder production Techniques	**6**	**K2 (Understanding)**	**CO2**
(b)	**Discuss** the Characteristics of various shapes of Powders	**6**	**K2 (Understanding**	**CO2**

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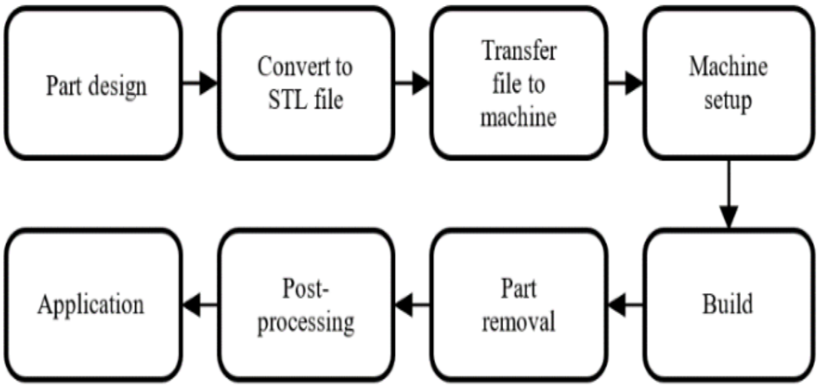
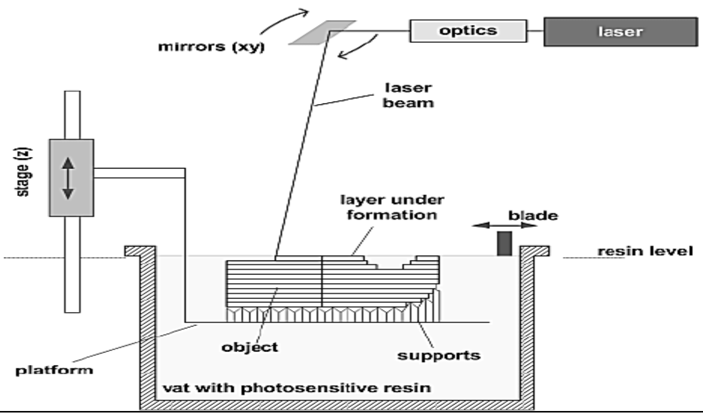
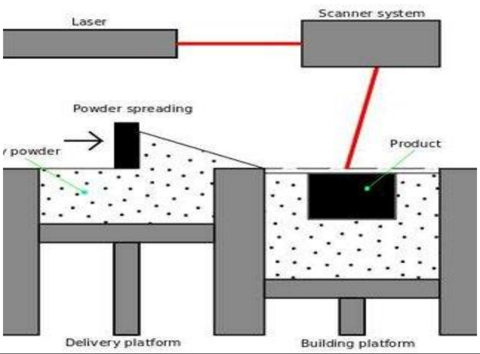
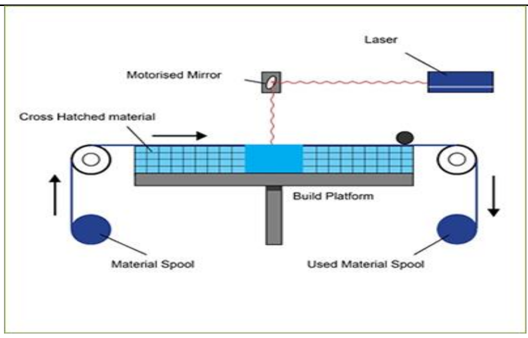
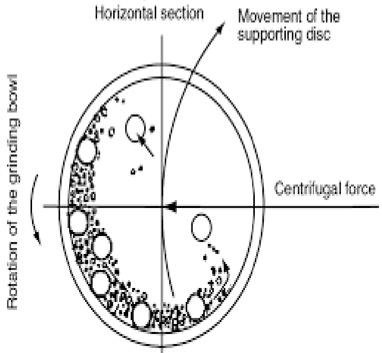
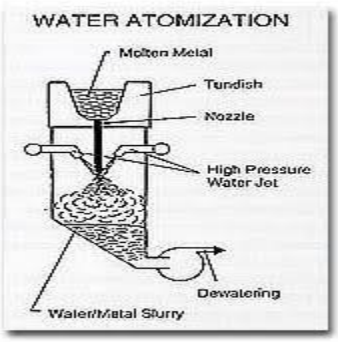
SET B Scheme & Solution of FIRST Internal Test, 2019-20

Course Code/Title: 15ME82/ Additive Manufacturing: VIII SEM A&B

Question Number	Solution	Marks Allotted
	PART – A	
1 (a)	Flow Chart **discuss** AM Process Chain AM Process Chain Theory.  	**3M** **3M**
1 (b)	**Compare** Additive and CNC machining process (Minimum 6 points)	**6M**
1 (C)	Explanation of stereolithography  	**3M** **3M**
2 (a)	Explanation of Discrete particle System  	**2 M** **4M**
2 (b)	Merits of Liquid polymersystem. Demerits of Liquid polymersystem.	**3M** **3M**

<table>
<tr><td>2 (c)</td><td>

Solid sheet System Theory</td><td>4M

2M</td></tr>
<tr><td>3 (a)</td><td>Ball milling method and Water Atomization theory


</td><td>2 M

4M</td></tr>
<tr><td>3 (b)</td><td>Powder Metallurgy process
Commercial advantages of Powder Metallurgy process</td><td>3M
3M</td></tr>
<tr><td>4 (a)</td><td>Chemical powder production Techniques
There are four main processes used in powder production: solid-state reduction, atomization, electrolysis, and chemical.</td><td>6M</td></tr>
<tr><td>4 (b)</td><td>Characteristics of various shapes of Powders</td><td>6M</td></tr>
</table>

Course In-charge

Signature of HOD

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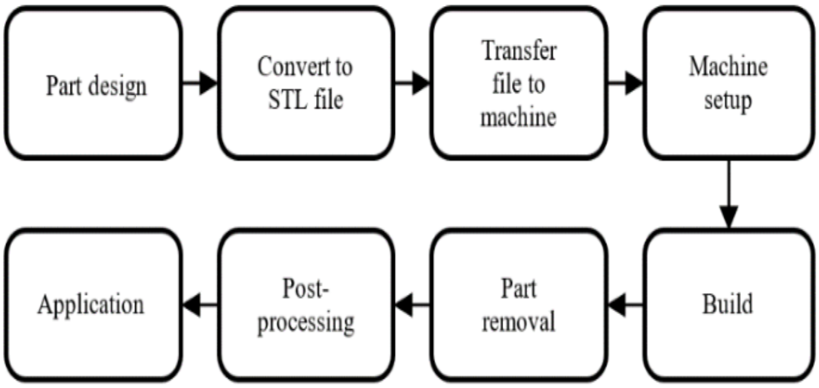
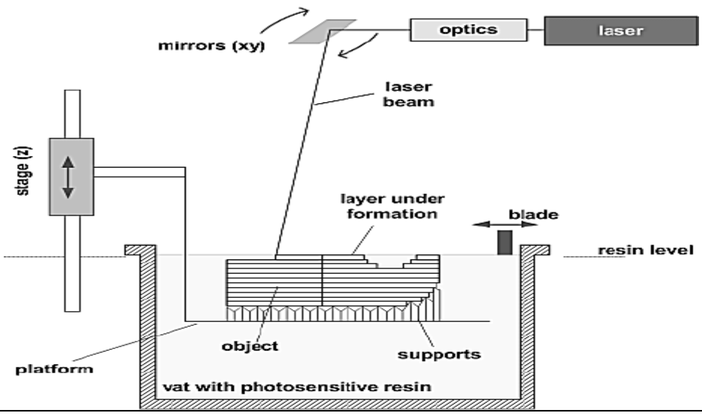
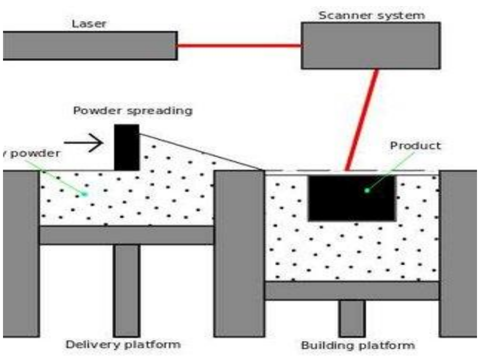
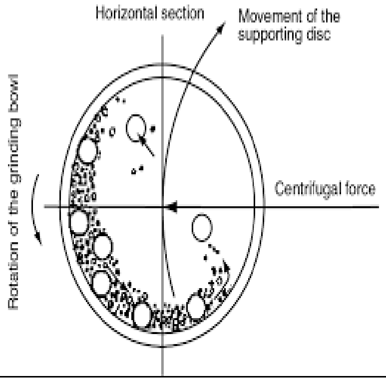
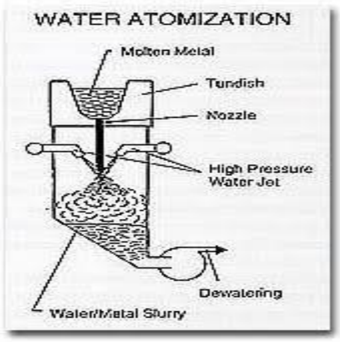
K.S INSTITUTE OF TECHNOLOGY BANGALURU – 560109

SET A Scheme & Solution of FIRST Internal Test, 2019-20

Course Code/Title: 15ME82/ Additive Manufacturing: VIII SEM A&B

1 (a)	Detail about evolution of additive manufacturing	**6M**
1 (b)	Flow Chart **discuss** AM Process Chain 	**6M**
1 (C)	Explanation of stereolithography 	**3M** **3M**
2 (a)	Merits Liquid polymer system Demerits of Liquid polymersystem	**2M** **4M**
2 (b)	Explanation of Discrete particle System 	**2M** **4M**
2 (c)	Merits of Laminated objectmanufacturing process Demerits of Laminated objectmanufacturing process	**3M** **3M**
3 (a)	History of Powder Metallurgy	**6M**
3 (b)	Powder Metallurgy process Metallurgical advantages of Powder Metallurgy process	**3M** **3M**

4 (a)	Ball milling method and Water Atomization theory  	**2M** **4M**
4 (b)	Characteristics of various shapes of Powders	**6M**

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II SESSIONAL TEST QUESTION PAPER 2019 – 20 EVEN SEMESTER

Set A

USN										

Degree : B.E | **Semester: VIII**
Branch : Mechanical Engg | **Course Code: 15ME82**
Course Title : ADDITIVE MANUFACTURING | **Date: 2.04.2020**
Duration : 90Minutes | **Max Marks: 30**

Note: Answer all questions

Q No.	Question	Marks	K Level	CO mapping
1	**Discuss** Nano technology. Explain the top down and bottom up approaches with flowchart, list the advantages and limitations of Nano particles.	6	K2 (Understanding)	CO3
2	**Explain** the sol gel process, chemical vapour condensation process	6	K2 (Understanding)	CO3
3	**Explain** the Thyristors, Diodes and Triacs	6	K2 (Understanding)	CO3
4	**Explain** any one hydraulic and pneumatic motors	6	K2 (Understanding)	CO2
5	**Explain** the mechanical grinding process ,Gascondensation process.	6	K2 (Understanding)	CO4

Note:

1. Strictly adhere to the timings
2. After answering to the questions, within 5 minutes photocopy of the complete answer script with CAMSCANNER convert to PDF file, save with your USN number and send it to respective faculty Email ID "**. manjunathbr@ksit.edu.in".**

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Manju.B.R
Course In-charge

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II SESSIONAL TEST QUESTION PAPER 2019 – 20 EVEN SEMESTER

USN										

Set B

Degree : B.E **Semester: VIII**
Branch : Mechanical Engg **Course Code: 15ME82**
Course Title : ADDITIVE MANUFACTURING **Date: 2.04.2020**
Duration : 90Minutes **Max Marks: 30**

Note: Answer all questions

Q No.	Question	Marks	K Level	CO mapping
1	**Explain** the Thyristors, Diodes and Triacs	6	K2 (Understanding)	CO3
2	**Discuss** Nano technology. Explain the top down and bottom up approaches with flowchart, list the advantages andlimitations of Nano particles.	6	K2 (Understanding)	CO3
3	**Explain** any one hydraulic and pneumatic motors	6	K2 (Understanding)	CO2
4	**Explain** the mechanical grinding process ,Gascondensation process.	6	K2 (Understanding)	CO4
5	**Explain** the sol gel process, chemical vapour condensation process	6	K2 (Understanding)	CO2

Note:

1. Strictly adhere to the timings
2. After answering to the questions, within 5 minutes photocopy of the complete answer script with CAMSCANNER convert to PDF file, save with your USN number and send it to respective faculty Email ID ". **manjunathbr@ksit.edu.in".**

Manju.B.R
Course In-charge

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SETA **Scheme & Solution of Second Internal Test,**

Course Code/Title: 15ME82/ ADDITIVE MANUFACTURING : VIIISEM

Question Number	Solution	Marks Allotted
	PART – A	
1	Define Nano technology Topdown and bottom up approaches with flowchart Advantages and limitations of Nano particles.	**2M** **2M** **2M**
2	Explanation of sol gel process Explanation of chemical vapour condensation process	**3M** **3M**
3	Explanation of Thyristors, Explanation of Diodes Explanation of Triacs	**2M** **2M** **2M**
4	Explanation of hydraulic motors Explanation of Pneumatic motors	**3M** **3M**
5	Mechanical grinding process , Gascondensation process.	**3M** **3M**

Murthy U.B.
Course In-charge

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SETB **Scheme & Solution of Second Internal Test,**

Course Code/Title: 15ME82/ ADDITIVE MANUFACTURING : VIIISEM

Question Number	Solution	Marks Allotted
	PART – A	
1	Explanation of Thyristors, Explanation of Diodes Explanation of Triacs	**2M** **2M** **2M**
2	Define Nano technology Topdown and bottom up approaches with flowchart Advantages and limitations of Nano particles	**2M** **2M** **2M**
3	Explanation of hydraulic motors Explanation of Pneumatic motors	**3M** **3M**
4	Mechanical grinding process , Gascondensation process	**3M** **3M**
5	Explanation of sol gel process Explanation of chemical vapour condensation process	**3M** **3M**

Murthu.B.P
Course In-charge

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III SESSIONAL TEST QUESTION PAPER 2019 – 20 EVEN SEMESTER

Set A

Degree	**: B.E**	**Semester:**	**VIII**
Branch	**: Mechanical Engg**	**Course Code:**	**15ME82**
Course Title	**: ADDITIVE MANUFACTURING**	**Date:**	**28-05-2020**
Duration	**: 90Minutes**	**Max Marks:**	**30**

Note: Answer all questions

Q No.	Question	Marks	K Level	CO mapping
1	**Briefly** explain challenges in Nanotechnology	6	K2 (Understanding)	CO4
2	**Intrepret** a neat sketch, explain describe a Flame assisted ultrasonicspray Pyrolysis and Chemical vapour Condensation process	6	K2 (Understanding)	CO4
3	**Explain** the working principle of scanning Electron microscope	6	K2 (Understanding)	CO5
4	**Outline** NC, CNC and DNC System	6	K2 (Understanding)	CO5
5	**Outline** Continuous and Discrete control systems	6	K2 (Understanding)	CO5

COURSE INCHARGE

1) **Mr.B.R.MANJUNATH:SEC-A and Dr.B.S.AJAYKUMAR SEC-B.**

INSTRUCTIONS

A. Strictly adhere to the timings

B. .After answering to the questions, within 5 minutes photocopy of the complete answer script with CAMSCANNER convert to PDF file, save with your USN number and send it to respective faculty Email ID "**1) manjunathbr@ksit.edu.in** for 8th sem section "A" Students and

C. **ajaykumarbs @ksit.edu.in**.for "B" Students respectively.

Manju.B.R
Course In-charge

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IIISESSIONAL TEST QUESTION PAPER 2019 – 20 EVEN SEMESTER

Set B

USN										

Degree : B.E **Semester:** VIII
Branch : Mechanical Engg **Course Code:** 15ME82
Course Title : ADDITIVE MANUFACTURING **Date:** 28-05-2020
Duration : 90Minutes **Max Marks:** 30

Note: Answer all questions

Q No.	Question	Marks	K Level	CO mapping
1	**Outline** Continuous and Discrete control systems	6	K2 (Understanding)	CO5
2	**Outline** NC, CNC and DNC System	6	K2 (Understanding)	CO5
3	**Explain** the working principle of scanning Electron microscope	6	K2 (Understanding)	CO5
4	**Intrepret** a neat sketch, explain describe a Flame assisted ultrasonicspray Pyrolysis and Chemical vapour Condensation process	6	K2 (Understanding)	CO4
5	**Briefly** explain challenges in Nanotechnology	6	K2 (Understanding)	CO4

COURSE INCHARGE

2) **Mr.B.R.MANJUNATH:SEC-A and Dr.B.S.AJAYKUMAR SEC-B.**

INSTRUCTIONS

A. Strictly adhere to the timings
B. .After answering to the questions, within 5 minutes photocopy of the complete answer script with CAMSCANNER convert to PDF file, save with your USN number and send it to respective faculty Email ID "**1) manjunathbr@ksit.edu.in** for 8th sem section "A" Students and
C. **ajaykumarbs @ksit.edu.in**.for "B" Students respectively.

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Course In-charge

K.S INSTITUTE OF TECHNOLOGY BANGALURU –560109

SETA **Scheme & Solution of Third Internal Test,**

Course Code/Title: 15ME82/ ADDITIVE MANUFACTURING : VIIISEM

Question Number	Solution	Marks Allotted
	PART – A	
1	challenges in Nanotechnology	**6M**
2	Explanation of Flame assisted ultrasonicspray Pyrolysis Explanation of Chemical vapour Condensation process	**3M** **3M**
3	Principle of scanning Electron microscope Sketches	**3M** **3M**
4	NC System CNC System DNC System	**2M** **2M** **2M**
5	Differentiate between Continuous and Discrete control systems	**3M** **3M**

Murthu.B.P
Course In-charge

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SETB Scheme & Solution of Third Internal Test,

Course Code/Title: 15ME82/ ADDITIVE MANUFACTURING : VIIISEM

Question Number	Solution	Marks Allotted
PART – A		
1	challenges in Nanotechnology	6M
2	Explanation of Flame assisted ultrasonicspray Pyrolysis Explanation of Chemical vapour Condensation process	3M 3M
3	Principle of scanning Electron microscope Sketches	3M 3M
4	NC System CNC System DNC System	2M 2M 2M
5	Differentiate between Continuous and Discrete control systems	3M 3M

Murthu.B.R
Course In-charge

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K.S. Institute of Technology
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KS INSTITUTE OF TECHNOLOGY BANGALORE

DEPARTMENT OF MECHANICAL ENGINEERING

NAME OF THE STAFF : MANJUNATHA.B.R

SUBJECT CODE/NAME : 15ME82/Additive Manufacturing

SEMESTER/YEAR : VIII SEM

ACADEMIC YEAR : 2019-2020

Marks list of I,II AND III rd internals

		IA1				IA2				IA3			
USN NO	**NAME OF STUDENT**	**CO1**	**CO2**	Assignment	Total	**CO2**	**CO3**	Assignment	Total	**CO4**	**CO5**	Assignment	Total
		18	12	10		18	6			12	18		
1KS16ME002	ABHIJEETH.B.BHAT	17	9	10	36	18	6	10	34	12	18	10	40
1KS16ME004	ABHILASH.S	14	10	10	34	18	6	10	34	12	18	10	40
1KS16ME006	ABHISHEK PAREEK	17	10	10	37	18	6	10	34	12	18	10	40
1KS16ME008	AMOGHA.M.KEKUDA	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME009	ASHOK KUMAR KARMALI	17	12	10	39	18	6	10	34	12	18	10	40
1KS16ME010	ASHWIN MAIYA.M	17	10	10	37	18	5	10	33	10	18	10	38
1KS16ME011	BHARATHKUMAR.P	15	11	10	36	18	5	10	33	10	18	10	38
1KS16ME012	BHARGAV JOSHI	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME013	BHUVAN BHARADWAJ.V.K	17	11	10	38	18	5	10	33	12	16	10	38
1KS16ME014	CHANDAN KUMAR.N.P	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME015	CHIRAG.B.P	17	11	10	38	18	5	10	33	10	18	10	38
1KS16ME016	DEEPAK.R.GOWDA	AB	AB	10	10	18	6	10	34	12	18	10	40
1KS16ME019	HARISH HADIMANI	17	11	10	38	18	6	10	34	12	18	10	40

1KS16ME021	HARSHA.S	17	11	10	38	18	5	10	33	12	18	10	40
1KS16ME022	HARSHAVARDHAN.N	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME023	HARSHITH.S	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME024	HEMANTH.R	17	10	10	37	18	6	10	34	12	18	10	40
1KS16ME025	HEMANTH KUMAR.D.L	AB	AB	10	10	18	6	10	34	12	18	10	40
1KS16ME026	HITESH.C.S	17	11	10	38	18	5	10	33	12	16	10	38
1KS16ME027	IMRAN KHAN	15	6	10	31	18	4	10	32	12	14	10	36
1KS16ME028	IRANNA CHANABASAPPA TELI	17	10	10	37	18	5	10	33	10	18	10	38
1KS16ME029	JAGADISH.P.SHETTI	AB	AB	10	10	18	6	10	34	12	18	10	40
1KS16ME030	JAYANTH.P	AB	AB	10	10	18	6	10	34	12	18	10	40
1KS16ME031	JAYDEEP.B	18	10	10	38	18	5	10	33	12	16	10	38
1KS16ME032	JUNAID KHAN	17	9	10	36	18	5	10	33	10	18	10	38
1KS16ME033	KANISHKA.P.SHANKAR	17	6	10	33	18	6	10	34	12	18	10	40
1KS16ME035	KAUSHIK.K.H	AB	AB	10	10	18	5	10	33	12	16	10	38
1KS16ME036	KIRAN PRAKASH AKOLKAR	17	10	10	37	18	5	10	33	12	16	10	38
1KS16ME038	M.VENKATESH KASHYAP	15	6	10	31	18	6	10	34	12	18	10	40
1KS16ME040	MADAN.S	17	10	10	37	18	6	10	34	12	18	10	40
1KS16ME044	MANOJ.R	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME045	MOHAMMED YASIR RIAZ	AB	AB	10	10	18	5	10	33	12	16	10	38
1KS16ME046	MOHAN KUMAR.N	AB	AB	10	10	18	5	10	33	10	18	10	38
1KS16ME047	NAGARJUN.S	AB	AB	10	10	18	4	10	32	12	14	10	36
1KS16ME048	NAGARJUN.S	17	11	10	38	18	5	10	33	10	18	10	38
1KS16ME049	NAGESH.T.S	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME052	NAVEEN DESHPANDE	15	9	10	34	18	6	10	34	12	18	10	40
1KS16ME053	NITHIN.N	16	12	10	38	18	6	10	34	12	18	10	40
1KS16ME054	P.VIGNESH	18	10	10	38	18	6	10	34	12	18	10	40
1KS16ME055	PAPPU KUMAR SINGH	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME057	PAVITHRA.B	AB	AB	10	10	18	6	10	34	12	18	10	40
1KS16ME056	PAVAN KUMAR.L	17	6	10	33	18	6	10	34	12	18	10	40
1KS16ME058	PECHU MUTHU.S	17	12	10	39	18	6	10	34	12	18	10	40
1KS16ME060	PRAJWAL KRISHNA	AB	AB	10	10	18	6	10	34	12	18	10	40

1KS16ME061	PRAKASH RAJU.S	6	10	10	26	18	6	10	34	12	18	10	40
1KS16ME062	PRAMOD.R	17	12	10	39	18	6	10	34	12	18	10	40
1KS16ME063	PRAMOD RAJ.K	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME064	PRANAV.J.ATHREY	AB	AB	10	10	18	6	10	34	12	18	10	40
1KS16ME067	RAJKUMAR.S.K	17	11	10	38	18	6	10	34	12	18	10	40
1KS16ME069	RAMESH PAL.P	AB	AB	10	10	16	4	10	30	10	14	10	34
1KS16ME070	RISHI.R.NAIK	16	9	10	35	18	6	10	34	12	18	10	40
1KS16ME073	SAGAR.N	17	10	10	37	18	6	10	34	12	18	10	40
1KS16ME075	SHAIK MOINUDDIN	17	9	10	36	18	6	10	34	12	18	10	40
1KS16ME076	SHARATH.S.YADAV	17	6	10	33	18	6	10	34	12	18	10	40
1KS16ME406	BALAJI .C	17	6	10	33	18	6	10	34	12	18	10	40
1KS16ME419	PRAVEEN KUMAR M	17	6	10	33	18	5	10	33	10	18	10	38
1KS15ME015	BHARATH .R	AB	AB	10	10	18	5	10	33	10	18	10	38
1KS15ME018	CHETAN KUMAR M	17	11	10	38	18	6	10	34	10	18	10	38
1KS15ME028	HARITHUS.V	AB	AB	10	10	16	5	10	31	12	14	10	36
1KS15ME042	MAHANTESH	AB	AB	10	10	16	5	10	31	12	14	10	36
1KS15ME046	MUTTURAJ V KESANUR	AB	AB	10	10	16	4	10	30	10	14	10	34
1KS15ME048	RAMA KRISHNA .N	6	11	10	27	18	5	10	33	10	18	10	38
1KS15ME052	PARIKSHITH A	AB	AB	10	10	18	6	10	34	12	18	10	40
1KS15ME058	R. THEJAS	6	8	10	24	18	6	10	34	12	18	10	40
1KS15ME098	THEJAS CHANDRA K N	17	11	10	38	18	6	10	34	12	18	10	40
1KS15ME110	PRAJWAL URS.P	15	6	10	31	18	6	10	34	12	18	10	40
1KS14ME115	CHANNAPPAGOUDA	6	7	10	23	18	6	10	34	12	18	10	40

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Course In-charge

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DEARTMENT OF MECHANICAL ENGINEERING

TEACHING AND LEARNING

PEDAGOGY REPORT

Academic Year	2019-20 (EVEN SEM)
Name of the Faculty	Mr. Manjunatha B R
Course Name /Code	Additive Manufacturing /15ME82
Semester/Section	VIII SEM/A
Activity Name	PPT on Introduction toGraphics
Topic Covered	All modules
No. of Participants	74
Objectives/Goals	To understand the complete 3D PRINTING Process
ICT Used	PPTS
Appropriate Method/Instructional materials/Exam Questions -	
Relevant PO's	PO1, PO2,PO5,PO8,PO12
Significance of Results/Outcomes	The students were able to acquire the knowledge of additive manufacturing manufacturing process
Reflective Critique	-
Proofs (Photographs/Videos/Reports/Charts/Models) PPTS OF ALL MODULES	

Munju.B.R

Course In-charge

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K.S. Institute of Technology
Bengaluru - 560 109

ADDITIVE MANUFACTURING
(15ME82)

Course Objectives:

Students will be able to

1. Understand the additive manufacturing process, polymerization and powder metallurgy process

2. Understand characterization techniques in additive manufacturing.

3. Acquire knowledge on CNC and Automation.

Module 1

Introduction to Additive Manufacturing: Introduction to AM, AM evolution, Distinction between AM & CNC machining, Advantages of AM,

AM process chain: Conceptualization, CAD, conversion to STL, Transfer to AM, STL file manipulation, Machine setup, build , removal and clean up, post processing.

Classification of AM processes: Liquid polymer system, discrete particle system, molten material systems and Solid sheet system.

Post processing of AM parts: Support material removal, surface texture improvement, accuracy improvement, aesthetic improvement, preparation for use as a pattern, property enhancements using non-thermal and thermal techniques.

Guidelines for process selection: Introduction, selection methods for a part, challenges of selection

AM Applications: Functional models, Pattern for investment and vacuum casting, Medical models, art models, Engineering analysis models, Rapid tooling, new materials development, Bi-metallic parts, Re-manufacturing. Application examples for Aerospace, defense, automobile, Bio-medical and general engineering industries

Module 2

System Drives and devices: Hydraulic and pneumatic motors and their features, Electrical motors AC/DC and their features

Actuators: Electrical Actuators; Solenoids, Relays, Diodes, Thyristors, Triacs, Hydraulic and Pneumatic actuators, Design of Hydraulic and Pneumatic circuits, Piezoelectric actuators, Shape memory alloys.

Module 3

POLYMERS & POWDER METALLURGY

Basic Concepts: Introduction to Polymers used for additive manufacturing: polyamide, PF resin, polyesters etc. Classification of polymers, Concept of functionality, Polydispersity and Molecular weight [MW], Molecular Weight Distribution [MWD]

Polymer Processing: Methods of spinning for additive manufacturing: Wet spinning, Dry spinning. Biopolymers, Compatibility issues with polymers. Moulding and casting of polymers, Polymer processing techniques

General Concepts: Introduction and History of Powder Metallurgy (PM), Present and Future Trends of PM

Powder Production Techniques: Different Mechanical and Chemical methods, Atomisation of Powder, other emerging processes.

Characterization Techniques: Particle Size & Shape Distribution, Electron Microscopy of Powder, Interparticle Friction, Compression ability, Powder Structure, Chemical Characterization

Microstructure Control in Powder: Importance of Microstructure Study, Microstructures of Powder by Different techniques

Powder Shaping: Particle Packing Modifications, Lubricants & Binders, Powder Compaction & Process Variables, Pressure & Density Distribution during Compaction, Isotactic Pressing, Injection Moulding, Powder Extrusion, Slip Casting, Tape Casting.

Sintering: Theory of Sintering, Sintering of Single & Mixed Phase Powder, Liquid Phase Sintering Modern Sintering Techniques, Physical & Mechanical Properties Evaluation, Structure-Property Correlation Study, Modern Sintering techniques, Defects Analysis of Sintered Components

Application of Powder Metallurgy: Filters, Tungsten Filaments, Self-Lubricating Bearings, Porous Materials, Biomaterials etc.

Module 4

NANO MATERIALS & CHARACTERIZATION TECHNIQUES:

Introduction: Importance of Nano-technology, Emergence of Nanotechnology, Bottom up Top-down approaches, challenges in Nanotechnology

Nano-materials Synthesis and Processing: Methods for creating Nanostructures; Processes for producing ultrafine powders- Mechanical grinding; Wet Chemical Synthesis of Nano-materials- sol-gel process; Gas Phase synthesis of Nano-materials- Furnace, Flame assisted ultrasonic spray pyrolysis; Gas Condensation Processing (GPC), Chemical Vapour Condensation(CVC).

Optical Microscopy - principles, Imaging Modes, Applications, Limitations.

Scanning Electron Microscopy (SEM) - principles, Imaging Modes, Applications, Limitations.

Transmission Electron Microscopy (TEM) - principles, Imaging Modes, Applications, Limitations.

X- Ray Diffraction (XRD) - principles, Imaging Modes, Applications, Limitations.

Scanning Probe Microscopy (SPM) - principles, Imaging Modes, Applications, Limitations.

Atomic Force Microscopy (AFM) - basic principles, instrumentation, operational modes, Applications, Limitations.

Electron Probe Micro Analyzer (EPMA) - Introduction, Sample preparation, Working procedure, Applications, Limitations.

Module 5

MANUFACTURING CONTROL AND AUTOMATION

CNC technology - An overview: Introduction to NC/CNC/DNC machine tools, Classification of NC /CNC machine tools, Advantage, disadvantages of NC /CNC machine tools, Application of NC/CNC

Part programming: CNC programming and introduction, Manual part programming: Basic (Drilling, milling, turning etc.), Special part programming, Advanced part programming, Computer aided part programming (APT)

Introduction: Automation in production system principles and strategies of automation, basic Elements of an automated system. Advanced Automation functions. Levels of Automations, introduction to automation productivity

Control Technologies in Automation: Industrial control system. Process industry vs discrete manufacturing industries. Continuous vs discrete control. Continuous process and its forms. Other control system components.

Course Outcomes

1. Understand the different process of Additive Manufacturing. Using Polymer, Powder and Nano materials manufacturing.
2. Analyze the different characterization techniques.
3. Describe the various NC, CNC machine programming and Automation techniques.

TEXT BOOKS:

1. Chua Chee Kai, Leong Kah Fai, “Rapid Prototyping: Principles & Applications”, World Scientific, 2003.
2. G Odian Principles of Polymerization, Wiley Iner science John Wiley and Sons, 4th edition, 2005
3. Mark James Jackson, Microfabrication and Nano manufacturing, CRC Press, 2005.
4. Powder Metallurgy Technology, Cambridge International Science Publishing, 2002.
5. P. C. Angelo and R. Subramanian: Powder Metallurgy- Science, Technology and Applications, PHI, New Delhi, 2008.
6. Mikell P Groover, Automation, Production Systems and Computer Integrated Manufacturing, 3rd Edition, Prentice Hall Inc., New Delhi, 2007.

REFERENCE BOOKS:

1. Wohler's Report 2000 - Terry Wohlers - Wohler's Association -2000
2. Computer Aided Manufacturing - P.N. Rao, N.K. Tewari and T.K. Kundra Tata McGraw Hill 1999
3. Ray F. Egerton, Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM, Springer, 2005.
4. P. C. Angelo and R. Subramanian: Powder Metallurgy- Science, Technology and Applications, PHI, New Delhi, 2008.

Introduction to Additive Manufacturing

The term ‘additive manufacturing’ was given by the ASTM F42 committee.

•Technology that can make anything.

•Eliminates many constraints imposed by conventional manufacturing

•Leads to more market opportunities.

Additive Manufacturing (AM) refers to a process by which digital 3D design data is used to build up a component in layers by depositing material.

Additive manufacturing, also known as 3D printing, rapid prototyping or freeform fabrication,

Additive manufacturing is ‘the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies’ such as machining.

It became a suitable process to produce complex metal net shape parts, and not only prototypes, as before.

Additive manufacturing now enables both a design and industrial revolution, in various industrial sectors such as Aerospace, Energy, Automotive, Medical, Tooling and Consumer Goods.

Photo: Examples of direct metal laser sintering

Photo: Selective laser sintered (SLS)

The evolution of additive manufacturing

For the past few decades, additive manufacturing (AM) has developed from rapid prototyping using simple 3D printers to a complex manufacturing technology that enables the production of functional finished components. Additive manufacturing is evolving due in part to the expanding number of materials that are now being explored and used, such as composites, ceramics, and metal alloys. While a greater number of manufacturers are adopting AM technologies as they have become more commercially viable and more and more materials can be used, many still view it as simply a tool for rapid prototyping.

AT A CROSSROADS

Additive manufacturing is growing rapidly

The industry grew by 35.2% last year, according to Wohlers Report 2015[1]

but, according to a survey of 100 industrial manufacturers:

Over 50% are merely experimenting with 3D printing or using it for rapid prototyping only[2]

signaling the continuing potential for AM to revolutionize manufacturing as we know it today

AM applications timeline

This timeline lays out past, present and potential future AM developments and applications. (courtesy of Graham Tromans)

1988-1994	rapid prototyping
1994	rapid casting
1995	rapid tooling
2001	AM for automotive
2004	aerospace (polymers)
2005	medical (polymer jigs and guides)
2009	medical implants (metals)
2011	aerospace (metals)
2013-2016	nano-manufacturing
2013-2017	architecture
2013-2018	biomedical implants
2013-2022	in situ bio-manufacturing
2013-2032	full body organs

Distinction between AM & CNC machining

From their building methods to what applications they can handle, CNC machining and 3D printing offer creative solutions in vastly different ways. Finding out their differences and strengths will help you find which one is right for you and your business.

3D printers are typically more efficient than traditional manufacturing. The printer uses the materials that make up the item it's creating, whereas traditional manufacturing methods such as CNC Machining require more materials for the mold to work. On average, 3D printers produce less waste than traditional manufacturing methods.

However, when production is large-scale, traditional manufacturing methods have a distinct advantage. Assembly lines are faster than a 3D printer in mass production because printers build layer by layer. In the hours that it could take to 3D print a product, an assembly line could have mass-produced hundreds of the same product.

Additionally, 3D printers can only use the area of the printing bed for making parts. Large-scale parts might not fit in that space. While the parts can be broken down into smaller pieces 3D printers can build, that might not be cost-effective and will take time. Traditional manufacturing has the advantage of the assembly line's labor and will be able to produce items on a larger scale. Future 3D printers could be able to build larger items, but not on the level of what CNC machines offer with regard to quality and quantity.

3D printers can manipulate different materials such as plastics, metals and polymers. However:

Not all 3D printers can use these materials. It takes separate machines for each material.

3D printers cannot work with every material that traditional manufacturers use due to high melting points.

Some projects might not be able to consider using 3D printers if they require specific materials that are incompatible with the printers.

DIFFERENCE BETWEEN AM & CONVENTIONAL MACHINING

Conventional Machining Process	Additive Manufacturing Process
Produce a model by removing material bit by bit -	Produce a model by adding material in layers
- Subtraction process	Addition process
Complex geometry limited	Complex geometry unlimited
Increased lead time & cost	Reduced lead time & cost

Material Usage for CNC and 3D

CNC machining works with a variety of materials. They can use:

1. Metal alloys
2. Woods
3. Acrylic
4. Modeling foam
5. Thermoplastics
6. Machining wax

CNC machines have heating systems that can manage heavy materials. These materials are used to build substantial parts for engines, aircraft and other machines. They need to be exact, dependable and durable. The cutting tools for the design might have to switch, but most tools are standardized to fit any CNC machine.

3D printing doesn’t have this variety, using materials like plastics or resins. They can’t produce items strong enough to withstand intense environments like airplanes or other machinery. Also, 3D printers can’t switch between materials. Certain 3D printers are for specific kinds of material.

Advantages/ Benefits of AM

a) Produces fit and functional parts.

b) Quick and cost effective process.

c) Reduced material waste.

d) Increased customisation.

e) Tooling eliminated, cost and time of tooling reduced.

f) Reduces expensive design errors before manufacture.

g) Reduces the lead time for new product development.

h) Helps in detecting design errors before manufacture.

i) AM machines are environmentally friendly and can be easily operated.

ADDITIVE MANUFACTURING PROCESS

a) Creation of Solid 3D CAD model - Solid Works, Pro-E, UG, CATIA

b) Conversion of CAD to STL format - Standard Triangulation Language / Tessellation- CAD to 3Dplanar triangles.

STL File format is the universal for all RP Techniques

a) (Magic -Materialise – *RP software- enables to check errors & repair, cut STL file and* orientation)

b) Pre-process software Slices the 3D object STL file into thin 2D cross-section (layer thickness0.01- 0.7mm)

c) Building Process - Construction of model one layer above the another

d) Post-process - Cleaning & finishing

AM process chain

A series of steps goes into the process chain required to generate a useful physical part from the concept of the same part using additive manufacturing processes. Depending on the technology and, at times the machines and components, the process chain is mainly made up of six steps:

a) Generation of CAD model of the design;
b) Conversion of CAD model into AM machine acceptable format;
c) CAD model preparation;
d) Machine setup;
e) Part removal;
f) Post-processing.

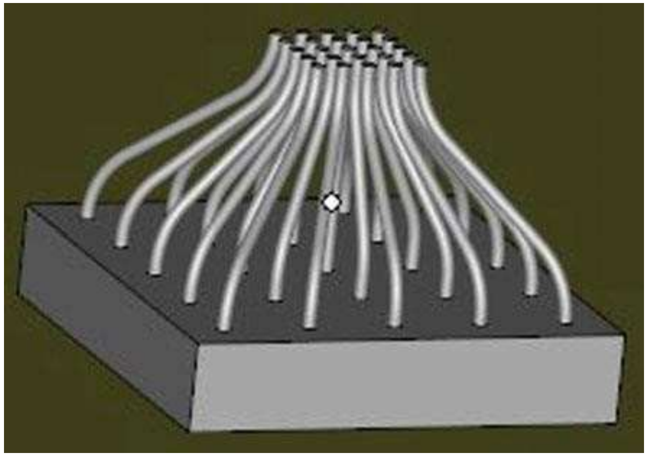
These steps can be grouped or broken down and can look different from case to case, but overall the process chain from one technology remains similar to that of a different technology. The process chain is also constantly evolving and can change as the existing technologies develop and new technologies surface.

a. Generation of Computer-Aided Design Model of Design

In general, the AM process chains start with 3D CAD modeling. The process of producing a 3D CAD model from an idea in the designer’s mind can take on many forms, but all requires CAD software programs. There are a large number of CAD programs with different modeling principles, capabilities, accessibilities, and cost. Some examples include Autodesk Inventor, Solid works, Creo, NX, etc.

b. Conversion of CAD Model into AM Machine Acceptable Format

Almost all AM technology available today uses the Stereo Lithography (STL) file format. Shown in below Fig. is an example part in its STL format.



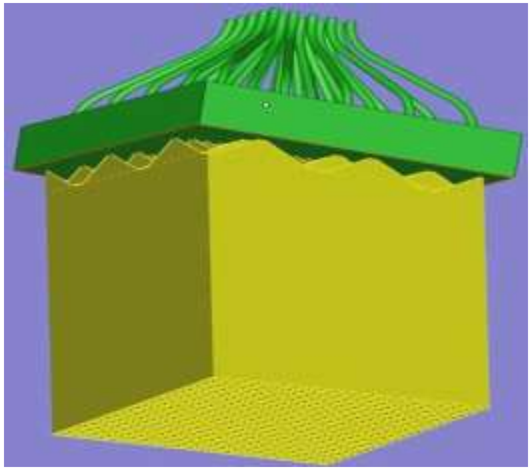
STL format has been consider the de facto standard, it has limitations intrinsic to the fact that only geometry information is stored in these files while all other information that a CAD model can contain is eliminated. Information such as unit, color, material, etc. can play critical role in the functionality of the built part is lost through the file translation process.

The “AMF” format was developed specifically to address these issues and limitations, and is now the ASTM/ISO standard format. Beyond geometry information, it also contains dimensions, color, material, and additional information is also possible with this file format.

c. CAD Model Preparation

Once a correct STL file is available, a series of steps is required to generate the information an AM system needs to start the build process. The needed information varies, depending on the technology but in general these steps start with repairing any errors within the STL file. Once the errors have been repaired, a proper orientation of the 3D model with respect to the build platform/envelope is then decided. Following the orientation, the geometry, density, geometry of support structures are decided and generated in 3D model space and assigned to the part model. The process then progresses to slicing the 3D model defined by the STL as well the support structure into a given number of layers of a desired height each representing a slice of the part and support models. Within each slice the cross-sectional geometry is kept constant.

STL file has been processed and machine specific information to allow placement of the material unit into the desired location in a controlled manner to construct the physical model layer by layer.



Support structure generated on the model

d. STL File Preparation

The CAD model preparation starts with importing an STL, or other compatible file formats, into the pre-process software program (e.g., Magic’s). Once imported, the dimensions can be modified if needed. Once the model is in desired dimensions, a series of steps is carried out to correct possible errors in the model file. These errors can include missing triangles, inverted or double triangles, transverse triangles, open edges and contours, and shells. Each type of error can cause issues in the building process or result in incorrect parts and geometries. While some errors such as shells and double triangles are non-critical and can sometimes be tolerated, errors such as inverted triangles and open contours can cause critical issue in the building process and needs to be resolved during STL preparation.

d. Machine Setup

Machine preparation can roughly be divided into two groups of tasks: **machine hardware setup, and process control.**

Hardware setup entails cleaning of build chamber from previous build, loading of powder material, a routine check of all critical build settings and **process controls** such as gas pressure, flow rate, oxygen sensors, etc. Details of how each task in this group is carried out can vary from one system to another, but overall once the machine hardware setup is complete, the AM system is ready to accept the build files (slices generated from previous step) and start the build.

e. Build Removal

Once the build completes, the laser metal powder bed technology allows for immediate discharging of build chamber and recovery of finished part. The unpacking process typically involves raising the platform in the build chamber and removing loose powder at the same time. The loose powder from one process can be re-used and has to go through a series of sieving steps to remove contaminates and unwanted particulates.

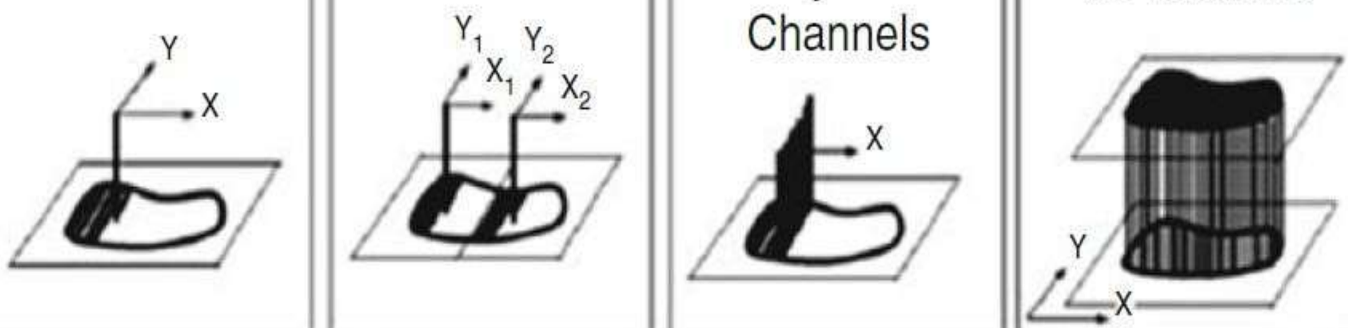
SLM part being extracted from build chamber

f. Post-processing

Depending on AM technology used to create the part, the purpose, and requirements of the finished part, the post-fabrication processes can vary in a wide range. It can require anything from no post process to several additional steps of processing to change the surface, dimensions, and/or material properties of the built part.

III. CLASSIFICATION OF AM PROCESSES

There are numerous ways to classify AM technologies. A popular approach is to classify **according to baseline technology**, like whether the process uses lasers, printer technology, extrusion technology, etc.



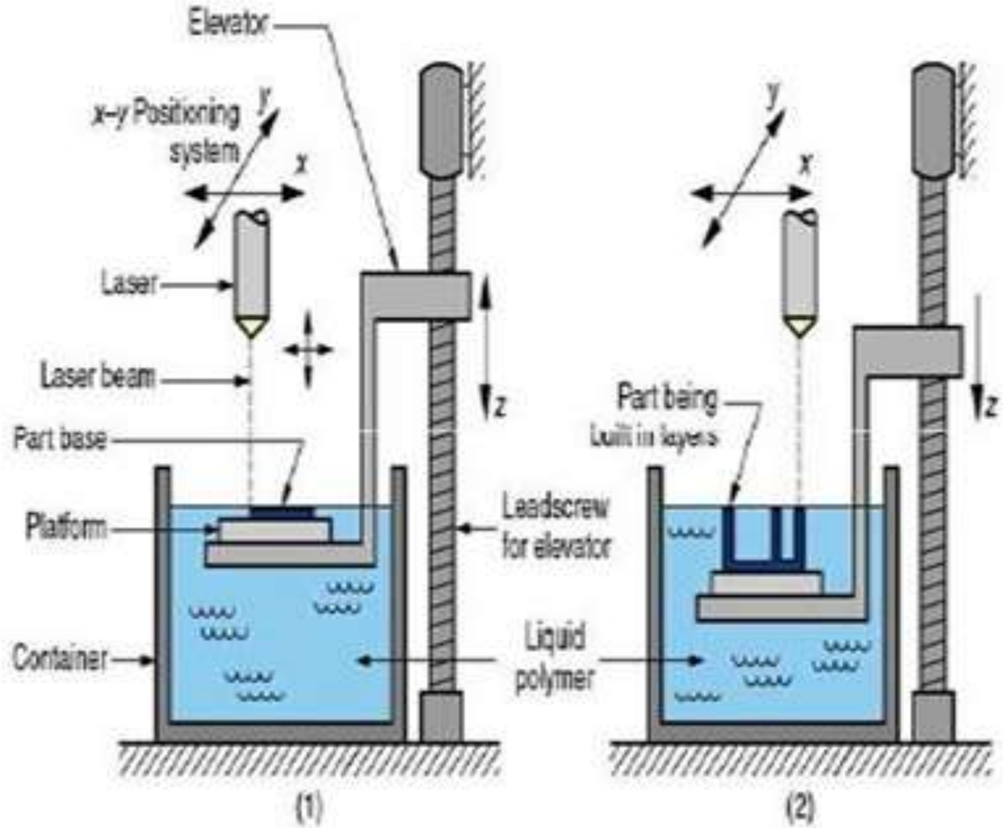
	1D Channel	2x1D Channels	Array of 1D Channels	2D Channel
Liquid Polymer	SLA (3D Sys)	Dual beam SLA (3D Sys)	Objet	Envisiontech MicroTEC
Discrete Particles	SLS (3D Sys), LST (EOS), LENS Phenix, SDM	LST (EOS)	3D Printing	DPS
Molten Mat.	FDM, Solidscape		ThermoJet	
Solid Sheets	Solido PLT (KIRA)			

. Liquid Polymer Systems

The first commercial system was the 3D Systems Stereo lithography process based on liquid photopolymers. A large portion of systems in use today are, in fact, not just liquid polymer systems but more specifically liquid photopolymer systems. However, this classification should not be restricted to just photopolymers, since a number of experimental systems are using hydrogels that would also fit into this category.

Using this material and a 1D channel or 2X1D channel scanning method, the best option is to use a laser like in the Stereo lithography process. Droplet deposition of polymers using an array of 1D channel can simplify the curing process to a floodlight (for photopolymers) or similar method.

Stereo lithography



•One of the most important additive manufacturing technologies currently available.
•The first ever commercial RP systems were **resin-based systems** commonly called stereo lithography or SLA.
•The resin is a liquid photosensitive polymer that cures or hardens Stereo lithography when exposed to **ultraviolet radiation**.
•This technique involves the curing or solidification of a liquid photosensitive polymer through the use of the irradiation light source.

- The source supplies the energy that is needed to induce a chemical reaction (curing reaction), bonding large no of small molecules and forming a highly cross-linked polymer.
- The UV light comes from a laser, which is controlled to scan across the surface according to the cross-section of the part that corresponds to the layer.
- The laser penetrates into the resin for a short distance that corresponds to the layer thickness.
- The first layer is bonded to a platform, which is placed just below the surface of the resin container.
- The platform lowers by one-layer thickness and the scanning is performed for the next layer. This process continues until the part has been completed.

b. Discrete Particle Systems

Discrete particles are normally powders that are generally graded into a relatively uniform particle size and shape and narrow size distribution. The finer the particles the better, but there will be problems if the dimensions get too small in terms of controlling the distribution and dispersion. Again, the conventional 1D channel approach is to use a laser, this time to produce thermal energy in a controlled manner and, therefore, raise the temperature sufficiently to melt the powder.

Polymer powders must therefore exhibit thermoplastic behavior so that they can be melted and re- melted to permit bonding of one layer to another. There are a wide variety of such systems that generally differ in terms of the material that can be processed.

The two main polymer-based systems commercially available are the **SLS technology** marketed by 3D Systems and the **EOSint processes** developed by the German company EOS.

Application of printer technology to powder beds resulted in the (original) 3D printing (3DP) process.

Droplet printing technology is used to print a binder, or glue, onto a powder bed. The glue sticks the powder particles together to form a 3D structure. This basic technique has been developed for different applications dependent on the type of powder and binder combination. The most successful approaches use low-cost, starch- and plaster- based powders with inexpensive glues, as commercialized by ZCorp, USA, which is now part of 3D Systems. Ceramic powders and appropriate binders as similarly used in the Direct Shell Production Casting (DSPC) process used by Soligen as part of a service to create shells for casting of metal parts.

c. Molten Material Systems

Molten material systems are characterized by a pre-heating chamber that raises the material temperature to melting point so that it can flow through a delivery system. The most well-known method for doing this is the Fused Deposition Modeling (FDM) material extrusion technology developed by the US Company Stratasys. This approach extrudes the material through a nozzle in a controlled manner. Two extrusion heads are often used so that support structures can be fabricated from a different material to facilitate part cleanup and removal.

A single jet piezoelectric deposition head lays down wax material. Another head lays down a second wax material with a lower melting temperature that is used for support structures. The droplets from these print heads are very small so the resulting parts are fine in detail. To further maintain the part precision, a **planar cutting process** is used to level each layer once the printing has been completed. Supports are removed by inserting the complete part into a temperature-controlled bath that melts the support material away, leaving the part material intact. The use of wax along with the precision of Solidscape machines makes this approach ideal for precision casting applications like jewelry, medical devices, and dental castings. Few machines are sold outside of these niche areas.

The 1D channel approach, however, is very slow in comparison with other methods and applying a parallel element does significantly improve throughput. The **ThermoJet technology** from 3D Systems also deposits a wax material through droplet-based printing heads. The use of parallel print heads as an array of 1D channel effectively multiplies the deposition rate. The ThermoJet approach, however, is not widely used because wax materials are difficult and brittle when handled. ThermoJet machines are no longer being made, although existing machines are commonly used for investment casting patterns.

d. Solid Sheet Systems

One of the earliest AM technologies was the Laminated Object Manufacturing (LOM) system from Helisys, USA. This technology used a laser to cut out profiles from sheet paper, supplied from a continuous roll, which formed the layers of the final part. Layers were bonded together using a heat- activated resin that was coated on one surface of the paper. Once all the layers were bonded together the result was very much like a wooden block. A hatch pattern cut into the excess material allowed the user to separate away waste material and reveal the part.

Post processing of AM parts

What is post-processing?

Post-processing is an essential stage of additive manufacturing. It's the last step in the manufacturing process, where parts receive finishing touches such as smoothing and painting.

Why is post-processing important?

Post-processing improves the **QUALITY** of parts and ensures that they meet their **design specifications**. The finishing process can enhance a part's **Surface Characteristics, Geometric Accuracy, Aesthetics, Mechanical Properties**, and more.

A metal additive manufacturing (AM) part is essentially "welded" to the build plate, and you will not be able to pull it off without some assistance. Even then, the AM part will need post processing before it is ready to use. Here are some costs associated with post processing AM parts.

Powder Removal: AM parts build "down" in a powder-bed fusion system as new layers are added to the top, which means that parts are covered in powder when they are done. After the build has finished and the parts/build plate has cooled, the machine operator has to remove all of the powder from the build volume and sieve/filter/recycle it for later use, assuming you want to reuse it. This is not an expensive step, but it does take time.

Stress Relief: The heating and cooling of the metal as the part builds layer-by-layer leads to internal stresses that must be relieved before the part is removed from the build plate. Otherwise, the part may warp or even crack. Stress-relieving the part requires an oven or furnace (preferably with environmental controls) that is big enough to fit the entire build plate. Many recommend using an oven with an inert environment to minimize oxidation on the part surface. Others prefer a vacuum furnace, which costs a lot more.

Part Removal: Most companies use wire EDM to remove parts from the build plate, however many machine shops are starting to use a band saw because it is faster and the bottoms of the parts must be finished anyway. Keep in mind that materials such as Inconel strain-harden as they are worked, making it difficult to remove them from the build plate with just a band saw.

Heat Treatment: Heat treatment (aging, solution annealing and so on) improves the microstructure and mechanical properties of the parts and is necessary for nearly all AM parts. In many cases, this step also requires an environmentally controlled furnace with the ability to regulate the temperature and cool-down schedule. The heat treatment may affect the dimensions of the parts, so most people prefer to heat-treat parts before they machine/finish them. The American Society for Testing and Materials (ASTM) just released a standard for thermal post-processing of metal AM parts. Heat treatment is depending on the material and how many parts are being treated.

Hot Isostatic Pressing: Instead of heat treatment, many aerospace companies are starting to use hot isostatic pressing (HIP), which is frequently used in the casting industry to improve the fatigue life of cast parts. A HIP system costs substantially more than a furnace/oven and comes with its own safety measures due to the high pressures (100 megapascals or more) at which it operate.

Machining: Machining of mating Interfaces, Surfaces, Threads, Support Structures and more likely will be required to ensure dimensional accuracy of the finished part. Few AM parts meet specifications "as built," and if nothing else, the surface of the part that was connected to the build plate will need to be finished. Most manufacturing companies already have machining systems on hand, but registering parts and establishing data for machining can be tricky, especially for complex, organically shaped parts made with AM. Accessing internal channels or cooling passages that need to be machined can also increase costs. The cost here is highly dependent on the material and the job as well as the featuring needed to hold the part.

Surface Treatments: Surface finishing also might be required to improve surface finish/quality, reduce surface roughness, clean internal channels or remove partially melted particles on a part. When outsourced, these costs can easily run in the hundreds if not thousands of dollars

Inspection and Testing: Metrology, inspection and nondestructive testing using white/blue-light scanning, dye-penetrate testing, ultrasonic testing, computed tomography (CT) scanning and more will be needed after post processing and possibly at multiple points during post processing. Destructive testing of sample parts and analysis of witness coupons (for example, tensile bars), powder chemistry, material microstructure and more also may be needed to gather data to help with process qualification and ultimately part certification. Most companies will have a range of metrology and non-destructive testing methods on hand, but AM parts with internal channels, lattice structures and other internal enhancements may require CT scanning to ensure clear passageways, evaluation of internal geometries and more.

GUIDELINES FOR PROCESS SELECTION

INTRODUCTION

The initial purpose of rapid prototyping technology was to create parts as a means of visual and demonstrative communication. Since those early days of rapid prototyping, the applications of additive manufacturing processes have expanded considerably. According to **Wohlers and Associates**, parts from AM machines are used for a number of purposes, including:

a) Visual Aids
b) Presentation models
c) Functional models
d) Fit and assembly
e) Patterns for prototype tooling
f) Patterns for metal castings
g) Tooling components
h) Direct digital/rapid manufacturing

AM processes, like all materials processing, are constrained by material properties, speed, cost, and accuracy. The performance capabilities of materials and machines lag behind conventional manufacturing technology (e.g., injection molding machinery), although the lag is decreasing. Speed and cost, in terms of time to market, are where AM technology contributes, particularly for complex or customized geometries.

With the growth of AM, there is going to be increasing demand for software that supports making decisions regarding which machines to use and their capabilities and limitations for a specific part design. **In particular, software systems can help in the decision-making process for the capital investment of new technology**, providing accurate estimates of cost and time for quoting purposes, and assistance in process planning.

Selection Methods for a Part

- **Decision Theory**

Decision theory has a rich history, evolving in the 1940s and 1950s from the field of economics. Although there are many approaches taken in the decision theory field, the focus in this chapter will be only on the **utility theory approach**. Broadly speaking, there are three elements of any decision.

- Options – Items from which the decision maker is selecting
- Expectations – Possible outcomes for each option
- Preferences – How the decision maker values each outcome.

Assume that the set of decision **options** is denoted as A= {A_1, A_2,... ., A_n}. In engineering applications, one can think of outcomes as the performance of the options as measured by a set of evaluation criteria. More specifically, in AM selection, an outcome might consist of the time, cost, and surface finish of a part built using a certain AM process, while the AM process itself is the option.

Expectations of outcomes are modeled as functions of the options, X=g(A), and may be modeled with associated uncertainties.

Preferences model the importance assigned to outcomes by the decision maker. For example, a designer may prefer low cost and short turn-around times for a **concept model**, while being willing to accept a poor surface finish.

In **utility theory**, preferences are modeled as utility functions on the expectations. Expectations are then modeled as expected utility. The best alternative is the one with the greatest expected utility.

Selection the indication of preference, based on multiple attributes, for one among several alternatives.

Compromise the improvement of an alternative through modification **Coupled and hierarchical decisions** that are linked together, such as selection–selection, compromise–compromise, or selection–compromise.

The selection problems are divided into two related sub-problems. The first sub problem is referred to as "**Determining Feasibility**," while the second is simply called "**Selection**."

Approaches to Determining Feasibility

The problem of **identifying suitable materials and AM machines** with which to fabricate a part is surprisingly complex. As noted previously, there are many possible applications for an AM part. For each application, one should consider the suitability of **available materials, fabrication cost and time, surface finish and accuracy requirements, part size, feature sizes, mechanical properties, resistance to chemicals**, and other application-specific considerations. To complicate matters, the number and capability of commercial materials and machines continue to increase. So, in order to solve the AM machine and process chain selection problems.

To date, most approaches to determining feasibility have taken a **knowledge-based approach** in order to deal with the qualitative information related to AM process capability. One of the better-developed approaches was presented by **Deglin and Bernard**. Their **approach utilized two reasoning methods**, **case-based and the bottom-up generation of processes;** the strengths of each compensated for the other's weaknesses.

A group at the **National University of Singapore (NUS)** developed an AM decision system that was integrated with a database system. **Their selection system was capable of identifying feasible material/machine combinations, estimating manufacturing cost and time, and determining optimal part orientations.** From the feasible material/machines, the user can then select the most suitable combination. Their approach to determining feasible materials and processes is broadly similar to the work of Deglin and Bernard.

One was developed at the **Helsinki University of Technology**. Through **a series of questions, the selector acquires information about the part accuracy, layer thickness, geometric features, material, and application requirements.** The user chooses one of 4–5 options for each question.

Approaches to Selection

As stated earlier, there have been a number of approaches taken to support the selection of AM processes for a part. Most aid selection, but only in a qualitative manner, as described earlier. **Several methods have been developed in academia that is based on the large literature on decision theory.**

While the basic advantages of using **Decision Support Problem (DSPs**) of any type lie in providing **context and structure** for engineering problems, regardless of complexity, they also facilitate the recording of viewpoints associated with these decisions, for completeness and future reference, and evaluation of results through post solution sensitivity analysis. The standard Selection DSP has been applied to many engineering problems and has recently been applied to AM selection. Note that the decision options for AM selection are feasible material-process combinations.

Expectations are determined by **rating the options** against the attributes. **Preferences** are modeled using **simple importance values.**

Rank ordering of options is determined using a weighted-sum expression of importance and attribute ratings. An extension to include utility theory has recently been accomplished, as described next.

CHALLENGES OF SELECTION

Different users will require different things from an AM machine. Machines vary in terms of cost, size, a range of materials, an accuracy of a part, time of build, etc. It is not surprising to know that the more expensive machines provide the wider range of options and, therefore, it is important for someone looking to buy a new machine to be able to understand the costs vs. the benefits so that it is possible to choose the best machine to suit their needs.

Approaching a manufacturer or distributor of AM equipment is one way to get information concerning the specification of their machine. Such companies are obviously biased towards their own product and, therefore, it is going to be difficult to obtain truly objective opinions. **Conventions and exhibitions** are a good way to make comparisons, but it is not necessarily easy to identify the usability of machines. Contacting existing users is sometimes difficult and time-consuming, but they can give very honest opinions. This approach works best if you are already equipped with background information concerning your proposed use of the technology.

When looking for advice about suitable selection methods or systems, it is useful to consider the following points.

a) The information in the system should be unbiased wherever possible.
b) The method/system should provide support and advice rather than just a quantified result.
c) The method/system should provide an introduction to AM to equip the user with background knowledge as well as advice on different AM technologies.
d) A range of options should be given to the user in order to adjust requirements and show how changes in requirements may affect the decision.
e) The system should be linked to a comprehensive and up-to-date database of AM machines.
f) Once the search process has completed, the system should give guidance on where to look next for additional information.

AM Applications

Rapid Prototyping: Models and parts for research purposes can be easily manufacture whenever required. Easy to make changes in the models as per the research proceedings.

- **Food:** making food items such as chocolates, candy, pasta, pizza using 3D printing technique .
- **Apparel:** Products such as customize shoes, clothes and eye wears are being manufactured.
- **Vehicle:** car whose whole body was 3D printed
- **Firearms:** Defense arms such as guns, rifles and safety equipment has also been manufacture by AM.
- **Medical:** medical devices, specific implants, hearing aids, dental products and medicines are being manufacture by AM.

•**Bioprinting**

Bioprinting refers to manufacturing artificial biological organs and body parts capable of working like original ones.

In this process, **layers of living cells** are deposited onto a gel medium or sugar matrix and slowly built up to form three dimensional structures including **vascular systems.**

In 2013, Chinese scientists began printing ears, livers, and kidneys, with living tissue.

In 2014, researchers at the University of Hasselt, in Belgium had successfully printed a new jawbone for an 83-year-old woman.

•**Space**

In September 2014, “SpaceX” delivered the first zero gravity 3D printers to the International Space Station (ISS).

In December 2014, NASA emailed CAD drawings for a socket wrench to astronauts aboard the ISS, who then printed the tool using its 3D printer.

The European Space Agency delivered its new advance Portable Onboard 3D Printer to the International Space Station in the end of 2015.

Assignment questions

1. Define additive manufacturing (AM)?
2. Distinguish between AM and CNC.
3. List applications and advantages of CNC.
4. List and explain stages of AM.
5. Classify AM Process, explain any one in each processes.
6. Explain post-processing of AM part.
7. Explain guideline for process selection.
8. Explain applications of AM in different areas.

MODULE 2

SYSTEM DRIVES, DEVICES, AND ACTUATORS

CONTENT:

System Drives and devices: Hydraulic and pneumatic motors and their features, Electrical motors AC/DC and their features

Actuators: Electrical Actuators; Solenoids, Relays, Diodes, Thyristors, Triacs, Hydraulic, and Pneumatic actuators, Design of Hydraulic and Pneumatic circuits, Piezoelectric actuators, Shape memory alloys.

SYSTEM DRIVES, DEVICES, AND ACTUATORS

A **System Drives** is a complex combination of various components that can be defined as systems where perception, decision making, and operation of the automobile are performed by electronics and machinery instead of a human driver, and as an introduction of automation into road traffic. This includes handling of the vehicle, destination, as well as awareness of surroundings. While the automated system has control over the vehicle, it allows the human operator to leave all responsibilities to the system.

The device is a thing made or adapted for a particular purpose, especially a piece of mechanical or electronic equipment.

Actuators are those components of a fluid power system, which produces mechanical work output. They develop force and displacement, which is required to perform any specific task. The task may be of any kind, to move, to press, to lift, to clamp. Actuators are common for both hydraulic and pneumatic systems.

HYDRAULIC MOTORS AND THEIR FEATURES

Hydraulic motors

Hydraulic motors are rotary actuators. However, the name rotary actuator is reserved for a particular type of unit that is limited in rotation to less than 360°. A hydraulic motor is a device which converts fluid power into rotary power or converts fluid pressure into torque. Torque is a function of pressure or, in other words, the motor input pressure level is determined by the resisting torque at the output shaft. A hydraulic pump is a device which converts mechanical force and motion into fluid power. A hydraulic motor is not a hydraulic pump when running backward. A design that is completely acceptable as a motor may operate very poorly as a pump in certain applications. Differences between a hydraulic motor and a hydraulic pump are given in Table.

DIFFERENCES BETWEEN A HYDRAULIC MOTOR AND A HYDRAULIC PUMP

Hydraulic Motor	Hydraulic Pump
It is a device for delivering torque at a given pressure.	It is a device for delivering flow at a given pressure.
The main emphasis is on mechanical efficiency and torque that can be transmitted.	The main emphasis is on volumetric efficiency and flow.
Motors usually operate over a wide range of speed, from a low RPM to high RPM	Pumps usually operate at high RPM.
Most designed for bidirectional applications such as braking loads, rotary tables.	In most situations, pumps usually operate in one direction.
Motors may be idle for a long time	Pumps usually operate continuously.
Motors are subjected to high side loads (from gears, chains, belt-driven pulleys).	The majority of pumps are not subjected to side loads. Usually, pumps are pad mounted on power pack top and shaft is connected to the prime mover directly.

Comparison between a Hydraulic Motor and an Electric Motor

Electric Motor	Hydraulic Motor
Electric motors cannot be stopped instantly. Their direction of rotation cannot be reversed instantly. This is because of the air gap between the rotor and the stator and the weak magnetic field.	Hydraulic motors can be stalled for any length of time. Their direction of rotation can be instantly reversed and their rotational speed can be infinitely varied without affecting their torque. They can be braked instantly and have immense torque capacities.
Electric motors are heavy and bulky.	Hydraulic motors are very compact compared to electric motors. For the same power, they occupy about 25% of the space required by electric motors and weigh about 10% of electric motors.
Moment of an inertia-to-torque ratio is nearly 100.	Moment of an inertia-to-torque ratio is nearly 1.

Applications

Hydraulic motors have become popular in industries. Hydraulic motors can be applied directly to the work. They provide excellent control for acceleration, operating speed, deceleration, smooth reversals, and positioning. They also provide flexibility in design and eliminate much of the bulk and weight of mechanical and electrical power transmission. The applications of hydraulic motors in their various combinations with pumping units are termed hydrostatic transmission.

A hydrostatic transmission converts mechanical power into fluid power and then reconverts fluid power into shaft power. The advantages of hydrostatic transmissions include power transmission to remote areas, infinitely variable speed control, self-overload protection, reverse rotation capability, dynamic braking, and a high power-to-weight ratio. Applications include material-handling equipment, farm tractors, railway locomotives, buses, lawnmowers, and machine tools.

New fields of application are being discovered constantly for hydrostatic transmissions. Farm implements, road machinery, material-handling equipment, Numerical Control (NC) machines high-performance aircraft, military uses, and special machinery are only a few new fields expanding through the use of fluid power transmission. Many automobiles, railway locomotives, and buses use a hydrostatic transmission.

Classification of Hydraulic Motors

There are two types of hydraulic motors:

(a) High-speed low-torque motors and

(b) low–speed high-torque motors.

In high-speed low-torque motors, the shaft is driven directly from either the barrel or the cam plate, whereas in low-speed high-torque motors, the shaft is driven through a differential gear arrangement that reduces the speed and increases the torque. Depending upon the mechanism employed to provide shaft rotation, hydraulic motors can be classified as follows:

- Gear motors
- Vane motors
- Piston motors
- Axial piston-type motors.
- Radial piston-type motors.

Gear motors are the least efficient, most dirt-tolerant and have the lowest pressure rating of 3. Piston motors are the most efficient, least dirt-tolerant and have high-pressure ratings. Vane and piston motors can be fixed or variable displacement, but gear motors are available with only fixed displacement.

Gear Motor: A gear motor develops torque due to hydraulic pressure acting against the area of one tooth. Two teeth are trying to move the rotor in the proper direction, while one net tooth at the center mesh tries to move it in the opposite direction. In the design of a gear motor, one of the gears is keyed to an output shaft, while the other is simply an idler gear. Pressurized oil is sent to the inlet port of the motor. The pressure is then applied to the gear teeth, causing the gears and output shaft to rotate. The pressure builds until enough torque is generated to rotate the output shaft against the load. The side load on the motor bearing is quite high because all the hydraulic pressure is on one side. This limits the bearing life of the motor. The schematic diagram of the gear motor is shown in Fig.

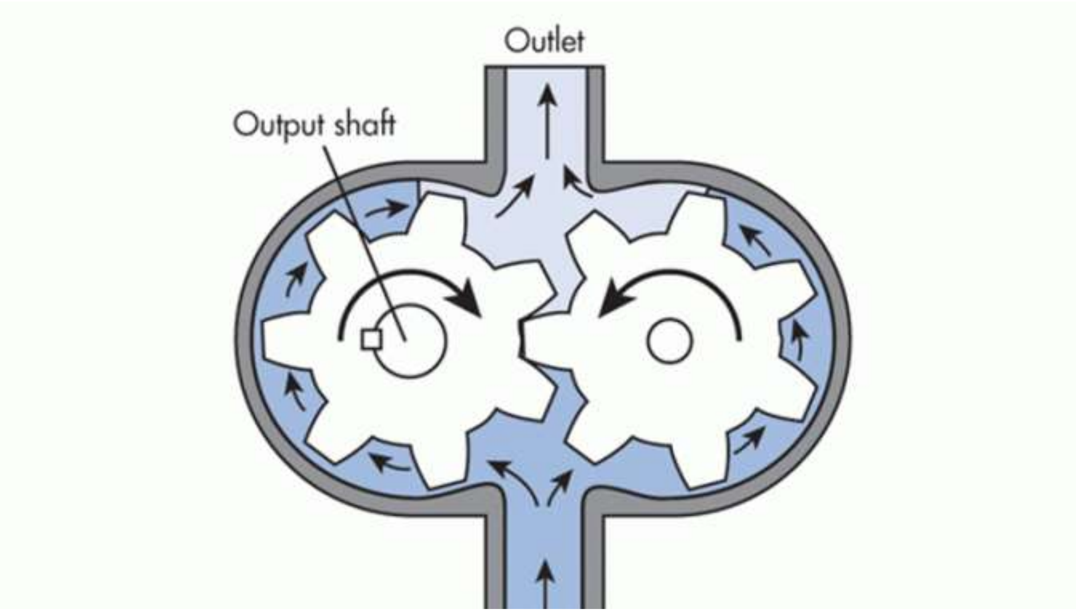


Fig: schematic diagram of the gear motor

Most of the gear motors are bidirectional. Reversing the direction of flow can reverse the direction of rotation. As in the case of gear pumps, volumetric displacement is fixed. Due to the high pressure at the inlet and low pressure at the outlet, a large side load on the shaft and bearings is produced. Gear motors are normally limited to 150 bar operating pressures and 2500 RPM operating speed. They are available with a maximum flow capacity of 600 LPM. The gear motors are simple in construction and have good dirt tolerance, but their efficiencies are lower than those of vane or piston pumps and they leak more than the piston units. Generally, they are not used as servo motors. Hydraulic motors can also be of internal gear design. These types can operate at higher pressures and speeds and also have greater displacements than external gear motors.

Vane Motor

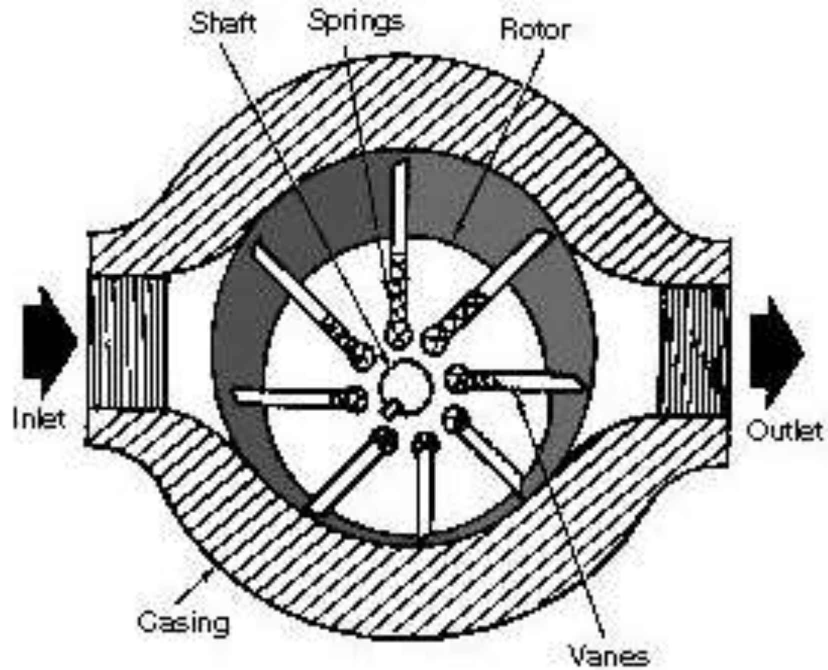


Figure: unbalanced vane motor

Figure shows an unbalanced vane motor consisting of a circular chamber in which there is an eccentric rotor carrying several spring or pressure-loaded vanes. Because the fluid flowing through the inlet port finds more area of vanes exposed in the upper half of the motor, it exerts more force on the upper vanes, and the rotor turns counterclockwise. Close tolerances are maintained between the vanes and ring to provide high efficiencies.

The displacement of a vane hydraulic motor is a function of eccentricity. The radial load on the shaft bearing of an unbalanced vane motor is also large because all its inlet pressure is on one side of the rotor.

The radial bearing load problem is eliminated in this design by using a double-lobed ring with diametrically opposite ports. Side force on one side of a bearing is canceled by an equal and opposite force from the diametrically opposite pressure port. The like ports are generally connected internally so that only one inlet and one outlet port are brought outside. The balanced vane-type motor is a reliable open-loop control motor but has more internal leakage than piston-type and therefore generally not used as a servo motor.

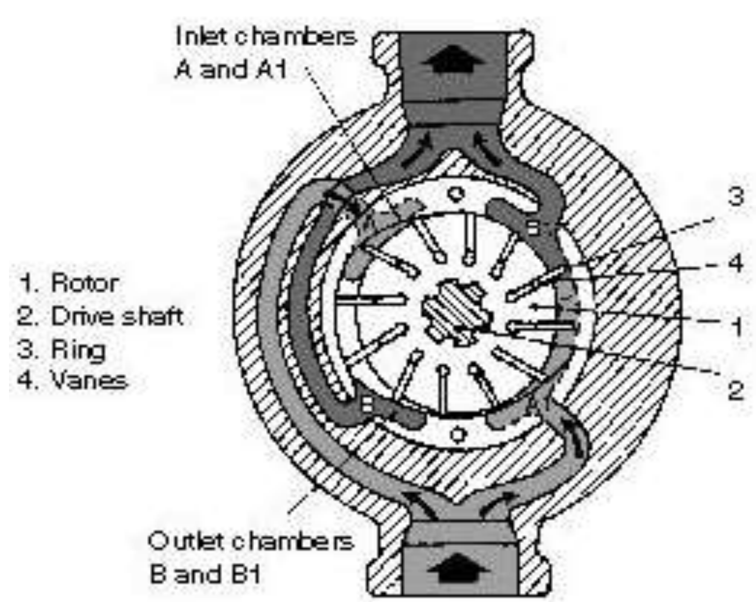


Figure: balanced vane motor.

Piston Motors

Piston motors are classified into the following types

- According to the piston of the cylinder block and the drive shaft, piston motors are classified as follows:
    - Axial piston motors.
    - Radial piston motors.

- According to the basis of displacement, piston motors are classified as follows:
    - Fixed-displacement piston motors.
    - Variable-displacement piston motors.

Axial Piston Motors

In axial piston motors, the piston reciprocates parallel to the axis of the cylinder block. These motors are available with both fixed-and variable-displacement feature types. They generate torque by pressure acting on the ends of pistons reciprocating inside a cylinder block.

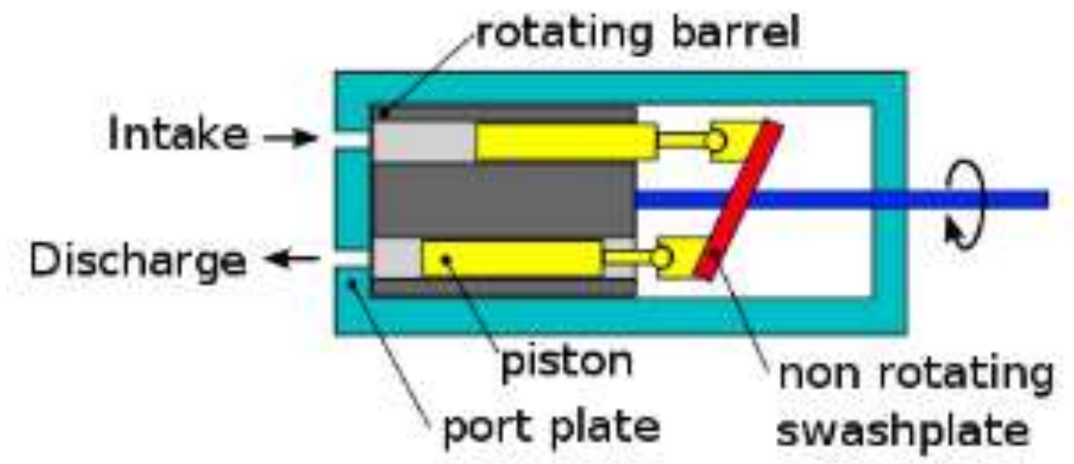


Figure: Inline piston motor

The figure illustrates the inline design in which the motor, driveshaft and cylinder block are centered on the same axis. The pressure acting on the ends of the piston generates a force against an angled swashplate. This causes the cylinder block to rotate with a torque that is proportional to the area of the pistons. The torque is also a function of the swash-plate angle. The inline piston motor is designed either as a fixed or a variable-displacement unit. The swashplate determines the volumetric displacement.

In variable-displacement units, the **swashplate** is mounted on the swinging yoke. The angle can be varied by various means such as a lever, handwheel or servo control. If the offset angle is increased, the displacement and torque capacity increase but the speed of the drive shaft decreases. Conversely, reducing the angle reduces the torque capability but increases the drive shaft speed.

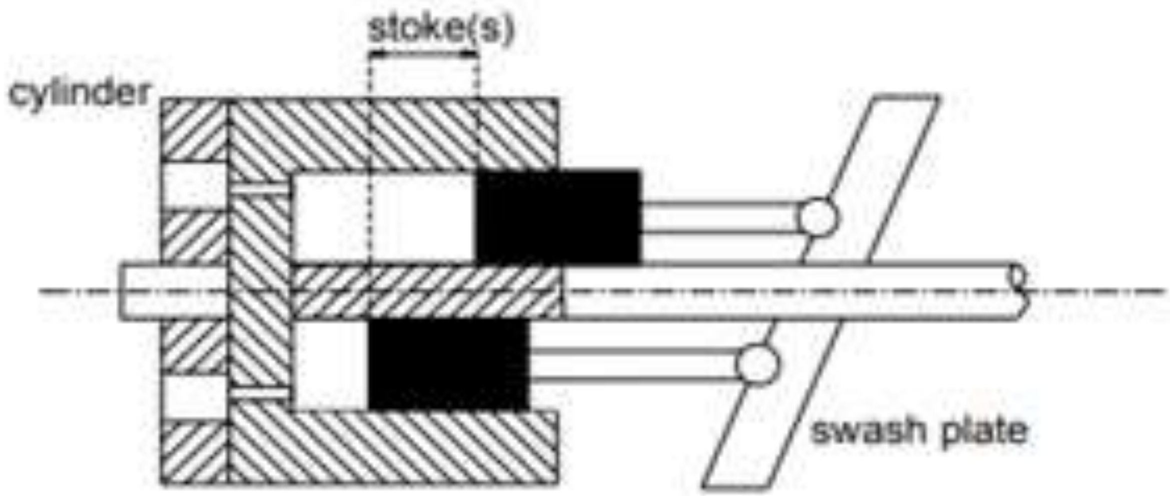


Fig: swashplate

Bent-Axis Piston Motors

A bent-axis piston motor is shown in Fig. This type of motor develops torque due to pressure acting on the reciprocating piston. In this motor, the cylinder block and driveshaft mount at an angle to each other so that the force is exerted on the drive shaft flange.

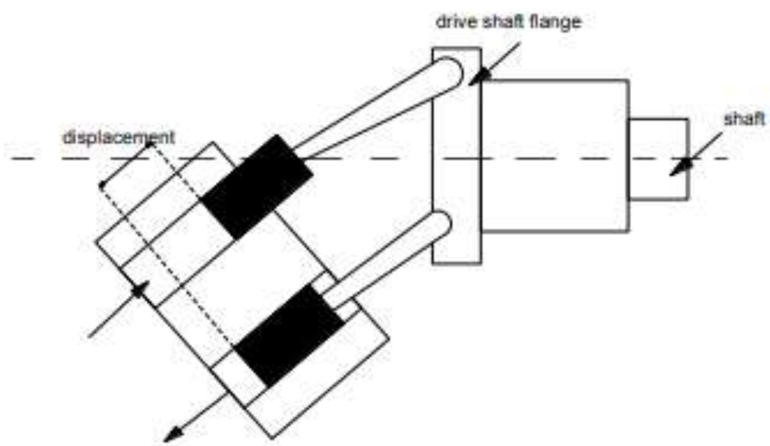


Figure: Inline piston motor

Speed and torque depend on the angle between the cylinder block and the drive shaft. The larger the angle, the greater the displacement and torque, and the smaller the speed. This angle varies from 7.5° (minimum) to 30° (maximum). This type of motor is available in two types, namely fixed-displacement type, and variable-displacement type.

Radial Piston Motors

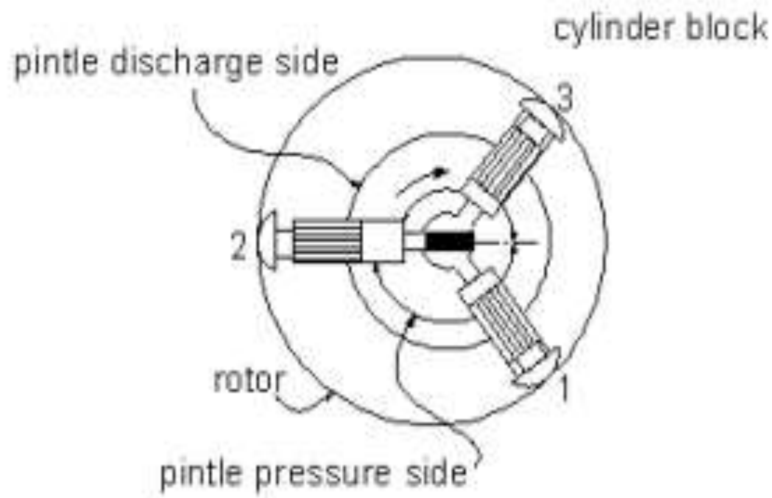


Figure: Radial piston motor

In radial piston-type motors, the piston reciprocates radially or perpendicular to the axis of the output shaft. The basic principle of operation of the radial piston motors is shown in Fig. Radial piston motors are low-speed high-torque motors that can address a multifarious problem in diverse power transfer applications.

PNEUMATIC MOTORS AND THEIR FEATURES

Pneumatic motor

A pneumatic motor (air motor) or compressed air engine is a type of motor which does mechanical work by expanding compressed air. Pneumatic motors generally convert the compressed air energy to mechanical work through either linear or rotary motion. Linear motion can come from either a diaphragm or piston actuator, while rotary motion is supplied by either a vane type air motor, piston air motor, air turbine or gear type motor.

Pneumatic motors have existed in many forms over the past two centuries, ranging in size from hand-held motors to engines of up to several hundred horsepower's (HP). Some types rely on pistons and cylinders; others on slotted rotors with vanes (vane motors) and others use turbines. Many compressed air engines improve their performance by heating the incoming air or the engine itself. Pneumatic motors have found widespread success in the hand-held tool industry, but are also used stationary in a wide range of industrial applications. Continual attempts are being made to expand their use to the transportation industry. However, pneumatic motors must overcome inefficiencies before being seen as a viable option in the transportation industry.

Classification of linear Pneumatic Motors

To achieve linear motion from compressed air, a system of pistons is most commonly used. The compressed air is fed into an air-tight chamber that houses the shaft of the piston. Also inside this chamber, a spring is coiled around the shaft of the piston to hold the chamber completely open when the air is not being pumped into the chamber. As air is fed into the chamber the force on the piston shaft begins to overcome the force being exerted on the spring. As more air is fed into the chamber, the pressure increases and the piston begin to move down the chamber. When it reaches its maximum length the air pressure is released from the chamber and the spring completes the cycle by closing off the chamber to return to its original position.

Piston motors are the most commonly used in hydraulic systems. Essentially, piston motors are the same as hydraulic motors except they are used to convert hydraulic energy into mechanical energy. Piston motors are often used in series of two, three, four, five, or six cylinders that are enclosed in the housing. This allows for more power to be delivered by the pistons because several motors are in sync with each other at certain times of their cycle.

Rotary vane motors

A type of pneumatic motor, known as a rotary vane motor, uses air to produce rotational motion to a shaft. The rotating element is a slotted rotor that is mounted on a drive shaft. Each slot of the rotor is fitted with a freely sliding rectangular vane. The vanes are extended to the housing walls using springs, cam action, or air pressure, depending on the motor design. Air is pumped through the motor input which pushes on the vanes creating the rotational motion of the central shaft. Rotation speeds can vary between 100 and 25,000 rpm depending on several factors which include the amount of air pressure at the motor inlet and the diameter of the housing.

One application for vane-type air motors is to start large industrial diesel or natural gas engines. Stored energy in the form of compressed air, nitrogen or natural gas enters the sealed motor chamber and exerts pressure against the vanes of a rotor. This causes the rotor to turn at a high speed. Because the engine flywheel requires a great deal of torque to start the engine, reduction gears are used. Reduction gears create high torque levels with lower amounts of energy input. These reduction gears allow for sufficient torque to be generated by the engine flywheel while it is engaged by the pinion gear of the air motor or air starter.

Rotary vane motors normally are used in applications requiring low- to medium-power outputs.

•Simple and compact vane motors most often drive portable power tools, but certainly are used in a host of mixing, driving, turning, and pulling applications as well.

•The vanes are biased to seal against the housing interior wall by springs, cam action, or air pressure, depending on the design.

•The centrifugal force that develops when the rotor turns aids this sealing action.

•Torque develops from pressure acting on one side of the vanes.

•Torque at the output shaft is proportional to the exposed vane area, the pressure, and the moment arm (radius from the rotor centerline to the center of the exposed vane) through which the pressure acts.

). PNEUMATIC VANE MOTORS

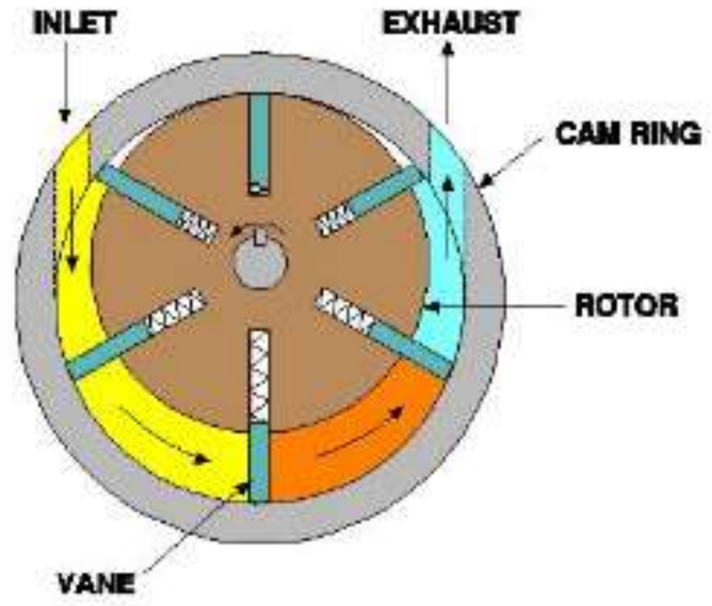


Fig: Pneumatic Vane Motors

- In the slot, there are generally 3 to 10 vanes.
- To enable the vanes to come out of the slots they are designed with compression spring or pressure air.
- For motors equipped with an even number of vanes, a connecting pin links diametrically opposite vanes so that as the bore surface pushes one vane in, the pin pushes the other vane.
- But leakage probability will be there when the vane tip wears out.
- Vane motors run at 100 to 25,000 rpm.

PNEUMATIC PISTON TYPE MOTORS

•Piston air motors are used in applications requiring high power, high starting torque, and accurate speed control at low speeds.

•They have either two, three, four, five, or six cylinders arranged either axially or radially within housing.

•Output torque is developed by pressure acting on pistons that reciprocate within the cylinders.

•The power developed by a piston motor depends on the inlet pressure, the number of pistons, and piston area, stroke, and speed.

Radial and axial-piston motors have one significant limitation: they are internally lubricated, so oil and grease supplies must be checked periodically and replenished.

Radial-piston motors:

- Feature robust, oil-lubricated construction and are well-suited to continuous operation.
- They have the highest starting torque of any air motor and are particularly beneficial for applications involving high starting loads.
- Overlapping power impulses provide smooth torque in both forward and reverse directions.
- Sizes range to about 35 hp for speeds to 4,500 rpm.

Axial-piston motors

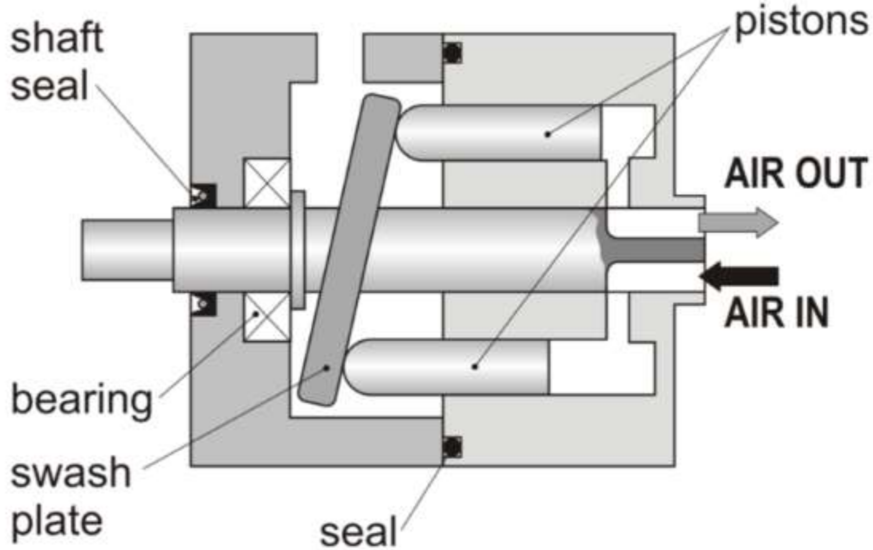


Fig: Axial-piston motors

- Are more compact than radial-piston motors, making them ideal for mounting in close quarters.
- Their design is more complex and costly than vane motors, and they are grease lubricated.
- However, axial-piston motors run smoother and deliver maximum power at much slower speeds than vane motors can.
- Axial- piston motors also tolerate higher ambient temperatures. The maximum size is about 3-1/2 hp.

PNEUMATIC TURBINE MOTORS

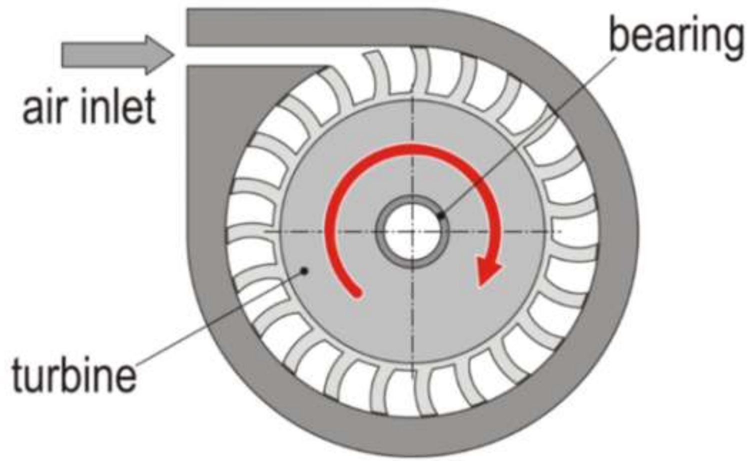


Fig: Turbine Motors

- It converts low-velocity high-pressure air to high-velocity low-pressure air by passing it through metering nozzles.
- A major advantage of this is that there is no rubbing or sliding contact between the rotating parts and the body cavity.
- This reduces wear and lubricated air is not required to seal and lubricant problems.
- The application is advisable only in low ambient temperature because of the lubricant problem.
- These are high-speed low torque motor for the same volume of air than piston vane type.

PNEUMATIC GEROTOR MOTORS

- These gerotor type motor are mostly used for low rpm pressure applications such as 20-30 rpm.
- Hence they may not be suitable for high torque application.

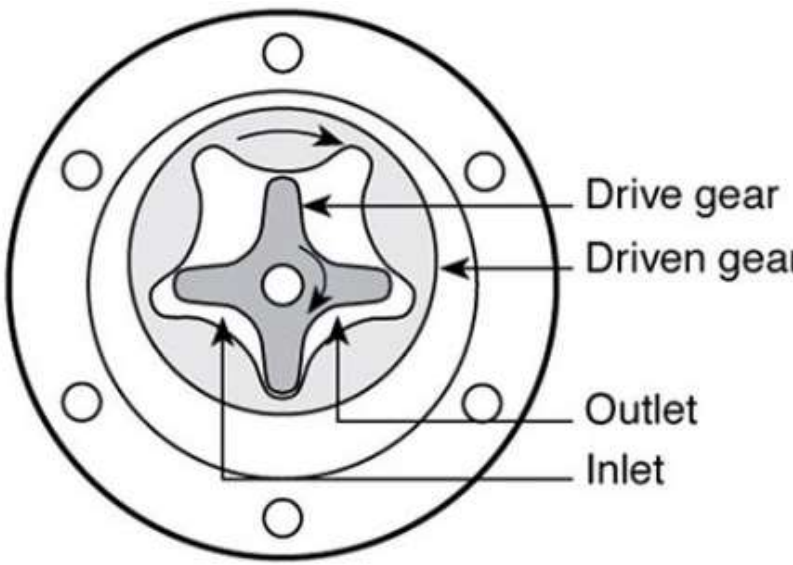


Fig: Gerotor

ADVANTAGES OF AIR MOTORS

•Variable speed. Easy to use.

•Low weight. Inexpensive.

•Stall w/o damage - perfect for conditions where motor works install conditions. Runs cool - especially in overload conditions.

•Explosion Proof

•Instantaneously reverses - except when specifically noted.

APPLICATIONS OF AIR MOTORS

•Construction Engineering. Hand –tools.

•Mining Engineering. Woodworking fields.

•Mechanical applications like hammering, riveting and drilling. Indoor manufacturing plants.

•Mobile/portable equipment at sea or on land. Non-electrical for hazardous locations.

•Emergency back-up to electric motors for critical operations. Outdoor / remote / underwater equipment.

ELECTRICAL MOTORS AC/DC AND THEIR FEATURES

Electrical motors

As we know, an electric motor plays a vital role in every sector of the industry, and also in a wide range of applications. There are a variety of types of electric motors are available in the market. The selection of these motors can be done based on the operation and voltage and applications. Every motor has two essential parts namely the field winding & the armature winding. The main function of field winding is to produce the fixed magnetic field, whereas the armature winding looks like a conductor that is arranged within the magnetic field. Because of the magnetic field, the armature winding uses energy to generate an adequate torque to make the motor shaft turn. Currently, the classification of the DC motor can be done based on the winding connections, which means how the two coils in the motor are connected.

Types of Electric Motors

The types of Electric motors are available in three main segments like AC motor, DC motor, & special purpose motors.

Electric Motors		
DC Motors	**AC Motors**	**Other Motors**
1. DC Shunt Motor	1. Induction Motor	1. Stepper Motor
2. Separately Excited Motor	2. Synchronous Motor	2. Brushless motor
3. DC Series Motor		3. Hysteresis motor
4. PMDC Motor		4. reluctance motor
5. DC Compound Motor		5. universal motor

Module 3

BASIC CONCEPTS: POLYMERS & POWDER METALLURGY

BASIC CONCEPTS: POLYMERS

Introduction to Polymers used for additive manufacturing: polyamide, PF resin, polyesters etc. Classification of polymers, Concept of functionality, Polydispersity and Molecular weight [MW], Molecular Weight Distribution [MWD]

Polymer Processing: Methods of spinning for additive manufacturing: Wet spinning, Dry spinning. Biopolymers, Compatibility issues with polymers. Moulding and casting of polymers, Polymer processing techniques

BASIC CONCEPTS: POWDER METALLURGY

General Concepts: Introduction and History of Powder Metallurgy (PM), Present and Future Trends of PM

Powder Production Techniques: Different Mechanical and Chemical methods, Atomization of Powder, other emerging processes.

Characterization Techniques: Particle Size & Shape Distribution, Electron Microscopy of Powder, Interparticle Friction, Compression ability, Powder Structure, Chemical Characterization

Microstructure Control in Powder: Importance of Microstructure Study, Microstructures of Powder by Different techniques

Powder Shaping:

Particle Packing Modifications, Lubricants & Binders, Powder Compaction & Process Variables, Pressure & Density Distribution during Compaction, Isotactic Pressing, Injection Moulding, Powder Extrusion, Slip Casting, Tape Casting.

Sintering: Theory of Sintering, Sintering of Single & Mixed Phase Powder, Liquid Phase Sintering Modern Sintering Techniques, Physical & Mechanical Properties Evaluation, Structure-Property Correlation Study, Modern Sintering techniques, Defects Analysis of Sintered Components

Application of Powder Metallurgy:

Filters, Tungsten Filaments, Self-Lubricating Bearings, Porous Materials, Biomaterials etc.

POLYMERS

What are Polymers?

A Polymer is a large molecule or a macro molecule which essentially is a combination of many sub units. Polymers are all created by the process of polymerization wherein their constituent elements called **monomers**, are reacted together to form polymer chains i.e 3-dimensional networks forming the polymer bonds. The type of polymerization mechanism used depends on the type of functional groups attached to the reactants. In biological contexts, almost all macro molecules are either completely polymeric or are made up of large polymeric chains.

Examples Of Polymers

As we are aware that polymers are a large molecule made of subunits which are repetitive in nature and are connected through chemical bonds. Even Though, plastic is usual example of polymers, here are few more:

Proteins such as nails, hairs and tortoise shell

In trees and paper, cellulose is a polymer

DNA

cream

Rubber

Graphene

Introduction to Polymers used for additive manufacturing

Polyamide (Nylon 6)

Being a solid material, polyamide powder has the attractive feature of being self-supporting for the generated product sections. This makes support structure unnecessary. Polyamide allows the production of fully functional prototypes or end-use parts with high mechanical and thermal resistance. Polyamide parts have excellent long-term stability and are resistant against most chemicals. They can be made watertight by impregnation. **The PA material used by Materialize is certified as biocompatible and food-safe under certain conditions.**

Polyamides account for the vast majority of 3D prints made on SLS (Selective Laser Sintering) systems. Relatively new to desktop material extrusion polyamide is a tough, durable material that can obtain medical certifications. In desktop 3D printing moisture makes a material that is difficult to print and also to keep. In closed SLS systems, this is not a problem but incorrect storage will degrade powder.

Applications for Polyamides

Fiber applications

- 50% into tire cords (nylon 6 and nylon 6,6)
- rope, thread, cord,belts, and filter cloths.
- Monofilaments- brushes, sports equipment, and bristles (nylon 6,10)

Plastics applications

- bearings, gears, cams
- rollers, slides, door latches, thread guides
- clothing, light tents, shower curtains, umbrellas
- electrical wire jackets (nylon 11)

Adhesive applications

- hot melt or solution type
- thermoset reacting with epoxy or phenolic resins
- flexible adhesives for bread wrappers, dried soup packets, bookbinding:

Phenol formaldehyde resins

Phenol formaldehyde resins are synthetic polymers obtained by the reaction of phenol or substituted phenol with formaldehyde. Used as the basis for Bakelite. They have been widely used for the production of molded products including billiard balls, laboratory countertops, and as coatings and adhesives.

Phenol formaldehyde resins (PFs) are condensation polymers and are obtained by condensing phenol with formaldehyde in the presence of an acidic or alkaline catalyst.

These are thermosetting polymers

Thermosets: The polymers which on heating change irreversibly into hard rigid and infusible materials are called **thermosetting polymers**.

These polymers are usually prepared by heating relatively low molecular mass, semi fluid polymers, which becomes infusible and form an insoluble hard mass on heating. The hardening on heating is due to the formation of extensive cross-linking between different polymeric chains. This lead to the formation of a 3-Dimensional network of bonds connecting the polymer chains. Since the 3D network structure is rigid and does not soften on heating, the thermosetting polymers can not be reprocessed.

Some important examples of thermosetting polymers are Urea-Formaldehyde resin and Melamine-Formaldehyde resins.

Properties:-

Phenol- formaldehyde resins having **low degree** of polymerization are **soft**. They possess excellent adhesive properties and are usually used as bonding glue for laminated wooden planks and in varnishes.

Phenol- formaldehyde resins having **high degree** of polymerization are hard, rigid, scratch-resistant and infusible. They are resistant to non-oxidizing acids, salts and many organic solvents. They can withstand very high temperatures. They act as excellent electrical insulators also.

Uses:-

They are used for making molded articles such as radio and TV parts, combs, fountain pen barrels, phonograph records etc. They are used for making decorative laminates, wall coverings etc. They are used for making electrical goods such as switches, plugs etc. They are used for impregnating fabrics wood and paper. They are used as bonding glue for laminated wooden planks and in varnishes. Sulphonated phenol-formaldehyde resins are use as ion-exchange resins.

Polyesters

Polyester (Terylene) is a category of polymers which contains the ester functional group in their main chain.

Although there are many polyesters, the term "polyester" as a specific material most commonly refers to the Polyethylene Terephthalate(PET).

Polyester can also be classified into two types

1. Saturated polyesters.
2. Unsaturated polyesters.

Saturated polyesters-polyesters in which the polyester backbones are saturated. These are, not as reactive as unsaturated polyesters. They consist of low molecular weight liquids used as plasticizers.

Unsaturated polyesters refer -in which the backbone consists of **alkyl thermosetting resins** characterized by vinyl instauration. They are mostly used in reinforced plastics.

Chemical properties polyester.

•**Effects of moisture:** N Polyester absorbs only a very small amount of moisture and the tenacity and elongation are unaffected by moisture.

•**Effects of bleaches:** Not affected by oxidizing and reducing bleaches.

•**Effects of acids:** Polyester fibers are highly resistant to mineral and organic acids. Weak acid cannot effect on them even on boiling. Strong mineral acid such as H_2SO_4 can only hydrolyze them on boiling for hours together.

•**Effects of alkali:** Polyester is very much resistant to alkalis. Only strong hot alkalis result in a slow thinning of the diameter by saponification.

•**Effects of organic solvents:** Resistant to all dry cleaning solvents.

•**Dye ability:** Disperse dye and some pigments can be used for coloration.

•**Effects of sunlight:** Have good resistance to sunlight but becomes weak when exposing in sunlight for a long time.

Thermal properties of Polyester

Polyester fiber is the most thermally stable synthetic fiber. If heat setting is not done properly then shrinkage occurs. At high-temperature polyester melts and burns.

Softening temperature: 690C

Melting temperature: 250-265°C

Sticking temperature: 230-240°C

Ironing temperature: 1350 C

Thermo plasticity ‘Thermo plasticity’ means capable of being shaped or molded when heated. Thermoplastic fibers heated under strictly controlled temperatures soften and can then be made to conform to a flat, creased or pleated configuration. When cooled, thermoplastic fibers will retain the desired configuration that remains flat, pleated or creased. Polyester textile materials can be permanently heated. Textile fibers classed as thermoplastic are acetate, triacetate, acrylic, nylon, and polyester.

End uses of Polyester

1. **As apparel:** Men's wear, women's wear, children's wear, trousers, skirts, suits, jackets, blouses and every form of clothing are made by polyester fibers.
2. **As blended fabrics:** Polyesters are widely used in blends with cotton, wool, acrylic, nylon etc fibers for making quality fabrics. Blends with cotton and wool are very popular.
3. As **home furnishings**: Carpets, curtains, long curtains, sheets, pillow covers, wall coverings, upholstery etc are made of polyester fibers.
4. As **industrial use**: Polyester fibers are used in the manufacturing of tire cord, power belt, ropes, tarpaulin, nets, hoses, conveyor belt etc. It is also used in making a floppy disk, liners etc.

Classification of Polymers

- By Origin
- By Monomer
- By Thermal Response
- By Mode of Formation
- By Structure
- By Application & Physical Properties
- By Tactility

Concept of functionality

The ability to perform a task or function; that set of functions that something is able or equipped to perform.

Functionality in polymer chemistry

According to International Union of Pure and Applied Chemistry (IUPAC), the functionality of a monomer is defined as the number of bonds that a monomer's repeating unit forms in a polymer with other monomers.

Definition of functionality: the quality or state of being functional a design that is admired both for its beauty and for its functionality especially: the set of functions or capabilities associated with computer software or hardware or an electronic device data management functionalities such as data integrity, security, recoverability, and manageability

Polydispersity

The state of being polydisperse. A measure of the degree to which a colloid is polydisperse. PDI or Polydispersity index is a very important index in Polymer chemistry. for wide molecular weight distribution i.e, if the polymer chain lengths are not uniform in size then PDI will not be close to unity and PDI will be close to unity of the chain lengths are uniform. PDI close to 1, does have a few advantages as well as a few disadvantages as well:

Advantages are Good mechanical properties, good crystalline nature, high impact strength etc.

Disadvantages are Poor processability, High viscosity etc. The reverse is true for polymers having PDI not close to unity.

Molecular weight [MW]

The term molecular weight is commonly used to describe the mass of a polymer molecule. With the advent of advanced detection methods, the meaning of the term has become more obscure as the properties of individual molecules can now be observed. All elements have a defined mass dependent upon their isotopic composition. The atomic mass or less precisely the atomic weight of an element can be defined as the weighted average of all the naturally occurring isotopes using the carbon 12 scale and is given by the formula:

$$M_r = \frac{\sum_{i=1}^{i} A_i \cdot M_i}{\sum_{i=1}^{i} A_i}$$

Where A_i = Abundance of a specific isotope

M_i = Mass of a specific isotope

Molecules (including polymers) are formed by bonding multiple atoms together. The relative molecular mass is equivalent to the atomic mass but it applies to molecules. It is obtained by summing the atomic mass of all of the atoms in the molecule. The molecular weight, molar mass, and relative molecular mass are often used as synonymous terms to describe the weight or mass of a particular type of molecule. The molecular mass is synonymous to the monoisotopic mass of a compound and is specific for one isotope.

Polymers are large molecules formed using a repeating subunit. In most contexts, the molecular weight of a polymer refers to the relative molecular mass. The monoisotopic mass can also be determined in some cases. It is typically observed that monoisotopic composition is reserved for determinations made by LCMS (**Liquid chromatography–mass spectrometry)** while most other methods result in a relative molecular mass.

Polymer Molecular Weight

The term molecular weight as it is applied to polymeric materials implies something different from what is generally meant for small molecules. This is due to the fact that a polymer sample does not have a single molecular weight but rather a range of values (See Jordi white paper “Definition of a Polymer” for more information). In a given sample there may be polymer chains which contain widely different numbers of repeat units. In fact, most polymers contain some residual monomer (Degree of Polymerization “DP” = 1) and some chains which contain several hundred repeat units (DP > 100). These molecules will differ in relative molecular mass by several orders of magnitude.

For this reason, the molecular weight of a polymer is reported using averages. These averages are intended to describe the distribution of molecular weight values for the polymer chains. Three different molecular weight averages are commonly used to provide information about polymers. These are the number average molecular weight (Mn), weight average molecular weight (Mw)and viscosity average molecular weight. In addition, several other averages are used to lesser extents including the Z average molecular weight (Mz) and the Z+1 average molecular weight (Mz+1).

Molecular Weight Distribution [MWD]

A. Molecular Weight Distribution represents the frequency of the polymer lengths
B. The frequency can be Narrow or Broad
C. The narrow distribution represents polymers of about the same length.
D. The broad distribution represents polymers with varying lengths
E. MW distribution is controlled by the conditions during polymerization
F. MW distributions can be symmetrical or distorted.

Polymer Processing: Methods of spinning for additive manufacturing: Wet spinning

This is the oldest, most complex and also the most expensive method of man-made yarn manufacture. This type of spinning is applied to polymers which do not melt and dissolve only in non-volatile or thermal unstable solvents.

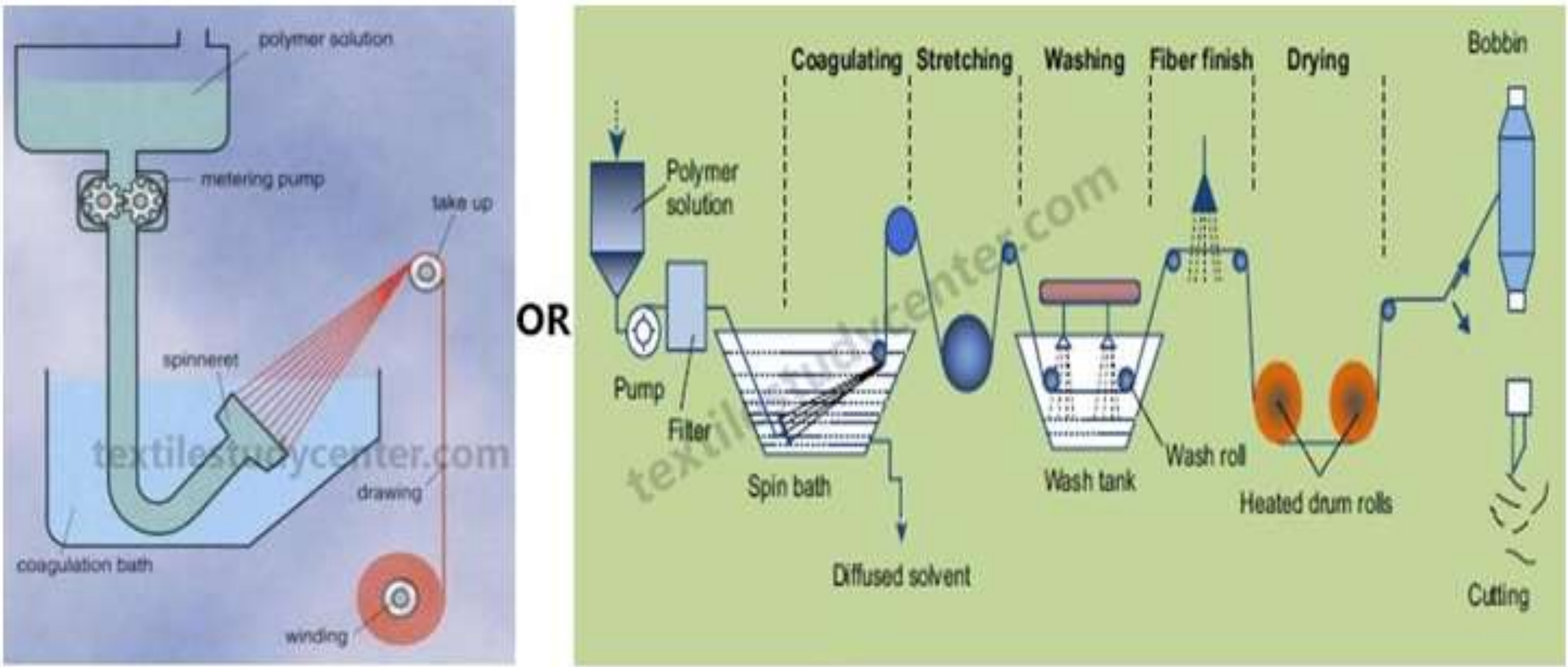


Fig: Wet Spinning Process

Spinning process:

In wet spinning, a non-volatile solvent is used to convert the raw material into a solution.

The solvent is extruded through the spinneret either by simply washing it out or by a chemical reaction between the polymer solution and a reagent in the spinning bath.

After extrusion, the solvent is removed in a liquid coagulation medium.

Finally, the filament yarn either is immediately wound onto bobbins or is further treated for certain desired characteristics or end use.

Example: Wet spinning is used in the production of aramid, Lyocell, PVC, Vinyon (PVA), viscose rayon, spandex, acrylic, and modacrylic fibers.

Advantages:

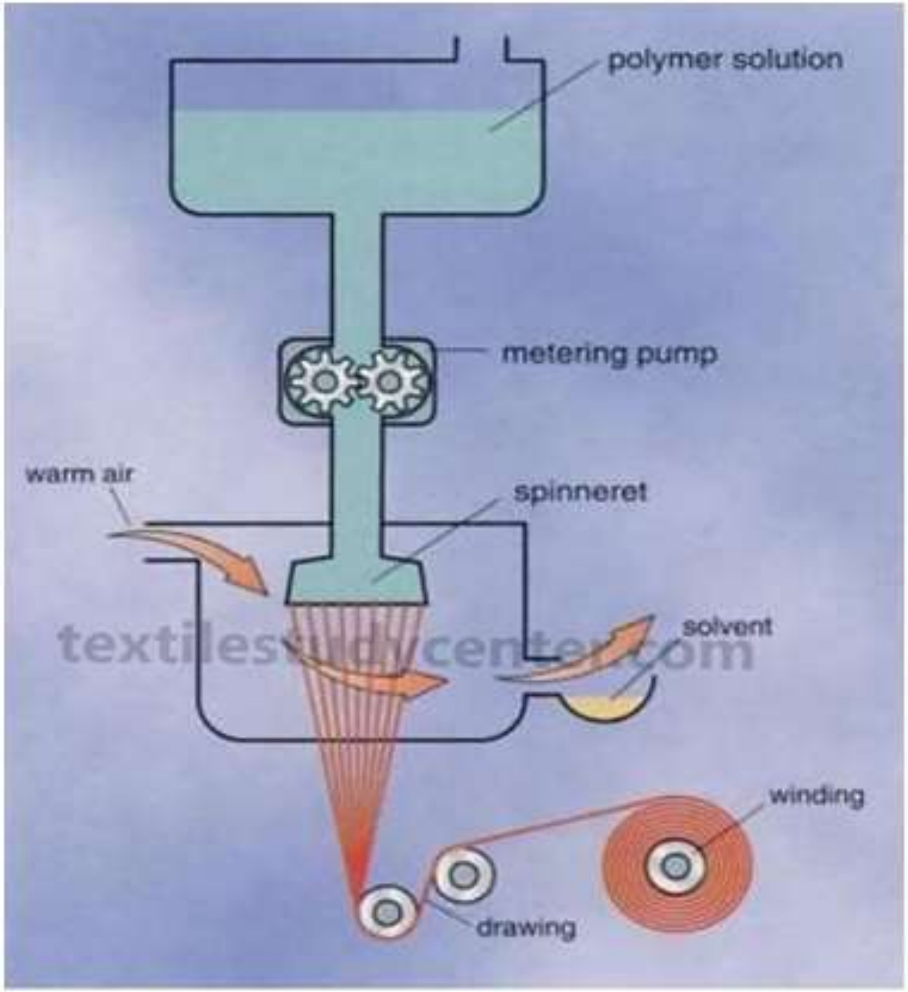
Large draws can be handled

Disadvantages:

- Slow (70-150 yds/min)
- Washing to remove impurities
- Solvent and chemical recovery

Dry spinning

Dry spinning is used for polymers that need to be dissolved in a solvent. Solvent spinning (dry spinning and wet spinning) are used by 30% of the fibers.



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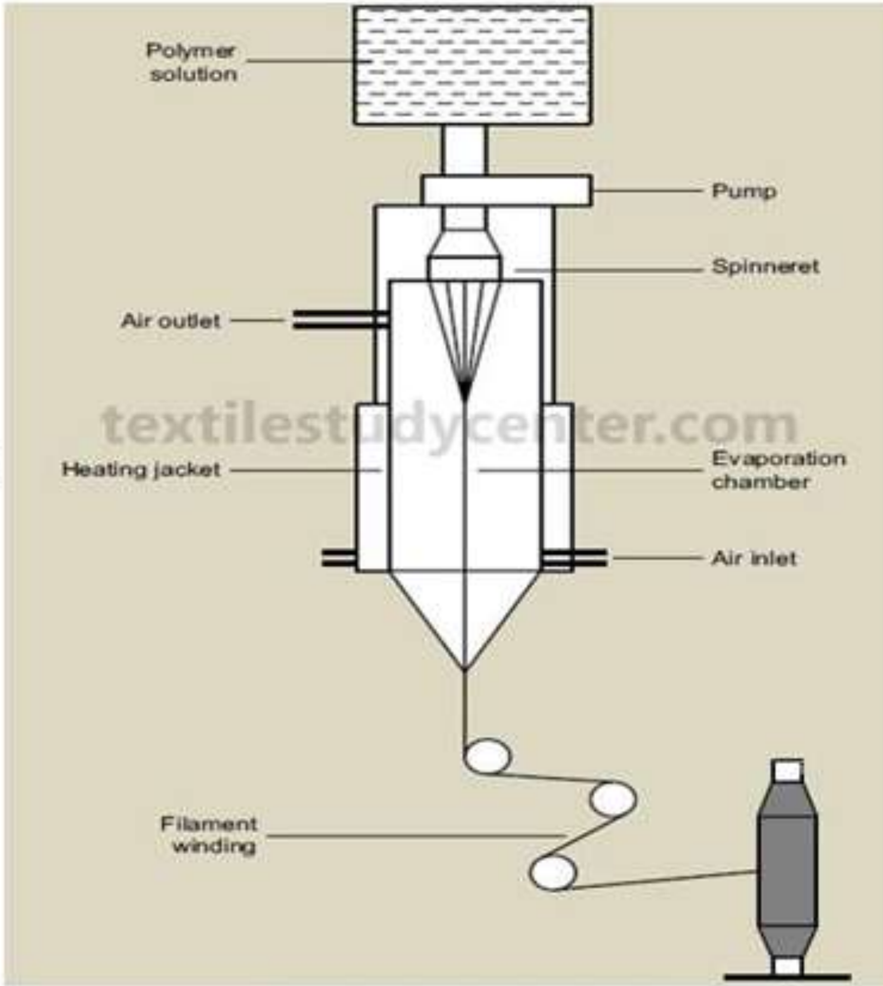


Fig: Dry Spinning Process

Spinning process:

In dry spinning, a unstable solvent is used to dissolve the raw materials and form a salutation.

Then the solution is purified by a filter.

The solution is extruded through a spinneret into a warm air chamber where the solvent evaporates, solidifying the fine filaments.

Finally, the filament yarn either is immediately wound onto bobbins or is further treated for certain desired characteristics or end use.

Example:

Dry spinning is used in the production of acetate, triacetate, and some acrylic, modacrylic, spandex, and vinyon (PVC, PVA) fibers.

Advantages:

- Yarn does not require purification

Disadvantages:

- Flammable solvent hazards
- Solvent recovery
- Slow (200-400 yds/min)

Biopolymers

It is a polymer that is developed from living beings. It is a biodegradable chemical compound that is regarded as the most organic compound in the ecosphere. The name “Biopolymer” indicates that it is a biodegradable polymer.

Biopolymer History

This polymer has been present on earth for billions of years. It is older than synthetic polymers such as plastics.

Example of Biopolymer

Some Biopolymer examples are

- Proteins
- Carbohydrates
- DNA (Deoxyribo Nucleic Acid)
- RNA (Ribo Nucleic Acid)
- Lipids Nucleic acids Peptides
- Polysaccharides (such as glycogen, starch, and cellulose)

All these biopolymers account for a greater part of the human body as well as the ecosphere.

DNA biopolymer is the most important for humans. The entire body structure, as well as genetic behaviors that pass from parents to children, is based on it. Both DNA and RNA are composed of nucleic acids that alternate in definite patterns to encode a huge amount of genetic data.

The most common biopolymer is **Cellulose**. It is also the most abundant organic compound on this planet. It comprises of 33% of all plant component on Earth.

Biopolymer Classification

There are four main types of Biopolymers.

a. Sugar based Biopolymers

Starch or Sucrose is used as input for manufacturing Poly hydroxybutyrate. Sugar based polymers can be produced by blowing, injection, vacuum forming, and extrusion.

Lactic acid polymers (Polyactides) are created from milk sugar (lactose) that is extracted from potatoes, maize, wheat, and sugar beet. Polyactides are resistant to water and can be manufactured by methods like vacuum forming, blowing and injection molding.

b. Starch-based Biopolymers

Starch acts as a natural polymer and can be obtained from wheat, tapioca, maize, and potatoes. The material is stored in tissues of plants as one way carbohydrates. It is composed of glucose and can be obtained by melting starch. This polymer is not present in animal tissues.

c. Biopolymers based on Synthetic materials

Synthetic compounds that are obtained from petroleum can also be used for making biodegradable polymers such as **aliphatic-aromatic copolyesters.** Though these polymers are manufactured from synthetic components, they are completely compostable and biodegradable.

d. Cellulose-based Biopolymers

This polymer is composed of glucose and is the primary constituent of plant cellular walls. It is obtained from natural resources like Cotton, Wood, Wheat, and Corn.

The production of biopolymer may be done either from animal products or agricultural plants.

These are used for packing cigarettes, CDS and confectionary.

Biopolymer Types

There are primarily two types of Biopolymer, one that is obtained from **living organisms** and another that is produced from **renewable resources** but require polymerization. Those created by living beings include proteins and carbohydrates.

Biopolymer Structure

Unlike synthetic polymers, Biopolymers have a well-marked structure. These polymers have a uniformly distributed set of molecular mass and appear as a long chain of worms or a curled up string ball under a microscope. This type of polymer is differentiated based on their chemical structure.

Biopolymer Uses

These polymers play an essential role in nature. They are extremely useful in performing functions like storage of energy, preservation, and transmittance of genetic information and cellular construction.

- **Sugar based polymers**, such as Polyactides, naturally degenerate in the human body without producing any harmful side effects. This is the reason why they are used for medical purposes. Polyactides are commonly used as surgical implants.
- **Starch-based biopolymers** can be used for creating traditional plastic by extruding and injection molding.
- **Biopolymers based on synthetic** are used to manufacture substrate carpets.
- **Cellulose-based Biopolymers,** such as cellophane, are used as a packaging material. These chemical compounds can be used to make thin wrapping films, food trays and pellets for sending fragile goods by shipping.

Molding and casting of polymers

What is Plastic Moulding?

Plastic molding is the process of shaping plastic using a rigid frame or mold. The technique allows for the creation of objects of all shapes and sizes with huge design flexibility for both simple and highly complex designs. A popular manufacturing option, plastic molding techniques are responsible for many

car parts,

containers,

signs

other high volume items.

Plastic Moulding Techniques

The underlying concept of plastic molding is placing liquid polymer into a hollow mold so that the polymer can take its shape, often with **various ranges of pressure and heat required**. There are different plastic molding techniques available to accomplish this including

Rotational molding,

Injection molding,

Blow molding,

Compression molding

to name just a few. Each technique has its benefits and is best suited for the creation of specific items.

Rotational Moulding

The rotational molding technique consists of 4 separate operations:

Preparing the Mould

The process begins with filling a hollow mold with a predetermined quantity of polymer powder or resin. This powder can be pre-compounded to the desired color. More often than not the powdered resin is polyethylene (PE) although other compounds such as polyvinyl chloride (PVC) and nylons can also be used. The oven is preheated by convection, conduction, (or in some cases radiation) to temperature ranges around 260°C - 370°C, depending on the polymer used. When the powder is loaded into the mold it is closed, locked, and loaded into the oven.

Heating and Fusion

Inside the oven, the mold is bi-axially rotated (i.e., rotated around two axes) as the polymer melts and coats the inside of the mold. The rotation speed is slow, less than 20 rotations/minute; the process is not centrifugal. During this phase of the rotational molding, process timing is critical. If the mold spends too much time inside the oven the polymer will degrade - this will reduce its impact strength. If it spends too little time inside the oven melting of the polymer will be incomplete and it will not fully join together on the mold wall, creating large bubbles in the item.

Cooling the Mould

After the meeting has been consolidated to the desired level and the timing is right, the mold is removed from the oven and cooled. Cooling of the mould is typically done with air (by fan), water or sometimes a combination of both. Cooling allows the polymer to solidify to the desired shape and shrink slightly so that it can then be handled by the operator and removed from the mold. The cooling time can typically be measured in tens of minutes. It is important that the cooling rate is carefully measured because rapid cooling causes the polymer to shrink too fast and warps the part.

Unloading / Remolding

When it has cooled sufficiently to be handled and the polymer can retain its shape, the mold is opened and the part is removed. The molding process can then be repeated by adding the polymer powder to the mold.

The Plastic Injection Moulding Process

Because of its high viscosity, in order for plastic injection molding to be successfully melted polymer must be injected into a hollow mold with a large force.

Preparing the Mould

Feeding the polymer resin (pellets) down to the auger (screw) is a large open-bottomed container. An electric (or hydraulic) motor is responsible for turning the auger inside a heated cylinder which feeds the pellets up through the grooves of the auger. A gate before the mold cavity restricts the flow of the melt into the mold and limits backflow. The pressure created by pushing the forward through the grooves up to the gate also produces heat on the inside of the cylinder which helps to melt the polymer and prepare it for injection into the mold.

Injection of Polymer Melt Into the Mould

As the auger moves forward it injects polymer melt into the mold at high pressure (typically 10,000 - 30,000 psi), holds it, and adds more melt to ensure the contraction due to cooling and solidification does not leave gaps in the final product. Eventually, the gate solidifies and isolates the mold from the injection cylinder.

❖1 psi is approximately equal to 6895 N/m2

Cooling the Mould

Molds are typically air or water cooled. Sometimes small holes are bored into the mold that allows a cooling liquid (such as water) to be circulated. Injection mold cooling consumes about 85% of the cycle time for the entire process.

Unloading / Remolding

After solidification, the clamp holding the two halves of the mold together closed is opened allowing the part to be removed. The injection molding process can then be repeated.

Polymer Casting:

- Operations carried out on polymeric materials to increase their utility.
- The conversion of polymeric raw materials into useful finished products. Processes of polymer casting:
- Thermoforming
- Compression and transfer molding
- Rotational molding and sintering
- Extrusion
- Extrusion-based processes
- Injection molding
- Blow molding
- Plastic foam molding

Selection of a process depends upon:

- Quantity and production rate.
- Dimensional accuracy and surface finish.
- Size of the final product.
- Form and detail of the product.
- Nature of material.

Phases of polymer processing:

- **Heating -** To soften or melt the plastic.
- **Shaping/Forming-**Under the constraint of some kind like the application of specific pressure.
- **Cooling -** So that it retains its shape.

Thermoplastics start as regular pellets or sheet and can be re-melted.

Thermosets start as liquids often called "resins", or powders which need heat for the shaping phase.

a. Thermoforming

Thermoforming is the process where a thermoplastic polymer sheet is **heated** & **deformed** into the desired shape.

Process :

- Heating plastic sheet to the temperature wherein softens.
- Stretching the softening polymer against a cold mold surface.
- Cooling the finished part and trimming excess plastics.

Steps of thermoforming :

- Heating: Heating is accomplished by **a radiant electric heater** which is located by at the distance of 125mm(5 in.) from the sheet.
- Forming: after heating, the polymer sheet is converted or formed into various either air pressure, vacuum or mechanical.

So, according to the forming techniques, thermoforming are 3 types

- Vacuum forming
- Pressure forming
- Mechanical forming

POWDER METALLURGY (PM)

•PM is Metal processing technology in which parts are produced from metallic powders

•PM parts can be mass produced to net shape or near net shape, eliminating or reducing the need for subsequent machining.

•PM process wastes very little material~97% of starting powders are converted to product PM parts can be made with a specified level of porosity, to produce porous metal parts Examples: filters, oil-impregnated bearings, and gears.

•Certain metals that are difficult to fabricate by other methods can be shaped by PM Tungsten filaments for lamp bulbs are made by PM

•Powder metallurgy is used for manufacturing products or articles from powdered metals by placing these powders in molds and are compacting the same using heavy compressive force.

•Typical examples of such article or products are grinding wheels, filament wire, magnets, welding rods, tungsten carbide cutting tools, self-lubricating bearings electrical contacts and turbines blades having high-temperature strength.

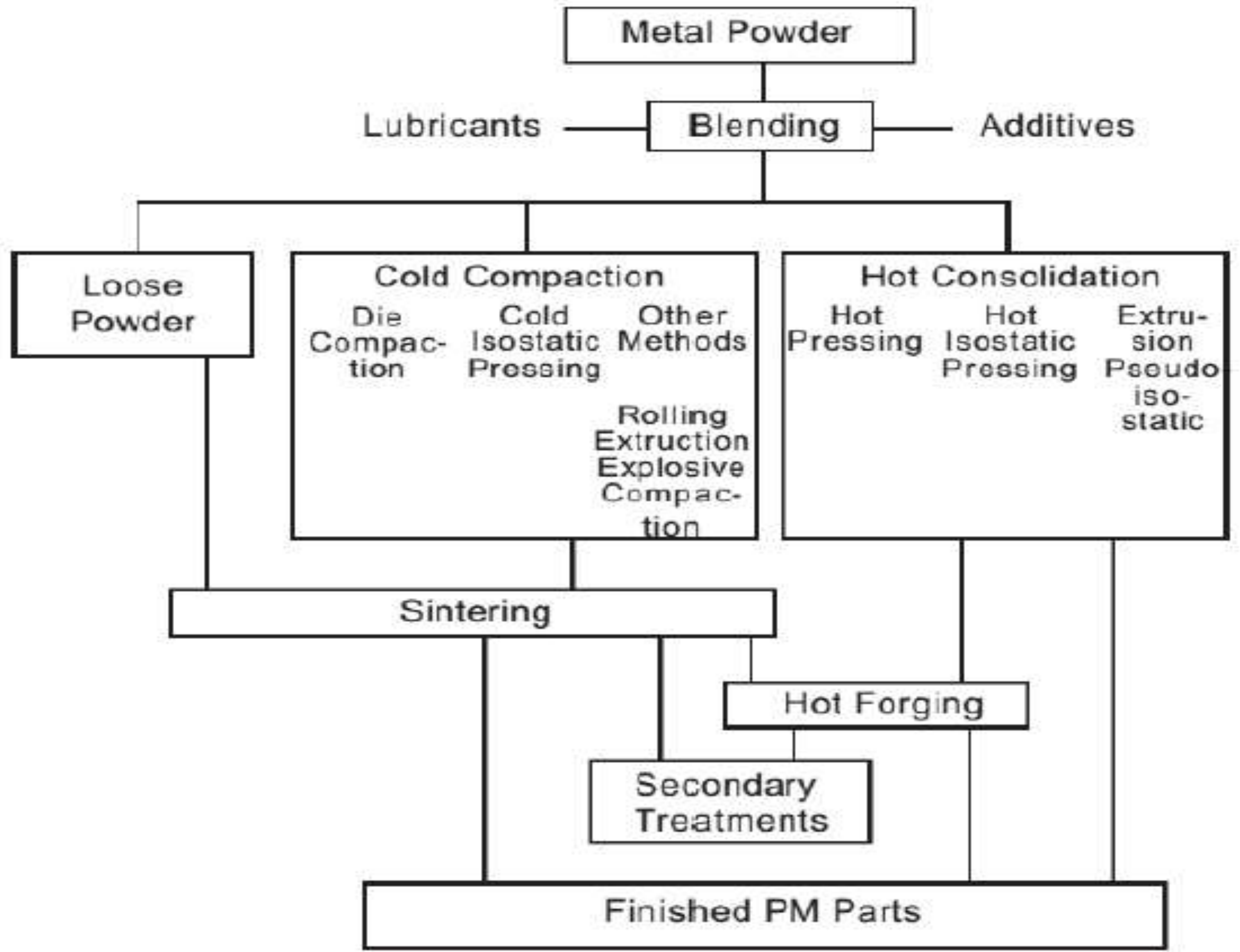
•The manufacture of parts by powder metallurgy process involves the manufacture of powders, blending, compacting, sintering and a number of secondary operations such as sizing, coining, machining, plating, and heat treatment.

•The compressed articles are then heated to temperatures much below their melting points to bind the particles together and improve their strength and other properties. Few non-metallic materials can also be added to the metallic powders to provide an adequate bond or impart some of the needed properties.

•The products made through this process are very costly on account of the high cost of metal powders as well as of the dies used.

•The powders of almost all metals and a large number of alloys and nonmetals may be used. The application of the powder metallurgy process is economically feasible only for high mass production.

•Parts made by powder metallurgy process exhibit properties, which cannot be produced by conventional methods. Simple shaped parts can be made to size with high precision without waste, and completely or almost ready for installation.


Metal Powder
Lubricants
Blending
Additives
Loose Powder
Cold Compaction
Die Compac-tion
Cold Isostatic Pressing
Other Methods
Rolling Extruction Explosive Compac-tion
Hot Consolidation
Hot Pressing
Hot Isostatic Pressing
Extru-sion Pseudo iso-static
Sintering
Hot Forging
Secondary Treatments
Finished PM Parts

Trends of Powder Metallurgy Technology

In the overall material process technology industry, there are a variety of products utilizing P/M. Currently, main P/M products of Hitachi Powdered Metals comprise structural parts, tribological parts (self lubricating bearings, wear-resistant parts, and high-temperature heat-resistant wear-resistant parts), and magnetic parts (soft magnetic materials).

Structural parts

Structural parts make up a large portion of P/M products. Their main ingredient is iron alloys. Engineers have sought to improve their properties as they apply them successively to different products: home appliances, OA equipment, motorcycles, agricultural machinery, and automobile parts. As a result, their performance has grown, as has its demand. In the past ten years, parts for transport machinery have led to the growth in the demand of P/M products. Pulleys, sprockets, and parts for variable valve control systems in order to increase fuel efficiency have grown 1.5 times. Although this trend is not expected to change for a while even with the transition to hybrid electric vehicles and electric vehicles, P/M products are being developed to support greater fuel efficiency and the acceleration in the greening of technology by focusing on the following: making parts thinner and lighter, inhibiting degradation in dimensional precision with sintering and thermal processing, replacing thermal processing with sinter-hardening, and increasing cost performance by actively using low-cost chromium as an element for strengthening P/M products.

Tribological Parts

These parts are strongly related to abrasion and lubrication. The field has grown as original P/M alloy compositions and material microstructure are being actively utilized; these developments could not have been accomplished with wrought steel.

Hitachi Powdered Metals is producing oil-impregnated bearings and wear-resistant parts as well as high-temperature heat resistant, wear-resistant parts. The applications of oil- impregnated bearings have grown through their use in home appliances, audio equipment, office equipment, and automobiles. Recently, we have also been developing advanced technologies that support high contact pressure and low coefficient of friction for use in environmentally-friendly products, such as ICT (Information and Communication Technology) equipment and construction machinery. In the area of wear-resistant materials, valve guides and valve seats, which conventionally have been cast, are being replaced by low-cost yet high-performance sintered parts. The development of materials is helping engines perform better, making cars leaner for greater fuel efficiency and adapting to changes in the fueling environment due to flexible-fuel vehicles. Under the same trend, heat- and wear- resistant materials for turbochargers are also being developed to meet the rise in the temperature of fuel exhaust gases and the downsizing of turbochargers.

Magnetic Parts

In recent years, to support ICT equipment that rapidly continues to become faster, use higher frequencies, become smaller and denser, and save more energy, achieving high permeability and lower core loss in the high-frequency region is being required for soft magnetic materials. This means that the needs of advanced magnetic materials are growing for both present-day automobiles, in which electronic controls are becoming increasingly advanced, and for next-generation hybrid electric vehicles and electric cars. Hitachi Powdered Metals is making advances in the development of technologies including sintered magnetic parts consisting of structural and magnetic materials, and powder cores (or soft magnetic cores [SMC]) that feature low core loss in high-frequency regions.

Next-Generation High-Performance Parts

We are focusing on micronization as the next-generation technology for the fields of information home appliances and the life sciences. We are developing technologies for compacting micro parts that are difficult to industrially produce with machining and metal injection molding (MIM). Another area is the development of products that can directly contribute to the field of environmental energy. As a company participating in the century of the environment, Hitachi Powdered Metals is advancing the development of thermoelectric conversion technology that regenerates energy from waste heat and thermoelectric conversion modules as products utilizing this technology.

Powder Production Techniques

The choice of a specific technique for powder production depends on particle size, shape, microstructure, chemistry of powder and also on the cost of the process.

- **Mechanical methods of powder production:**
  1) Chopping or Cutting
  2) Abrasion methods
  3) Machining methods
  4) Milling
  5) Cold-stream Process.
- **Chemical methods of powder production:**
- Reduction of oxides
- Precipitation from solutions
- Thermal decomposition of compounds
- Hydride decomposition
- Thermit reaction
- Electrochemical methods
- **Physical methods of powder production:**
- Water atomization
- Gas atomization
- Special atomization methods

Mechanical methods of powder production:

- **Chopping or Cutting:**

In this process, strands of hard steel wire, in diameter as small as 0.0313 inches are cut up into small pieces by means of a milling cutter.

This technique is actually employed in the manufacturing of cut wire shots which are used for Peening or shot cleaning.

Limitations:

It would be difficult and costly to make powders by this method and for this reason, it is not profitable to discuss the technique in detail.

•**Rubbing or Abrasion Methods:**
These are all sorts of ways in which a mass of metal might be attacked by some form of abrasion.

•**Rubbing of Two Surfaces:**
When we rub two surfaces against each other, hard surface removes the material from the surface of soft material.
•Contamination

•**Filling:**
Filing as a production method has been frequently employed, especially to alloy powders, when supplies from conventional sources have been unobtainable. Such methods are also used for the manufacture of coarse powders of dental alloys. Filing can also be used to produce finer powder if its teeth are smaller.
•Commercially not feasible.

•**Scratching:**

If a hard pin is rubbed on some soft metal the powder flakes are produced. Scratching is a technique actually used on a large scale for the preparation of course magnesium powders.

•Scratching a slab of magnesium with hardened steel pins.

•A revolving metal drum to the surface of which is fixed a scratching belt.

The drum, which is about 8 inches in diameter, rotates at a peripheral speed of approximately 2500 ft./min. The slab of magnesium metal, 14 in. wide by 1.75 in. thick enters through a gland in the drum casing and presses against the steel pins.

•**Machining:**

A machining process a lathe or a milling cutter in which something more than just scratching is involved since the attacking tool actually digs under the surface of the metal and tears it off.

On lathe machine, by applying small force we get fine chips. A large amount of machining scrap is produced in machining operations. This scrap in the form of chips and turnings can be further reduced in size by grinding.

•small scale production.

Disadvantages:

•Lack of control on powder characteristics, including chemical contamination such as oxidation, oil, and other metal impurities.

•The shape of the powder is irregular and coarse.

Advantages:

•For consuming scrap from another process, machining is a useful process.

•Presently the machined powder is used with high carbon steel and some dental amalgam powders.

These are the methods used for high production rate. Best examples of mechanical production methods are **the Milling Process** and **Cold Stream Process.**

- **Milling:**

The basic principle of the milling process is the application of an impact and shear forces between two materials, a hard and a soft, causing soft material to be ground into fine particles.

Milling techniques are suitable for brittle materials. Two types of milling are;

- Ball Milling
- Attrition Milling.

Ball Milling:

Ball milling is an old and relatively simple method for grinding large lumps of materials into smaller pieces and powder form.

A principle of the process:

The principle is simple and is based on the **impact and shear forces**. Hard balls are used for mechanical combination of brittle materials and producing powders.

Milling Unit:

The basic apparatus consists of the following;

- A ball mill or jar mill which mainly consists of a rotating drum lined from inside with a hard material.
- Hard balls, as a grinding medium, which continue to impact the material inside the drum as it rotates/rolls.

Grinding Mechanism:

During milling, the following forces cause fracture of material into powder.

Impact Forces: These are caused by the instantaneous striking of one object on the other. (Impact is the instantaneous striking of one object by another. Both objects may be moving or one may be stationary).

Shear Forces: These are caused as one material slides/rubs against the other.

•**<u>Cold Stream Process</u>**

This process is based on impact phenomenon caused by impingement of high-velocity particles against a cemented carbide plate.

The unit consists of A feed container;

A compressor capable of producing a high-velocity stream of air (56 m^3/min.) operating at 7MPa (1000 psi)

A target plate made of cemented tungsten carbide, for producing impact;

A classifying chamber lined with WC while the supersonic nozzle and target generally are made of cemented tungsten carbide.

Mechanism of the Process:

The material to be powdered is fed in the chamber and from there falls in front of the high-velocity stream of air.

This air causes the impingement of material against the target plate, where material due to impaction is shattered into powder form. This powder is sucked and is classified in the classifying chamber. Oversize is recycled and fine powder is removed from the discharge area.

•Rapidly expanding gases leaving the nozzle creates a strong cooling effect through adiabatic expansion.

This effect is greater than the heat produced by pulverization.

- **CHEMICAL METHODS**
- Almost all metallic elements can be produced in the form of powders by suitable chemical reactions or decomposition.

Mostly chemical methods are based on the decomposition of a compound into the elemental form with heating or with the help of some catalyst.

In most cases, such processes involve at least two reactants.

- a compound of the metal
- at reducing agent

REDUCTION OF METAL OXIDES

Manufacturing of metal powder by reduction of oxides is extensively employed, particularly for Fe, Cu, W(Tungsten), and Mo (Molybdenum).

Advantages:

- A variety of reducing agents can be used and a process can be economical when carbon is used.
- Close control over particle size
- Porous powders can be produced which have good compressive properties.
- Adaptability either to very small or large manufacturing units and either batch or continuous processes.

Limitations:

- A process may be costly if reducing agents are gases.
- Large volumes of reducing gas may be required, and circumstances, where this is economically available, may be limited; in some cases, however, costs may be reduced by recirculation of the gas.
- The purity of the finished product usually depends entirely upon the purity of the raw material, and economic or technical considerations may set a limitation to that which can be attained.
- Alloy powders cannot be produced.

Physical Methods

Atomization

- Gas Atomization
- Water Atomization
- Cryogenic Liquid Atomization
- Centrifugal Atomization

Atomization

Atomization is the most important production method for metal powders. The process generally consists of three stages:

1. Melting
2. Atomization (dispersion of the melt into droplets)
3. Solidification and cooling.

additional processing becomes necessary before the powders attain their desired properties, (reduction of surface oxides, degassing, size classification, etc.)

Melting

•In this stage, the most important criterion is whether melting and melt distribution require a **crucible** system or not. Crucibles are one of the main sources for pollution of atomized powders.

•The second criterion is the **heating source**. Essentially all melting techniques known in metallurgy can be used, e.g., **Induction, Arc, Plasma, And Electron-beam Melting**, but some of these may also contribute to pollution, as for example in arc melting.

Solidification

During the solidification and cooling stage, the **cooling rate** is the controlling parameter. Cooling rate depends on:

•The **dimensions** of the liquid droplets or solid powder particles,

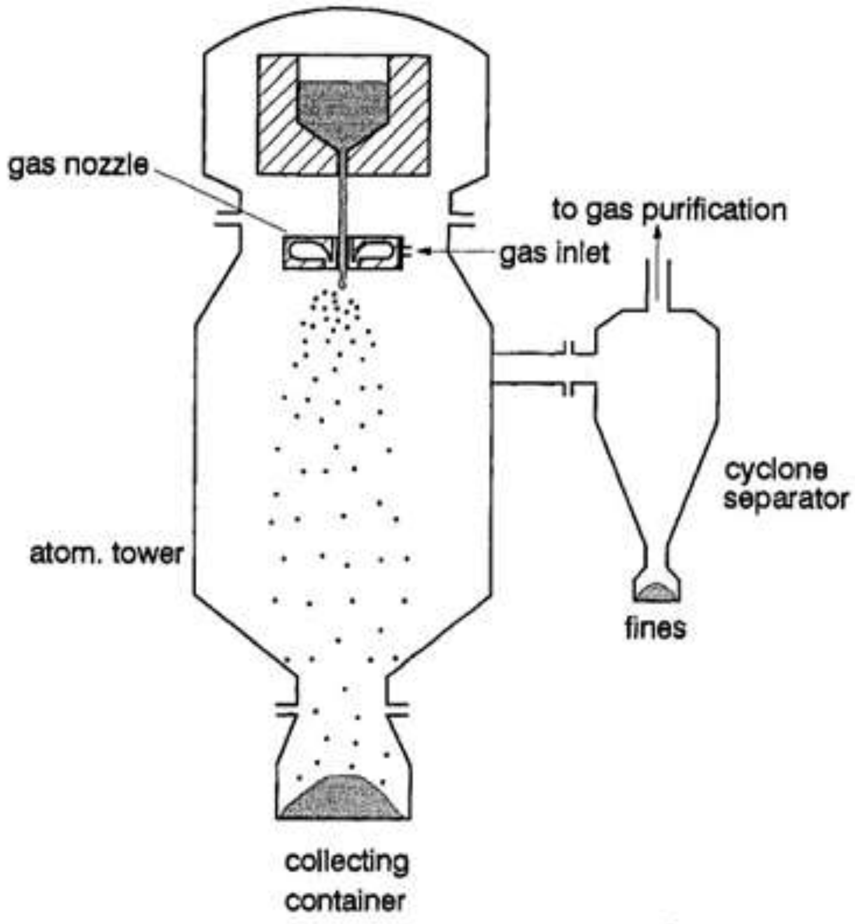
•The **type of heat transfer** from the particles to the surrounding medium.

The undercooking prior to nucleation and cooling rate are the controlling factors for determining the microstructure of the powder particles, as well as for the dimensions of the atomization unit.

Gas Atomization

Air, Nitrogen, Argon or Helium is used, depending on the requirements determined by the metal to be atomized.

Here, melted initial material is collapse with the gas within the chamber. Heat is transferred from the liquid droplets to the surrounding gas. And liquid solidifies.



Vertical atomization unit Atomization can be undertaken either in vertical or horizontal units. Production of Fine Particles;

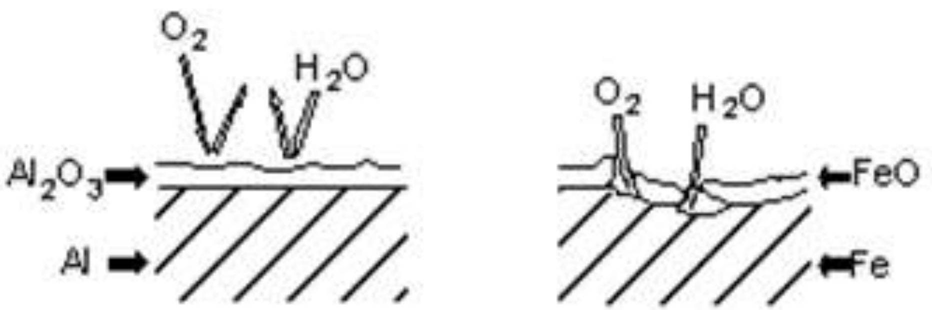
•a high velocity of the atomizing fluid

•small melt stream (droplet) diameters

•High density, and low viscosity and surface tension of the melt the nozzle design is an important key to success or failure of a gas atomization system.

The mean particle size of gas atomized powders is in the range of 20-300 μm.

The particle shape is spherical or close to spherical. Irregular particle shapes can only be produced in systems where reactions between the gas and the liquid metal cause the formation of solid surface layers. This is the case, for example, in the air atomization of aluminum.



•Melt atomization by air is used in the production of the so-called 'Roheisen Zunder' (RZ) iron powder. This process starts from a cast iron melt. The surface oxides formed during atomization are reduced by the inherent carbon of the cast iron particles during a simple subsequent annealing treatment

$$3Fe_3C + Fe_3O_4 \rightarrow 12Fe + 2CO + CO_2$$

Inert gas atomization is applicable for all metallic alloys which can be melted. The main application is for high alloy products such as stainless steel, tool steels, iron, nickel- or cobalt-base super alloy powders, as well as aluminum alloy powders.

Limiting factors are the availability of suitable crucible and auxiliary/helpful melting process materials. Powders from refractory metals with high melting temperature and highly reactive materials, such as titanium alloys, are usually produced by other methods.

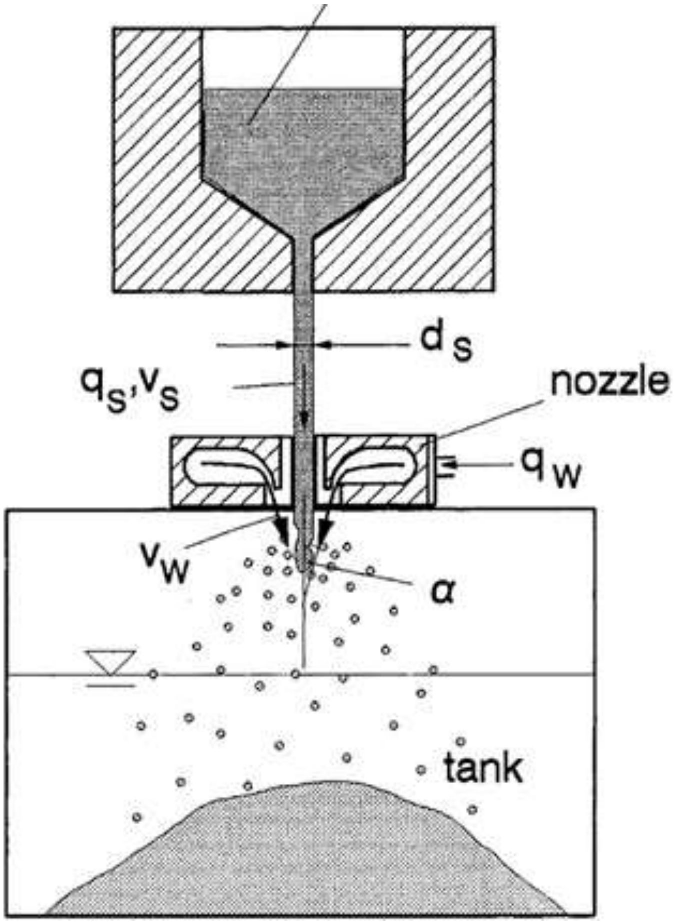
Liquid atomization

Water atomization

Cyrogenics Liquid atomization

Water atomization

Water atomization is mainly used for the production of **iron base powders**. The figure shows a scheme for a water atomization unit.



Scheme for a water atomization unit.

The starting material is melted and metallurgically treated in a separate furnace and then fed into a tundish (A large funnel with one or more holes at the bottom). The tundish provides a uniformly flowing vertical melt stream, which is split ups into droplets in the focal area of an arrangement of several water jets.

The impact from the high-pressure stream of water leads to the breakdown of the flowing metal.

High energy input to the water stream is needed.

In water atomization, a high-pressure water stream is forced through nozzles to form a disperse phase of droplets which then impact the metal stream.

In this method, large quantities of energy are required to supply the water at high pressure.

This production method is significant for low and high alloy steels, including stainless steel. Because of oxide formation, water atomization is **not likely to be used in the atomization of highly reactive metals** such as titanium and the super alloys. In general, water atomized powders **are irregular in shape**, with rough oxidized surfaces.

CRYOGENIC LIQUID ATOMIZATION,

a new version of atomization in which the melt is atomized with cryogenic liquid gas (argon or nitrogen) at –200C. During the process, the pressure of the liquid gas is increased up to 300 bar, while a recooling unit prevents the temperature from rising in spite of compression and prevents the cryogenic liquid from vaporizing instantaneously at the jet opening.

The resulting powder has the following properties:

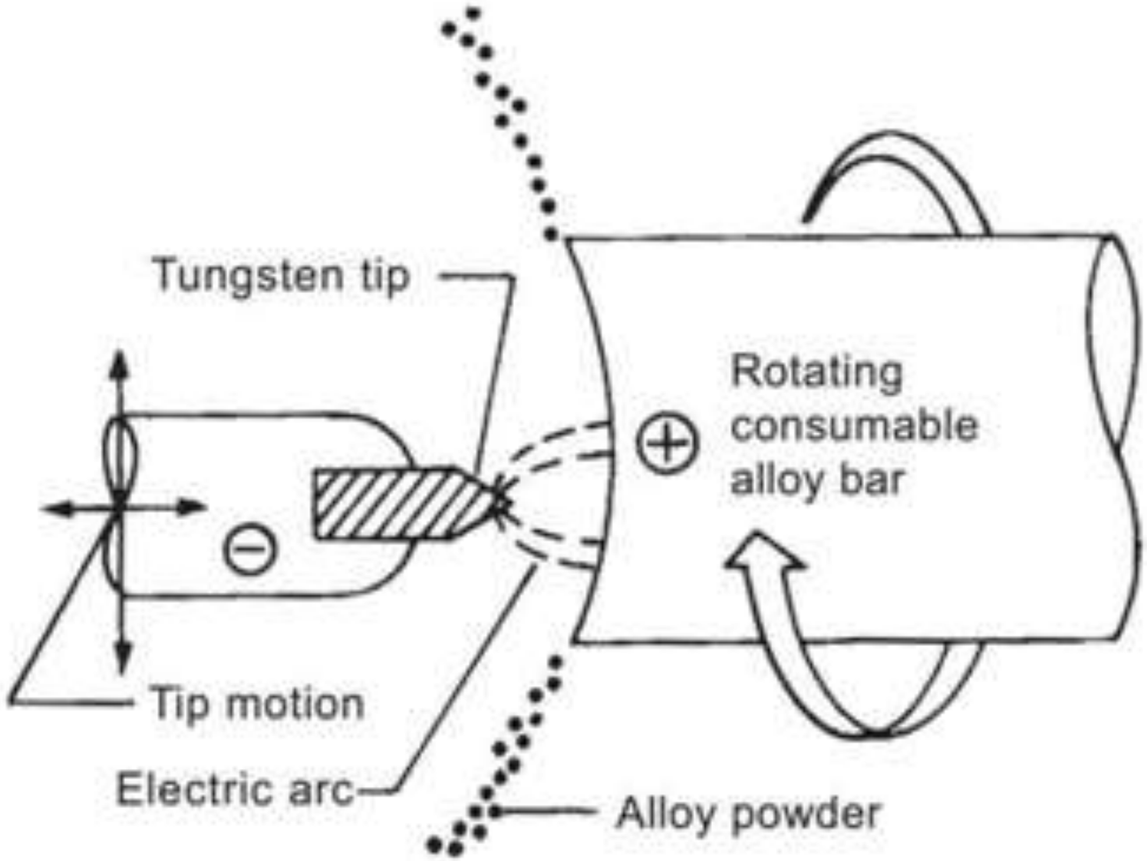
•It is much purer than the powder atomized with water and can be compared to the quality of the gas atomized powder.

•The cooling rate is ten times higher than in gas atomization and almost reaches the quality of water atomization. Particles of 100 μm in diameter, for example, are quenched for approximately 106 K/s.

•The powders are, as in gas atomization, spherical and have an average size of 6–125 μm. Show satisfactory results in cold forming, while having good flow ability. Gas atomized powders have poor green strength

CENTRIFUGAL ATOMIZATION

The basis of centrifugal atomization is the ejection of molten metal from a rapidly spinning container, plate or disc.



- The material in the form of a rod electrode is rotated rapidly while being melted at one end by an electric arc. Molten metal spins off the bar and solidifies before hitting the walls of the inert gas filled the outer container.

The process was developed primarily for the atomization by high purity low oxygen content titanium alloys and super alloys.

Powder particles are smooth and spherical with an average diameter of ~200 μm; the size range is 50–400 μm. Typically, yields run to ~75% for –35 mesh powder.

Particle size distribution

•Accurately controlled rotation of the anode is important so as to obtain in the desired range.

•As the surface tension of the liquid metal, centrifugal forces (related to rotation speed) to some extent by the 'aerodynamics' of the droplets trajectory through the inert cover gas.

•Spherical metal powders made by either REP (rotating electrode process) or gas atomization are not well suited for cold pressing into green compacts to be followed by sintering. They are used in more specialized applications where consolidation is achieved by hot isostatic pressing (HIP) or some other high-temperature method in which Interparticle voids are more readily closed.

Advantages of atomization,

- Freedom to alloy
- All particles have the same uniform composition
- Control of particle shape, size, and structure
- High purity
- Lower capital cost

Characterization Techniques:

Chemical Composition and Structure

The levels of impurity elements in metal powders can be very significant to both the processing and properties of the final product. It is necessary to know whether such elements are present in their elemental form or whether they are present in the form of a chemical compound. For example, reduced iron powder silicon is present as an impurity in the form of silica, which is insoluble in most acids.

The effect of impurity elements on the hardness of the particles and the degree of chemical reactivity during sintering will differ widely, depending on the actual form they are in. The annealing of the powder in a reducing atmosphere is an effective way of reducing oxygen contents.

The microstructure of the crystalline powder has a significant influence on the behavior of powder during compaction and sintering and on the properties of the final product.

Particle Size and Shape

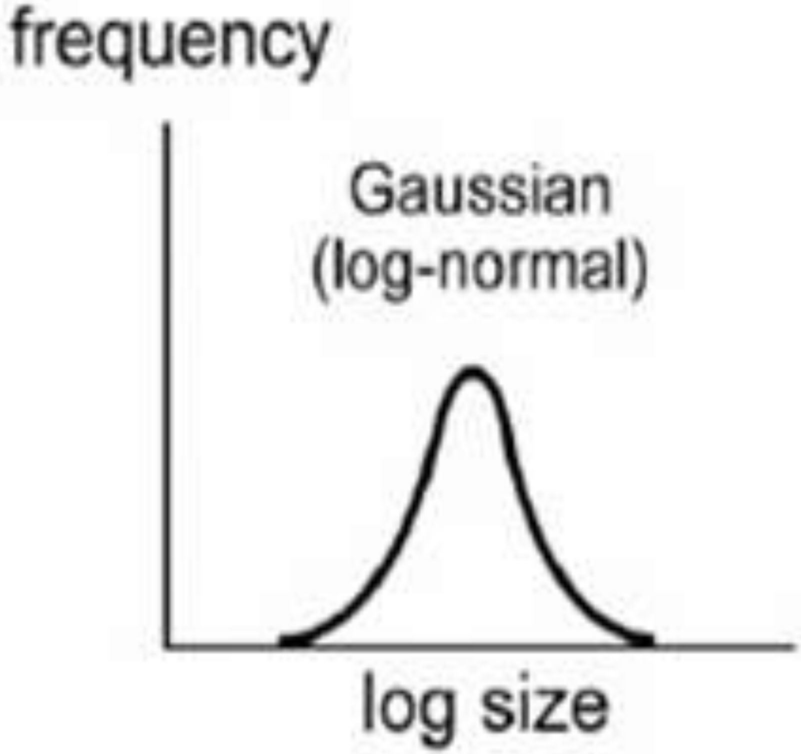
In a real mass of powder, all prepared in the same manner, all the particles will not have the same exact size, even though the shape may be essentially the same. Consequently, we must deal with size distribution when accurately describing powders.

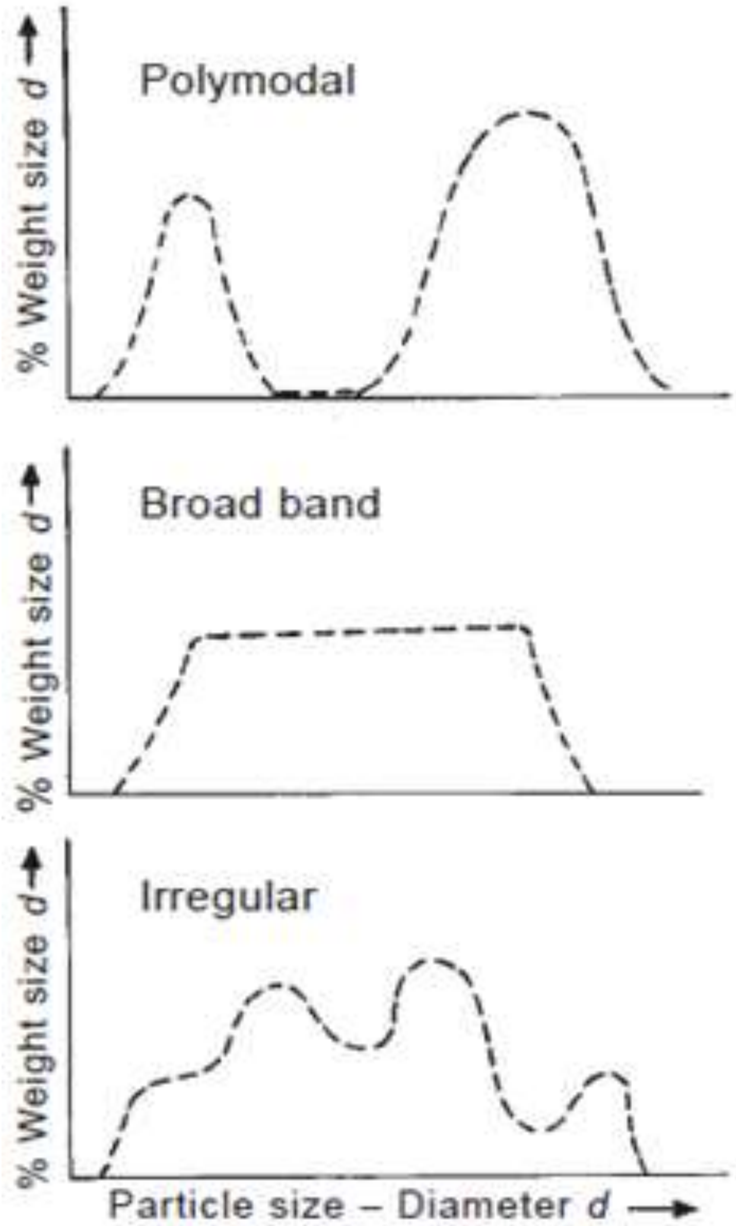
In **unimodal** distribution, there is one high point or maximum amount of a certain critical size.

The **polymodal** distribution consists of two or more narrow bands of particle sizes, each with a maximum, with virtually no particles between such bands.

The **broadband** distribution simply corresponds to a uniform concentration of particle sizes over a rather broad size interval with virtually no particles having sizes outside this range.

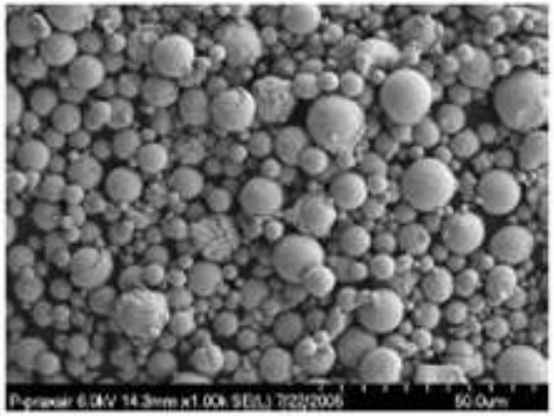
The **irregular** distribution represents a continuous and finite variation of particle sizes within a relatively broad range.

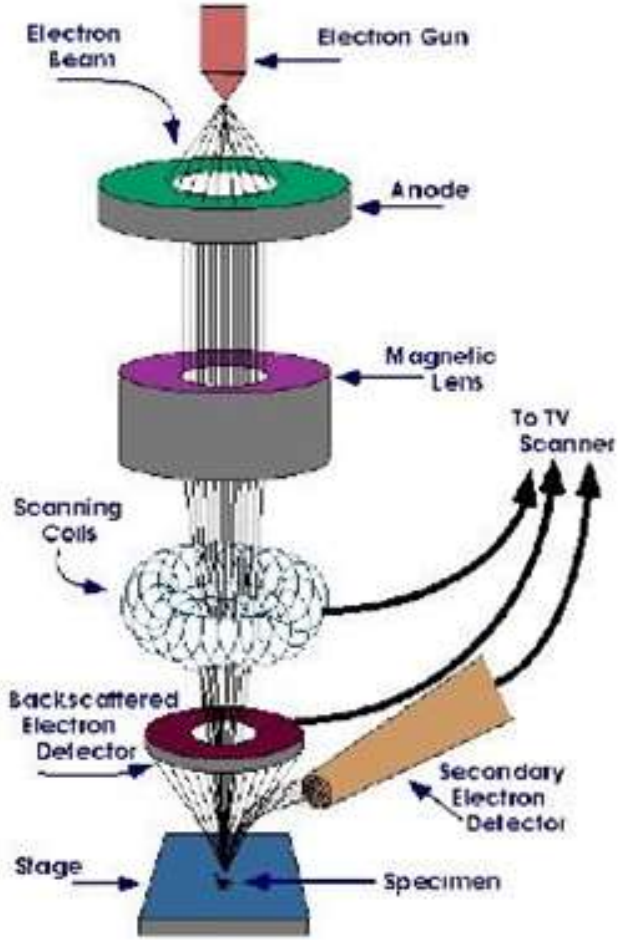

frequency
Gaussian
(log-normal)
log size


Polymodal
% Weight size d
Broad band
% Weight size d
Irregular
% Weight size d
Particle size – Diameter d

Scanning Electron Microscopy

It is also a direct method to measure the particle size of the particles. Optical microscopy or electron microscopy can be used to determine particle size.





Interparticle Friction & Flow Characteristics

•Friction between particles affects the ability of a powder to flow readily and pack tightly

•A common test of Interparticle friction is the angle of repose, which is the angle formed by a quantity of powders as they are poured from a narrow funnel

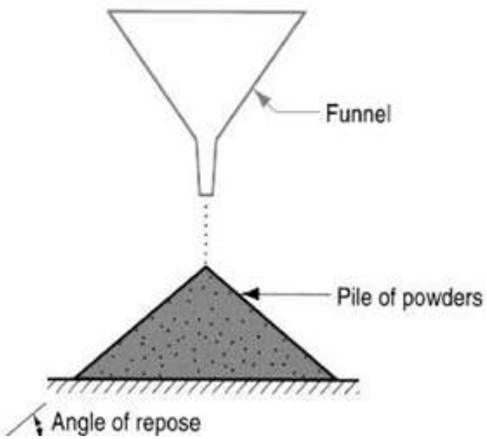
•Smaller particle sizes generally

Greater friction and steeper(vertical) angles

•Spherical shapes

The lowest Interparticle friction

•As shape deviates from spherical, friction between particles tends to increase



Compression ability

Compressibility is a measure to which a powder will compress or densify upon application of external pressure. Typically, a cylinder or rectangular test piece is made by pressing powder in a die, with pressure applied simultaneously from top and bottom.

The compressibility of the powder is influenced by factors like:

•The inherent hardness of the concerned metal or alloy,

•Particle shape,

•Internal porosity,

•Particle size distribution,

•Presence of nonmetallic,

•Addition of solid lubricants.

Compressibility, alternatively, is defined in terms of the densification parameter, which is equal to:

$$\text{Densification parameter} = \frac{\text{Green density} - \text{Apparent density}}{\text{Theoretical density} - \text{Apparent density}}$$

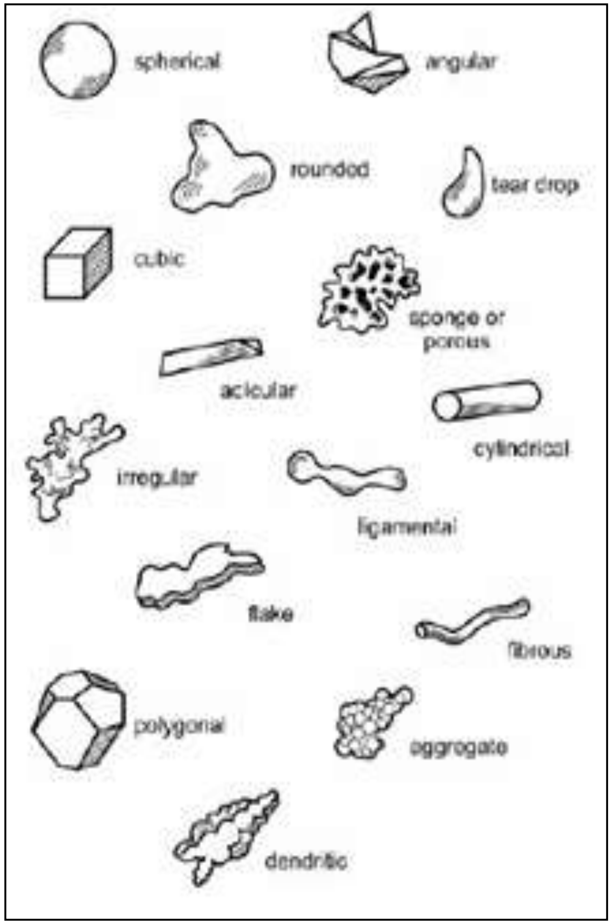
Compressibility, in general, increases with increasing apparent density. A rather large amount of densification occurs at relatively low compaction pressure.

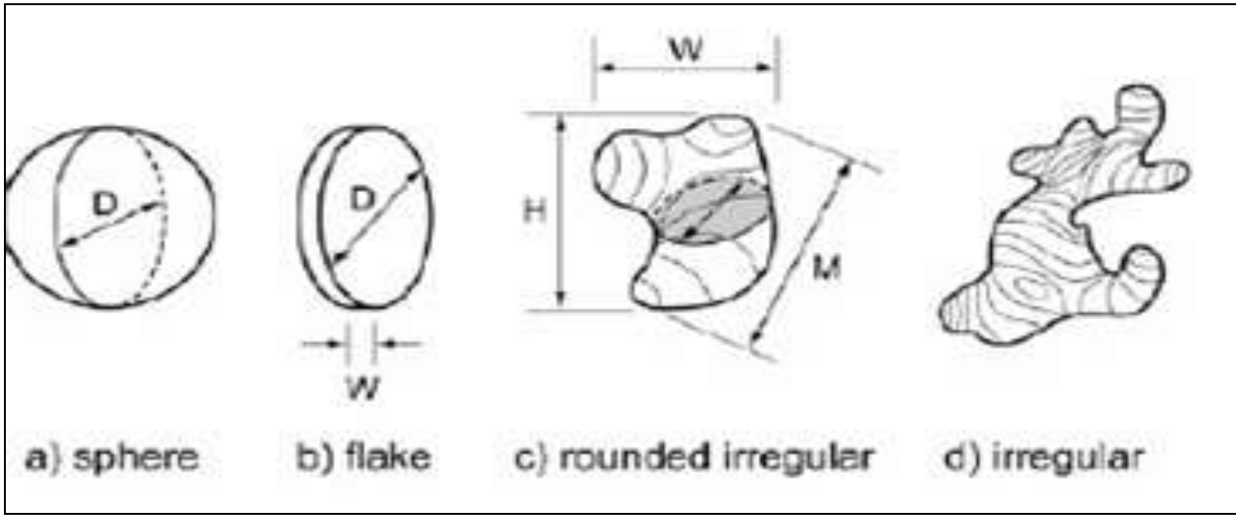
Powder Structure (particle shape)

There are various shape of metal powders such as

a) Spherical (carbonyl iron, condensed size, lead, atomization, precipitation from aqueous solution by gases).
b) Rounded or droplets (atomized copper, zinc, aluminum, tin, chemical composition).
c) Angular (mechanically disintegrated, cast iron, stainless steel obtained by intergranular corrosion).
d) Acicular (chemical decomposition)
e) Dendritic/ having a branched form (electrolytic silver, iron powder).
f) Flakes (ball milled copper, aluminum, and stamped metals).
g) Porous (reduction of oxides).
h) Irregular (atomization, reduction, chemical composition).
i) Fragmented.

Particle shape has a pronounced effect on the packing of powder and has an influence on its compacting and sintering properties and the mechanical strength of the sintered product thus, irregularly shaped particles have reduced apparent density and flow rate, good pressing and sintering properties, while spherical particles have maximum apparent density and flow rate but reduced pressing properties and good sintering characteristic.


spherical
angular
rounded
tear drop
cubic
sponge or porous
acicular
cylindrical
irregular
ligamental
flake
fibrous
polygonal
aggregate
dendritic


D
D
W
W
H
M
a) sphere
b) flake
c) rounded irregular
d) irregular

Chemical Characterization

Some of Chemical Characterization Techniques;

- XRF
- XRD
- EDX or EDXS (Detail explanation will be done in module 4)

Importance of Microstructure Study

Microstructures determine the Mechanical, Physical, and Chemical properties of materials. For example, the strength and hardness of materials are determined by the Number of Phases And Their Grain Sizes.

The electrical and magnetic properties and also the chemical behavior (corrosion) are determined by the grain size and defects (vacancies, dislocations, grain boundaries, etc.) present in the material.

The microstructure of a metal or alloy is not unique. It can be modified by different methods,

E.g. by:

Alloying additions, when a new phase may appear.

Deformation processing, when the grains may be elongated in the direction of working.

Phase transformations, when a completely new microstructure may develop. Two common examples are the transformation of austenite to

Martensite when quenching a steel

Pearlite when the steel is slowly cooled and annealed.

Table 1.1 Influence of atomic arrangement and microstructure on the properties of engineering metallic materials.

Property	Influence of atomic arrangements and atomic defects	Influence of microstructure
Mechanical (e.g., strength and ductility)	Strong	Strong
Electrical, magnetic, and thermal (e.g., resistivity, magnetization, conductivity)	Moderate to strong	Slight to strong
Chemical (e.g., corrosive resistance, catalytic potential)	Slight	Slight to moderate

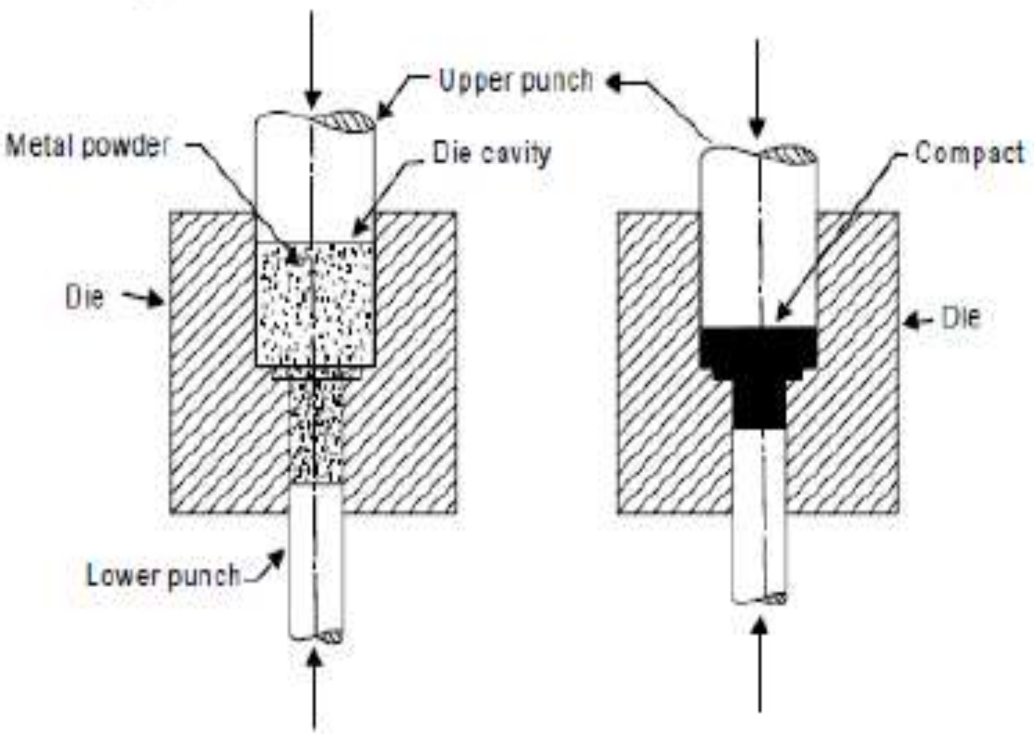
Microstructures of Powder by Different techniques

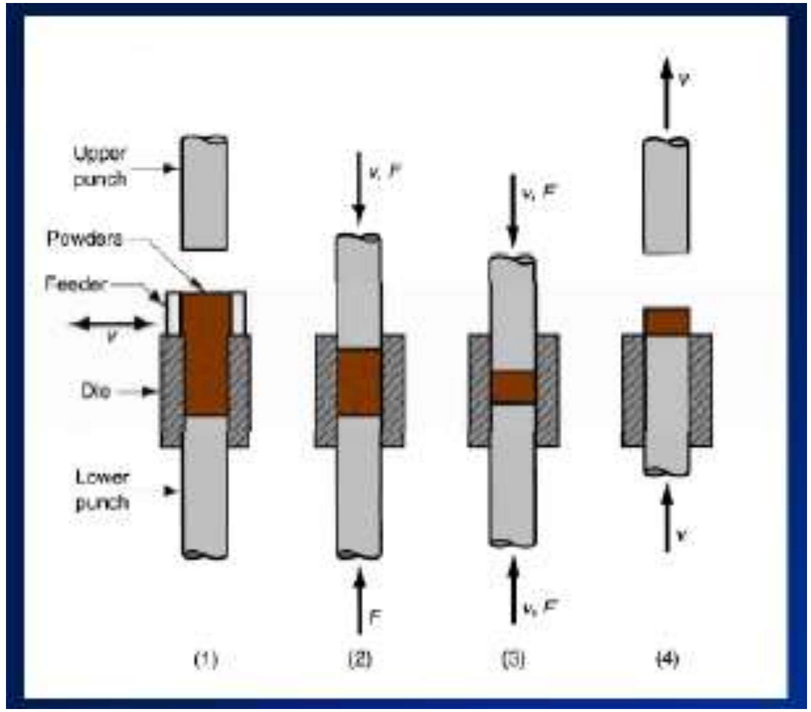
Table 1. Overview of powder characterisation techniques commonly used in AM.

	Technique	Materials	Resolution	Particle size range	Advantages	Disadvantages
Particle morphology	Sieve analysis	Solids	Bin size dependent on the size of separation of sieves	20 µm–125 nm	Applicable to broad size range, minimal sample preparation, low cost	No insight into particle shape, longer measurement time, prone to blinding, particles with large aspect ratios can produce large uncertainties
	Microscopy	Dependent on microscope	$d = \frac{0.61\lambda}{NA}$ d – resolution distance λ – light source wavelength NA – numerical aperture	Determined by system resolution	Allows qualitative and quantitative observation of particle shape, flexibility for particle size and shape analysis	Cost increase with decreasing particle size, SEM and TEM sample preparation require more effort than optical microscopy
	Laser diffraction	Solids	Dependent on instrument design and data analysis algorithm	0.04–8000 µm	Short analysis time, does not require skilled labour, highly repeatable results	Errors can result from irregular particles, measurements dependent on instrument design, agglomeration detection is difficult
Particle chemistry	XPS	Conductive solids	1 µm	Any conductive particles larger than the X-ray spot size	Determination of overall compositions and chemical bonding allows depth profiling	Sputtering through spherical particles can be difficult, requires a skilled user, cannot detect H
	AES	Conductive solids	0.5–2 µm	Any conductive particles larger than the electron beam size	Elemental analysis at a lower penetration depth compared to XPS	Destructive
	EDS	Conductive solids	2 µm	Any conductive particles larger than the electron beam size	Very fast, allows for point scans, line scans, and mapping elemental analysis	Semi-quantitative
	Fourier transform IR spectroscopy	Organic materials, some use with metals	>15 µm	<1 µm	Able to determine the functional groups present in that material quickly and easily	Generally qualitative, must grind particles in order to allow transmittance of IR radiation
	Inductively coupled plasma – atomic emission spectroscopy	Primarily used for metals	20–50 µm	Particles must be completely dissolved in a liquid	Quantification of multiple elements at a wide concentration range	Destructive and expensive, unable to detect C, N, O, F, and H
	Inert gas fusion	Solids	Dependent on resolution of cells used to analyse H, N, and O	Any	Allows for detection of O, N, and H	Destructive
Particle microstructure	XRD	Solids	Phases must have concentrations ≥5%	Best when powder particles are <150 µm	Able to determine crystal structures of phases	Only able to measure phases present >5%
	FIB	Conductive solids	1 µm	Any conductive particles larger than the ion beam spot size	Allows for direct visualisation of powder microstructure, aids in TEM sample preparation and cross-sections	Redeposition of milled material
	Transmission electron microscopy	Electron transparent conductive solids	Atoms	If particles are larger than 500 nm, they must be thinned	Offers imaging and diffraction capabilities	Difficult sample preparation, requires a skilled user
	Thermal analysis	Solids and liquids	1–2°C	Any	Allows insight into the endo- and exothermic transitions associated with the sample	Destructive

Powder Compaction & Process Variables, Pressure & Density Distribution during Compaction

Compacting is the technique of converting loose powder in to compact accurately defined shape and size.





Conventional compaction method is pressing, in which opposing punches squeeze the powders contained in a die.

•This is carried out at room temperature in a die on a press machine. The press used for compacting may be either mechanically or hydraulically operated.

•The die consists of a cavity of the shape of the desired part. The metal powder is poured in the die cavity and pressure is applied using punches, which usually work from the top and bottom of the die as shown in Figure.

•Dies are usually made of **high-grade steel**, but sometimes **carbide dies** are used for long production runs.

•In the compacting process, the pressure applied should be uniform and applied simultaneously from above and below. The pressure applied should be high enough to produce **cold welding** of the powder. Cold welding imparts a green strength, which holds the parts together and allows them to be handled.

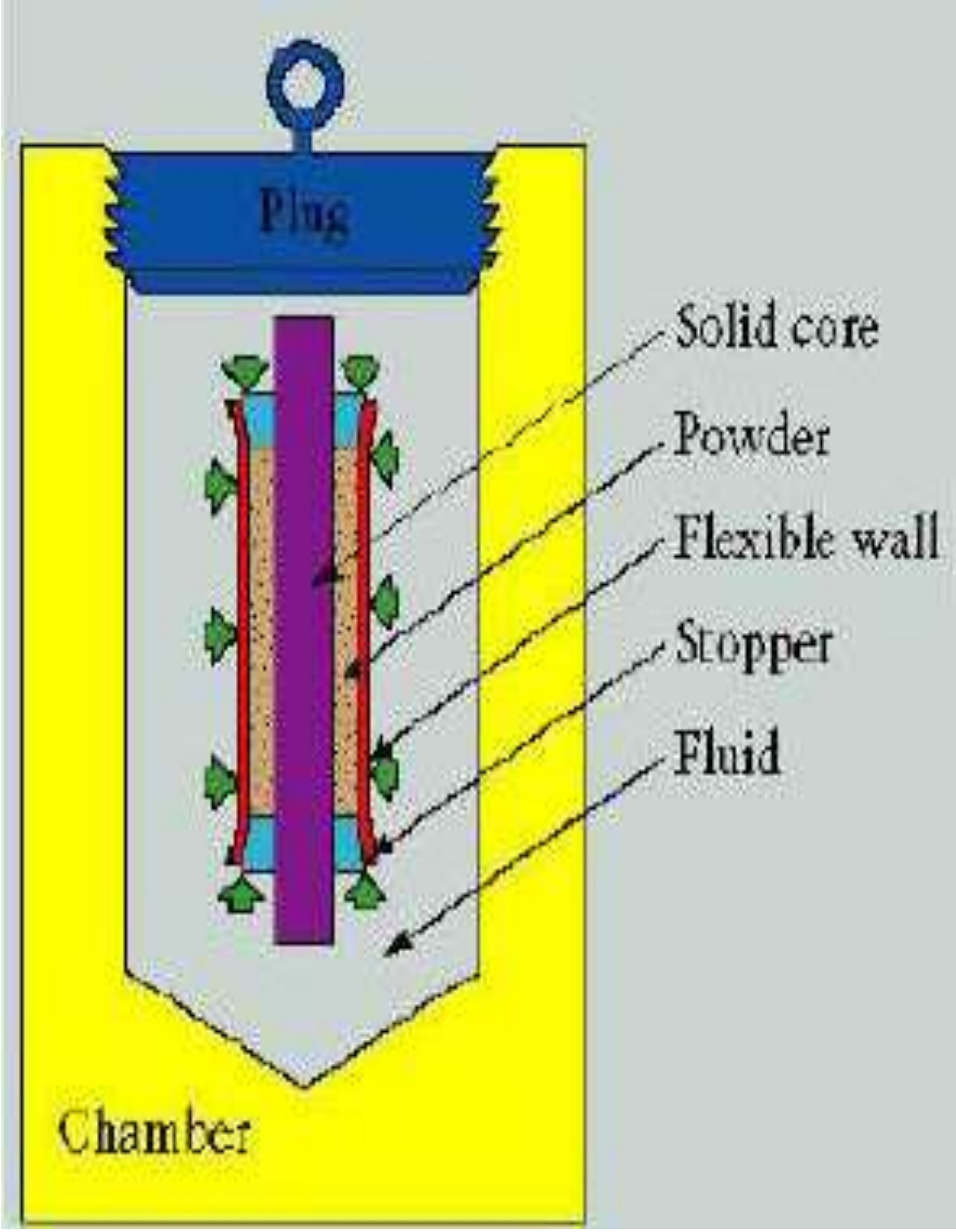
Isotactic Pressing

What is Isostatic Pressing?

Isostatic pressing is a powder metallurgy (PM) forming process that applies equal pressure in all directions on a powder compact thus achieving maximum uniformity of density and microstructure without the geometrical limitations of uniaxial pressing.

Isostatic pressing is performed "cold" or "hot." Cold Isostatic pressing (CIP) is used to compact green parts at ambient (existing or present) temperatures, while hot Isostatic pressing (HIP) is used to fully consolidate parts at elevated temperatures by solid-state diffusion. The HIP can also be used to eliminate residual porosity from a sintered PM part.

- Pressure is applied in a flexible mold.
- Glycerin, water, hydraulic oils, gases, rubber or plastics etc.
- Even pressure & density distribution
- Complex shapes
- Economical for very large products
- Excellent electrical properties
- Dimensional shrinkage is reduced
- Ductility is improved.


Plug
Solid core
Powder
Flexible wall
Stopper
Fluid
Chamber

Hot Isostatic Pressing

- Hot Isostatic pressing involves **applying pressure** and **temperature** simultaneously so that **molding** and **sintering** of the powder take place at the same time in the die.
- The effect **of time is important**, due to the viscous nature of the compact material, and the higher the temperature the shorter the time.

- Die materials include **steels, graphite, and ceramics**. High-speed steels may be used for short times **at 600°C and graphite for 700-3000°C.** However, **graphite dies are limited to pressures of 140 Kg/cm^2** and also react with metals to produce carbides.

Advantages of Hot pressing

- Reduction in gas content and shrinkage effect.
- Higher strength and hardness.
- Higher density and sound compacts
- Hot pressing breaks-down any oxide film and exposes fresh surfaces.

Disadvantages of Hot pressing

- The high cost of dies
- Pressure takes a considerable time to complete.

Application of Hot pressing

Hot pressing is used for the production of very hard cemented carbide parts.

Injection Moulding

The powder injection molding (PIM) process is an efficient method for the **high volume** production of shaped components from powders. powder injection molding (PIM) is a derivative of polymer injection molding and uses much of the same technology, along with batch sintering processes used in powder metallurgy and ceramic processing.

The PIM Process

In PIM, polymeric binders are pre-mixed with metal or ceramic powders. The mixture is heated in a screw-fed barrel and forced under pressure into a die cavity, where it cools and is subsequently ejected. The polymer is then removed and the component sintered to the required density.

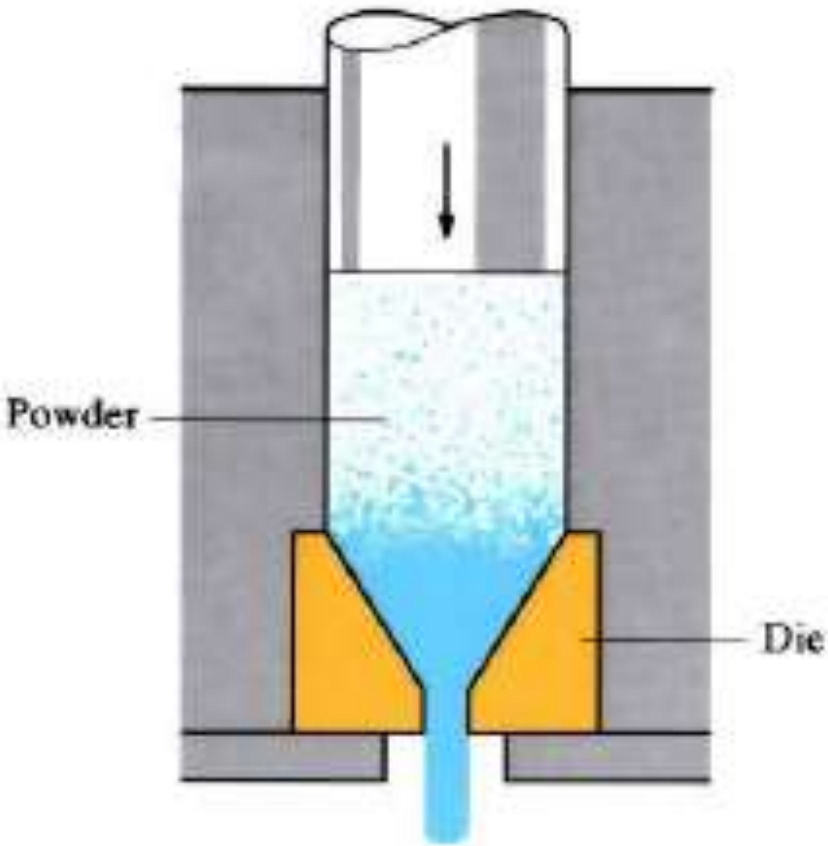
The powder injection molding process

The debonding stage, during which polymer is removed, can greatly influence the mechanical properties of the sintered component. A typical PIM injection molding mix contains 35 to 50 vol% of polymer. This must be removed without causing swelling of the component, surface blistering, or the formation of large pores, which cannot be removed during sintering and so reduce the final density and compromise mechanical properties. Multicomponent binder systems, where the polymers are removed by **solvents or degrade at different points of a thermal debonding cycle,** have shown considerable potential for minimizing debonding defects.

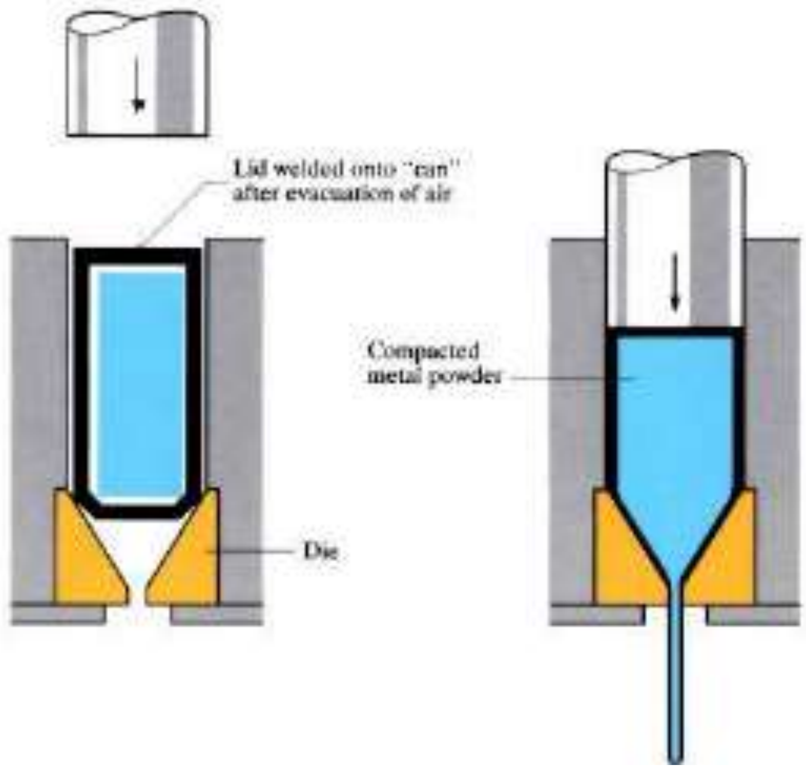
Powder Extrusion

Hydrostatic compressive stresses and shear forces act on the powders. In hot extrusion, the powder mixture is pre-compacted (‘canned') by heat compression until all air has been removed. The sealed can is then rammed by a punch until it adopts the shape of the die. Compacting pressure causes long sections of material to extrude from a small opening in the base of the die. In cold extrusion, a metal powder is compressed directly into the die, causing sections of metal to extrude from the small hole in the die base.

cold extrusion of metal powder



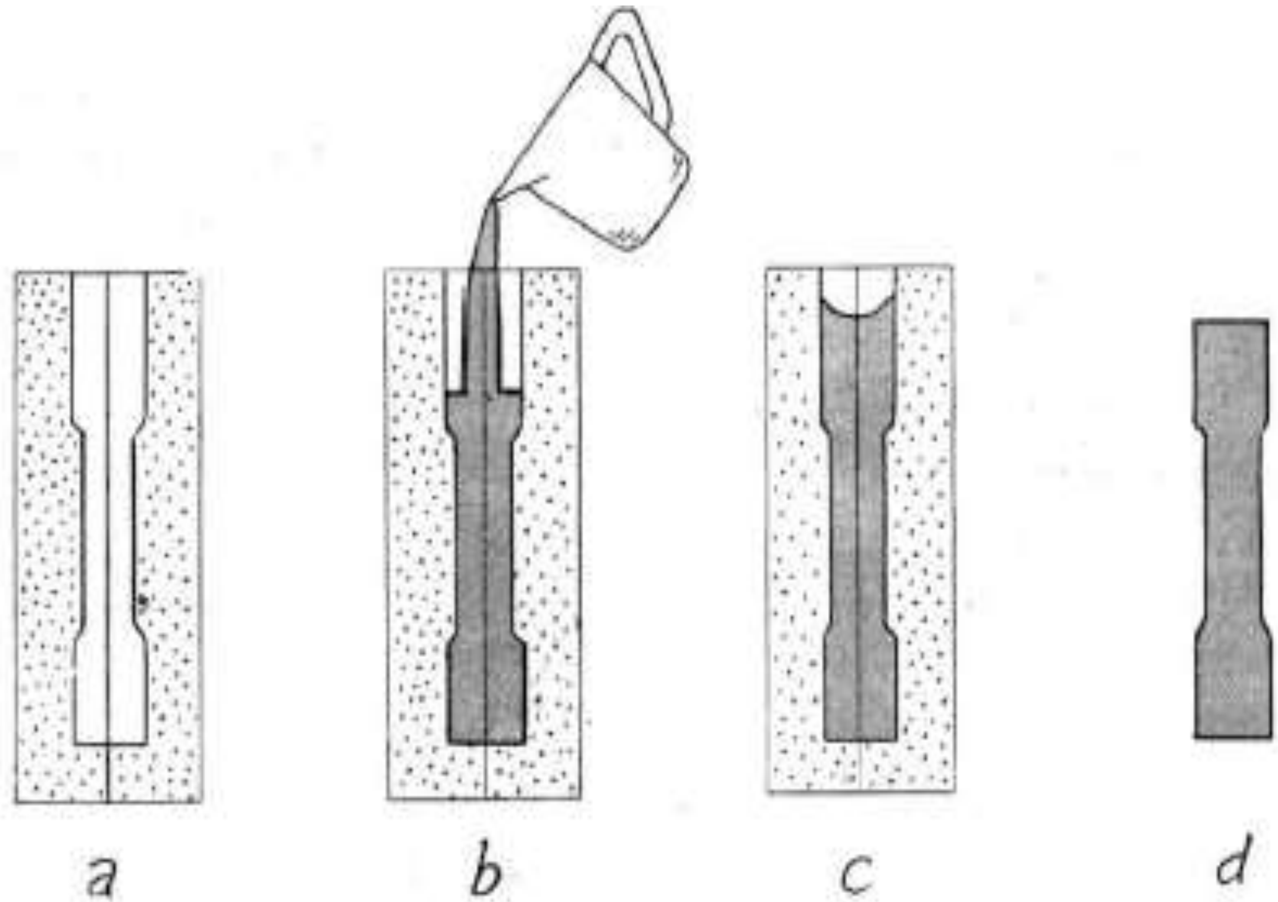
hot extrusion of metal powder



Manufacturer:

- Powders can be consolidated by cold or hot extrusion.
- Cold extrusion of powders requires a considerable amount of binders (up to 50%) such as paraffin waxes, starches, benzol, resins or shellac. This is removed during sintering of the cold extruded material, giving a large amount of porosity. The process is used for the production of carbide twist drills and cutters.
- Hot extrusion of powders is usually carried out by “canning" the powders in a mild steel can, which is evacuated and sealed at its end. This prevents oxidation of the powders at the high temperatures (which can be as high as 1400˚C for some of the refractory metals). Be achieved, leading to good densification to near theoretical density.
- The process is a batch-type process and in some instances has been superseded by the hot isostatic and Conform techniques.

Slip Casting



a. Assembled plaster mold
b. Filling the mold by slip
c. Absorbing water into plaster
d. Slip cast specimen

Fig. 1 Principles of slip casting.

This well-known ceramic process of slip casting can also be applied to certain metal powders, and parts of large dimensions or complicated shapes can be molded in this way. The process is characterized by the following steps:

1. Select the slip mixture. Variables are as follows: (1) powder particle size ranges; (2) type and amount of deflocculant; (3) water: metal ratio; (4) viscosity; (5) pH value.
2. Weigh the specific amount of powder. If more than one powder fraction is used in a slip, weigh the individual fractions and mix them.
3. Add the specified amount of deflocculant to the dry powder and blend.
4. Slowly add the appropriate amount of water, stirring mechanically while the water is being mixed.
5. Continue mechanical stirring until a smooth slip is observed and determine the pH value.
6. Alter the pH value to the selected one by adding either concentrated acid or hydroxide solution to the slip by constant checking by pH-meter.

- Allow the slip to set for a few hours to assure the removal of any air bubbles which may have been formed during stirring or degas in the vacuum.
- Apply a protective coating to the plaster of Paris mold.
- Pour the slip slowly into the plaster of Paris mold of the desired shape and size.
- Allow the slip to set for 10-20 hr in the mold so that the water can penetrate into the mold material.
- Carefully remove the metal powder slip casting from the mold and trim away any excess flash material.
- Dry the metal powder slip casting in an oven.
- Sinter at the desired temperature and time in order to obtain desired properties of the sintered material.

SLIP CASTING DISADVNTAGES

It is a well-known fact that conventional powder metallurgy, i. e., pressure-compacting of metal powders and subsequent sintering of the compact, has several severe disadvantages, such as:

•It is restricted to the production of small parts due to the capacity limitations of conventional presses, and due to the relatively high die cost.

•It does not permit pressing of certain complicated shapes due to the nonuniform pressure distribution in a mass of metal powders which is caused by the friction conditions existing during the application of pressure.

•It is economic only if applied to relatively large-scale production, on account of the relatively high cost of the hardened steel dies.

Tape Casting

Tape-casting technology is commonly used in the ceramics industry for the manufacture of thin, planar ceramic products of the large area with uniform surface quality and precise dimensions. Tape casting was performed utilizing the doctor- blade method at room temperature. The slurries were transferred into a double-chamber casting head, equipped with two blades adjusted to gap heights of 1,100 μm and 900 μm. Silicon coated Polymethyl Terephthalate (PET) film was used as a moving carrier. After drying, green tapes were removed from the carrier film with an average thickness of 350 μm. The tapes were cut into squares (20 mm×20 mm) by means of a hot knife. Laminates of similar geometry were produced by stacking together two green tapes, followed by lamination at a pressure of 10 MPa for 10 min and a temperature of 70°C; this temperature is above the glass transition temperature (Tg) of the binder-plasticizer system. The average density of the green tapes was determined by measuring the dimensions (hence the volume) of 15 pieces of tape by means of a micrometer, and weighing each piece of tape.

SINTERING

Theory of Sintering

Sintering may be considered the process by which an assembly of particles, compacted under pressure or simply confined in a container, chemically bond themselves into a coherent body under the influence of an elevated temperature. The temperature is usually below the melting point of the major constituent. Much of the difficulty in defining and analyzing sintering is based on the many changes within the material that may take place simultaneously or consecutively. **Densification or shrinkage** of the sintered part is very often associated with all types of sintering. However, sintering can take place without any shrinkage; expansion or no net dimensional change is quite possible. From the tooling point of view, it is preferred to avoid a very large amount of dimensional changes. The driving force for solid-state sintering is the excess surface free energy.

Sintering of Single & Mixed Phase Powder

Solid-state sintering

Definition: The fusing together of small particles by heating a powder sample below its melting point until its particles adhere to each other.

The type of sintering that is the simplest case, but the processes being fairly complex are that of the solid-state sintering. In this type of sintering, the powder does not melt; instead, the joining of the particles and the reduction in porosity occurs through atomic diffusion in the solid-state. Solid-state sintering involves material transport by volume diffusion. Diffusion can consist of the movement of atoms or vacancies along surface or grain boundaries or through the volume of the material. The driving force for solid-state sintering is the difference in the free energy or chemical potential between the free surfaces of the particles and the points of contact between adjacent particles.

Liquid Phase Sintering

Liquid phase sintering (LPS) is a process for forming high performance, multiple-phase components from powders. It involves sintering under conditions where solid grains coexist with a wetting liquid.

Liquid phase sintering method is getting more and more common, in which the presence of the liquid phase during all or part of the sintering cycle of material is used for enhanced densification.

- During the liquid phase sintering, a liquid phase coexists with a particulate solid at the sintering temperature
- The wetting liquid provides a capillary force that pulls the solid particles together and induces particle re-arrangement.
- The second phase chosen has a lower melting temperature than the main constituent.
- The sintering temperature is set just above the melting point of the added phase so that during sintering it forms a liquid phase that wets the solid particles.
- The pores in the compact are largely surrounded by the liquid phase and the driving force for sintering is liquid surface energy.
- With high liquid fractions, full density can be achieved almost entirely by rearrangement.
- Grain boundary ‘wetting’ breaks the polycrystalline particle into single crystal particles in the initial stages of liquid phase sintering. These single crystal particles then spheroidize and coarsen.

Wetting is a very important phenomenon which is happening during LPS.

Examples

- Powder Metallurgy parts

--Copper/Tin alloys--Iron/Copper structural parts --Tungsten Carbide/Cobalt cemented carbides

- Ceramics

Silicon Nitride with a glassy liquid phase (2wt% alumina + 6wt% yttria) -- SiC with Silicon liquid phase

Disadvantages of LPS

- Compact slumping (shape distortion) which occurs when too much liquid is formed during sintering.
- The same parameters which control the sintered microstructure often control the final properties.
- Useful application temperature of the material is sometimes limited by the presence of too much low melting point material.

<u>Modern Sintering techniques</u>

•**Conventional Sintering Process**

Dense Nanostructured ceramic materials are usually obtained by pressing and conventional sintering of nanopowders using pressure assisted methods, such as hot pressing, hot Isotactic pressing

•**Advanced sintering process**

Show great potential in ceramics processing Overcomes the problem of grain growth

1.Microwave sintering

2.Spark plasma sintering

3. High-frequency induction heat sintering

Microwave sintering

Microwave energy is a form of electromagnetic energy with the frequency range of 300MHz to 300 GHz. Microwave heating is a process in which the materials couple with microwaves, absorb the electromagnetic energy volumetrically, and transform into heat.

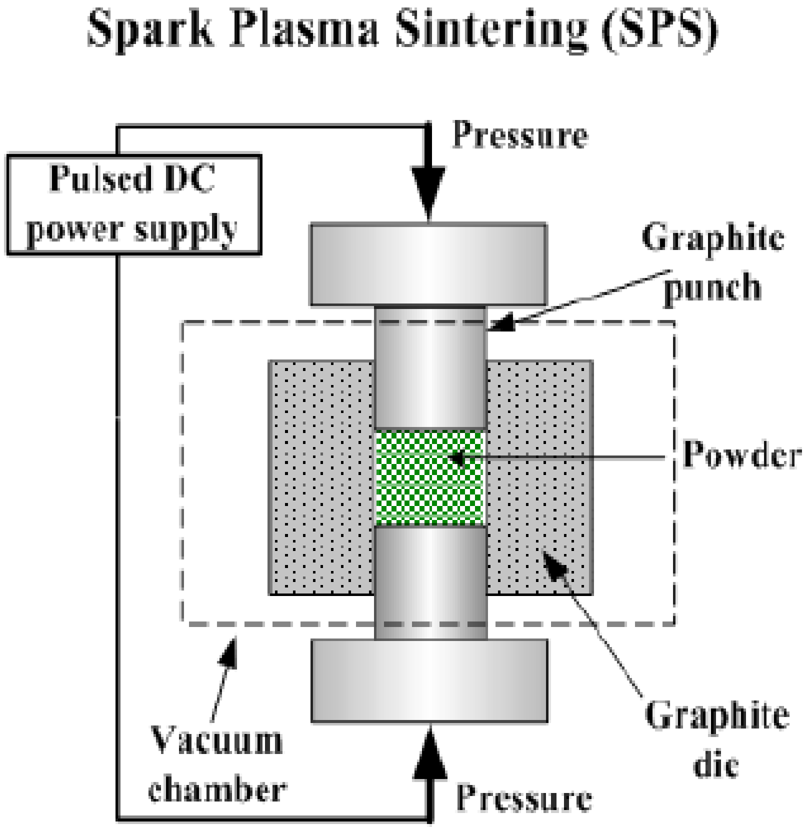
Fig. Simple micro ovens used in micro sintering

Advantages

- reduced energy consumption
- very rapid heating rates
- decreased sintering temperatures
- improved physical and mechanical properties

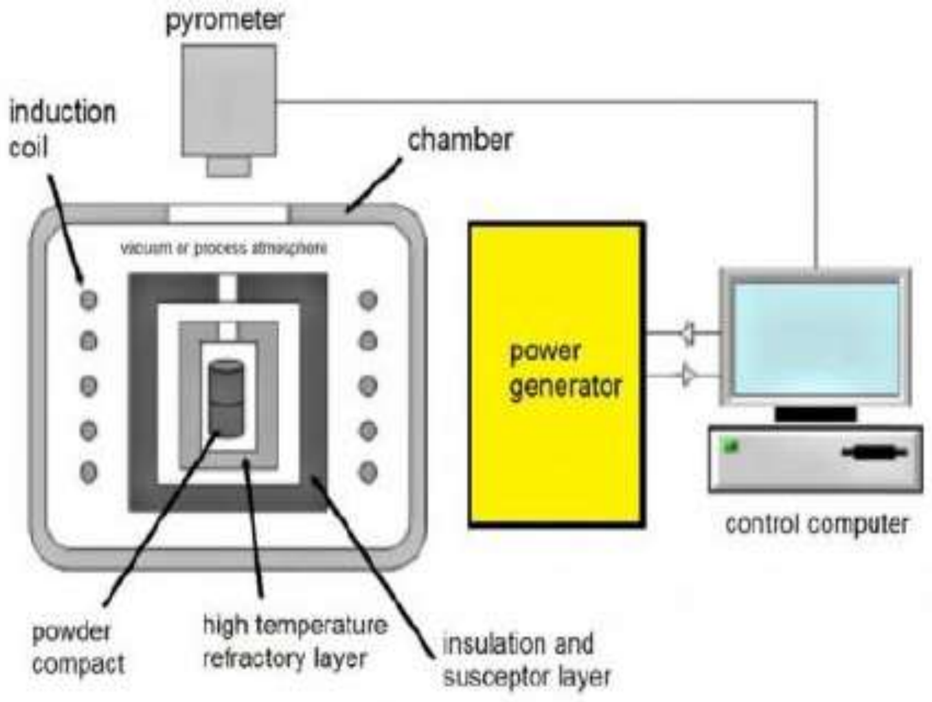
Spark plasma sintering

Instead of using an external heating source, a pulsed direct current is allowed to pass through the electrically conducting pressure die and, in appropriate cases, also through the sample. Die also acts as a heating source and that the sample is heated from both outside and inside.



3. **High-frequency induction heat sintering**

It is similar to hot pressing, which is carried out in a graphite die, but heating is accomplished by a source of high-frequency electricity to drive a large alternating current through a coil. This coil is known as the work coil. The passage of current through this coil generates a very intense and rapidly changing magnetic field in the space within the work coil.



Physical & Mechanical Properties Evaluation

Density

In general, the density achieved in sintered products is between 70 and 95 % of the fully dense wrought products, depending on the production technology in use and the type of application. Pores are of two types: (a) interconnected and (b) closed or isolated.

In the first case, the pores are connected with each other along the particle junctions. The pores are consequently irregular unless the particles are initially spherical. Such pores can remain as low as 5% of total porosity. The latter types of pores, i.e. closed pores, are pronounced when total porosity is low (<5%). They are often, but not necessarily, spherical.

The sintered density determination is carried out following the procedures of ISO standard 2738. This is valid both for dry parts and for parts that have been impregnated with oil. In case parts have been impregnated with thermosetting polymers, the true density is obtained graphically (Fig). This allows the calculation of the unknown density by determining the density of the part examined and assuming a degree of impregnation equal to 0.8. As most impregnating resins have a density of between 1 and 1.3, two straight lines have been drawn on the diagram defines the two limits of the band; intermediate points may be obtained by interpolation.

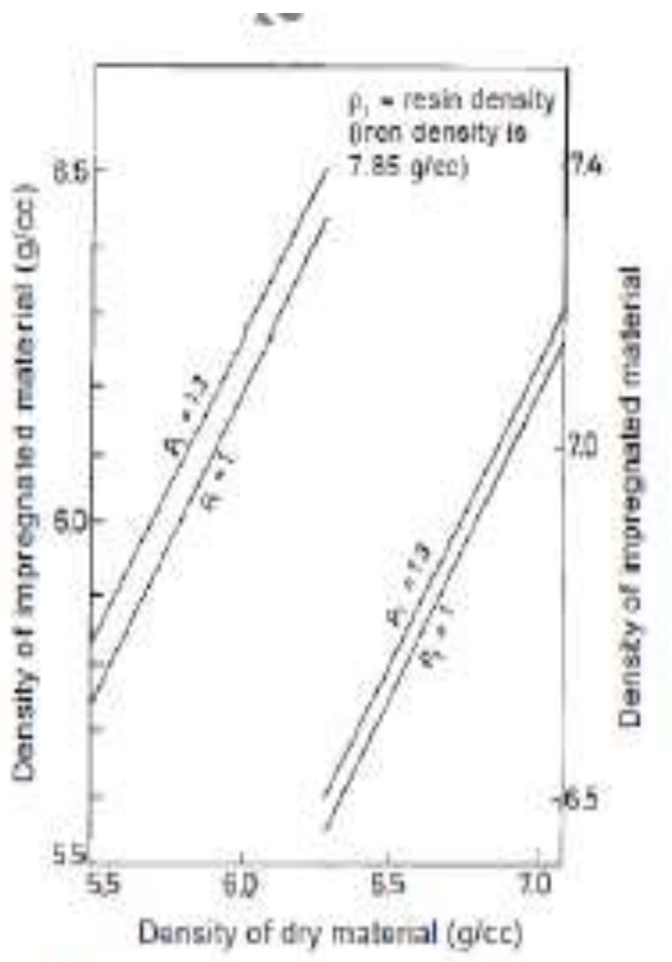


Fig. 10.1 True density of resin-impregnated parts.[1]

MECHANICAL PROPERTIES

The Metal Powder Industries Federation (MPIF) of USA has adopted the concept of minimum strength values for P/M materials for use in a structural application. it may be noticed that the P/M process offers equivalent minimum tensile strength values over a wide range of materials. It is seen as an advantage of the process that equivalent strengths can be developed by varying chemical composition, particle character, density and/or processing techniques.

The material may be specified as the basis of properties obtained in test samples made under a similar condition, but it is understood that the properties of sintered parts may not be identical to the test pieces because of shape effects. The test methods and instrumentation used are similar to those used for wrought products. The various national and international standards have been limited to standardizing the types of test pieces.

A brief description of various common mechanical properties is given as follows:

Hardness

the hardness value has great importance and provides indications of the mechanical behavior of sintered products. The indentation hardness of a sintered material is also strongly affected by its density because voids in the structure of material do not contribute to the support of indenter. The indentation of a porous material should be considered in apparent hardness. The ISO standard on apparent hardness recommends **Vickers** as the reference method but allows **Brinell and Rockwell methods** as alternatives.

It prevents direct conversion from one hardness scale to another. Though it is possible to compare one hardness scale with another provided both tests have been done on the products concerned, there are practical shortcomings in the tests currently specified. In **Vickers and Brinell tests**, surface preparation is critical, the tests are slow and require both visual judgment and use of a conversion table. Furthermore, automation is not practical.

The Rockwell test, on the other hand, uses heavy loads of 60–150 kg which is less responsive to the metallurgical structure of the material than density variations. In addition, the test is insensitive in the most common hardness ranges used in sintered metals. A possible alternative is the superficial Rockwell test using a 15 kg load.

Tensile Strength

The tensile properties of sintered products are directly influenced by porosity. Due to the presence of porosity, the tensile properties are somewhat lower than those of wrought materials of the same composition and structure. For sintered materials, machined test pieces are almost never used and test pieces are invariably obtained by pressing and sintering. The figure illustrates a typical MPIF test piece for tensile properties evaluation. With sintered materials care should be taken with their storage before testing because their interconnected porosity may give rise to internal corrosion. In the case of fully dense materials like P/M forged, the machined test pieces may be used. Porosity has a more pronounced effect on ductility than on strength. A pore content of a few percents can be rather detrimental to ductility. However, production variables, particularly in sintering, also have a significant effect on ductility, so that the ductility of similar materials of the same porosity but of different origins may differ widely.

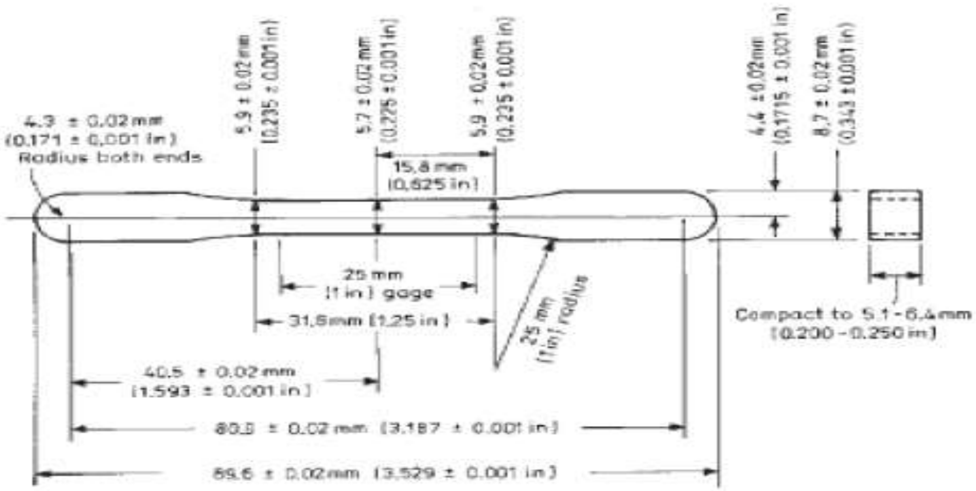


Fig. 10.2 MPIF tensile test piece dimensions.

Transverse Rupture Strength (Bending Strength)

This test is applicable only to materials of negligible ductility. The width and thickness of the specimens are measured accurately. The specimens are then broken in the testing fixture shown in Fig. In this fixture, the specimen is supported by two hard metal or hardened steel rods at 25.40 mm centers and another rod presses at the center of the specimen.

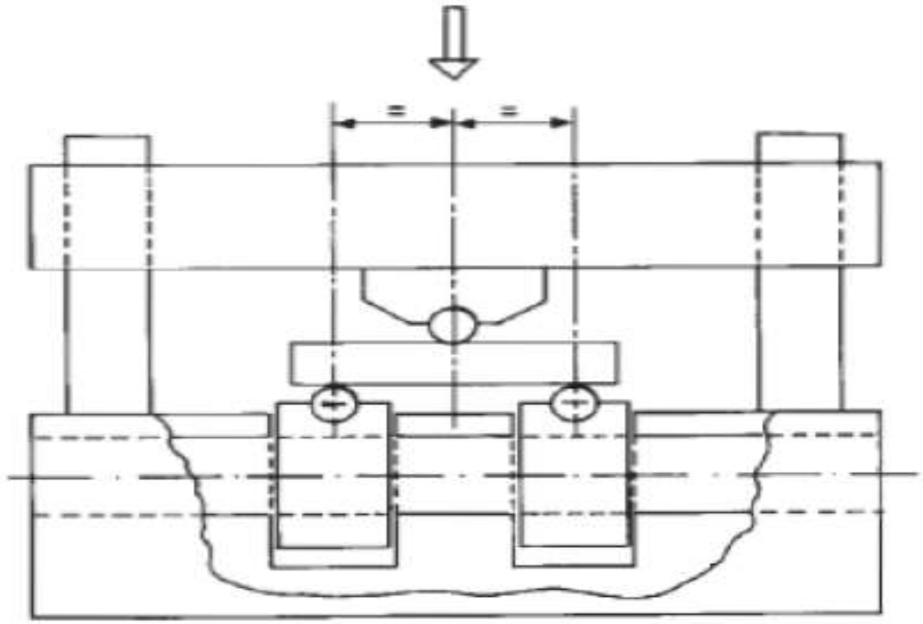


Fig. 10.3 Test fixture for transverse rupture strength.[1]

The test is performed in a universal testing machine and the breaking load recorded. The modulus of rupture is calculated as follows:

$$S = \frac{3PL}{2t^2W}$$

Where S is the modulus of rupture, N/mm^2; P is the breaking load, N; L is the distance between the supporting rods (25 ± 0.2 mm); t is the thickness of the specimen, mm; W is the width of the specimen, mm. At least five determinations should be made and the result is expressed as the arithmetic mean rounded up to the nearest 10.

Fatigue Properties

The influence of porosity is more important in fatigue tests than in other mechanical tests. Fatigue tests are important after surface treatment, hardening and nitriding of sintered steels. All such treatments raise the fatigue limit, as in pore-free materials. Above the fatigue limit, micro cracks are initiated at pores and inclusions and linked together to form the final crack, which generally gives in a mixed Tran's granular intergranular manner.

Structure-Property Correlation Study

Metallographic study of sintered products is essential to study the type and morphology of pores which affect various properties. Metallographic preparation of such material can lead to changes in the specimen surface which can cause invalid interpretation of the microstructure. Some examples of such changes are: 4

- Partial closing of pores by plastic deformation during grinding
- Break out of material around the pore
- The closing of pores with grinding debris
- Rounding of pore edges

The preparation sequence of metallographic specimens of porous materials may be described as follows:

Sample Preparation: An abrasive cut off wheel with water as coolant may be used for sectioning purpose. Thorough rinsing with water must be carried out in order to remove any cutting debris. Specimen mounting can be done as a usual practice.

Grinding: This can be done using SiC paper of 220 grit size using water as a coolant or an automatic grinding wheel. A speed of 300 rpm with a load of 90, 60 and 30 N is used for three grinding steps. After the grinding operation, the specimens are ultrasonically cleaned in an alcohol bath.

Impregnation: The process is necessary to seal the open porosity of the specimen so that abrasives, water, and etchants are not entrapped later on. If the specimen is not moisture free, ‘bleeding out' during etching may occur which causes staining of the surface. Vacuum impregnation is carried out with epoxy resin.

Regrinding: After impregnation, regrinding is carried out on 500 and 1000 grit silicon carbide paper.

Polishing: This operation is generally carried out with 6, 3 and 1 μm diamond polishing spray on an automatic wheel using a load of 90N, 60N and 30N for one minute each. Polishing on a cloth with a suspension of alumina may also be carried out. In unetched condition total porosity, pore size and shape, nonmetallic inclusions, additions like manganese sulfide for improved machinability, undissolved alloying elements, etc., may be observed.

Etching: Etching is generally performed by concentration. This facilitates the study of homogeneity of alloying, grain size and the presence of different phases.

Quality Control of Sintered Products - Some Case Studies

Sintered products are often used to replace traditional metals for cost saving or technical improvement or ideally both. In either case, it is necessary to quantify the service parameters in terms of physical, mechanical, and chemical properties. Moreover, while dealing with sintered products, one must emphasize the need for function awareness when specifying any material.

Unfortunately, in the powder metallurgy industry, there are not many records of past failures which may help in selecting a material that will satisfactorily perform a particular function. To simplify the matter, the first thing is to define the function of the component and develop functional tests which will determine whether the part will do the job. This brings out the importance of differentiating between material tests and product tests. The former provides information about the properties of the material of a test piece in relation to its intended applications. The product tests, however, specifically check the immediate fitness for service of the product and the batch from which it has been drawn.

A detailed analysis of the quality control aspect has been reported by Upadhyaya12 elsewhere.

Some factors which may handicap the quality of sintered products may be:

•Testing and inspection procedures which do not realistically reflect actual use situation, e.g. particle size yield in floor screening by vibroscreens vs. the laboratory routine screening.

•Arbitrary material substitution by the purchasing or manufacturing departments, without adequate engineering evaluation. This is very important in case of tool material selection for complex P/M parts.

•Crash design revisions to incorporate new features in existing designs with minimum tooling changes. Here a prototype development can help considerably in building up confidence.

•Failure to apply the same evaluation methods to purchased components or powders as are applied to internally manufactured ones.

•Failure to anticipate misapplication of the product by the user, for example in selecting the proper grade of cemented carbide for different cutting purposes.

- Too little consideration given to the wide variations in the physical and intellectual abilities of customers.
- Interpretation of the statistical quality control functions as absolute quality assurance rather than a basis for action.
- Inadequate advice to the user of safety procedures related to the product. For example, iron base metal powder sintered bearings are more suitable for higher loads and slower speeds than copper base bearings.
- The P/M process allows considerable cost variation if specific part requirements are not clear. Such a situation would consequently bring forth a considerable quality variation too.

For widely different costs; there may be various reasons such as

- Revision of tolerance
- The difference in manufacturing practices
- Introduction of supplementary processes such as repressing etc.
- Lack of any specified minimum density. In brief, gross differences in quality may lead to a serious misunderstanding of requirements.

APPLICATION OF POWDER METALLURGY

Some prominent powder metallurgy products are as follows:

- **Filters:** Powder metallurgy filters have greater strength and shock resistance than ceramic filters. Fiber metal filters, having porosity up to 95% and more, are used for filtering air and fluids.
- **Cutting Tools and Dies:** Cemented carbide cutting tool inserts are produced from tungsten carbide powder mixed with a cobalt binder.
- **Machinery Parts:** Gears, bushes, and bearings, sprockets, rotors are made from metal powders mixed with sufficient graphite to give the product desired carbon content.
- **Bearing and Bushes:** Bearing and bushes to be used with rotating parts are made from copper powder mixed with graphite.
- **Magnets:** Small magnets produced from different compositions of powders of iron, aluminum, nickel, and cobalt has shown excellent performance, far superior to that cast.

MODULE 4
NANO MATERIALS & CHARACTERIZATION TECHNIQUES

Introduction: Importance of Nano-technology, Emergence of Nanotechnology, Bottom up and Top-down approaches, challenges in Nanotechnology

Nano-materials Synthesis and Processing: Methods for creating Nanostructures; Processes for producing ultrafine powders- Mechanical grinding; Wet Chemical Synthesis of Nano-materials- sol-gel process; Gas Phase synthesis of Nano-materials- Furnace, Flame assisted ultrasonic spray pyrolysis; Gas Condensation Processing (GPC), Chemical Vapour Condensation (CVC).

Optical Microscopy -principles, Imaging Modes, Applications, Limitations.

Scanning Electron Microscopy (SEM) -principles, Imaging Modes, Applications, Limitations**.**

Transmission Electron Microscopy (TEM) -principles, Imaging Modes, Applications, **Limitations.**

X- Ray Diffraction (XRD) - principles, Imaging Modes, Applications, Limitations.

Scanning Probe Microscopy (SPM) - principles, Imaging Modes, Applications, Limitations. **Atomic Force Microscopy (AFM) -** basic principles, instrumentation, operational modes, Applications, Limitations.

Electron Probe Micro Analyzer (EPMA) - Introduction, Sample preparation, Working procedure, Applications, Limitations.

IMPORTANCE OF NANO-TECHNOLOGY

The development of nanotechnology is wide-ranging and could include medicine, military applications, computing and astronomy. Nanotechnology is being used already in sunscreens, self cleaning windows, stain repellent fabrics etc, The emergence of nanotechnology has led to the design, synthesis, and manipulation of particles in order to create a new opportunity for the utilization of smaller and more regular structures for various applications.

In recent years, Nano sized metal oxide particles have gotten much attention in various fields of application due to its unique optical, electrical, magnetic, catalytic and biomedical properties as well as their high surface to volume ratio and specific similarity for the adsorption of inorganic pollutants and degradation of organic pollutants in aqueous systems.

WHAT IS NANO TECHNOLOGY?

In the metric system of measurement, Nano means small (10^{-9}m) but of high strength, and emerging with large applications piercing through all the discipline of knowledge, leading to industrial and technological growth

References to Nano materials, nanoelectronics, Nano devices and Nano powders simply mean the material or activity can be measured in nanometers.

Nanotechnology is a fundamental, enabling technology, allowing us to do new things in almost every conceivable technological discipline.

Nanotechnology is:

Nanotechnology is the formation of useful or functional materials, devices and systems through control of matter on the nanometre length scale and exploitation of novel phenomena and properties which arise because of the nanometre length scale.

•Included of Nanomaterials with at least one dimension that measures between approximately 1 and 100 nm

•Comprised of Nanomaterials that exhibit unique properties as a result of their nanoscale size.

•Based on new nanoscale discoveries across the various disciplines of science and engineering.

•The exploitation of these Nanomaterials to develop new technologies/ applications or to improve on existing ones.

•Used in a wide range of applications from electronics to medicine to energy and more.

EMERGENCE OF NANOTECHNOLOGY

The history of nanotechnology traces the development of concepts and experimental work falling under the broad category of nanotechnology. The emergence of nanotechnology has led to the design, synthesis, and manipulation of particles in order to create a new opportunity for the utilization of smaller and more regular structures for various applications.

In recent years, Nano-sized metal oxide particles have gotten much attention in various fields of application due to its unique optical, electrical, magnetic, catalytic and biomedical properties as well as their high surface to volume ratio and specific affinity for the adsorption of inorganic pollutants and degradation of organic pollutants in aqueous systems.

Although it is a relatively recent development in scientific research, the development of its central concepts happened over a longer period of time. Although nanoparticles are associated with modern science, they were used by artisans as far back as the ninth century in Mesopotamia for creating a glittering/impressive effect on the surface of pots.

BASIC APPROACHES FOR SYNTHESIS

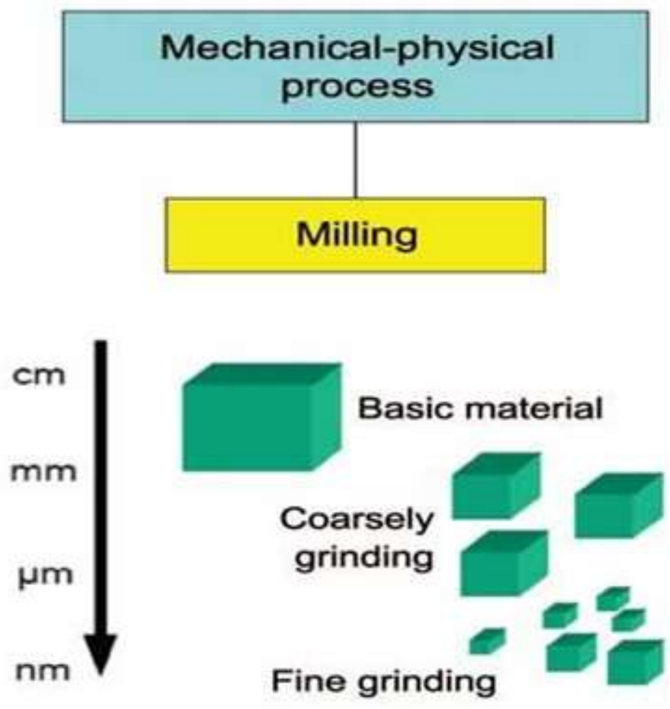
There are two types of approaches for synthesis of Nano material and fabrication of Nano structures.

Top-down approach

Bottom-up approach

Top-down method

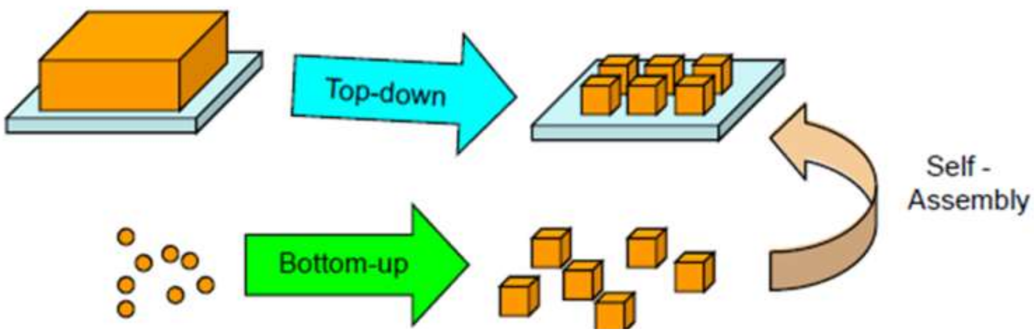
This mechanical production approach uses milling to crush micro particles. This approach is applied in producing metallic and ceramic Nanomaterials. In the first case Nanomaterials are derived from a bulk substrate and obtained by progressive removal of material, until the desired Nanomaterials is obtained. E.g.) Ball Milling, Sol-Gel, lithography



Bottom-up methods

This approach is also known as chemical approach. This is based on the physicochemical principles of molecular or atomic self-organization. This approach produces selected, more complex structures from atoms or molecules, better controlling sizes, shapes and size ranges. **Bottom-up** approach works in the opposite direction, the Nanomaterials, such as a nanocoating, are obtained starting from the atomic or molecular originator and gradually assembling it until the desired structure is formed.

E.g.) Plasma etching, Chemical vapour deposition.



In both methods two requisites are fundamental: control of the fabrication conditions (e.g. energy of the electron beam) and control of the environment conditions (presence of dust, contaminants, etc). For these reasons, nanotechnologies use highly sophisticated fabrication tools that are mostly operated in a vacuum in clean-room laboratories.

CHALLENGES IN NANOTECHNOLOGY

The challenges arising from nanotechnology is largely on target.

Five Grand Challenges to "stimulate research that is imaginative, innovative, timely and above all relevant to the safety of nanotechnology." They include the development of:

1. Instruments to assess environmental exposure to Nanomaterials.
2. Methods to evaluate the toxicity of nanomaterials.
3. Models for predicting the potential impact of new, engineered nanomaterials.
4. Ways of evaluating the impact of nanomaterials across their life cycle.
5. Strategic programs to enable risk-focused research.

Within the Five Grand Challenges, the authors set specific targets to achieve within specific timeframes. These include developing a "universal aerosol sampler" for measuring exposure to airborne nanomaterials, assessing whether fiber-shaped nanoparticles present a unique health hazard, and establishing ways of engineering nanomaterials that are "safe-by-design."

"It is generally accepted that, in principle, some nanomaterials may have the potential to cause harm to people and the environment," according to the authors. "Yet research into understanding, managing, and preventing risk often has a low priority in the competitive worlds of intellectual property, research funding and technology development."

PROCESSES FOR PRODUCING ULTRAFINE POWDERS- MECHANICAL GRINDING

Nanomaterials preparation

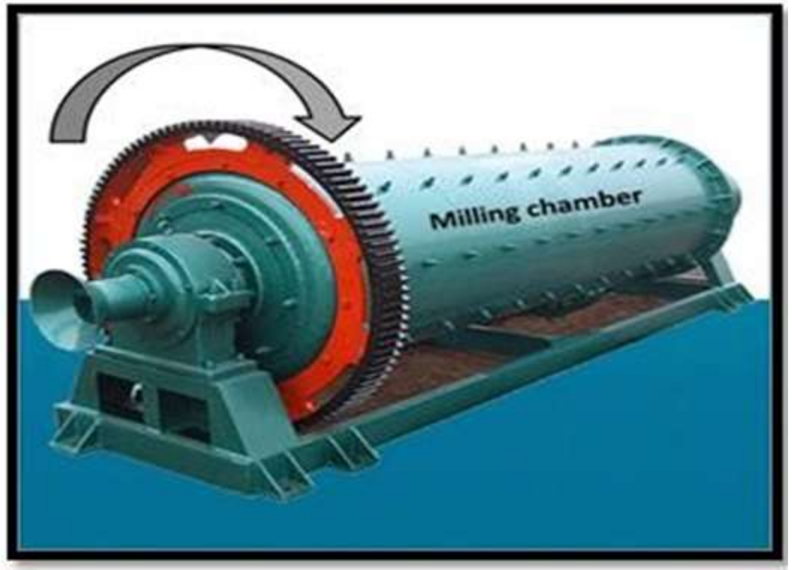
Physical Methods

- Ball milling
- Laser ablation
- Gas condensation processing (GPC)

Chemical Methods

- Sol-gel synthesis
- Solution phase (stabilizing Ligands)
- Precipitation method
- Chemical vapour condensation Catalytic chemical vapour deposition Template assisted CVD Electrochemical method

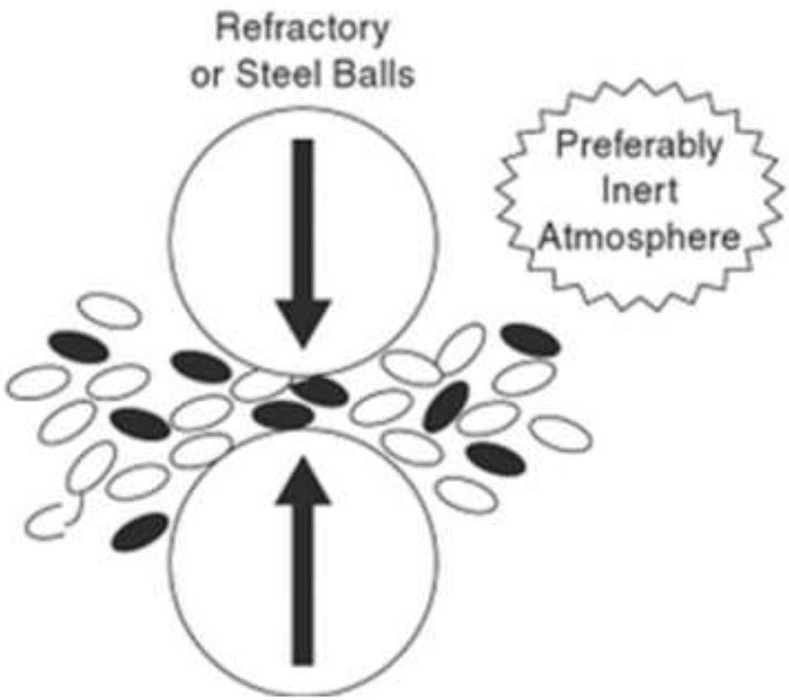
BALL-MILLING



Ball-milling of elemental powders has been thoroughly investigated in various conditions of energy transfer to identify the mechanisms by which materials deform to produce nanometre-sized grains, characterize the intergranular and intergranular defects of nanograined ground powders, and measure the resulting changes in properties with respect to those of coarse-grained elements, for instance mechanical, magnetic, hydrogen storage capacity Popular, simple, inexpensive and extremely scalable material to synthesize all classes of nanoparticles. Can produce amorphous or nanocrystalline materials.

Mechanical grinding down mechanism is used to obtain nanocrystalline structures from either single-phase powders or amorphous materials. Can use either refractory balls or steel balls or plastic balls depending on the material to be synthesized.

When the balls rotate at a particular rpm, the necessary energy is transferred to the powder which in turn reduces the powder of coarse grain-sized structure to ultrafine nanorange particle.



The energy transferred to the powder from the balls depends on many factors such as

- Rotational Speed of the balls
- Size of the balls
- Number of the Balls
- Milling time
- Ratio of ball to powder mass
- Milling medium /atmosphere

The selection of ball material influences the type of material obtained. E.g. harder material balls, synthesize softer materials. **Alpha-alumina and zirconia** are widely used ball materials due to their high grinding resistance values.

ADVANTAGES OF BALL MILLING

Scaling can be achieved up to tonnage quantity of materials for wider applications

DISADVANTAGES OF BALL MILLING

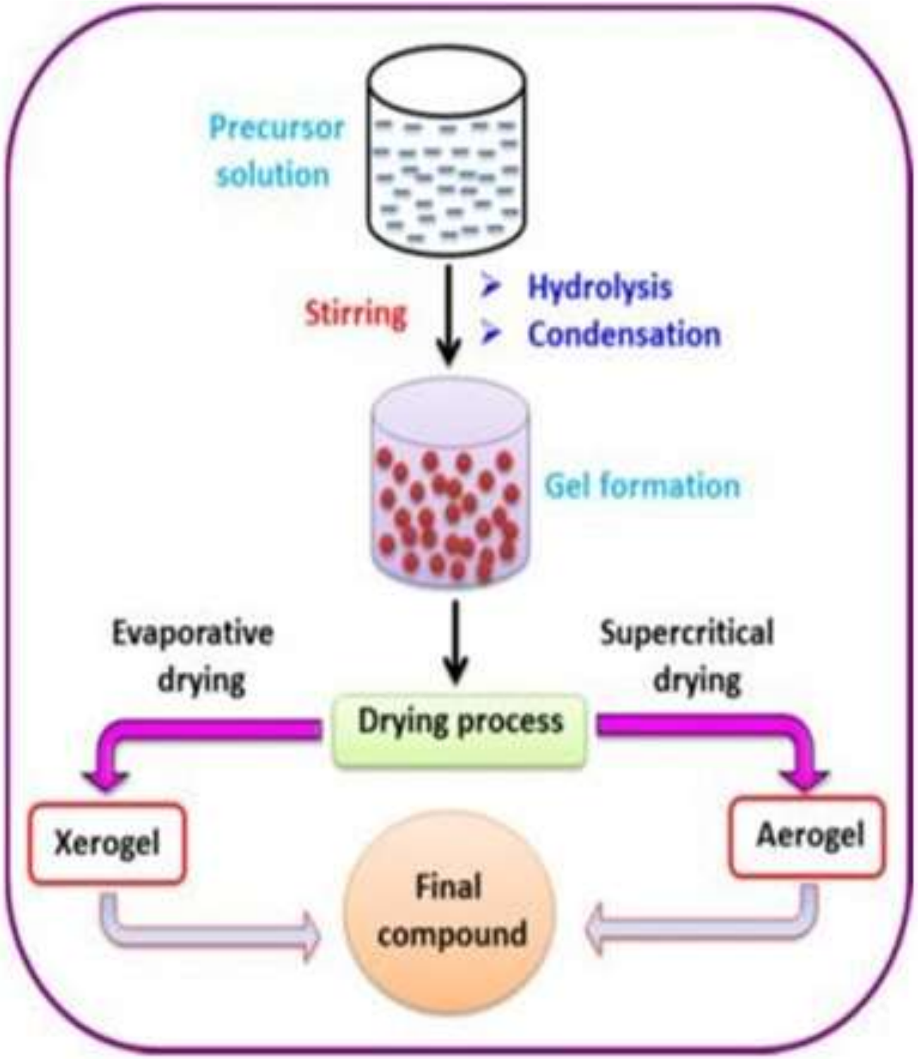
- Pollution of the milling media.
- Non-metal oxides require an inert medium, and vacuum or glove box to use powder particles.
- The milling process is restrictive.

WET CHEMICAL SYNTHESIS OF NANO-MATERIALS- SOL-GEL PROCESS

Wet Chemical Technique (Chemical solution deposition technique) which Produce high purity and homogeneous nanomaterials, particularly metal oxide nanoparticles Starting material from a chemical solution leads to the formation of a mixture having particles **suspended** in a continuous phase with another component known as SOL.

The SOL develops towards the formation of inorganic network containing a liquid phase called the GEL. The removal of liquid phase from the Sol yields the Gel. The particle size and shape are controlled by the Sol/Gel transitions.

The thermal treatment (firing/calcinations) of the gel leads to further poly condensation Reaction and enhances the mechanical properties of the products (i.e.) oxide nanoparticles.



PRECURSORS ⟶ Metal alkoxides and metal chlorides

Starting material is washed with water and dilute acid in alkaline solvent.

The material undergoes hydrolysis and polycondensation reaction which leads to the formation of colloids. Colloid System composed of solid particles is dispersed in solvent containing particles of size from 1nm to 1mm. The SOL is then evolved to form an inorganic network containing a liquid phase (GEL). The Sol can be further processed to obtain the substrate in a film, either by dip coating or Spin-coating or case into a contained with desired shape or powders by calcinations.

In core, the sol-gel process usually consists of 4 steps:

- The desired colloidal particles once dispersed in a liquid to form a sol.
- The deposition of sol solution produces the coatings on the substrates by spraying, dipping or spinning.
- The particles in sol are polymerized through the removal of the stabilizing components and produce a gel in a state of a continuous network.
- The final heat treatments pyrolyze the remaining organic or inorganic components and form an amorphous or crystalline coating.

Advantages of Sol-Gel Technique:

- Can produce **thin bond-coating** to provide excellent adhesion between the metallic substrate and the top coat.
- Can produce **thick coating** to provide corrosion protection performance.
- Can easily **shape** materials into complex geometries in a gel state.
- Can produce **high purity products** because the organometallics precursor of the desired ceramic oxides can be mixed, dissolved in a specified solvent and hydrolyzed into a sol, and subsequently a gel, the composition can be highly controllable.
- Can have **low temperature sintering** capability, usually 200-600°C.
- Can provide a **simple, economic and effective** method to produce high quality coatings.

Applications:

- It can be used in ceramics manufacturing processes, as an investment casting material.
- products fabricated with this process include various ceramic membranes for microfiltration, ultra filtration, nanofiltration, evaporation and reverse osmosis.

Gas Phase synthesis of Nano-materials

Synthesis methods of nanoparticles in the gas phase are based on homogeneous nucleation in the gas phase and subsequent condensation and coagulation.

Furnace

The simplest fashion to produce nanoparticles is by heating the desired material in a heat resistant crucible containing the desired material. This method is appropriate only for materials that have a high vapour pressure at the heated temperatures that can be as high as 2000°C. Energy is normally introduced into the originator by arc heating, electron beam heating or Joule heating. The atoms are evaporated into an atmosphere, which is either inert (e.g. He) or reactive (so as to form a compound). To carry out reactive synthesis, materials with very low vapour pressure have to be fed into the furnace in the form of a suitable precursor such as organometallics, which decompose in the furnace to produce a condensable material. The hot atoms of the evaporated matter lose energy by accident with the atoms of the cold gas and undergo condensation into small clusters via homogeneous nucleation.

In case a compound is being synthesized, these precursors react in the gas phase and form a compound with the material that is separately injected in the reaction chamber. The clusters would continue to grow if they remain in the supersaturated region. To control their size, they need to be rapidly removed from the supersaturated environment by a carrier gas. The cluster size and its distribution are controlled by only three parameters:

- The rate of evaporation (energy input)
- The rate of condensation (energy removal),
- The rate of gas flow (cluster removal).

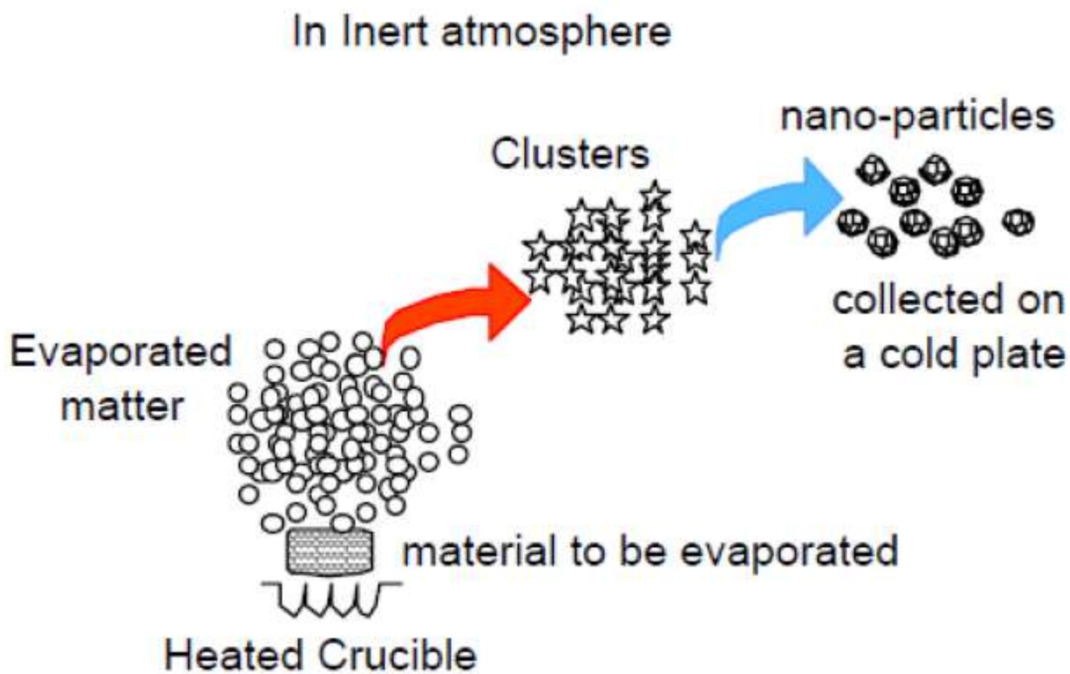


Fig. Schematic representation of gas phase process of synthesis of single phase nanomaterials from a heated crucible

Flame assisted ultrasonic spray pyrolysis

In this process, precursors are nebulised and then unwanted components are burnt in a flame to get the required material, e.g. ZrO_2 has been obtained by this method from a precursor of Zr $(CH_3CH_2CH_2O)_4$.

Flame hydrolysis that is a alternative of this process is used for the manufacture of fused silica. In the process, silicon tetrachloride is heated in an oxy-hydrogen flame to give highly dispersed silica. The resulting white amorphous powder consists of spherical particles with sizes in the range 7-40 nm.

The combustion flame synthesis, in which the burning of a gas mixture, e.g. acetylene and oxygen or hydrogen and oxygen, supplies the energy to initiate the pyrolysis of precursor compounds, is widely used for the industrial production of powders in large quantities, such as carbon black, fumed silica and titanium dioxide. However, since the gas pressure during the reaction is high, highly agglomerated powders are produced which is disadvantageous for subsequent processing.

The basic idea of low pressure combustion flame synthesis is to extend the pressure range to the pressures used in gas phase synthesis and thus to reduce or avoid the agglomeration. Low pressure flames have been extensively used by aerosol scientists to study particle formation in the flame.

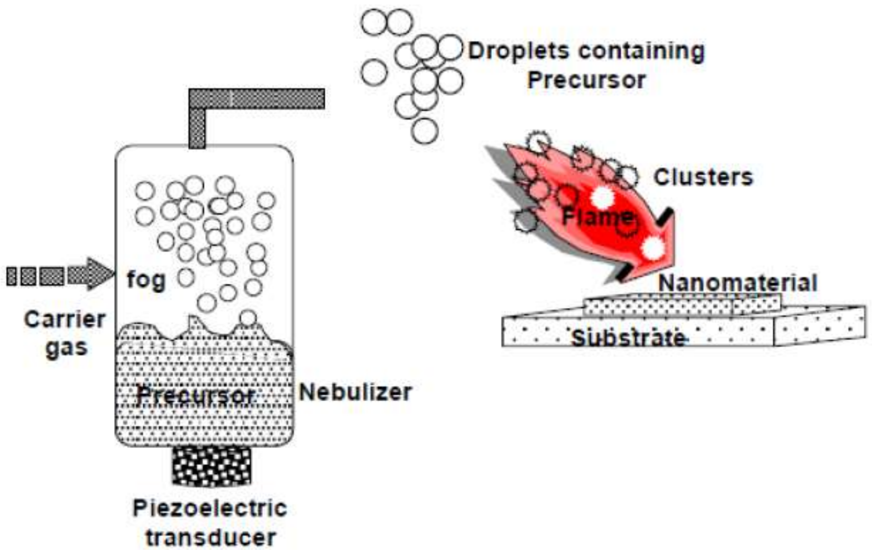
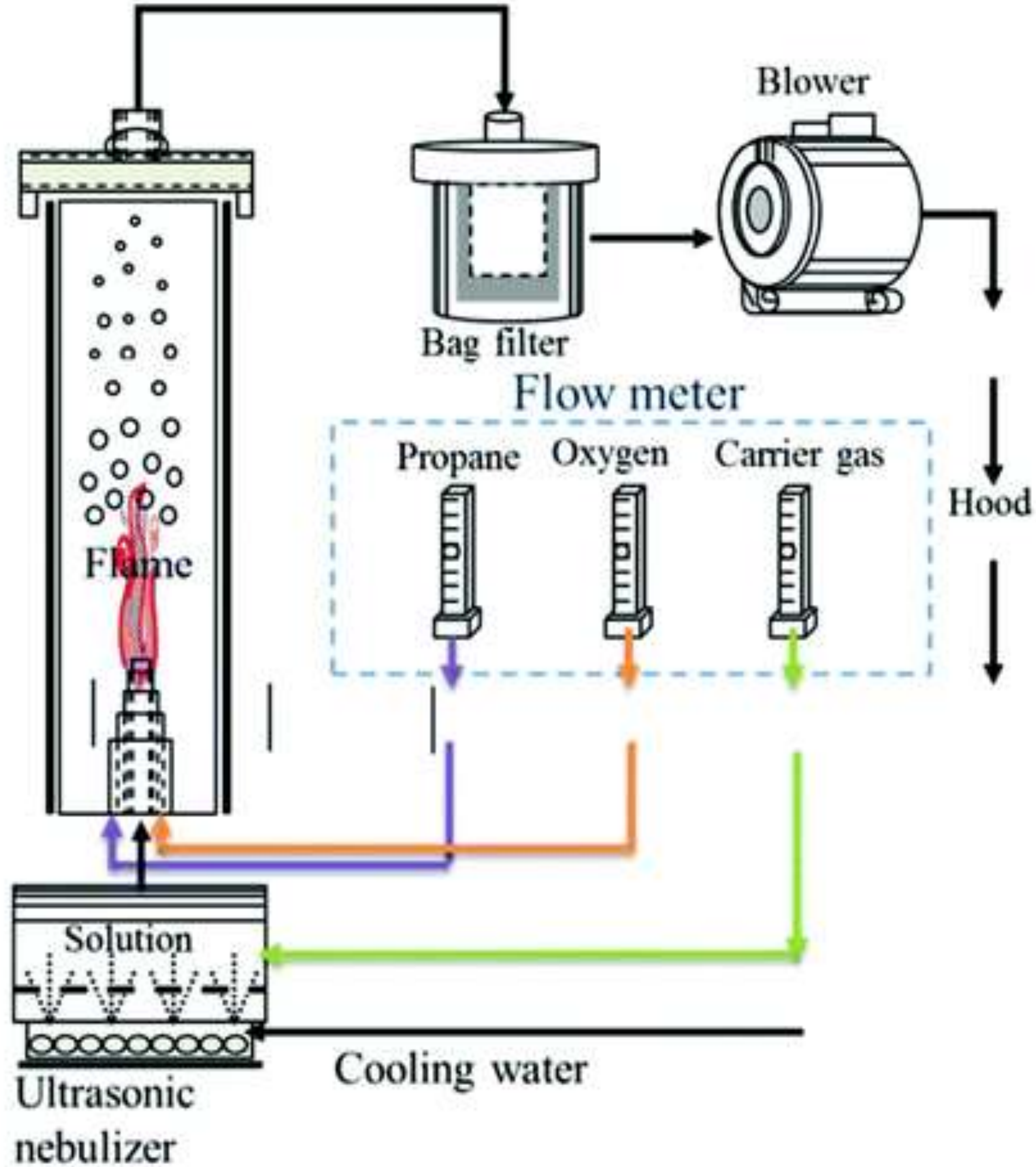


Fig. Flame assisted ultrasonic spray pyrolysis.

A key for the formation of nanoparticles with narrow size distributions is the exact control of the flame in order to obtain a flat flame front. Under these conditions the thermal history, i.e. time and temperature, of each particle formed is identical and narrow distributions result. However, due to the oxidative atmosphere in the flame, this synthesis process is limited to the formation of oxides in the reactor zone.



Flame Spray Pyrolysis (FSP)

Gas Condensation Processing (GPC)

In this technique, a metallic or inorganic material, e.g. a suboxide, is vaporized using thermal evaporation sources such as crucibles, electron beam evaporation devices or sputtering sources in an atmosphere of 1-50 mbar He (or another inert gas like Ar, Ne, Kr). Cluster form in the vicinity of the source by homogenous nucleation in the gas phase and grow by coalescence and incorporation of atoms from the gas phase.

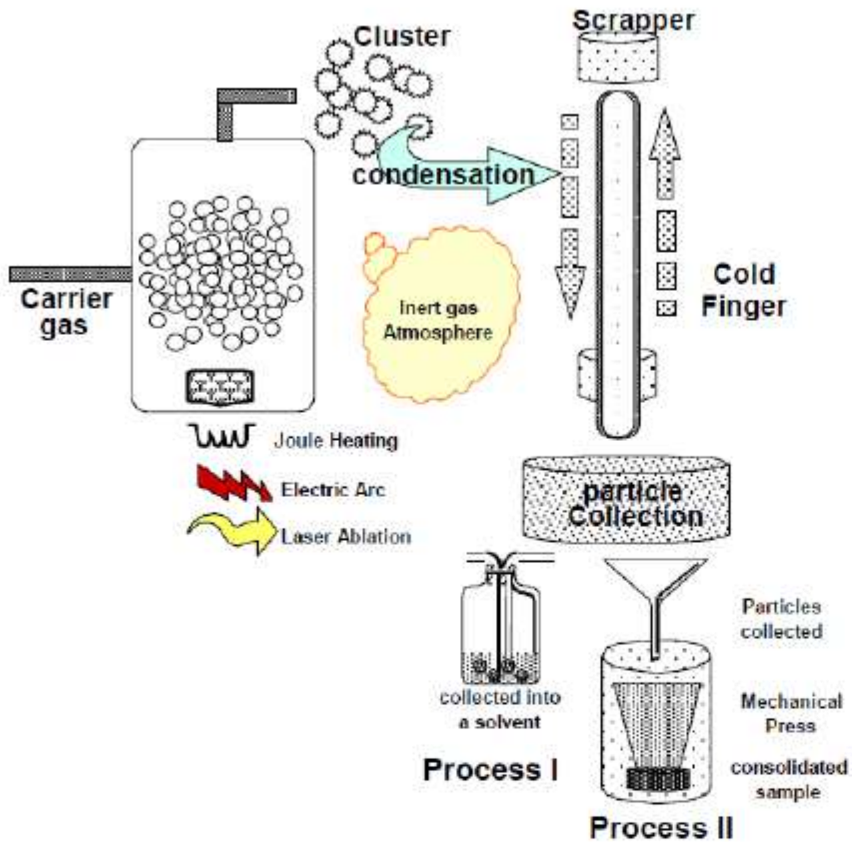


Fig. Gas Condensation Synthesis

The cluster or particle size depends critically on the residence time of the particles in the growth system and can be influenced by the gas pressure, the kind of inert gas, i.e. He, Ar or Kr, and on the evaporation rate/vapour pressure of the evaporating material. With increasing gas pressure, vapour pressure and mass of the inert gas used the average particle size of the nanoparticles increases. Even in more complex processes such as the low pressure combustion flame synthesis where a number of chemical reactions are involved the size distributions are determined to be lognormal.

Originally, a rotating cylindrical device cooled with liquid nitrogen was employed for the particle collection: the nanoparticles in the size range from 2-50 nm are extracted from the gas flow by thermophoretic forces and deposited loosely on the surface of the collection device as a powder of low density and no agglomeration.

Subsequently, the nanoparticles are removed from the surface of the cylinder by means of a scraper in the form of a metallic plate. In addition to this cold finger device several techniques known from aerosol science have now been implemented for the use in gas condensation systems such as corona discharge, etc. These methods allow for the continuous operation of the collection device and are better suited for larger scale synthesis of nanopowders. However, these methods can only be used in a system designed for gas flow, i.e. a dynamic vacuum is generated by means of both continuous pumping and gas inlet via mass flow controller.

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The synthesis of nanocrystalline pure metals is relatively straightforward as long as evaporation can be done from refractory metal crucibles (W, Ta or Mo). If metals with high melting points or metals which react with the crucibles, are to be prepared, sputtering, i.e. for W and Zr, or laser or electron beam evaporation has to be used.

Synthesis of alloys or intermetallic compounds by thermal evaporation can only be done in the exceptional cases that the vapour pressures of the elements are similar. As an alternative, sputtering from an alloy or mixed target can be employed. Composite materials such as Cu/Bi or W/Ga have been synthesized by simultaneous evaporation from two separate crucibles onto a rotating collection device. It has been found that excellent intermixing on the scale of the particle size can be obtained.

However, it should be mentioned that the scale-up of the gas condensation method for industrial production of nanocrystalline oxides by a company called nanophase technologies has been successful.

Chemical Vapour Condensation (CVC)

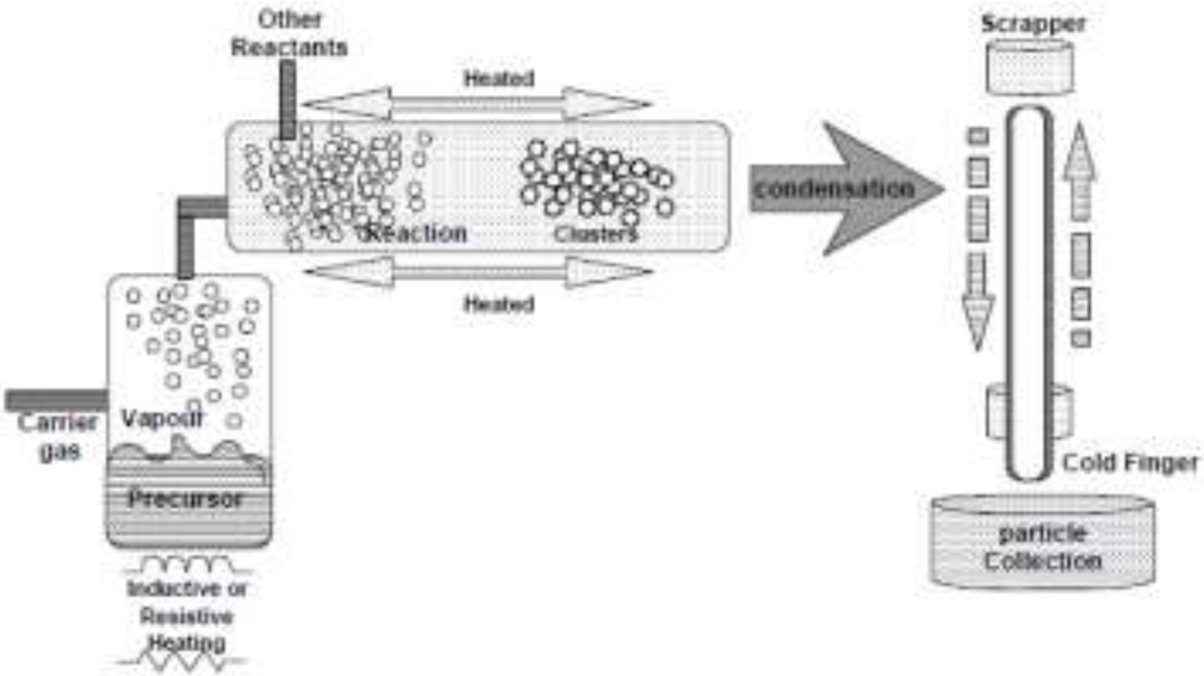
The original idea of the novel CVC process which is schematically shown below where, it was intended to adjust the parameter field during the synthesis in order to suppress film formation and enhance homogeneous nucleation of particles in the gas flow. It is readily found that the residence time of the precursor in the reactor determines if films or particles are formed. In a certain range of residence time both particle and film formation can be obtained.

Adjusting the residence time of the precursor molecules by changing the gas flow rate, the pressure difference between the precursor delivery system and the main chamber occurs.

Then the temperature of the hot wall reactor results in the fertile production of nanosizes particles of metals and ceramics instead of thin films as in CVD processing. In the simplest form a metal organic precursor is introduced into the hot zone of the reactor using mass flow controller. Besides the increased quantities in this continuous process compared to GPC has been demonstrated that a wider range of ceramics including nitrides and carbides can be synthesized. Additionally, more complex oxides such as BaTiO3 or composite structures can be formed as well.

The extension to production of nanoparticles requires the determination of a modified parameter field in order to promote particle formation instead of film formation. In addition to the formation of single phase nanoparticles by CVC of a single precursor the reactor allows the synthesis of,

- mixtures of nanoparticles of two phases or doped nanoparticles by supplying two precursors at the front end of the reactor, and
- Coated nanoparticles, i.e., n-ZrO_2 coated with n-Al_2O_3 or vice versa, by supplying a second precursor at a second stage of the reactor. In this case nanoparticles which have been formed by homogeneous nucleation are coated by heterogeneous nucleation in a second stage of the reactor.



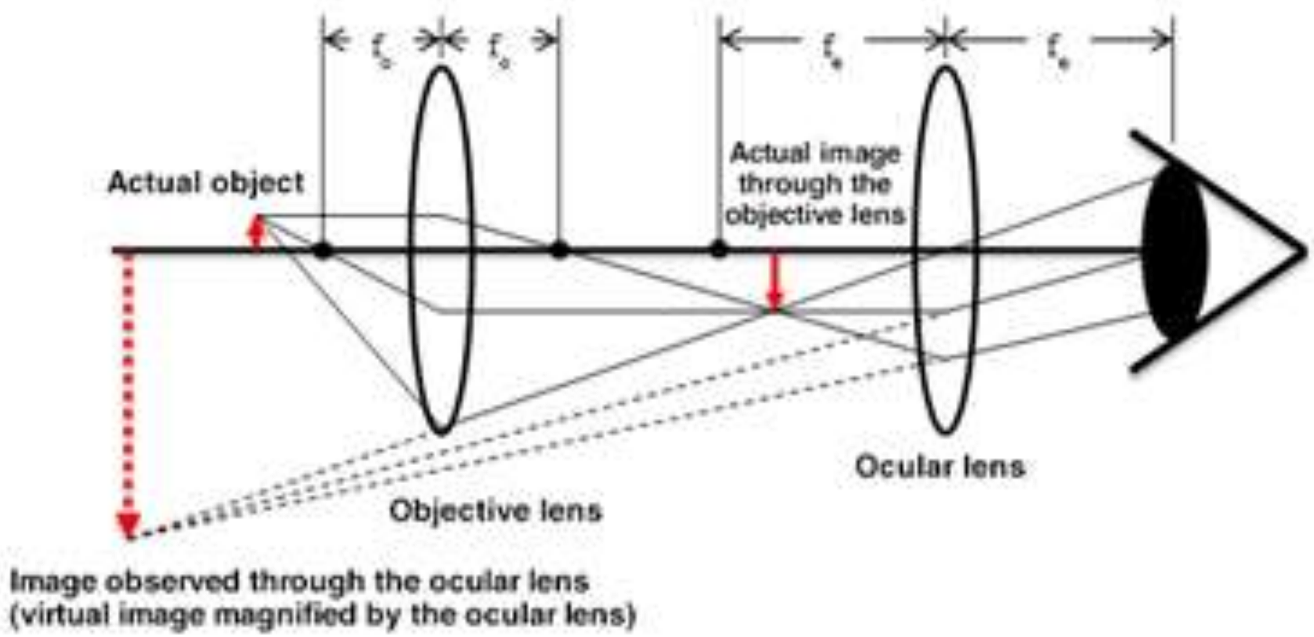
A schematic of a typical CVC reactor

Because CVC processing is continuous, the production capabilities are much larger than in GPC processing. Quantities in excess of 20g/hr have been readily produced with a small scale laboratory reactor. A further expansion can be envisaged by simply enlarging the diameter of the hot wall reactor and the mass flow through the reactor.

OPTICAL MICROSCOPY

PRINCIPLE

The optical microscope, often referred to as the light microscope, is a type of microscope that commonly uses visible light and a system of lenses to magnify images of small objects. Basic optical microscopes can be very simple, although many complex designs aim to improve resolution and sample contrast. Often used in the classroom and at home unlike the electron microscope this is used for closer viewing.



A general metallographic microscope mainly consists of an objective lens, ocular lens, lens tube, stage, and reflector. An object placed on the stage is magnified through the objective lens. When the target is focused, a magnified image can be observed through the ocular lens. A microscope is designed to emit light onto or through objects and magnify the transmitted or reflected light with the objective and ocular lenses.

IMAGE MODES

Light microscope can be visualized the object in two different modes (bright field/dark field) and both of these modes give different information of an object. Both of these modes are extensively been used to perform multiple task in the metallographic research.

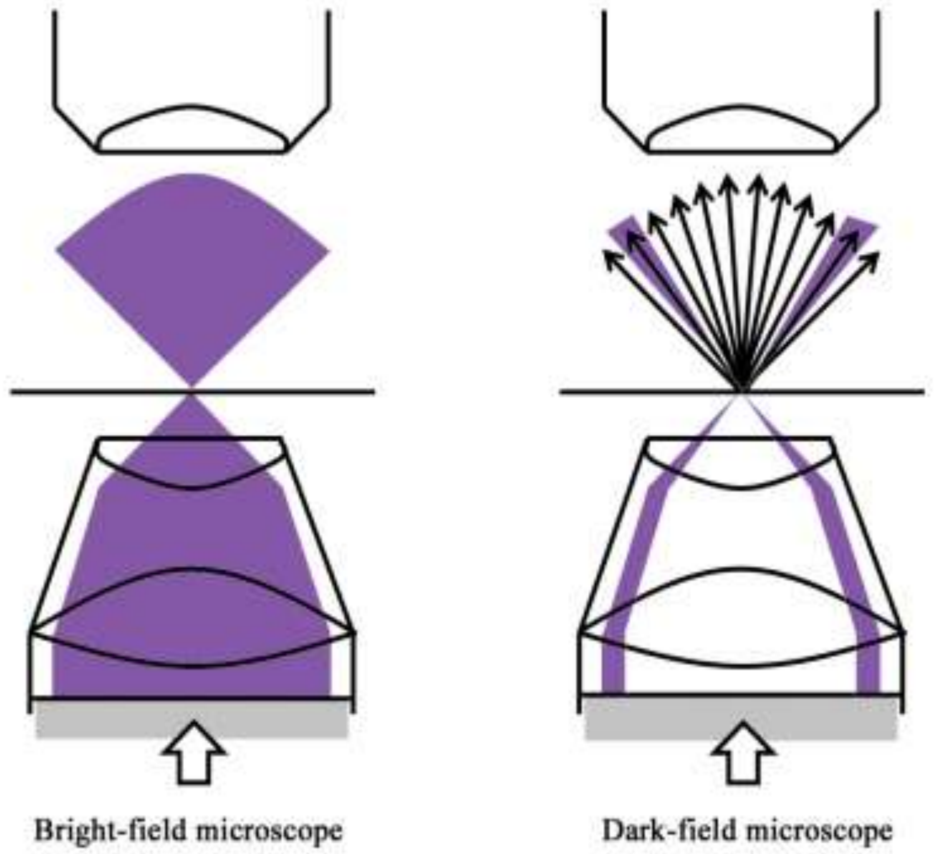


Figure: Optical diagrams of bright-field and dark-field microscopes

Bright field microscopy is the conventional technique. It is suitable for observing the natural colors of a specimen or the observation of stained samples. The specimen appears darker on a bright background.

Dark field microscopy shows the specimens bright on a dark background. Bright field microscopes that have a condenser with a filter holder can be easily converted to dark field by placing a patch stop filter into the filter holder. The specimens appear bright, because they reflect the light from the microscope into the objective. One disadvantage of dark field is that it is very sensitive to dust. A small amount of dust will already light up on the dark background.

APPLICATIONS OF OPTICAL MICROSCOPY

- Crystal morphology and symmetry
  - Crystal fragments (characteristic shape)
  - Classify isotropic and anisotropic substances
  - Check possible symmetry (parallel extinction)
- Phase identification, purity and homogeneity
  - Standard optical data (refractive indices and optical axes) for comparison
  - Phase analysis (impurities with separated crystalline/amorphous phase)
  - Single vs. twinned crystal
- Crystal defects grain boundaries and dislocations
  - Defects always present, even in single crystal,
  - Chemical etching may preferentially occur at stress sites.
- Refractive index determination
  - Becke line method:
  - Sample (n1) is immersed in a liquid (n2),
  - Out of focus, light is seen to emerge from region of higher.

ADVANTAGES AND DISADVANTAGES OF OPTICAL MICROSCOPE

Advantages

•Direct imaging with no need of sample pre-treatment, the only microscopy for real color imaging.

•Fast and adaptable to all kinds of sample systems, from gas, to liquid, and to solid sample systems, in any shapes or geometries.

•Easy to be integrated with digital camera systems for data storage and analysis.

Disadvantages

•Low resolution, usually down to only sub-micron or a few hundreds of nanometers, mainly due to the light diffraction limit.

ELECTRON MICROSCOPY

- An object cannot be perceived by our eyes directly.
- Electron microscopes were developed due to the limitations of light microscopes which are limited by the physics of light.
- Electron microscopes use the beam of the electron in place of light
- Electron microscopes are scientific instruments that use a beam of energy to examine objects on a very fine scale.
- The image produced by electron microscopes is perceived by CRT or X-ray plates.
- This required 10,000X plus magnification which was not possible using current optical microscopes.

TYPES OF ELECTRON MICROSCOPY

There are two basic models of the electron microscopes: *Scanning electron microscopes* (SEM) and *transmission electron microscopes* (TEM).

an SEM, the secondary electrons produced by the specimen are detected to generate an image that contains the **topological features of the specimen**.

The image in a TEM, on the other hand, is generated by the electrons that have **transmitted through a thin specimen.**

SCANNING ELECTRON MICROSCOPE (SEM)

A **Scanning Electron Microscope** (SEM) is a powerful magnification tool that utilizes focused beams of electrons to obtain information. The high resolution, three dimensional images produced by SEMs provide topographical, morphological and compositional information that makes them invaluable in a variety of science and industry applications.

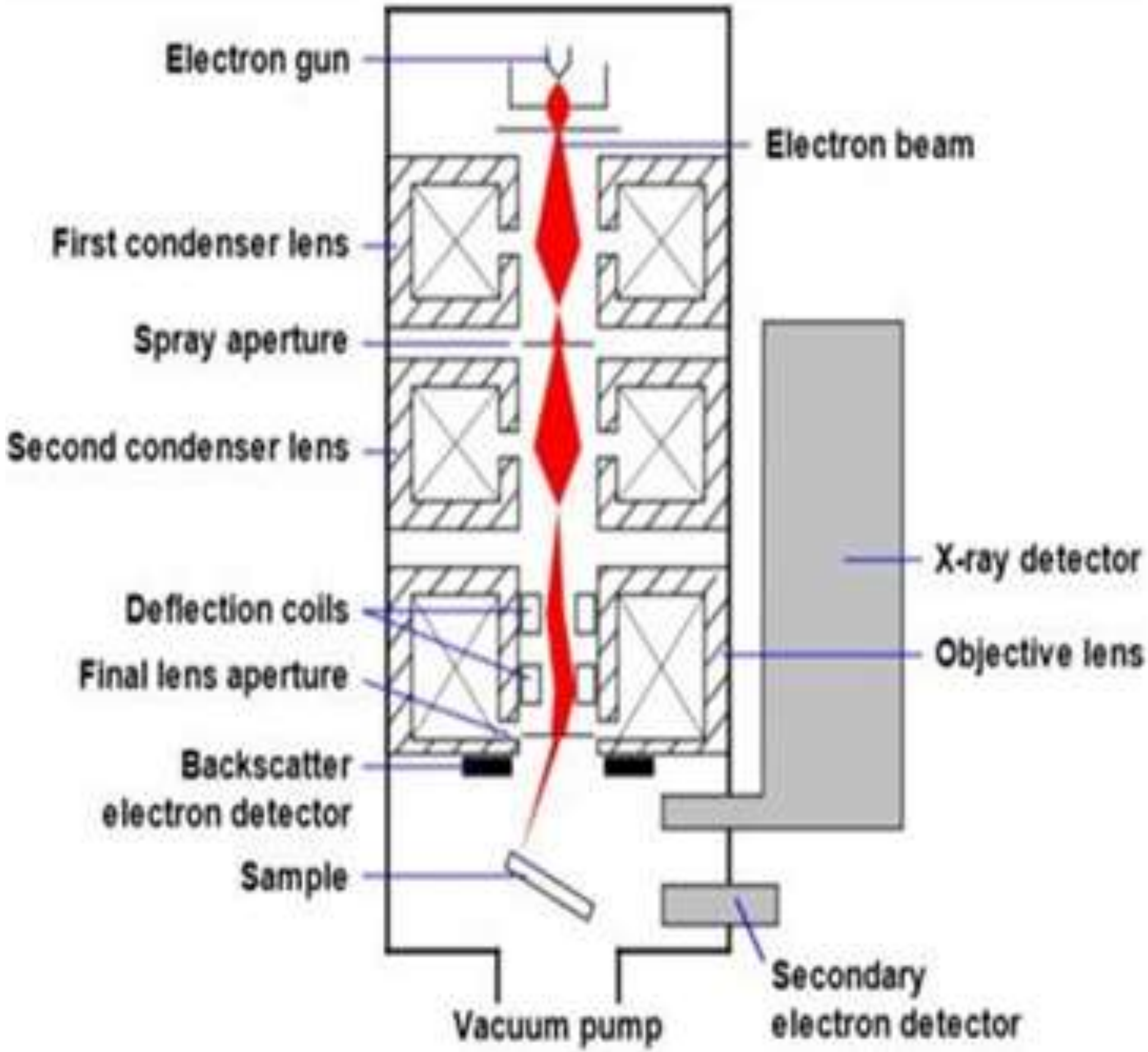
Working principle of SEM

The **main components** of a typical SEM are Electron Column, Scanning System, Detector(s), Display, Vacuum System and Electronic Controls.

• The **electron column** consists of an electron gun and two or more Electromagnetic lenses operating in a vacuum. The **electron gun** generates free electrons & accelerates these electrons to energies in the range 1-40 keV in the SEM.

• **Purpose** of the electron lenses is to create a small, focused electron survey on the Specimen. Most SEMs can generate an electron beam at the specimen surface with spot Size less than 10 nm. Maximum.

•**The size of a specimen** can be used up to 2.5 X 10^-7 nm.



Electron gun
Electron beam
First condenser lens
Spray aperture
Second condenser lens
X-ray detector
Deflection coils
Objective lens
Final lens aperture
Backscatter
electron detector
Sample
Vacuum pump
Secondary
electron detector

A Scanning Electron Microscope provides details surface information by tracing a sample in a raster pattern with an electron beam. The process begins with an electron gun generating a beam of energetic electrons down the column and onto a series of electromagnetic lenses. These lenses are tubes, wrapped in coil and referred to as solenoids. The coils are adjusted to focus the incident electron beam onto the sample; these adjustments cause fluctuations in the voltage, increasing/decreasing the speed in which the electrons come in contact with the specimen surface. Controlled via computer, the SEM operator can adjust the beam to control magnification as well as determine the surface area to be scanned. The beam is focused onto the stage, where a solid sample is placed. Most samples require some preparation before being placed in the vacuum chamber.

SEM Imaging

A variety of different preparation processes, the two most commonly used before SEM analysis are **splutter(fume) coating** for non-conductive samples and **dehydration** of most biological/metallurgical specimens. Also, all samples need to be able to handle the low pressure inside the vacuum chamber. The interaction between the incident electrons and the surface of the sample is determined by the acceleration rate of incident electrons, which carry significant amounts of kinetic energy before focused on the sample. When the incident electrons come in contact with the sample, energetic electrons are released from the surface of the sample. The scatter patterns made by the interaction yields information on the size, shape, texture, variety and composition of the sample.

A variety of detectors are used to attract different types of scattered electrons, including secondary and backscattered electrons as well as x-rays. Backscatter electrons are incidental electrons reflected backward; images provide composition data related to element and compound detection. Although topographic information can be obtained using a backscatter detector.

Diffracted backscatter electrons determine crystalline structures, orientation of minerals and micro-fabrics. X-rays, can provide elements and mineral information. SEM produces black and white, three-dimensional images. Image magnification can be up to 10 nanometers and intense interactions that take place on the surface of the specimen provide a greater depth of view, higher-resolution and ultimately a more detailed surface picture.

SEM APPLICATIONS

- SEMs have a variety of applications in characterizations of solid materials.
- Scanning Electron Microscope can detect and analyze surface fractures, provide information in microstructures, examine surface contaminations, reveal spatial variations in chemical compositions, provide qualitative chemical analyses and identify crystalline structures..
- SEMs can be an essential research tool in fields such as life science, biology, gemology, medical and forensic science, and metallurgy.
- SEMs have practical industrial and technological applications such as semiconductor inspection, production line of very small products and assembly of microchips for computers.

Advantages

- High resolution & Depth of focus ($1X10^{-6}$ nm)
- Elemental analysis attachments
- Almost all kinds of samples, conducting and non-conducting (stain coating needed)
- Based on surface interaction no requirement of the electron-transparent sample.
- Imaging at all directions through **x-y-z (3D)** rotation of the sample.

Disadvantages

- Cost
- More handles
- Vacuum
- Low resolution, usually above a few tens of nanometers.
- Usually required surface stain-coating with metals for electron conducting.

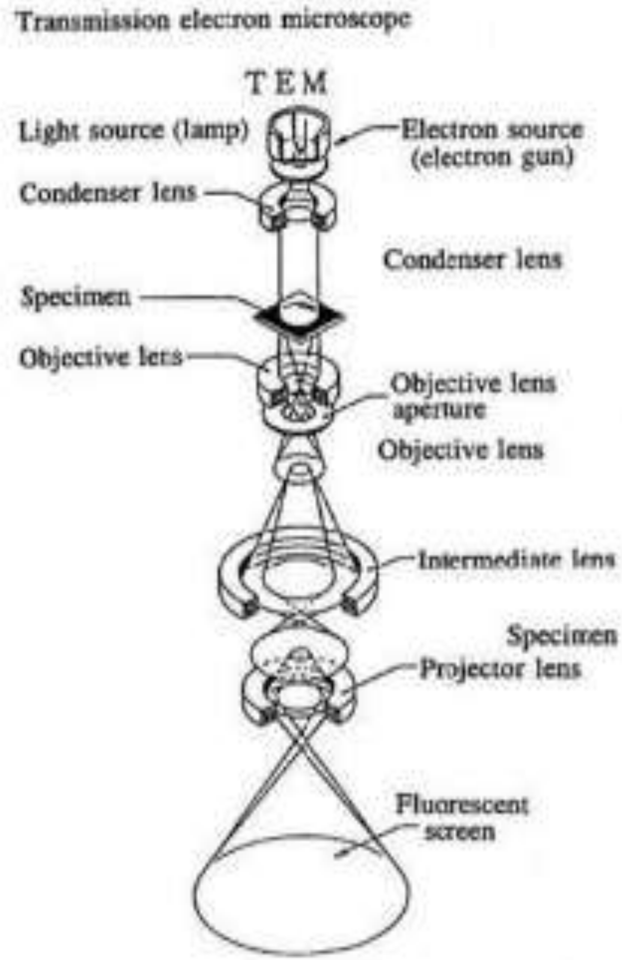
TRANSMISSION ELECTRON MICROSCOPY (TEM)

The transmission electron microscope is a very powerful tool for material science. A high energy beam of electrons is shone through a very thin sample, and the interactions between the **electrons and the atoms** can be used to observe features such as the crystal structure and features in the structure like **dislocations and grain boundaries**. Chemical analysis can also be performed.

PRINCIPLE

The TEM operates on the same basic principles as the light microscope but uses electrons instead of light. Because the wavelength of electrons is much smaller than that of light, the optimal resolution attainable for TEM images is **many orders of magnitude better than that from a light microscope.** Thus, TEMs can reveal the finest details of internal structure - in some cases as small as individual atoms.

WORKING



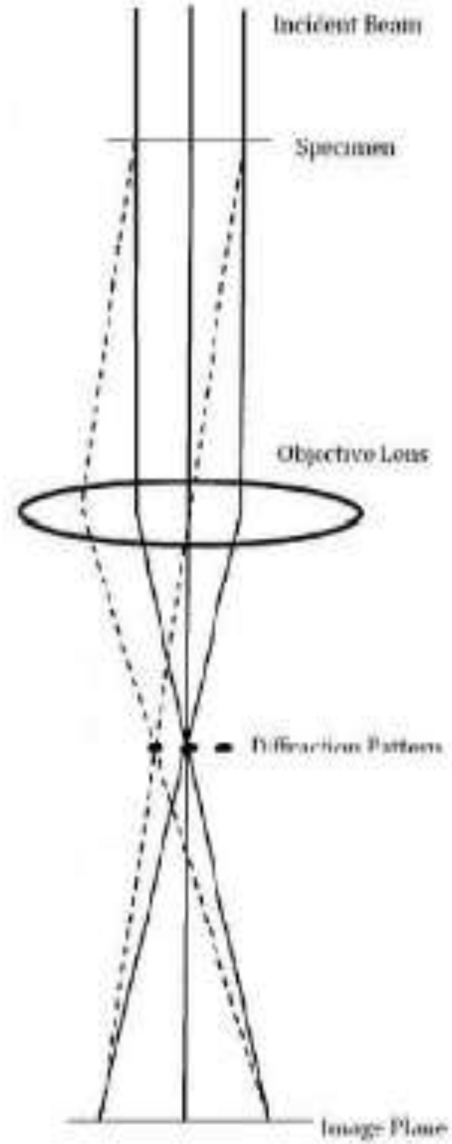


Fig 1 - General layout of a TEM describing the path of the electron beam in a TEM
Fig 2 - a ray diagram for the diffraction mechanism in TEM

The beam of electrons from the electron gun is focused on a small, thin, rational beam by the use of the condenser lens. This beam is restricted by the condenser aperture, which excludes high angle electrons. The beam then strikes the specimen and parts of it are transmitted depending upon the thickness and electron transparency of the specimen. This transmitted portion is focused by the objective lens into an image on a phosphor screen or charge-coupled device (CCD) camera. Optional objective apertures can be used to enhance the contrast by blocking out high-angle diffracted electrons. The image then passed down the column through the intermediate and projector lenses, is enlarged all the way.

The image strikes the phosphor screen and light is generated, allowing the user to see the image. The darker areas of the image represent those areas of the sample that fewer electrons are transmitted through while the lighter areas of the image represent those areas of the sample that more electrons were transmitted through.

Advantages and disadvantages of TEM

Advantages

- High resolution, as small as 0.2 nm.
- Direct imaging of crystalline lattice.
- define the defects inside the sample.
- No metallic stain-coating needed
- TEM can be used to study the growth of layers, their composition and defects in semiconductors.
- High resolution can be used to analyze the quality, shape, size, and density of quantum wells, wires, and dots.

Disadvantages

- Low sampling volume and rather a slow process of obtaining information.
- High capital and running cost.
- Special training required for the operation of the equipment.
- Difficult sample preparation.
- Samples which are not stable in vacuum are difficult to study.
- Magnetic samples require special care.
- Non-conducting samples require gold or carbon coating.
- Difficulty in the understanding of images.

TEM Applications

- A Transmission Electron Microscope is ideal for several different fields such as life sciences, nanotechnology, medical, biological and material research, forensic analysis, gemology, and metallurgy as well as industry and education.
- TEMs provide topographical, morphological, compositional and crystalline information.
- The images allow researchers to view samples on a molecular level, making it possible to analyze structure and texture.
- This information is useful in the study of crystals and metals but also has industrial applications.
- TEMs can be used in semiconductor analysis and production and the manufacturing of computers and silicon chips.
- Technology companies use TEMs to identify flaws, fractures, and damages to micro-sized objects; this data can help fix problems and/or help to make a more durable, efficient product.
- Colleges and universities can utilize TEMs for research and studies.
- TEM can be used to study the growth of layers, their composition, and defects in semiconductors.
- High resolution can be used to analyze the quality, shape, size, and density of quantum wells, wires, and dots.

X-RAY DIFFRACTION ANALYSES

X-ray diffraction is one of the important techniques for material characterization. The diffraction experiments using X - rays help to study the **structural properties of materials on the atomic scale**. The technique is also used to measure Crystalline size and to calculate lattice strain, chemical composition, state of ordering and to determine phase diagrams as well.

Basic Principle

Crystalline substances act as three - dimensional diffraction gratings for X-ray wavelengths comparable to the spacing of crystal planes in the lattice. X - Rays interact with electrons in atoms and elastically get scattered. The scattered waves from many atoms in the atomic plane can interfere with each other and if the waves are in phase they interfere usefully. **These diffracted X - rays contain information regarding the electron distribution in materials.**

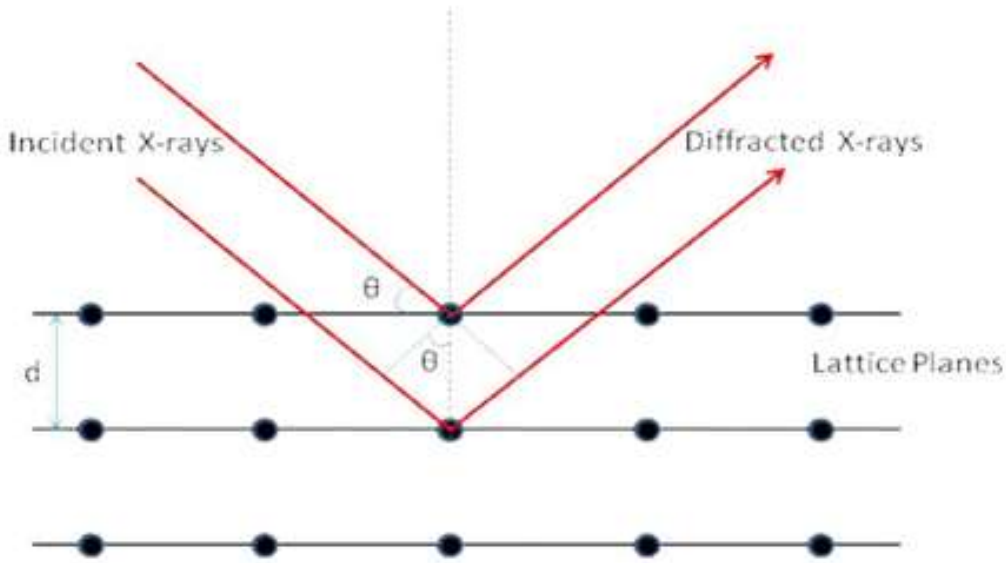


Figure: Diffraction of X - rays at the crystal lattice

POWDER X-RAY DIFFRACTION

Powder X-ray diffraction analysis has a wide range of applications from the basic distinction between **amorphous and crystalline materials** through phase analysis to full profile analysis. It provides a convenient and practical means for the qualitative identification of crystalline compounds. This application is based upon the fact that an X-ray diffraction pattern is unique for each crystalline substance. Thus, if an exact match can be found between the pattern of an unknown and an authentic sample, chemical identity can be assumed.

Instrumentation and sample selection

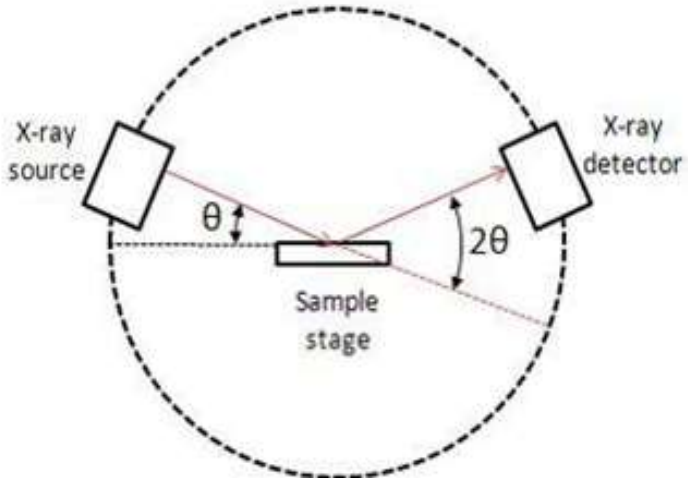


Figure: X - ray diffraction from a powder sample

In powder XRD, finely ground and homogenized sample is used. The sample may be held in thin-walled glass. The X–rays required for diffraction are monochromatized by filtering with the help of foils or crystal monochrometers. This X - rays are collimated and directed onto the sample. In powder form, a significant number of the crystallites can be expected to be oriented to fulfil the Bragg condition for reflection from every possible interplanar spacing. Thus, the sample and detector are rotated and the intensity of the reflected X - rays are recorded. A detector records and processes this X-ray signal and converts the signal to a count rate which is then output to a printer or computer monitor.

The goniometer is designed such that the sample rotates in the path of the collimated X - ray beam at an angle while the X - ray detector on an arm to collect the diffracted X - rays rotate at an angle of 2. For typical powder patterns, data is collected for a 2 range of 5° to 70° at a scan speed of 2° min. The position of a diffraction peak is dependent only on the size and shape of the unit cell.

APPLICATIONS

- X-ray powder diffraction is most widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds).
- The determination of unknown solids is critical to studies in geology, environmental science, material science, engineering and biology.
- Characterization of crystalline materials
- Identification of fine-grained minerals such as clays and mixed layer clays that are difficult to determine optically
- Determination of unit cell dimensions
- Measurement of sample purity
- Determining the thickness, roughness, and density of the film using glancing incidence x-ray reflectivity measurements

ADVANTAGES AND DISADVANTAGES

ADVANTAGES

•Powerful and rapid (<20min) technique for identification of an unknown mineral

•In most cases, it provides an unambiguous mineral determination

•Minimal sample preparation is required

•XRD units are widely available

•Data interpretation is relatively straight forward

DISADVANTAGES

•Homogeneous and single-phase material is best for identification of an unknown.

•Must have access to a standard reference file of inorganic compounds

•Requires tenths of a gram of material which must be ground into a powder

•For mixed materials, the detection limit is ~2% of the sample For unit cell determinations, indexing of patterns for non-isometric crystal systems is complicated

•Peak overlay may occur and worsens for high angle 'reflections'

SCANNING PROBE MICROSCOPY (SPM)

INTRODUCTION

Although SPM is an umbrella term that encompasses both the STM and AFM microscopy family, both techniques have developed in slightly different ways. Today, between them, there is a multitude of modes of operation.

For instance, AFM can measure forces such as mechanical contact force, Vander Waals forces, capillary forces, electrostatic forces, chemical bonding, magnetic forces, and even recovery forces, depending on the situation and its requirements.

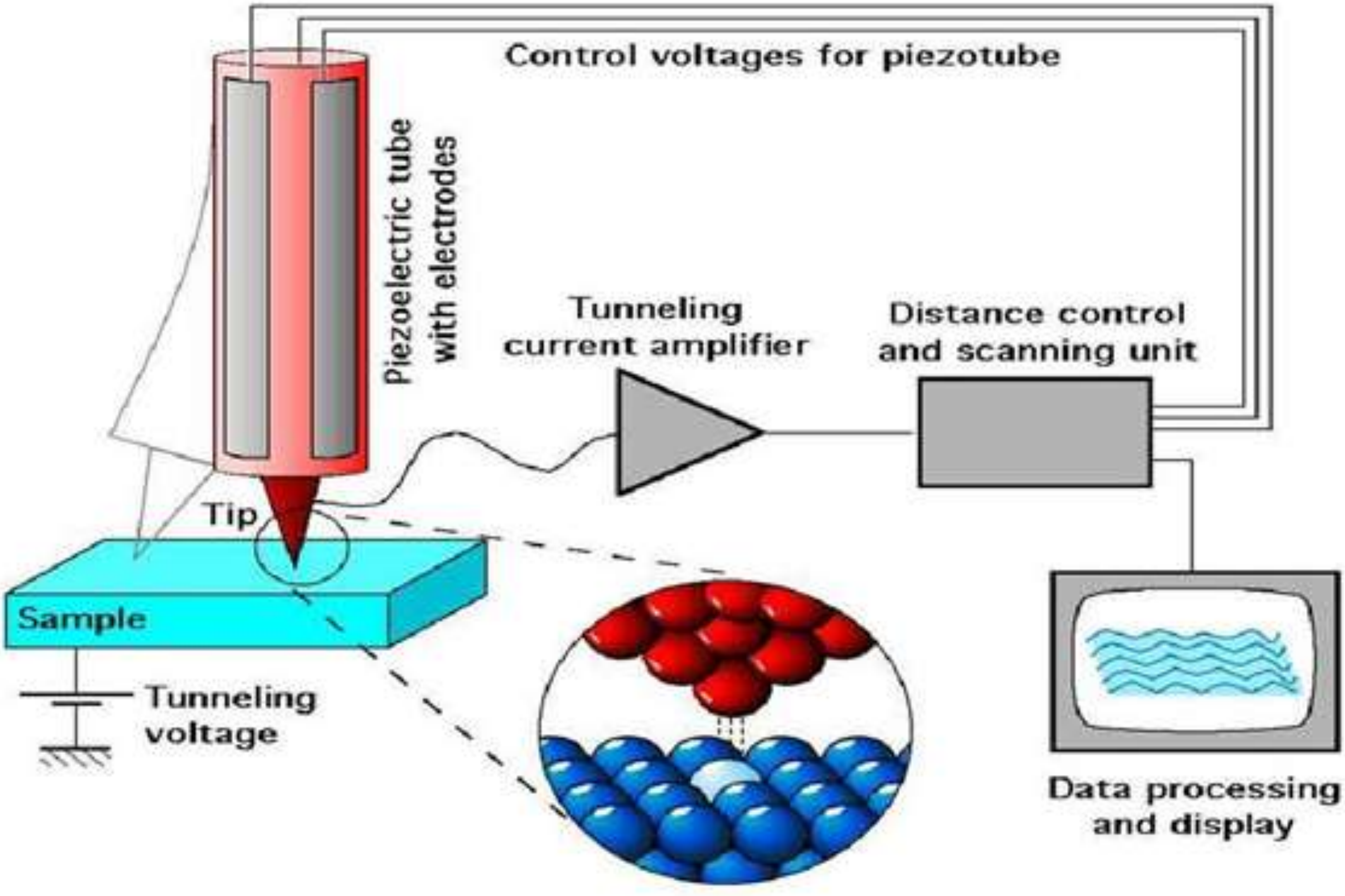
Scanning tunnelling microscopy (STM) requires the surface to be examined to have a conductive or partially conductive coating. To produce an image of the sample surface, STM measures the electrical tunnelling current between the scanning tip and the sample.

SPM or Scanning probe microscopy describes a range of techniques that utilize a very fine physical probe to scan across surfaces, thereby monitoring the interaction strength between the tip and surface producing images, profiles or maps of the surface.

PRINCIPLE

The primary principle of STM is that it operates in a vacuum. When a conducting tip is brought near the surface under examination, it initiates a difference in voltage between the probe and surface. This process enables the flow of electrons to tunnel through the vacuum space in-between. Naturally, the tunnelling current produced relies upon tip position, the applied voltage, and the local density of the sample.

Thus, the image is created as a result of monitoring the current as the tip scans across the surface. This technique was the fundamental break-through in imaging since it was the first time surfaces could be visualized at the atomic scale. The resolution of STM is not limited by diffraction; rather, it is limited only by the size of the probe-sample interaction volume, which can be in the order of a few picometers.



Control voltages for piezotube
Piezoelectric tube
with electrodes
Tunneling
current amplifier
Distance control
and scanning unit
Tip
Sample
Tunneling
voltage
Data processing
and display

WORKING

The probe in a scanning tunnelling microscope is a very fine metal tip at a high voltage. The tip is brought nearby of the surface and scanned across the surface in a raster pattern. The quantity that is measured is the tunnelling current flowing between the sample and the surface. The instrument can operate either in constant current mode or in constant height mode. In constant height mode, the tip scans the surface and current is recorded at each point. In a constant current mode, the current flowing between the tip and the sample is kept constant through a feedback loop that causes the sample stage to move closer to or farther from the tip; the signal obtained in constant current mode, therefore, is the distance between the tip and the specimen. An intrinsic limitation of scanning tunnelling microscopy is its inability to study the non-conducting surfaces. This led to the development of other types of microscopes including the atomic force microscope.

ADVANTAGES AND LIMITATIONS

Advantages

•Scanning Probe Microscopy provides researchers with a larger variety of specimen observation environments using the same microscope and specimen reducing the time required to prepare and study specimens.

•Specialized probes, improvements, and modifications to scanning probe instruments continue to provide faster, more efficient and revealing specimen images with minor effort and modification.

Disadvantages

•Unfortunately, one of the downsides of scanning probe microscopes is that images are produced in black and white or grayscale which can in some circumstances exaggerate a specimen’s actual shape or size.

•Computers are used to compensate for these exaggerations and produce real-time colour images that provide researchers with real-time information including interactions within cellular structures, harmonic responses, and magnetic energy.

Uses of SPM

•It provides an excellent method to study surfaces and, if required, even modify them using the techniques of nanolithography.

•Nanoscale measurements of friction, wear, adhesion and lubrication are examined.

•This allows the determination of the effect of atomic interactions and quantum effects on surface friction in the development of materials.

•SPM techniques are also extremely vital in electronics – both for the examination of silicon surfaces in component manufacture and the examination of interfaces in semiconductor materials.

•In biology and medicine, SPM techniques can be used to examine peptide structures and thereby determine their stiffness and structure.

•SPM can also map cell surfaces and determine the difference between healthy and diseased cells by examining the cell membrane's stiffness.

ATOMIC FORCE MICROSCOPY (AFM)

An atomic force microscope is a type of scanning probe microscope that records the **force between the probe and the specimen**. The working principle of an AFM can be understood like this: it has three basic components: **a probe, a positioner, and a processing unit**.

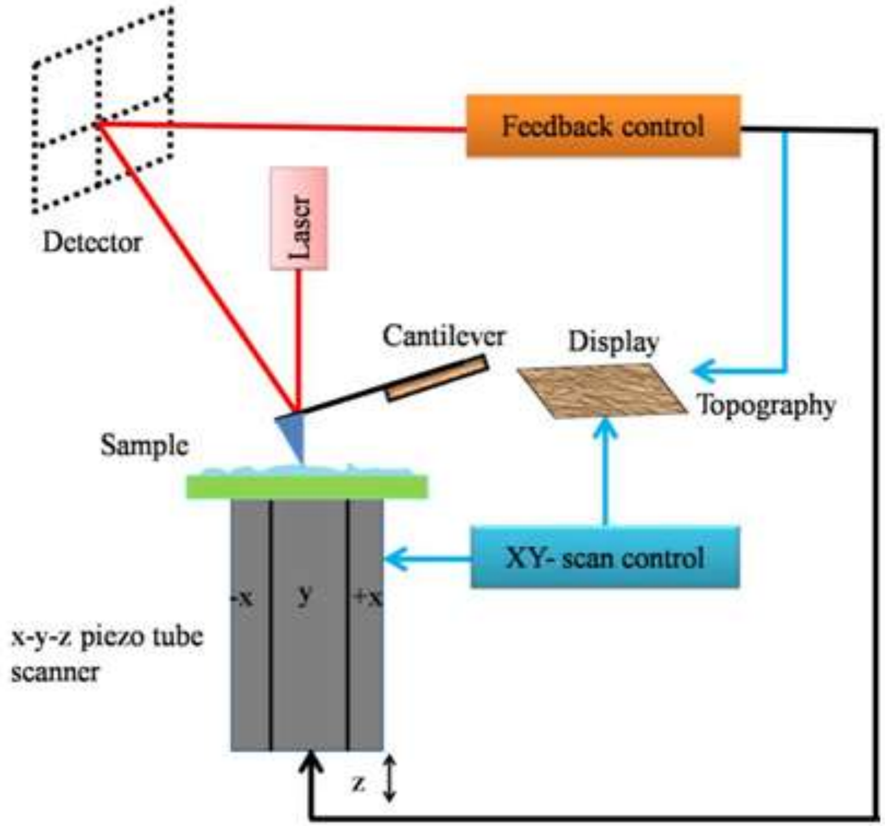


Figure: A schematic diagram of an atomic force microscope.

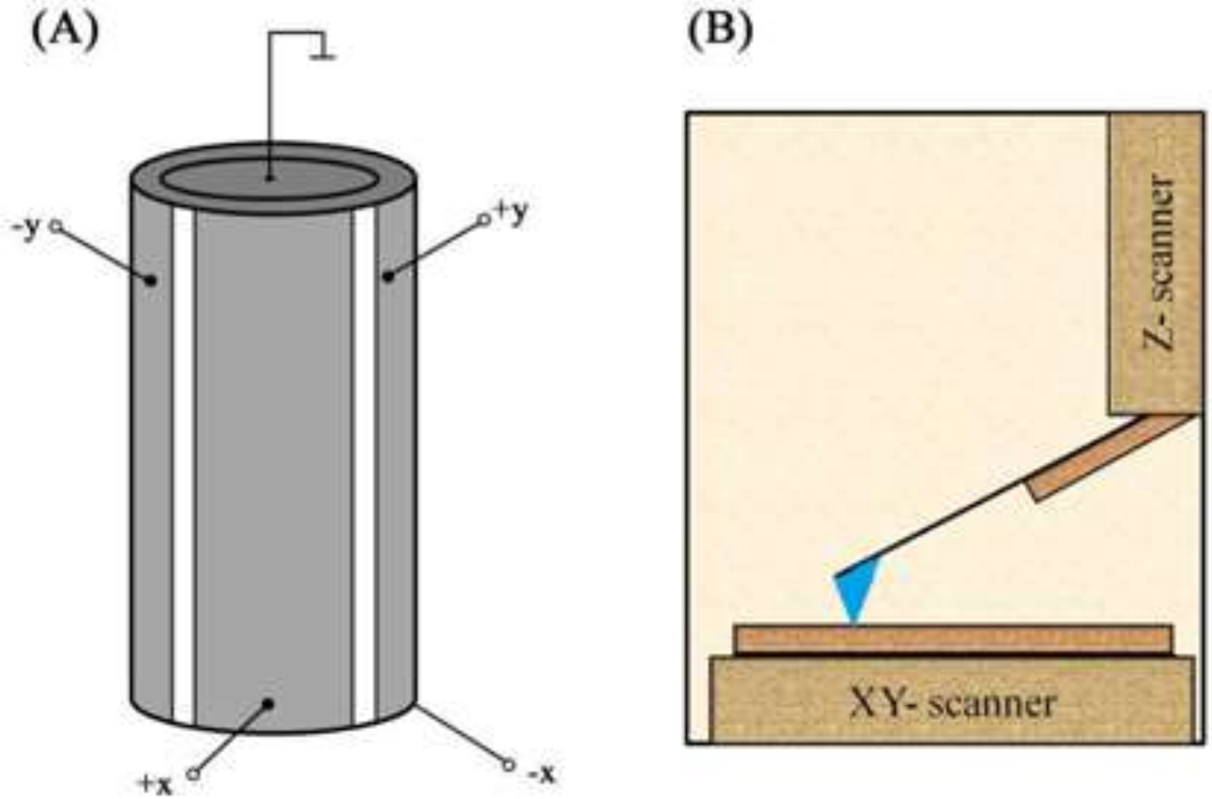


Figure: Piezoelectric scanners used in AFM: A piezoelectric tube (A) and a scanner having decoupled X-Y and Z piezoelectric elements (B).

An AFM has a pointed probe attached to a cantilever. The positioning of the cantilever concerning the specimen is achieved by the piezoelectric elements, called scanners. The piezoelectric element can be connected either to the cantilever or the specimen stage.

Modern AFM instruments use an alternative set of scanners wherein Z-scanner is separated from the X-Y scanner (Figure B).

A laser beam is focused on the cantilever that has a highly reflective surface. The laser beam reflected off the cantilever is focused on a position-sensitive photodiode quadrant. The cantilever is scanned over the sample surface in a raster pattern. Any deflection in the cantilever as a result of sample interaction causes displacement in the laser spot on the photodiode; this displacement signal is analyzed to calculate the deflection in the cantilever. Imaging can be performed in either constant-force mode (distance between the tip and the specimen is allowed to change) or constant-height mode (force between the tip and the specimen is allowed to change).

PROCEDURE

•Place the cantilever on the AFM head together with your assistant. Cantilevers are extremely fragile - use extreme caution when dealing with the cantilever.

•Start the SPM control program and camera program.

•From the SPM program, choose the mode as “Dynamic”. Click on “Camera light on”.

•Adjust the laser on the cantilever. Use the x and y probe alignment knobs.

•Adjust the photodiode. Never look directly into the laser beam.

•Place the first sample by positioning the metal disc with the sample in the centre of the scanner.

•After the required adjustments, start to approach the surface and find the surface. Keep the cabinet covered.

•Start scanning by setting the scan size to in the order of 10 μm x 10 μm

•When you have finished with the sample, move the tip well away from the surface by pressing “up”.

•Scan the other samples separately.

•Remove the sample. Shut down the system.

Modes of operation

There are three basic modes of AFM imaging.

1. Contact mode AFM,
2. Non-contact mode AFM,
3. Intermittent mode or tapping mode AFM,

•Force mode

Contact mode AFM: In contact mode AFM, the tip is brought in close contact with the specimen (in the repulsive regime) and scanned over the surface. As the tip is in contact with the sample throughout the scan, the frictional forces are very high. This mode of operation, therefore, may not be suitable for soft samples including biological samples.

Non-contact mode AFM: In non-contact mode AFM, a cantilever with very high spring constant oscillates very close to the sample (in the attractive regime). The quantities that are measured are changes in the oscillation amplitude and the phase. The forces between the tip and the sample are very small, of the order of piconewtons ($1pN = 10^{-12}N$). This mode is therefore well-suited for very soft samples but the resolution is compromised.

Intermittent mode or tapping mode AFM: A rigid cantilever oscillates so close to the specimen. The tip therefore occasionally touches the sample while scanning. This mode of imaging allows imaging with very high resolution and has become the method of choice for scanning the soft biological samples.

Force mode AFM: Force mode of AFM is not an imaging mode. A sample is brought close to the cantilever, pushed against it causing deflections in it, and then withdrawn. A plot of force (depends on the spring constant of the cantilever) against the distance is called a forced spectrum. Force mode is often used to study the interactions of the tip with the sample and to determine the mechanical properties of the specimen.

Advantages and Limitations

AFM Advantages

- An atomic force microscope is a powerful tool that is invaluable if you want to measure incredibly small samples with a great degree of accuracy.
- it does not require either a vacuum or the sample to undergo treatment that might damage it.
- At the limits of operation, however, researchers have demonstrated atomic resolution in high vacuum and even liquid environments.

AFM Disadvantages

- One of the major downsides is the single scan image size, which is of the order of 150x150 micrometers, compared with millimeters for a scanning electron microscope.
- Relatively slow scan time, which can lead to thermal drift on the sample.
- requiring improved signal-to-noise ratio, decreased thermal drift, and better detection and control of tip-sample forces, including the use of the sharp probe.

Applications

•The AFM has been applied to problems in a wide range of disciplines of the natural sciences, including solid-state physics, semiconductor science, and technology, molecular engineering, polymer chemistry and physics, surface chemistry, molecular biology, cell biology, and medicine.

•Applications in the field of solid-state physics include

(a) The identification of atoms at a surface,

(b) The evaluation of interactions between a specific atom and its neighboring atoms,

(c) The study of changes in physical properties arising from changes in an atomic arrangement through atomic manipulation.

•In molecular biology, AFM can be used to study the structure and mechanical properties of protein complexes and assemblies.

• In cellular biology, AFM can be used to attempt to distinguish cancer cells and normal cells based on the hardness of cells and to evaluate interactions between a specific cell and its neighboring cells in a competitive culture system.

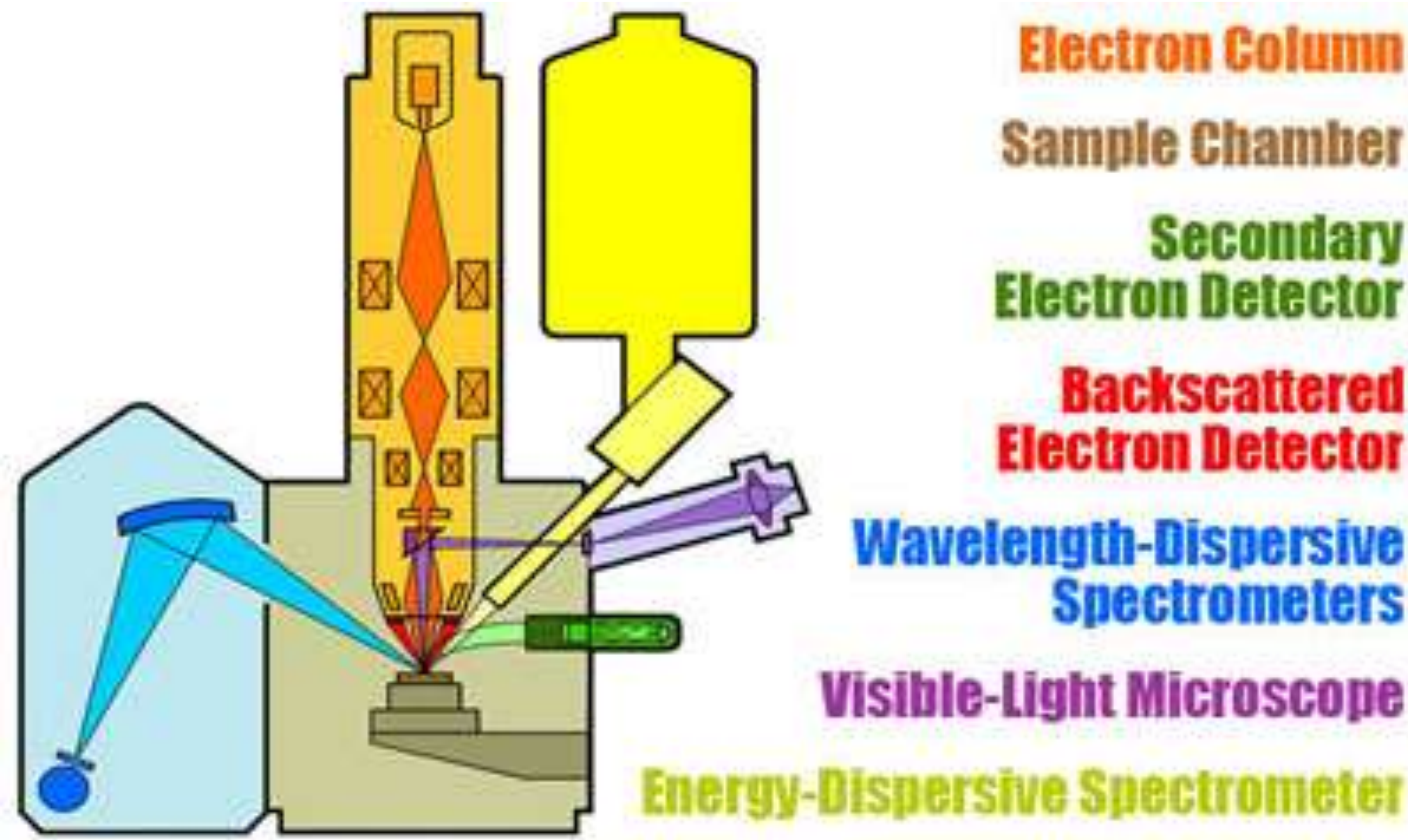
•AFM can also be used to indent cells, to study how they regulate the stiffness or shape of the cell membrane or wall.

ELECTRON PROBE MICRO ANALYZER (EPMA)

INTRODUCTION

EPMA is also informally called an **electron microprobe** or just **probe**. It is fundamentally the same as an SEM, with the added capability of chemical analysis. The primary importance of an EPMA is the ability to acquire precise, quantitative elemental analyses at very small "spot" sizes (as little as 1-2 microns), primarily by wavelength-dispersive spectroscopy (WDS). The spatial scale of analysis, combined with the ability to create detailed images of the sample, makes it possible to analyze geological materials *in situ* and to resolve complex chemical variation within single phases (in geology, mostly glasses, and minerals). The electron optics of an SEM or EPMA allow much higher resolution images to be obtained than can be seen using visible-light optics, so features that are irresolvable under a light microscope can be readily imaged to study detailed micro textures or provide the fine-scale context of an individual spot analysis.

Electron probe micro-analyzer (EPMA)



CONSTRUCTION

EPMA consists of four major components, from top to bottom:

Electron Gun – Produces electron

• Focusing lenses – Permit focused beam to hit sample

• Sample Stage – Allow precise positioning of sample under beam

• Optical System – Allows visual positioning of sample and selection of sample sites

• Spectrometers – Allow collection of X-rays emitted from the sample

A typical arrangement in a probe lab is a vertical electron-beam column, an array of detectors placed around the sample chamber block, a sample entry vacuum lock, a console to control operating conditions, screens to view control interfaces and sample output, and a computer for control of data acquisition.

WORKING PROCEDURE

An electron microprobe operates under the principle that if solid material is bombarded by an accelerated and focused electron beam, the incident electron beam has sufficient energy to release both matter and energy from the sample. These electron-sample interactions mainly liberate heat, but they also yield both derivative electrons and x-rays. most common interests in the analysis of geological materials are secondary and back-scattered electrons, which are useful for imaging a surface or obtaining an average composition of the material. X-ray generation is produced by inelastic collisions of the incident electrons with electrons in the inner shells of atoms in the sample; when an inner-shell electron is ejected from its orbit, leaving a vacancy, a higher-shell electron falls into this vacancy and must shed some energy (as an X-ray) to do so. These quantized x-rays are characteristic of the element. EPMA analysis is considered to be "non-destructive"; that is, x-rays generated by electron interactions do not lead to volume loss of the sample, so it is possible to reanalyze the same materials more than one time.

ADVANTAGES AND DISADVANTAGES

ADVANTAGES

•An electron probe is essentially the same instrument as an SEM but differs in that it is equipped with a range of crystal spectrometers that enable quantitative chemical analysis (WDS) at high sensitivity.

•An electron probe is a primary tool for chemical analysis of solid materials at small spatial scales (as small as 1-2 micron diameter); hence, the user can analyze even minute single phases (e.g., minerals) in a material (e.g., rock) with "spot" analyses.

•Spot chemical analyses can be obtained *in situ*, which allows the user to detect even small compositional variations within a textural context or chemically zoned materials.

•Electron probes commonly have an array of imaging detectors (SEI, BSE, and CL) that allow the investigator to generate images of the surface and internal compositional structures that help with analyses.

DISADVANTAGES

- Although electron probes can analyze for almost all elements, they are unable to detect the lightest elements (H, He and Li); as a result, for example, the "water" in hydrous minerals cannot be analyzed.
- Some elements generate x-rays with overlapping peak positions (by both energy and wavelength) that must be separated.
- Microprobe analyses are reported as oxides of elements, not as cations; therefore, cation proportions and mineral formulae must be recalculated following stoichiometric rules.
- Probe analysis also cannot distinguish between the different valence states of Fe, so the ferric/ferrous ratio cannot be determined and must be evaluated by other techniques.

APPLICATIONS

1. Geology
   - Crystal chemistry
   - Pressure, Temperature of equilibration
   - Mineral prospecting
   - Geochronology
2. Metallurgy
   - Trace analysis : C, N, ...
   - Segregation
   - Phase equilibrium
   - Non-destructive thin film analysis
3. Semi conductor industry
   - Defect analysis
   - Particle analysis
   - Thin Film analysis
   - Forensic sciences

MODULE 5
MANUFACTURING CONTROL AND AUTOMATION

CNC technology - An overview: Introduction to NC/CNC/DNC machine tools, Classification of NC /CNC machine tools, Advantage, disadvantages of NC /CNC machine tools, Application of NC/CNC

Part programming: CNC programming and introduction, Manual part programming: Basic (Drilling, milling, turning etc.), Special part programming, Advanced part programming, Computer aided part programming (APT)

Introduction: Automation in production system principles and strategies of automation, basic Elements of an automated system. Advanced Automation functions, Levels of Automations, introduction to automation productivity

Control Technologies in Automation: Industrial control system, Process industry vs. discrete manufacturing industries, Continuous vs. discrete control. Continuous process and its forms, other control system components.

PART-A

INTRODUCTION TO COMPUTER NUMERICAL CONTROL

The variety being demanded in view of the varying tastes of the consumer calls for a very small batch sizes. Small batch sizes will not be able to take advantage of the mass production techniques such as special purpose machines or transfer lines. Hence, the need for flexible automation is felt , where you not only get the benefits of rigid automation but are also able to vary the products manufactured thus bringing in the flexibility. Numerical control fits the bill perfectly and we would see that manufacturing would increasingly be dependent on numerical control in future.

NUMERICAL CONTROL (NC)

Numerical control of machine tools may be defined as a method of automation in which various functions of machine tools are controlled by letters, numbers and symbols. Basically a NC machine runs on a program fed to it. The program consists of precise instructions about the methodology of manufacture as well as movements. For example, what tool is to be used, at what speed, at what feed and to move from which point to which point in what path.

Since the program is the controlling point for product manufacture, the machine becomes versatile and can be used for any part. All the functions of a NC machine tool are therefore controlled electronically, hydraulically or pneumatically. In NC machine tools, one or more of the following functions may be automatic.

- Starting and stopping of machine tool spindle.
- Controlling the spindle speed.
- Positioning the tool tip at desired locations and guiding it along desired paths by automatic control of motion of slides.
- Controlling the rate of movement of tool tip (feed rate)
- Changing of tools in the spindle.

Functions of a machine tool

The purpose of a machine tool is to remove excess material. The machine tool should possess certain capabilities in order to fulfill these requirements. It must be

- Able to hold the work piece and cutting tool securely.
- Provided the sufficient power to enable the tool to cut the work piece material at economical rates.
- Capable of displacing the tool and work piece relative to one another to produce the required work piece shape.

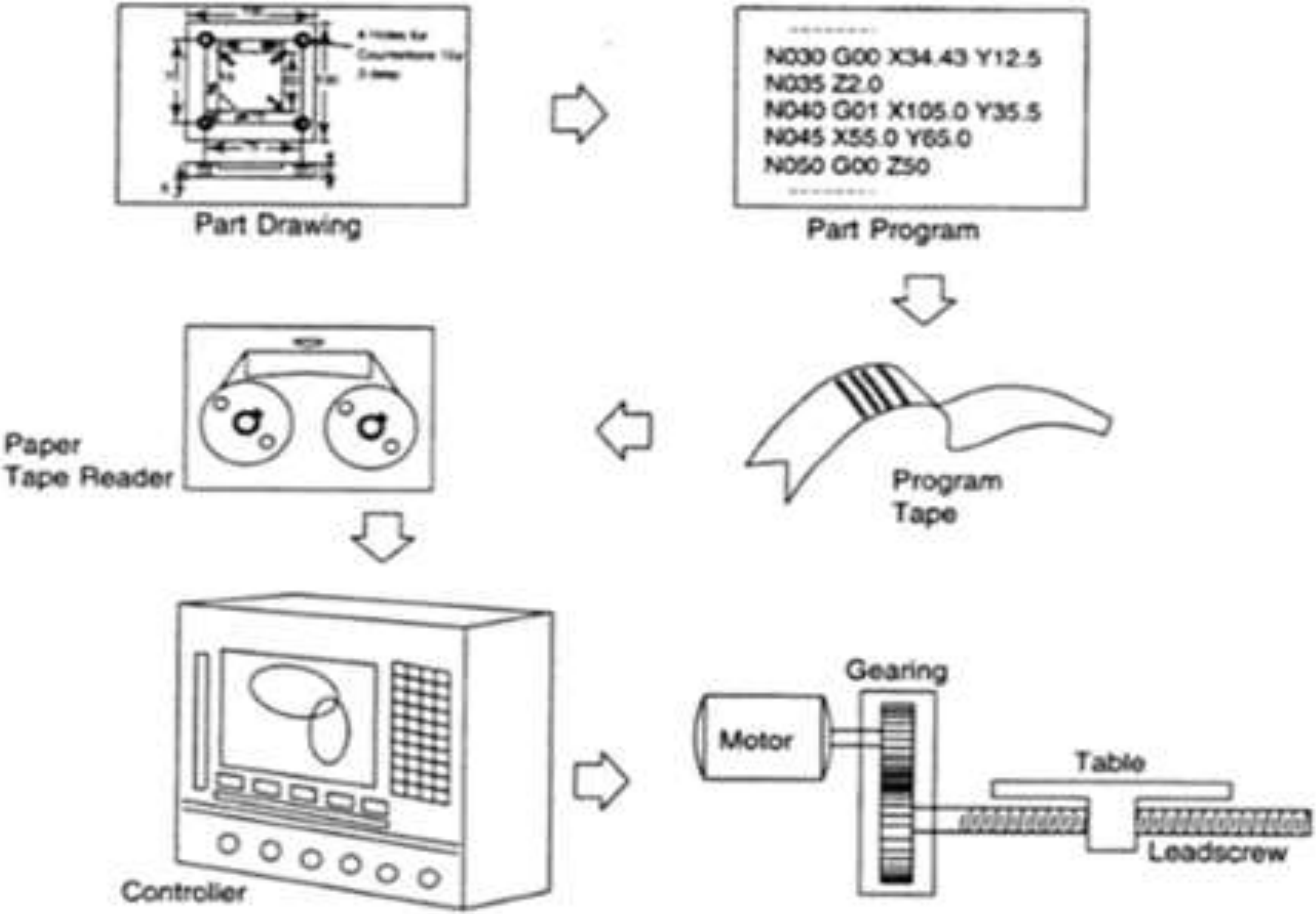


Fig. *Elements of NC Machine Tool Operation*

Advantages of NC machine tools:

1. **Reduced lead time:**

Lead time includes the time needed for planning, design and manufacture of jigs, etc. Since the need for special jigs and fixtures is often entirely eliminated, the whole time needed for their design and manufacture is saved.

•**Elimination of operator errors:**

The machine is controlled by instructions registered on the tape provided the tape is correct and machine and tool operate correctly, no errors will occur in the job.

•**Operator activity:**

The operator is relieved of tasks performed by the machine and is free to attend to matters for which his skills and ability are essential. Presetting of tools, setting of components and preparation and planning of future jobs fall into this category.

4. **Lower labor cost**

With the NC machines, it reduces the labor cost per job considerably.

5. **Smaller batches**

By the use of preset tooling and presetting techniques downtime between batches is kept at a minimum. Large storage facilities for work in progress are not required.

6. Longer tool life

Tools can be used at optimum speeds and feeds because these functions are controlled by the program.

7. Elimination of special jigs and fixtures

Because standard locating fixtures are often sufficient of work on machines. The cost of special jigs and fixture is frequently eliminated.

8. Flexibility in changes of component design

The modification of component design can be readily accommodated by reprogramming and altering the tape. Savings are affected in time and cost.

9. Reduced inspection.

The time spent on inspection and in waiting for inspection to begin is greatly reduced. Normally it is necessary to inspect the first component only once the tape is proved; the repetitive accuracy of the machine maintains a consistent product.

10. Reduced scrap

Operator error is eliminated and a proven tape results in accurate component.

11. Accurate costing and scheduling

The time taken in machining is predictable, consistent and results in a greater accuracy in estimating and more consistency in costing.

COMPUTER NUMERICAL CONTROL (CNC)

Evolution of CNC:

With the availability of microprocessors in mid 70’s the controller technology has made a tremendous progress. The new control systems are termed as computer numerical control (CNC) which are characterized by the availability of a dedicated computer and enhanced memory in the controller. These may also be termed “soft wired numerical control”.

There are many advantages which are derived from the use of CNC as compared to NC.

- Part program storage memory.
- Part program editing.
- Part program downloading and uploading.
- Part program simulation using tool path.
- Tool offset data and tool life management.
- Additional part programming facilities.
- Macros and subroutines.
- Background tape preparation, etc.

The controls with the machine tools these days are all CNC and the old NC control do not exist anymore.

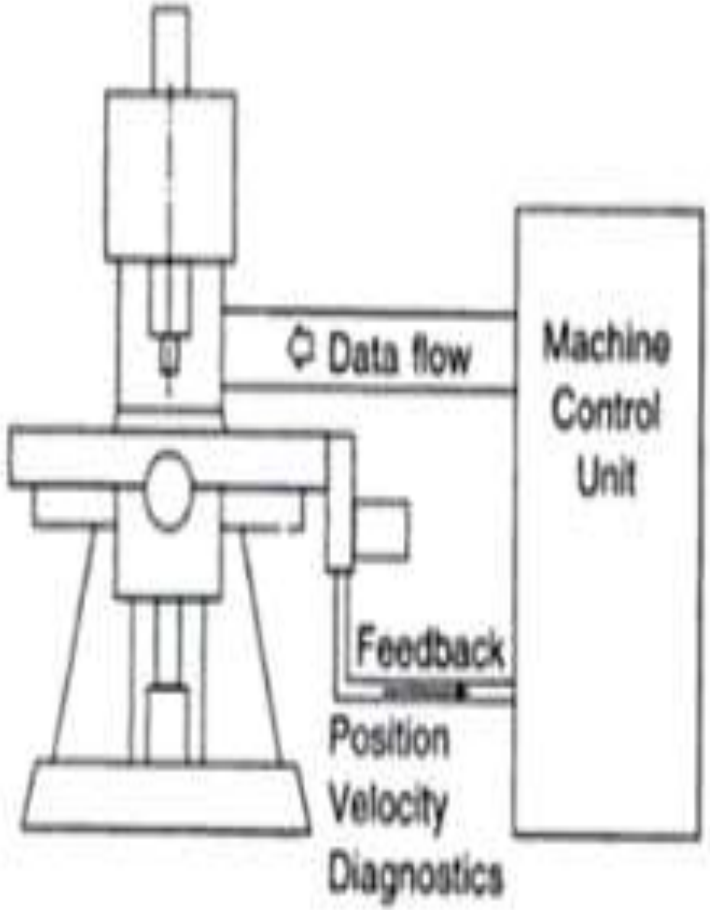


Fig. *The Data Processing in a CNC Machine Tool in Closed Loop Control*

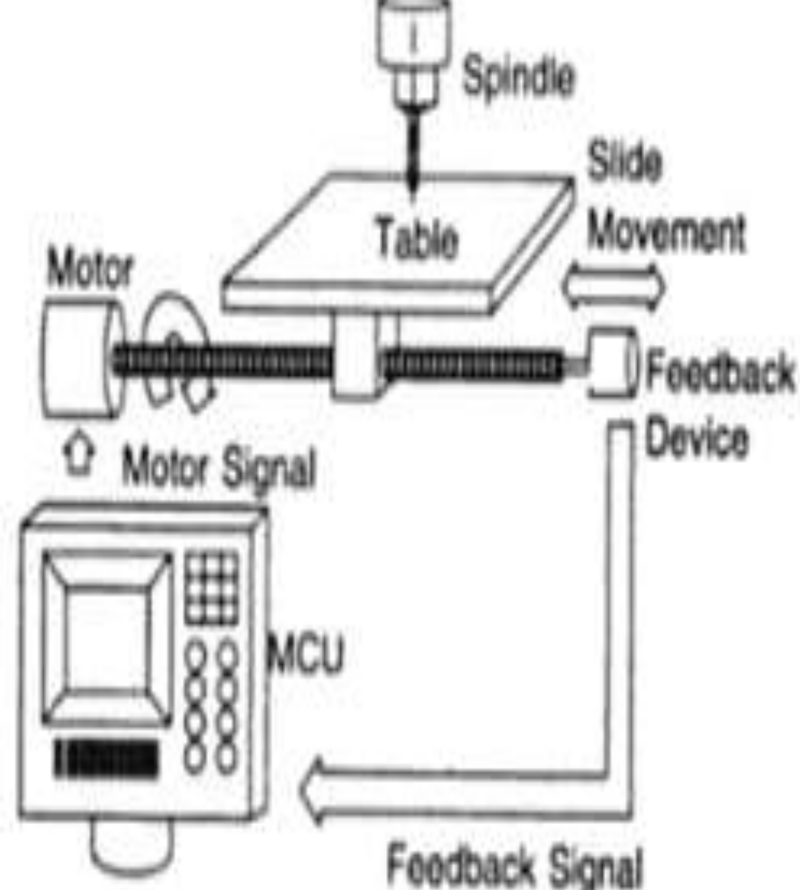


Fig. *The Data Processing in a CNC Machine Tool in Closed Loop Control*

Computer Numerical Control (CNC)

CNC refers to a computer that is joined to the NC machine to make the machine versatile. Information can be stored in a memory bank. The programme is read from a storage medium such as the punched tape and retrieved to the memory of the CNC computer. Some CNC machines have a magnetic medium (tape or disk) for storing programs. This gives more flexibility for editing or saving CNC programs. Figure illustrates the general configuration of CNC.

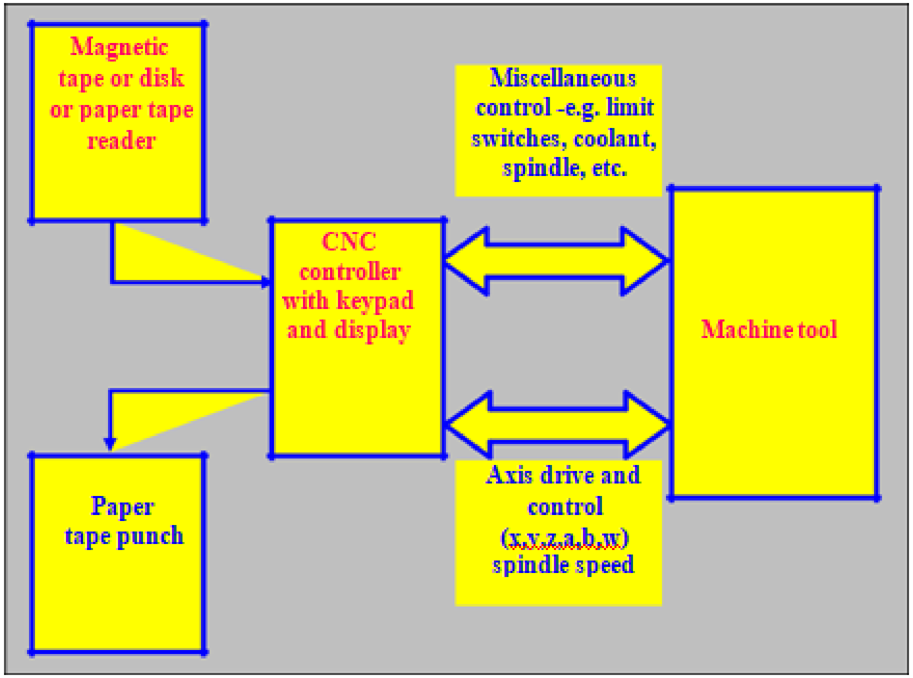


Figure: The general configuration of CNC.

CLASSIFICATION OF CNC MACHINE TOOLS

1) Based on the motion type 'Point-to-point & Contouring systems’

a. Point-to-point systems

Some machine tools for example drilling, boring and tapping machines etc, require the cutter and the work piece to be placed at a certain fixed relative positions at which they must remain while the cutter does its work. These machines are known as point -to-point machines as shown in figure and the control equipment for use with them are known as point-to-point control equipment.

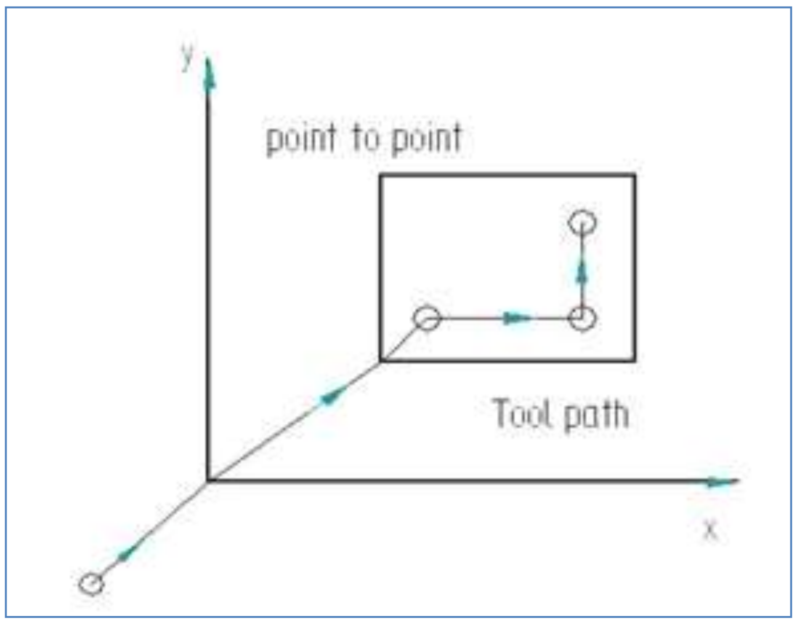
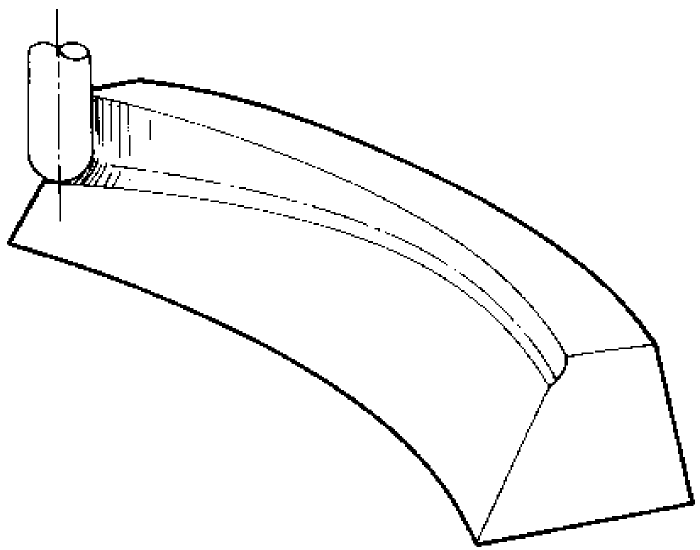


Figure: Point-to-point system

Contouring systems (Continuous path systems)

Other type of machine tools involves motion of work piece with respect to the cutter while cutting operation is taking place. These machine tools include milling, routing machines etc. and are known as contouring machines as shown in figures and the controls required for their control are known as contouring control. Contouring machines can also be used as point-to-point machines, but it will be uneconomical to use them unless the work piece also requires having a contouring operation to be performed on it.



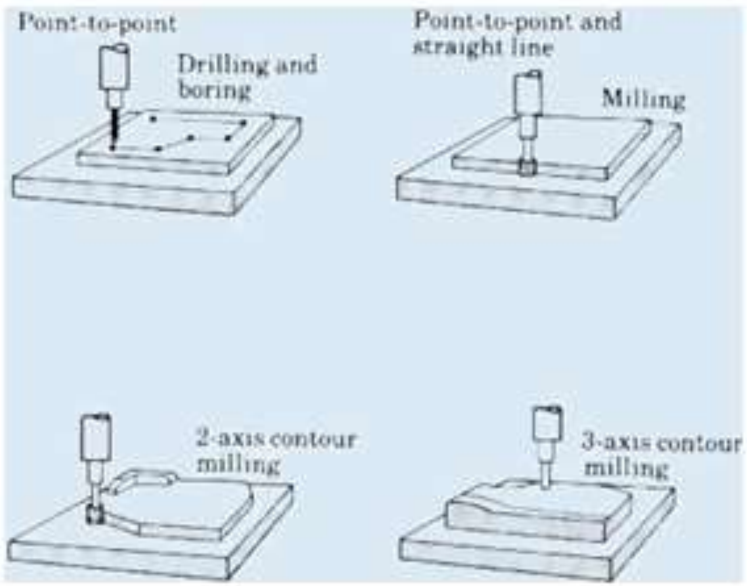


Figure: Contouring system & Contouring systems

•**Based on the control loops 'Open loop & Closed loop systems'**

•**Open loop systems:**

Programmed instructions are fed into the controller through an input device. These instructions are then converted to electrical pulses (signals) by the controller and sent to the servo amplifier to energize the servo motors. The primary drawback of the open-loop system is that there is no feedback system to check whether the **program position and velocity** has been achieved. If the system performance is affected by load, temperature, humidity, or lubrication then the actual output could deviate from the desired output. For these reasons the open -loop system is generally used in point-to-point systems where the accuracy requirements are not critical. Very few continuous-path systems utilize open-loop control.

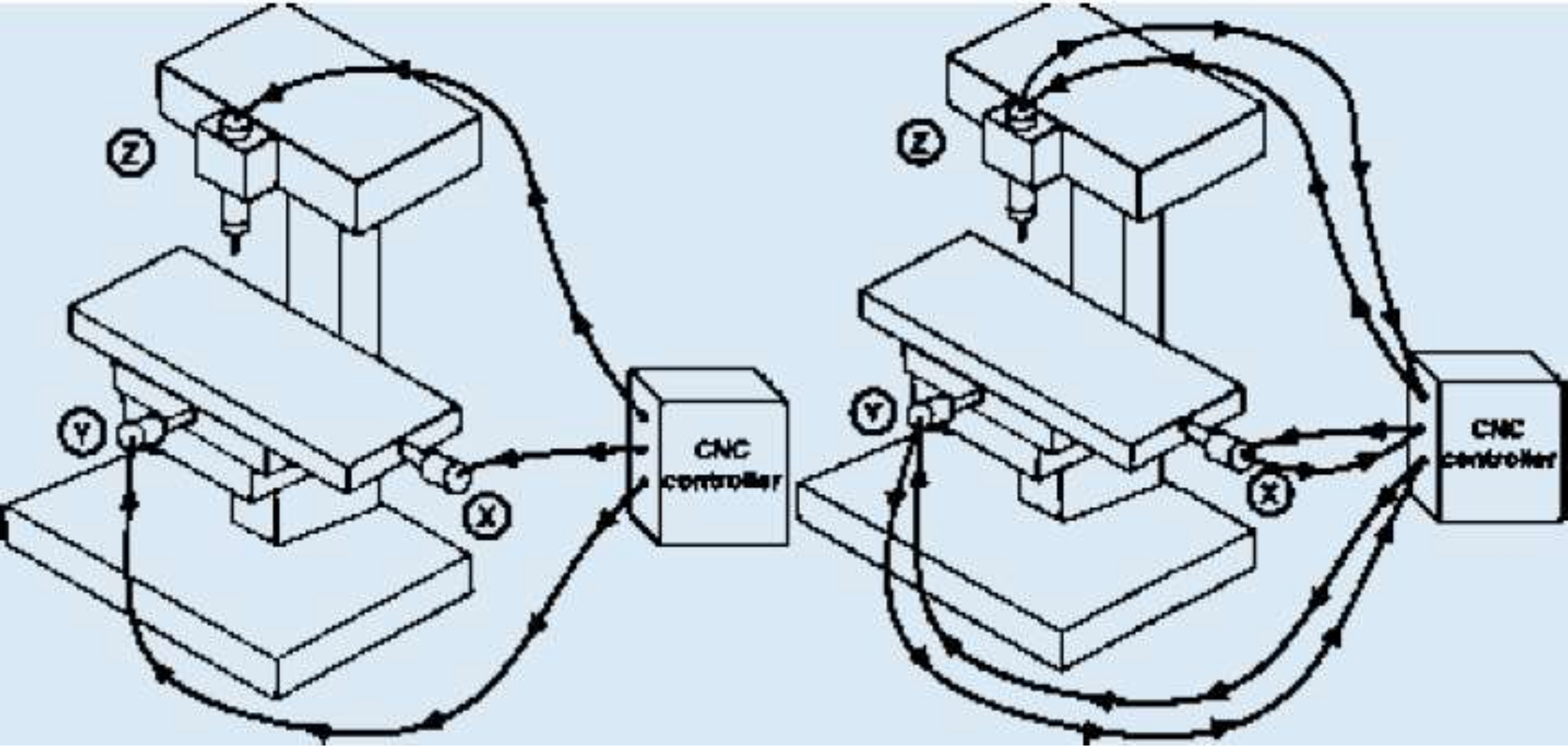


Figure (a) Open loop control system Figure (b) Closed loop control system

- **Closed loop systems**

The closed-loop system has a feedback subsystem to monitor the actual output and correct any discrepancy from the programmed input. These systems use position and velocity feedback. The feedback system could be either analog or digital. The analog systems measure the variation of physical variables such as position and velocity in terms of voltage levels. Digital systems monitor output variations by means of electrical pulses. To control the dynamic behavior and the final position of the machine slides, a variety of position transducers are employed. If a discrepancy is revealed between where the machine element should be and where it actually is, the sensing device signals the driving unit to make an adjustment, bringing the movable component to the required location. Closed-loop systems are very powerful and accurate because they are capable of monitoring operating conditions through feedback subsystems and automatically compensating for any variations in real-time.

(3) Based on the number of axes '2& 3, 4&5 axes CNC machines'

a. 2&3 axes CNC machines:

CNC lathes will be coming under 2 axes machines. There will be two axes along which motion takes place. The saddle will be moving longitudinally on the bed (Z -axis) and the cross slide moves transversely on the saddle (along X-axis). In 3-axes machines, there will be one more axis, perpendicular to the above two axes. By the simultaneous control of all the 3 axes, complex surfaces can be machined.

•4 & 5 axes CNC machines:

4 and 5 axes CNC machines provide multi-axis machining capabilities beyond the standard 3-axis CNC tool path movements. A 5-axis milling centre includes the three X, Y, Z axes, the A axis which is rotary tilting of the spindle and the B-axis, which can be a rotary index table.

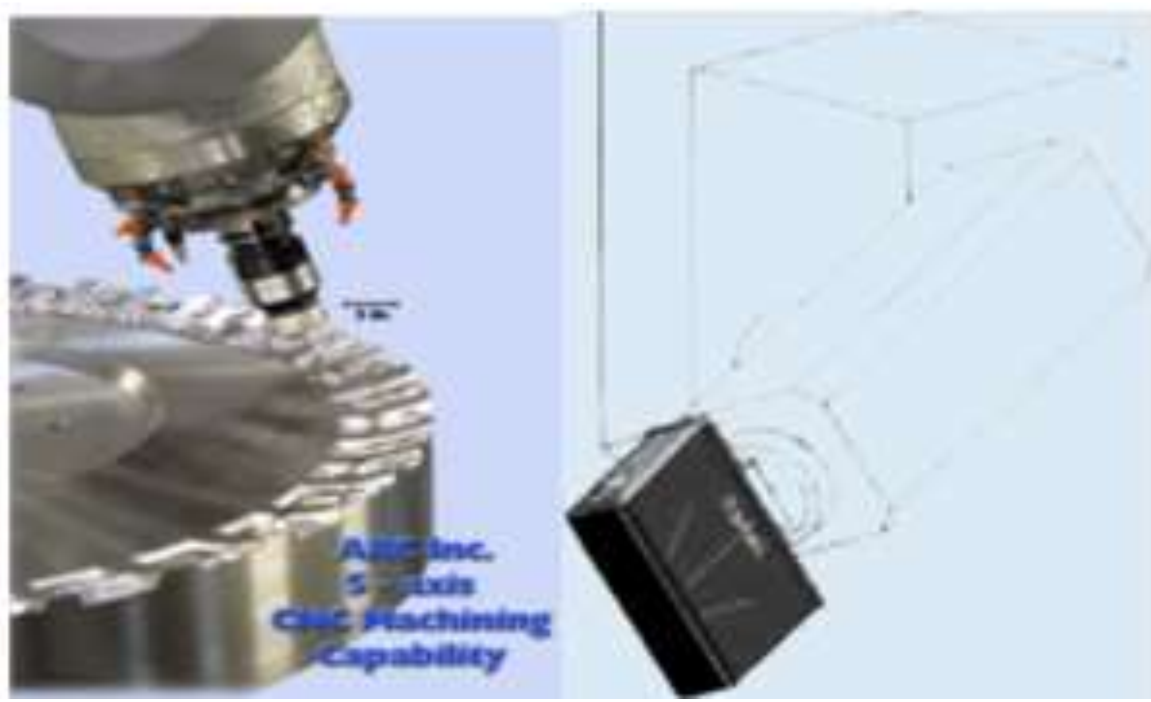


Figure: Five axes CNC machine

•**Based on the power supply ‘Electric, hydraulic or pneumatic systems’**

Mechanical power unit refers to a device which transforms some form of energy to mechanical power which may be used for driving slides, saddles or gantries forming a part of machine tool. The input power may be of electrical, hydraulic or pneumatic.

•**Electric systems:**

Electric motors may be used for controlling both positioning and contouring machines. They may be either A.C. or D.C. motor and the torque and direction of rotation need to be controlled.

b. hydraulic or pneumatic:

These hydraulic systems may be used with positioning and contouring machine tools of all sizes. These systems may be either in the form of rams or motors. Hydraulic motors are smaller than electric motors of equivalent power.

Advantages of CNC

- Increased productivity.
- High accuracy and repeatability.
- Reduced production costs.
- Reduced indirect operating costs.
- Facilitation of complex machining operations.
- Greater flexibility.
- Improved production planning and control.
- Lower operator skill requirement.
- Facilitation of flexible automation.

Limitations of CNC:

- High initial investment.
- High maintenance requirement.
- Not cost-effective for low production cost.

Applications

- CNC machine is used
- In the woodworking industry
- In the metal removal industry
- In the electrical discharge machining industry
- Laser welding in automobile industry
- Laser machining and Cutting
- In the metal fabrication industry

Other Industries where CNC machines are used: Many forms of lettering and engraving systems use CNC technology. Water jet machining uses a high pressure water jet stream to cut through plates of material. CNC is even used in the manufacturing of many electrical components. For example, there are CNC coil winders, and CNC terminal location and soldering.

Features of CNC

Computer NC systems include additional features beyond what is feasible with conventional hard-wired NC. These features, many of which are standard on most CNC Machine Control units (MCU), include the following:

•**Storage of more than one part program:** With improvements in computer storage technology, newer CNC controllers have sufficient capacity to store multiple programs.

•**Various forms of program input :** CNC controllers generally possess multiple data entry capabilities, such as punched tape, magnetic tape, floppy diskettes, RS-232 communications with external computers, and operator entry of program.

•**Program editing at the machine tool:** CNC permits a part program to be edited while it resides in the MCU computer memory. Hence, a part program can be tested and corrected entirely at the machine site, rather than being returned to the programming office for corrections.

•**Fixed cycles and programming subroutines:** Instead of writing the full instructions for the particular cycle into every program, a programmer includes a call statement in the part program to indicate that the macro cycle should be executed.

•**<u>Interpolation:</u>** Some of the interpolation schemes are normally executed only on a CNC system because of computational requirements. Linear and circular interpolation is sometimes hard-wired into the control unit, but helical, parabolic and cubic interpolations are usually executed by a stored program algorithm.

•**<u>Positioning features for setup:</u>** The alignment task can be facilitated using certain features made possible by software options in the CNC system. Position set is one of the features. With position set, the operator is not required to locate the fixture on the machine table with extreme accuracy.

•**<u>Cutter length and size compensation:</u>** One method involves manually entering the actual tool dimensions into the MCU. These actual dimensions may differ from those originally programmed. Compensations are then automatically made in the computed tool path. Another method involves use of a tool length sensor built into the machine. In this technique, the cutter is mounted in the spindle and the sensor measures its length. This measured value is then used to correct the programmed tool path.

•**<u>Acceleration and deceleration calculations:</u>** This feature is applicable when the cutter moves at high feed rates. It is designed to avoid tool marks on the work surface that would be generated due to machine tool dynamics when the cutter path changes abruptly.

•**<u>Communications interface:</u>** With the trend toward interfacing and networking in plants today, most modern CNC controllers are equipped with a standard RS -232 or other communications interface to link the machine to other computers and computer-driven devices. This is useful for various applications, such as downloading part programs from a central data file, collecting operational data such as work piece counts, cycle times, and machine utilization; and interfacing with peripheral equipment, such as robots that unload and load parts.

•**<u>Diagnostics:</u>** Many modern CNC systems possess a diagnostics capability that monitors certain aspects of the machine tool to detect malfunctions or signs of impending malfunctions or to diagnose system breakdowns.

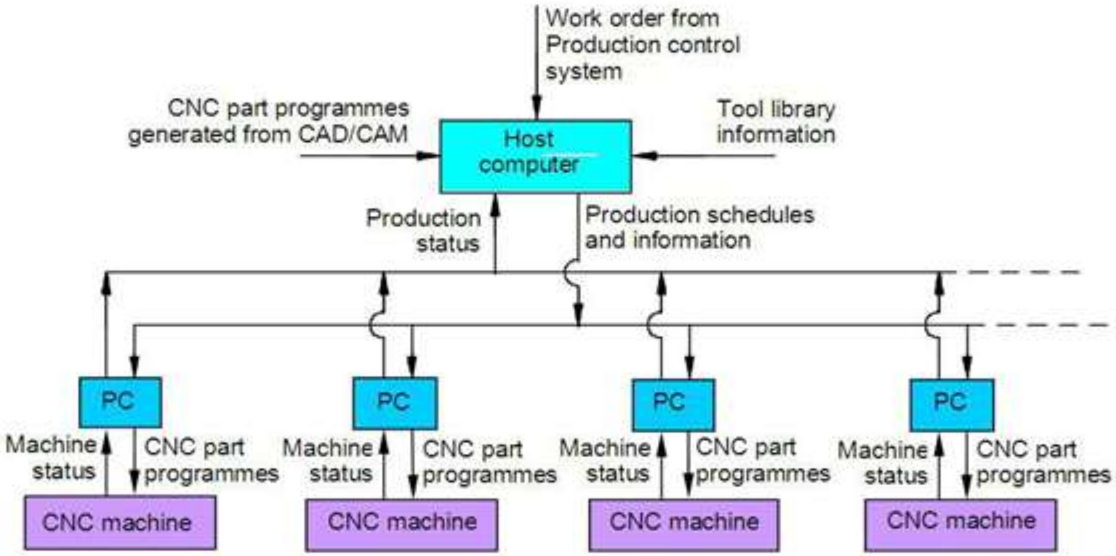


Figure: DNC system

In a Direct Numerical Control system (DNC), a mainframe computer is used to coordinate the simultaneous operations of a number NC machines as shown in the figures. The main tasks performed by the computer are to program and edit part programs as well as download part programs to NC machines. Machine tool controllers have limited memory and a part program may contain few thousands of blocks. So the program is stored in a separate computer and sent directly to the machine, one block at a time.

First DNC system developed was Molins System 24 in 1967 by Cincinnati Milacron and General Electric. They are now referred to as flexible manufacturing systems (FMS). The computers that were used at those times were quite expensive.

Part- b

CNC PART PROGRAMMING

CNC programming and Introduction

Manual part programming: Basic (Drilling, milling, turning etc.), Special part programming,

Advanced part programming,

Computer aided part programming (APT)

PROGRAMMING FUNDAMENTALS

Machining involves an important aspect of relative movement between **cutting tool and work piece**. In machine tools this is accomplished by either moving the tool with respect to work piece or vice versa.

In order to define relative motion of two objects, reference directions are required to be defined.

These reference directions depend on type of machine tool and are defined by considering an imaginary coordinate system on the machine tool.

A program defining motion of tool / work piece in this coordinate system is known as a part program.

•**Reference Point**

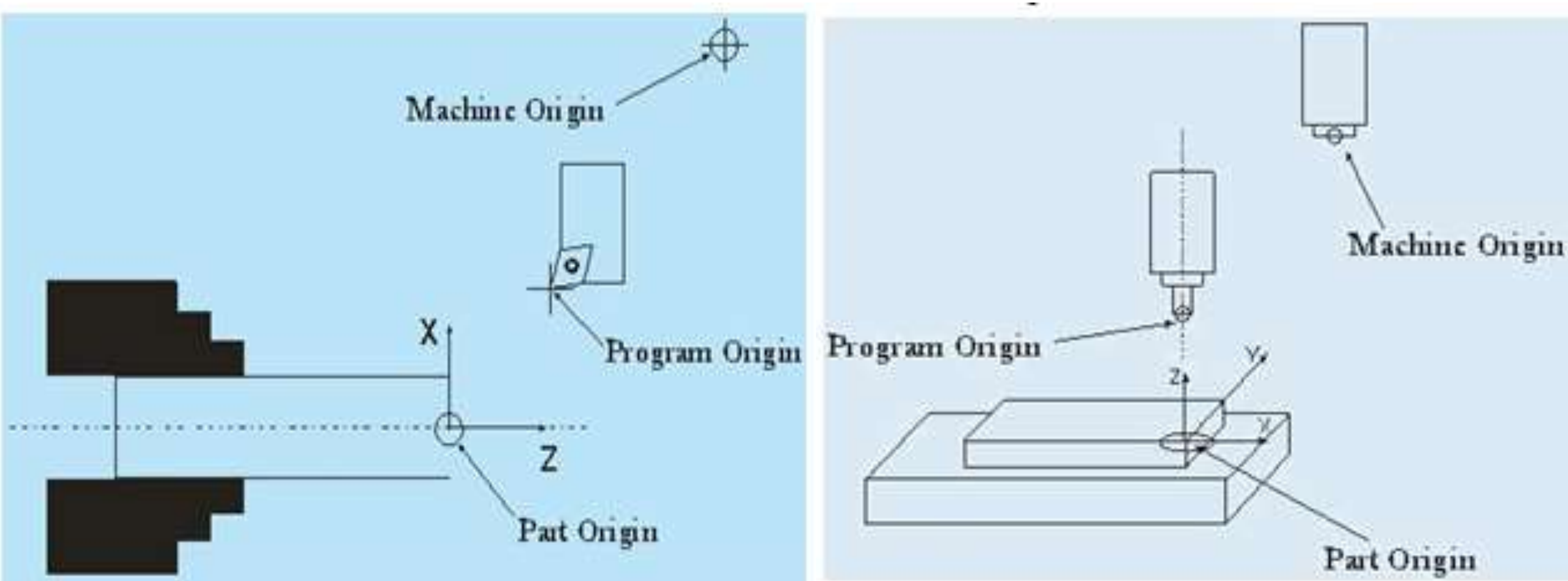


Figure: Reference points and axis on a lathe and Reference points and axis on a Milling Machine

a) Machine Origin

The machine origin is a fixed point set by the machine tool builder. Usually it cannot be changed. Any tool movement is measured from this point. The controller always remembers tool distance from the machine origin.

b) Program Origin

It is also called home position of the tool. Program origin is point from where the tool starts for its motion while executing a program and returns back at the end of the cycle. This can be any point within the workspace of the tool which is sufficiently away from the part. In case of CNC lathe it is a point where tool change is carried out.

c) Part Origin

The part origin can be set at any point inside the machine's electronic grid system. Establishing the part origin are also known as zero shifts, work shift, floating zero or datum. Usually part origin needs to be defined for each new setup. Zero shifting allows the relocation of the part. Sometimes the part accuracy is affected by the location of the part origin. Figure 1 and 2 shows the reference points on a lathe and milling machine.

2. Axis Designation

An object in space can have six degrees of freedom with respect to an imaginary Cartesian coordinate system. Three of them are liner movements and other three are rotary. Machining of simple part does not require all degrees of freedom. With the increase in degrees of freedom, complexity of hardware and programming increases. Number of degree of freedom defines axis of machine.

Axes interpolation means simultaneous movement of two or more different axes generate required contour.

•**Setting up of Origin**

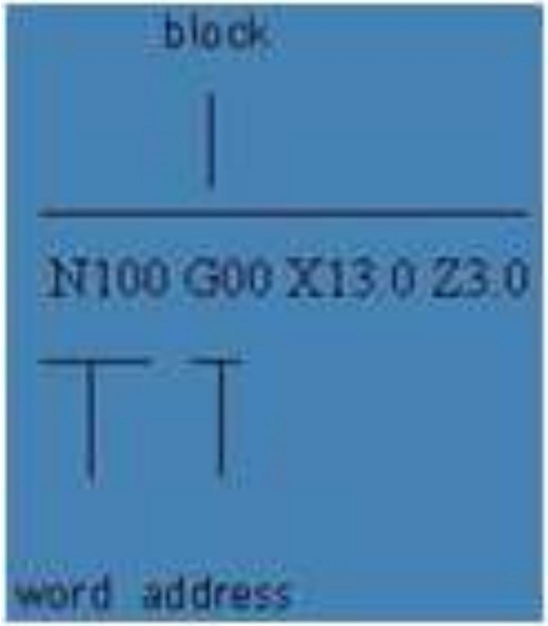
In case of CNC machine tool rotation of the reference axis is not possible. Origin can set by selecting three reference planes X, Y and Z. Planes can be set by touching tool on the surfaces of the work piece and setting that surfaces as X=x, Y=y and Z=z.

• **Coding Systems**

The programmer and the operator must use a coding system to represent information, which the controller can interpret and execute. A frequently used coding system is the Binary-Coded Decimal or BCD system. This system is also known as the EIA Code set because it was developed by Electronics Industries Association. The newer coding system is ASCII and it has become the ISO code set because of its wide acceptance.

CNC CODE SYNTAX

The CNC machine uses a set of rules to enter, edit, receive and output data. These rules are known as CNC Syntax, Programming format, or tape format. The format specifies the order and arrangement of information entered. This is an area where controls differ widely. There are rules for the maximum and minimum numerical values and word lengths and can be entered and the arrangement of the characters and word is important. The most common CNC format is the word address format and the other two formats are fixed sequential block address format and tab sequential format, which are obsolete. The instruction block consists of one or more words. A word consists of an address followed by numerals. For the address, one of the letters from A to Z is used. The address defines the meaning of the number that follows. In other words, the address determines what the number stands for. For example it may be an instruction to move the tool along the X axis, or to select a particular tool.



Most controllers allow suppressing the leading zeros when entering data. This is known as leading zero suppression. When this method is used, the machine control reads the numbers from right to left, allowing the zeros to the left of the significant digit to be omitted. Some controls allow entering data without using the trailing zeros. Consequently it is called trailing zero suppression. The machine control reads from left to right, and zeros to the right of the significant digit may be omitted.

TYPES OF CNC CODES

1. **Preparatory codes:** The term "preparatory" in NC means that it "prepares" the control system to be ready for implementing the information that follows in the next block of instructions. A **preparatory function** is designated in a program by the word address G followed by two digits. Preparatory functions are also called **G-codes** and they specify the control mode of the operation.

2. **Miscellaneous codes:** Miscellaneous functions use the address letter M followed by two digits. They perform a group of instructions such as coolant on/off, spindle on/off, tool change, program stop, or program end. They are often referred to as machine functions or **M-functions**.

Some of the M codes are given below.

M00 Unconditional stop

M02 End of program

M03Spindle clockwise

M04 Spindle counterclockwise

M05 Spindle stop

M06 Tool change

M30 End of program

In principle, all codes are either modal or non-modal. **Modal code stays in effect until cancelled by another code in the same group.** The control remembers modal codes. This gives the programmer an opportunity to save programming time. **Non-modal code stays in effect only for the block in which it is programmed**. Afterwards, its function is turned off automatically. For instance G04 is a non-modal code to program a dwell. After one second, which is say, the programmed dwell time in one particular case, this function is cancelled. To perform dwell in the next blocks, this code has to be reprogrammed. The control does not memorize the non-modal code, so it is called as one shot codes. One-shot commands are **non-modal**. Commands known as "canned cycles" (a controller's internal set of preprogrammed subroutines for generating commonly machined features such as internal pockets and drilled holes) are non-modal and only function during the call.

On some older controllers, cutter positioning (axis) commands (e.g., G00, G01, G02, G03, & G04) are non-modal requiring a new positioning command to be entered each time the cutter (or axis) is moved to another location.

CNC PART PROGRAMMING II

In the previous section, fundamentals of programming as well basic motion commands for milling and turning have been discussed. This section gives an overview of G codes used for changing the programming mode, applying transformations etc.

Programming modes

Programming mode should be specified when it needs to be changed from absolute to incremental and vice versa. There are two programming modes, absolute and incremental and is discussed below.

Absolute Dimension System: Data in absolute dimension system always refer to a fixed reference point in the drawing as shown in figure a above. This point has the function of a coordinate zero point as in figure. The dimension lines run parallel to the coordinate axes and always start at the reference point. Absolute dimensions are also called as “Reference dimensions”.

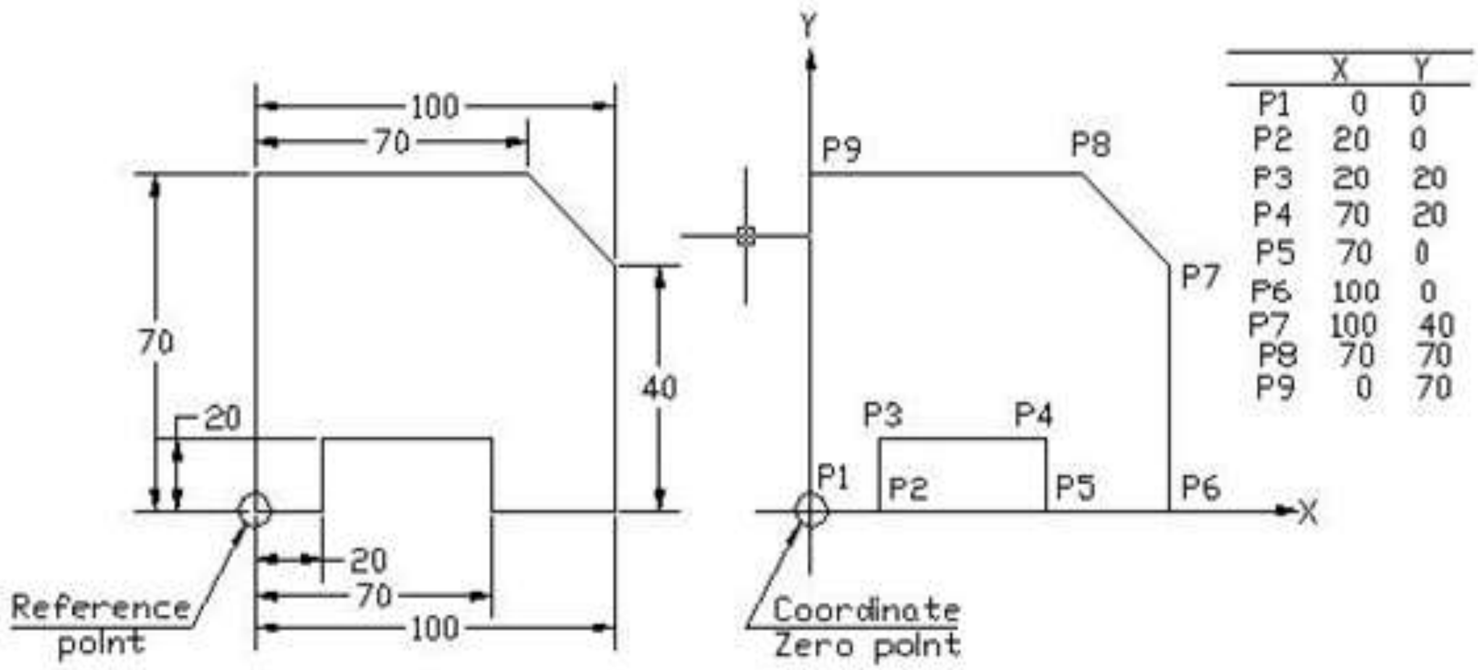
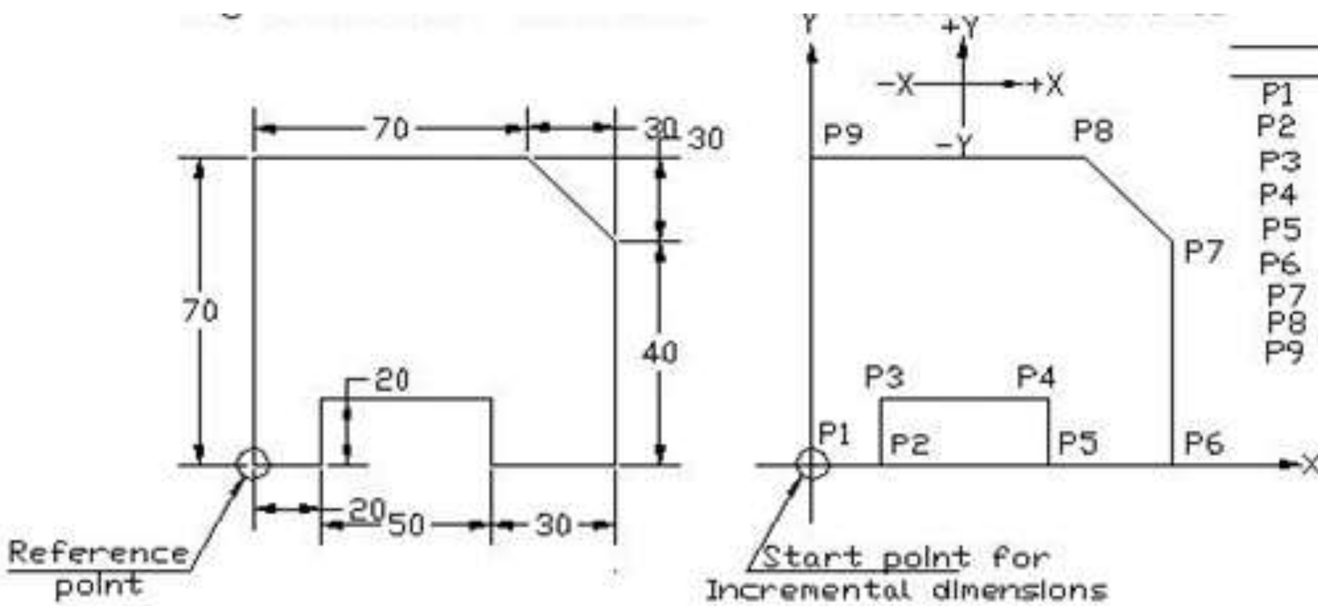


Fig A. Absolute Dimensions Absolute Coordinates

Incremental Dimension System: When using incremental dimension system, every measurement refers to a previously dimensioned position as shown in figure A below. Incremental dimensions are distance between adjacent points. These distances are converted into incremental coordinates by accepting the last dimension point as the coordinate origin for the new point. This may be compared to a small coordinate system, i.e. shifted consequently from point to point as shown in figurer. Incremental dimensions are also frequently called "Relative dimensions" or "Chain dimensions".



	X	Y
P1	0	0
P2	20	0
P3	0	20
P4	50	0
P5	0	-20
P6	30	0
P7	0	40
P8	-30	30
P9	-70	0

Fig B. Incremental Dimensions   Incremental Coordinates

Spindle control

The rotational speed of the tool, with respect to the work piece being cut, is called the spindle (or cutting) speed. The spindle speed is defined using the S address letter, followed by a numerical value, signifying the spindle RPM (revolutions per minute). The spindle speed value specified must fall between the machine tool RPM range for the command to be effective.

Tool selection

Tool profiles can be changed during a program using the tool function command. Each tool profile is assigned a number, which in the case of an ATC (Automatic Tool Changer) will also coincide with one of the free bays on its carousel magazine.

The tool number is defined using the address letter T, followed by a number assigned to the tool profile. To command a tool change, the MØ6 code would precede the number of the "new" tool required. For example, MØ6 TØ1

Feed rate control

The movement of the tool at a specified speed for cutting is called the Feed rate.

The feedrate is defined using the F address letter followed by a numerical value.

Using the G2Ø code, the feedrate is defined in Inches per minute.

Using the G21 code, the feedrate is defined in Millimeters per minute.

Tool radius Compensation

When milling a contour, the tool radius center is used as the reference point on the tool while writing the program, but the part is actually cut by the point on the cutter periphery. This point is at 'r' distance from the tool center. This means that the programmer should shift the tool center away from the part in order to perform the cutting by the tool cutting edge. The shift amount depends upon the part geometry and tool radius. This technique is known as tool radius compensation or cutter radius compensation.

In case of machining with a single point cutting tool, the nose radius of the tool tip is required to be accounted for, as programs are being written assuming zero nose radius. The tool nose radius center is not only the reference point that can be used for programming contours. On the tool there is a point known as imaginary tool tip, which is at the intersection of the lines tangent to the tool nose radius.

Cutter compensation allows programming the geometry and not the tool path. It also allows adjusting the size of the part, based on the tool radius used to cut part. This is useful when cutter of the proper diameter is not found. This is best explained in the Figure.

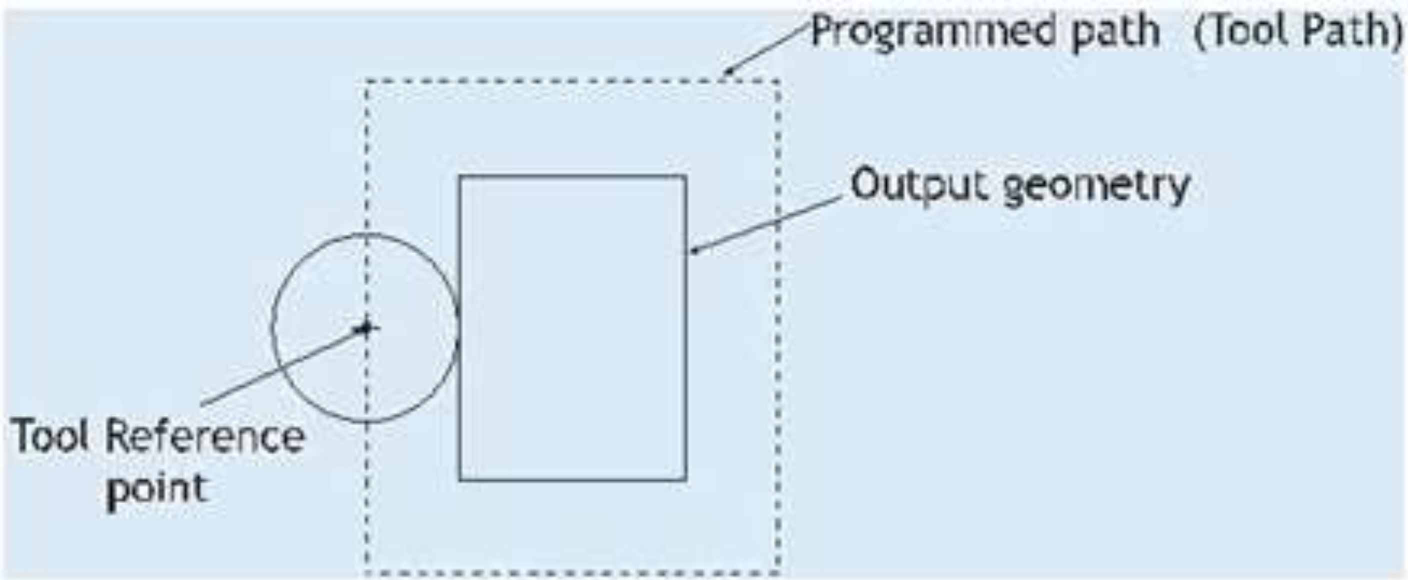


Figure. Cutter diameter compensation

The information on the diameter of the tool, which the control system uses to calculate the required compensation, must be input into the control unit's memory before the operation. Tool diameter compensation is activated by the relevant preparatory functions (G codes) as shown in Figure.

Compensation for tool radius can be of either right or left side compensation. This can be determined by direction of tool motion. If you are on the tool path facing direction of tool path and if tool is on your left and work piece is on your right side then use G41 (left side compensation). For, reverse use other code G42 (Right side compensation). Both the codes are modal in nature and remain active in the program until it is cancelled by using another code, G40.

Subroutines

Any frequently programmed order of instruction or unchanging sequences can benefit by becoming a subprogram. Typical applications for subprogram applications in CNC programming are:

- Repetitive machining motions
- Functions relating to tool change
- Hole patterns
- Grooves and threads
- Machine warm-up routines
- Pallet changing
- Special functions and others

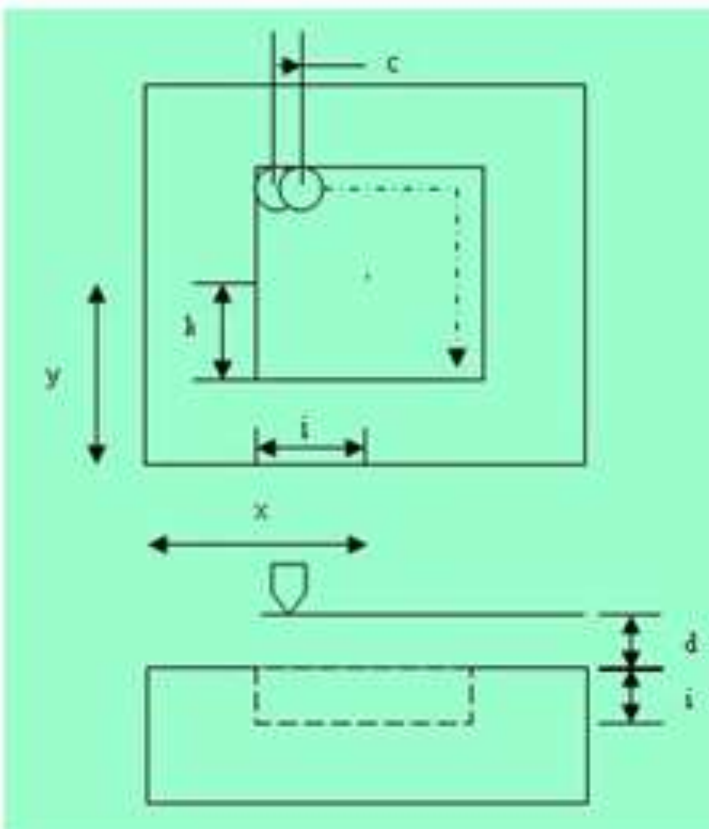
Structurally, subprograms are similar to standard programs. They use the same syntax rules. The benefits of subroutines involve the reduction in length of program, and reduction in program errors. There is a definition statement and subroutine call function.

Canned Cycles

A canned cycle is a preprogrammed sequence of events / motions of tool / spindle stored in memory of controller. Every canned cycle has a format. Canned cycle is modal in nature and remains activated until cancelled. Canned cycles are a great resource to make manual programming easier. Often underutilized, canned cycles save time and effort.

Machining a Rectangular pocket

This cycle assumes the cutter is initially placed over the center of the pocket and at some clearance distance (typically 0.100 inch) above the top of the pocket. Then the cycle will take over from that point, plunging the cutter down to the "peck depth" and feeding the cutter around the pocket in ever increasing increments until the final size is attained. The process is repeated until the desired total depth is attained. Then the cutter is returned to the center of the pocket at the clearance height as shown in figure.



NOTE: The overall length and width of the pocket, rather than the distance of cutter motion, are programmed into this cycle. For machining a circular pocket, the same syntax with code G88 is used

Figure. Pocket machining

MISCELLANEOUS FUNCTION (M CODES) AND PREPAROTARY CODES (G-CODES)

The lists of G codes and M codes that can be used in **milling machines and Lathe Machine** are given below.

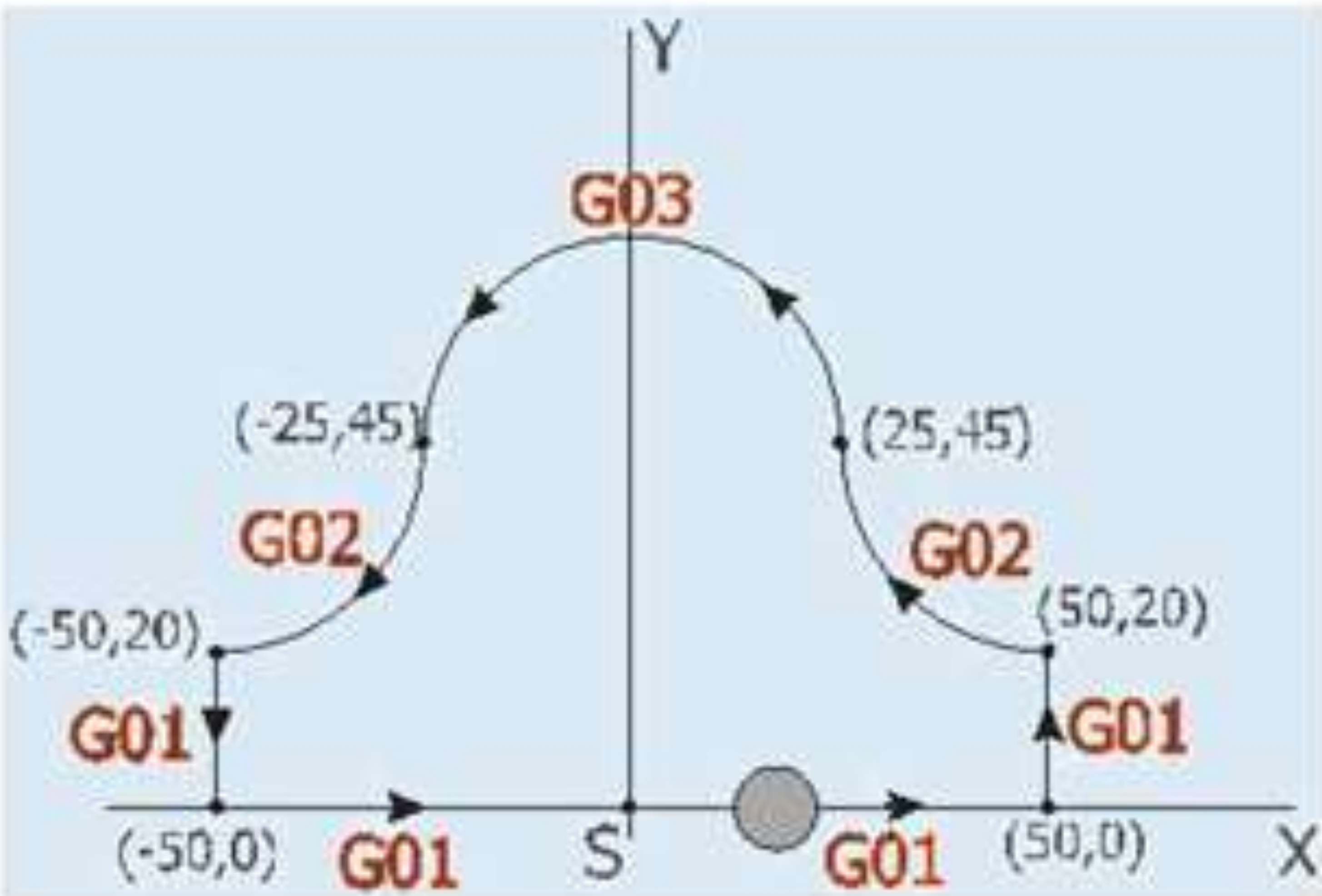
M CODES FUNCTION		G CODE FUNCTION	
M00	Program stop	G00	Rapid positioning
M01	Optional stop	G01	Linear interpolation
M02	Program stop	G02	Circular interpolation CW
M03	Spindle clockwise rotation	G03	Circular interpolation CCW
M04	Spindle anti-clockwise rotation	G04	Dwell
M05	Spindle stop	G20	Input in inch
M06	Tool change	G21	Input in mm
M08	Coolant on	G28	Return to reference point
M09	Coolant off	G40	Cutter compensation cancel
M10	Vice on	G41	Cutter compensation left
M11	Vice off	G42	Cutter compensation right
M13	Coolant, spindle CW	G43	Tool length compensation (+)
M14	Coolant, spindle CCW	G44	Tool length compensation (-)
M30	Program stop and rewind	G49	Tool length compensation cancel
M70	X mirror on	G73	Peck drilling cycle
M71	Y mirror on	G74	Counter tapping cycle
M80	X mirror off	G76	Fine boring cycle
M81	Y mirror off	G80	Canned cycle cancel
M98	Subprogram call	G81	Drilling cycle, spot boring
M99	Subprogram off/exit	G82	Drilling cycle, counter boring
		G83	Peck drilling cycle
		G84	Tapping cycle
		G85	Boring cycle
		G90	Absolute command
		G91	Incremental command
		G92	Programming of absolute zero point
		G94	Feed per minute
		G95	Feed per revolution

Lists of G codes and M codes that can be used in **Lathes** are given below.

M CODES FUNCTION		G CODE FUNCTION	
M00	Program stop	G00	Rapid positioning
M01	Optional stop	G01	Linear interpolation
M02	Program stop	G02	Circular interpolation CW
M03	Spindle clockwise rotation	G03	Circular interpolation CCW
M04	Spindle anti-clockwise rotation	G04	Dwell
M05	Spindle stop	G20	Input in inch
M06	Tool change	G21	Input in mm
M08	Coolant ON	G28	Return to reference point
M09	Coolant OFF	G32	Thread cutting
M10	Vice open	G40	Cutter compensation cancel
M11	Vice close	G41	Tool nose radius compensation left
M30	Program end and rewind	G42	Tool nose radius compensation right
M98	Subprogram call	G50	Spindle speed clamping
M99	Subprogram off/exit	G70	Finishing cycle
		G71	Multiple turning cycle
		G72	Multiple repeating cycle
		G73	Pattern repeating cycle
		G74	Peck drilling cycle
		G75	Grooving cycle
		G76	Thread cutting cycle
		G90	Box turning cycle
		G94	Box facing cycle
		G98	Feed per minute
		G99	Feed per revolution

ILLUSTRATIVE EXAMPLE PROGRAM

Example 1:



O5678	Program number
N02 G21	Metric programming
N03 M03 S1000	Spindle start clockwise with 1000rpm
N04 G00 X0 Y0	Rapid motion towards (0,0)
N05 G00 Z-10	Rapid motion towards Z= -10 plane
N06 G01 X50	Linear interpolation
N07 G01 Y20	Linear interpolation
N08 G02 X25 Y45 R25	Circular interpolation clockwise(cw)
N09 G03 X-25 Y45 R25	Circular interpolation counter clockwise(ccw)
N10 G02 X-50 Y20 R25	Circular interpolation clockwise(cw)
N11 G01 Y0	Linear interpolation
N12 G01 X0	Linear interpolation
N13 G00 Z10	Rapid motion towards Z=10 plane
N14 M05 M09	Spindle stop and program end

PART PROGRAMMING WITH APT

APT is a short form that stands for Automatically Programmed Tooling. APT is not a language; it is also the computer program that processes the APT statements to calculate the corresponding cutter positions and generate the machine tool control commands. To program in APT, the programmer must first define the part geometry. Then the tool is directed to various point locations and along surfaces of the work part to accomplish the required machining operations. The viewpoint of the programmer is that the work piece remains stationary, and the tool is instructed to move relative to the part. To complete the program, speeds and feeds must be specific, tools must be called, tolerances must be given for circular interpolation, and so forth.

There are four basic types of statements in the APT language.

- **Geometry statements** are used to define the geometry elements that comprise the part.
- **Motion commands** are used to specify the tool path
- **Postprocessor statements** control the machine tool operation, for example, to specify speeds and feeds, set tolerance values for circular interpolation, and actuate other capabilities of the machine tool.
- **Auxiliary statements** are a group of miscellaneous statements used to name the part program, insert comments in the program, and accomplish similar functions.

These statements are constructed of APT vocabulary words, symbols, and numbers, all arranged using appropriate punctuation. APT vocabulary words consist of six or fewer characters. Most APT statements include a slash (/) as part of the punctuation. APT vocabulary words that immediately precede the slash are called **major word**s, whereas those that follow the slash are called **minor words**.

APT Geometry Statements

The geometry of the part must be defined to identify the surfaces and features that are to be machined. Accordingly, the points, lines, and surfaces must be defined in the program prior to specifying the motion statements. The general form of APT geometry statements is the following:

SYMBOL = GEOMETRY TYPE/DESCRIPTIVE DATA

An example of such a statement is

P1 = POINT/20.0, 40.0, 60.0

An APT geometry statement consists of three sections.

- The first is the symbol used to identify the geometry element. A symbol can be any combination of six or fewer alphabetical and numerical characters, at least one of which must be alphabetical. Also, the symbol cannot be an APT vocabulary word.
- The second section of the APT geometry statement is an APT major word that identifies the type of geometry element. Examples are **POINT, LINE, CIRCLE and PLANE.**
- The third section of the APT geometry statement provides the descriptive data that define the element precisely, completely, and uniquely.

Points:

Specification of a point is most easily accomplished by designating its x , y, and z-coordinates.

P1 = POINT/20.0, 40.0, 60.0

Where, the descriptive data following the slash indicate x, y and z-coordinates. The specification can be done in either inches or millimeters (metric). We use metric values in our examples.

As an alternative, a point can be defined as the intersection of two intersecting lines, as in the following:

P1 = POINT/INTOF, L1, L2

Where, the APT word INTOF in the descriptive data stands for “INTERSECTION OF”. Other methods of defining points are also available.

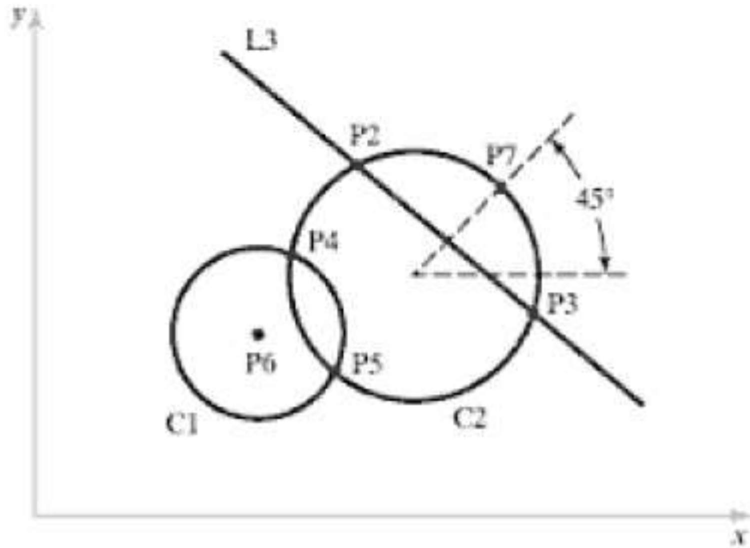


Figure 1 Defining a point using intersections of previously defined lines and circles.

The associated points are identified in the following APT statements:

P2= POINT/YLARGE, INTOF, L3, C2

P2= POINT/XSMALL, INTOF, L3, C2

P3= POINT/XLARGE, INTOF, L3, C2

P3= POINT/YSMALL, INTOF, L3, C2

P4= POINT/YLARGE, INTOF, C1, C2

P5= POINT/YSMALL, INTOF, C1, C2

P6= POINT/CENTER, C1

P7= POINT/C2, ATANGL, 45

Lines:

A line defined in APT is considered to be of infinite length in both directions. Also, APT treats a line as a vertical plane that is perpendicular to the x-y plane. The easiest way to specify a line is by two points through which it passes, as in Figure 2:

L1= LINE/P1, P2

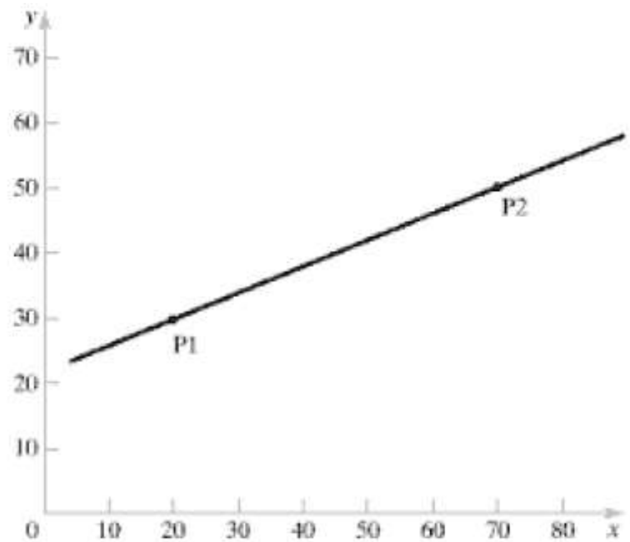


Figure 2 Defining a line using two previously defined points.

The same line can be defined by indicating the coordinate positions of the two points by giving their x-,y-, and z-coordinates in sequence; for example,

L1= LINE/20, 30, 0, 70, 50, 0

In some situations, the part programmer may find it more convenient to define a new line as being parallel to or perpendicular to one of the axes or another line that has been previously defined; for example, with reference to Figure 3,

L5= LINE/P2, PARLEL, L3

L6= LINE/P2, PERPTO, L3

L7= LINE/P2, PERPTO, XAXIS

Where, PARLEL and PERPTO are APT's way of spelling "parallel to" and "perpendicular to", respectively.

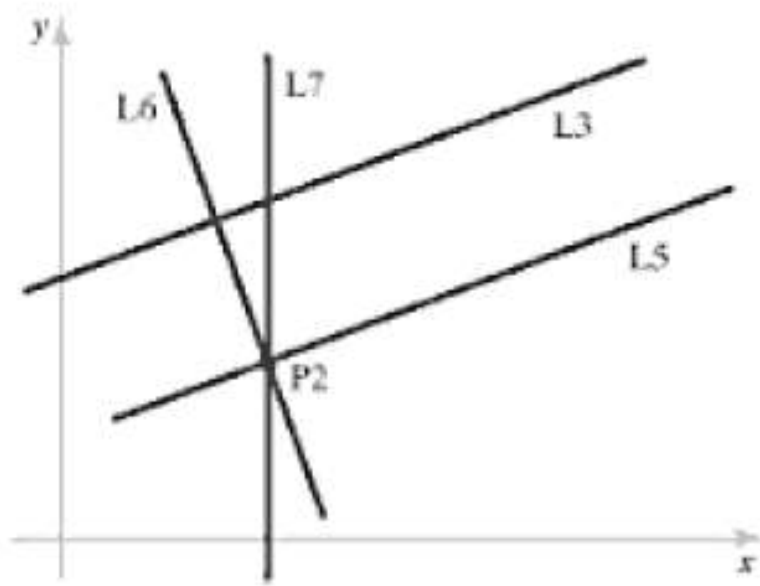


Figure 3: Defining a line using a point and parallelism or perpendicularity to another line

Lines can also be defined in relation to a point and a circle, as in Figure 4, as in the geometry statements

L1= LINE/P1, LEFT, TANTO, C1

L2=LINE/P1, RIGHT, TANTO, C1

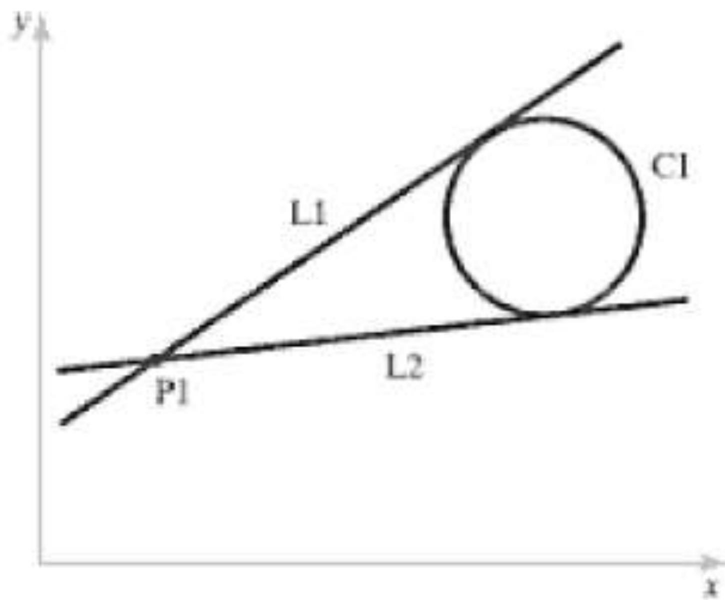


Figure 4 Defining a line using a point and a circle.

Where, the words LEFT and RIGHT are used by looking in the direction of the circle from the point P1, and TANTO means “tangent to”.

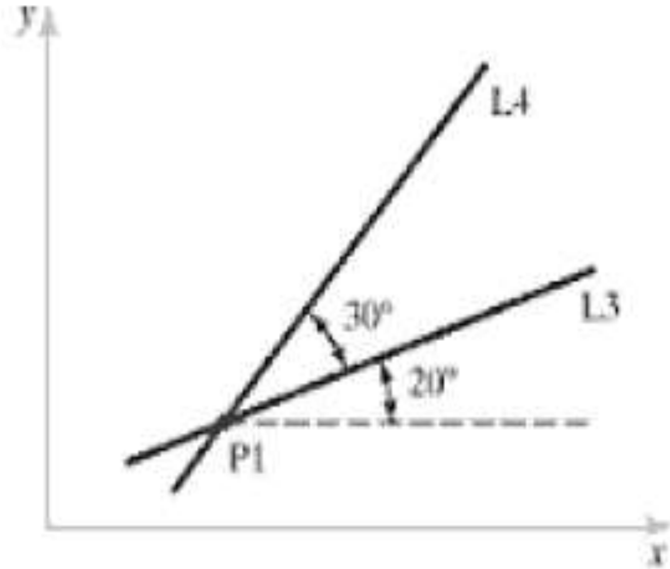


Figure 5 Defining a line using a point and the x-axis or another

Finally, lines can be defined using a point and the angle of the line relative to the x-axis or some other line, as in Figure. The following statements illustrate the definitions:

L3= LINE/P1, ATANGL, 20, XAXIS

L4= LINE/P1, ATANGL, 30, L3

Planes:

A plane can be defined by specifying three points through which the plane passes, as in the following:

PL1= PLANE/P1, P2, P3

Of course, the three points must be non-collinear. A plane can also be defined as being parallel to another plane that has been previously defined; for instance,

PL2= PLANE/P2, PARLEL, PL1

This states that plane PL2 passes through point P2 and is parallel to plane PL1. In APT, a plane extends indefinitely.

Circles:

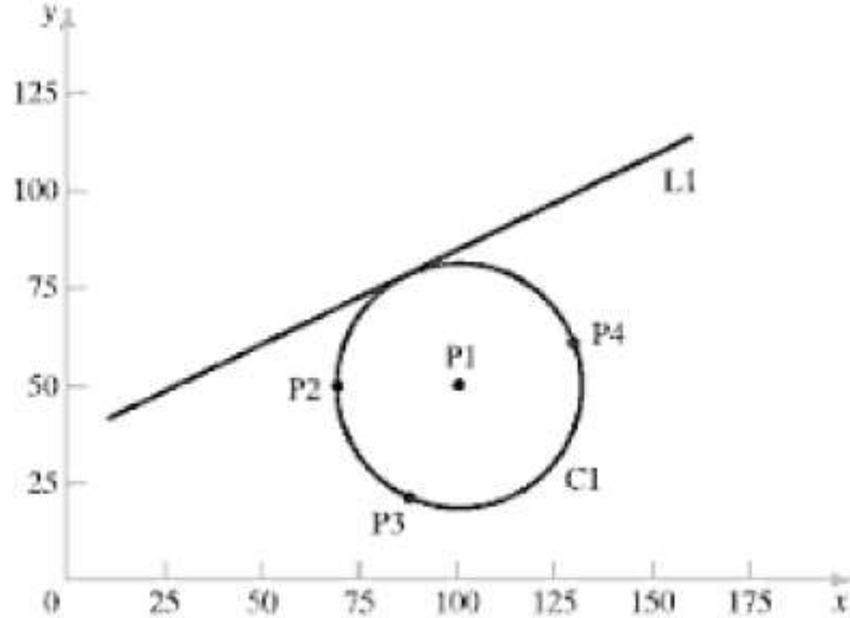


Figure 6 Defining a circle.

In APT, a circle is considered to be a cylindrical surface that is perpendicular to the x-y plane and extends to infinity in the z-direction. The easiest way to define a circle is by its center and radius, as in the following two statements, illustrated in Figure 6.

C1= CIRCLE/CENTER, P1, RADIUS, 32

C1= CIRCLE/CENTER, 100, 50, 0, RADIUS, 32

Two additional ways of defining a circle utilize previously defined points P2, P3, and P4, or line

L1 in the same figure:

C1= CIRCLE/CENTER, P2, P3, P4 (P2, P3 and P4 must not be collinear)

C1= CIRCLE/CENTER, P1, TANTO, L1

Other ways to define circles make use of existing lines L2 and L3 in Figure 7. The statements for the four circles in the figure are the following:

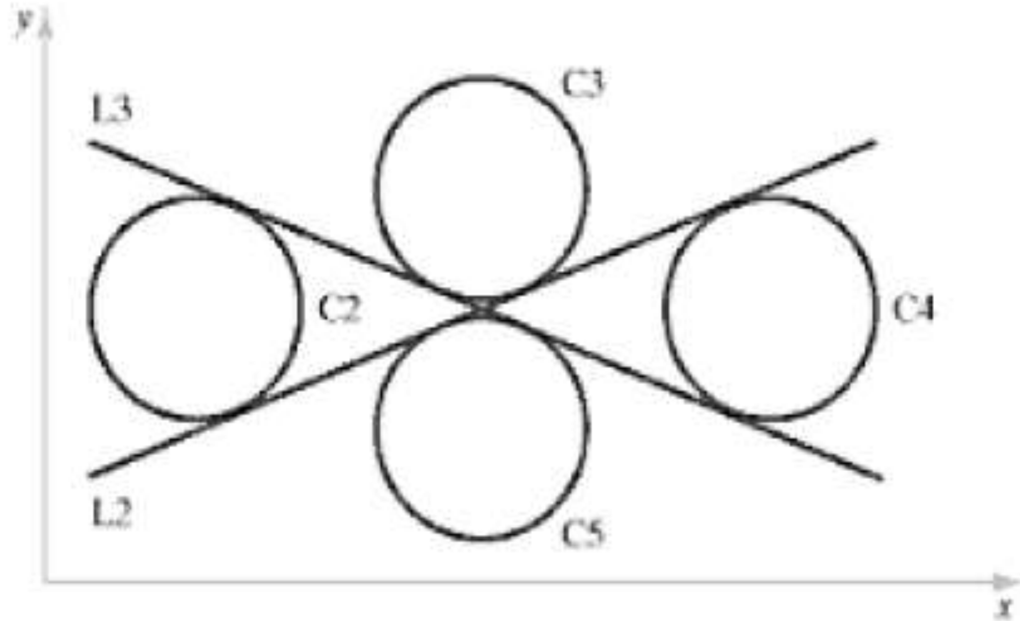


Figure 7 **Defining a circle using two intersecting lines.**

C2= CIRCLE/XSMALL, L2, YSMALL, L3, RADIUS, 25
C3= CIRCLE/YLARGE, L2, YLARGE, L3, RADIUS, 25
C4= CIRCLE/XLARGE, L2, YLARGE, L3, RADIUS, 25
C5= CIRCLE/YSMALL, L2, YSMALL, L3, RADIUS, 25

Ground Rules:

Certain ground rules must be obeyed when formulating APT geometry statement. Following are four important rules in APT:

- Coordinate data must be specified in the order x, then y, then z, because the statement is interpreted to mean x = 20.5 mm, y = 40.0 mm, and z = 60.0 mm

    P1=POINT/20.5, 40.0, 60.0

- Any symbols used as descriptive data must have been previously defined: for example, in the statement the two lines L1and L2 must have been previously defined. In setting up the list of geometry statements, the APT programmer must be sure to define symbols before using them in subsequent statements.

    P1=POINT/INTOF, L1, L2

- A symbol can be used to define only one geometry element. The same symbol cannot be used to define two different elements. For example, the following statements would be incorrect if they were included in the same program:

    P1=POINT/20, 40, 60
    P1=POINT/30, 50, 70

- Only one symbol can be used to define any given element. For example, the following two statements in the same part program would be incorrect:

    P1=POINT/20, 40, 60
    P2=POINT/20, 40, 60

Contouring motions:

Contouring commands are more complicated that PTP commands because the tool's position must be continuously controlled throughout the move. To exercise this control, the tool is directed along two intersecting surfaces until it reaches a third surface, as shown in Figure.

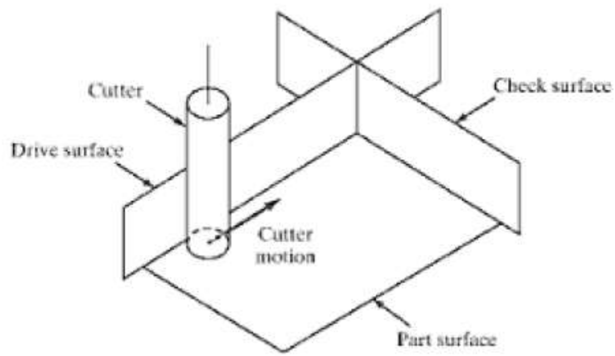


Figure 8 Three surfaces in APT contouring motions that guide the cutting tool.

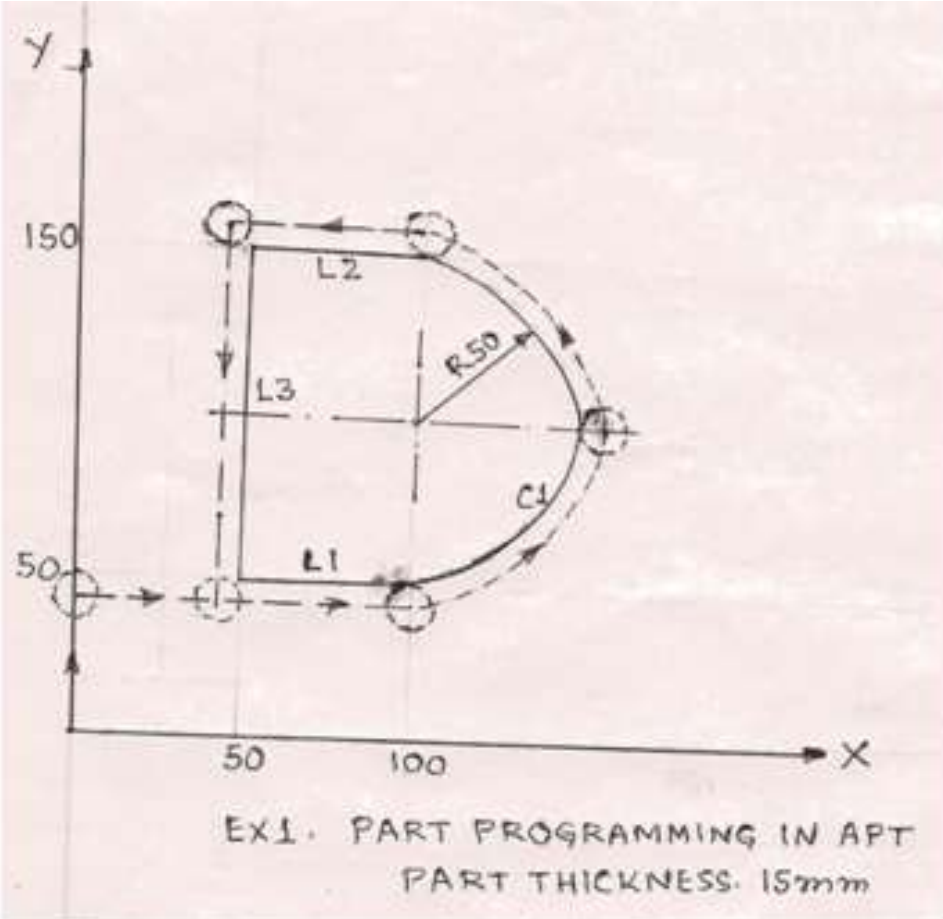
These three surfaces have specific names in APT:

•**Drive surface:** This is the surface that guides the side of the cutter. It is pictured as a plane in our figure.

•**Part surface:** This is the surface, again pictured as a plane, on which the bottom or nose of the tool is guided.

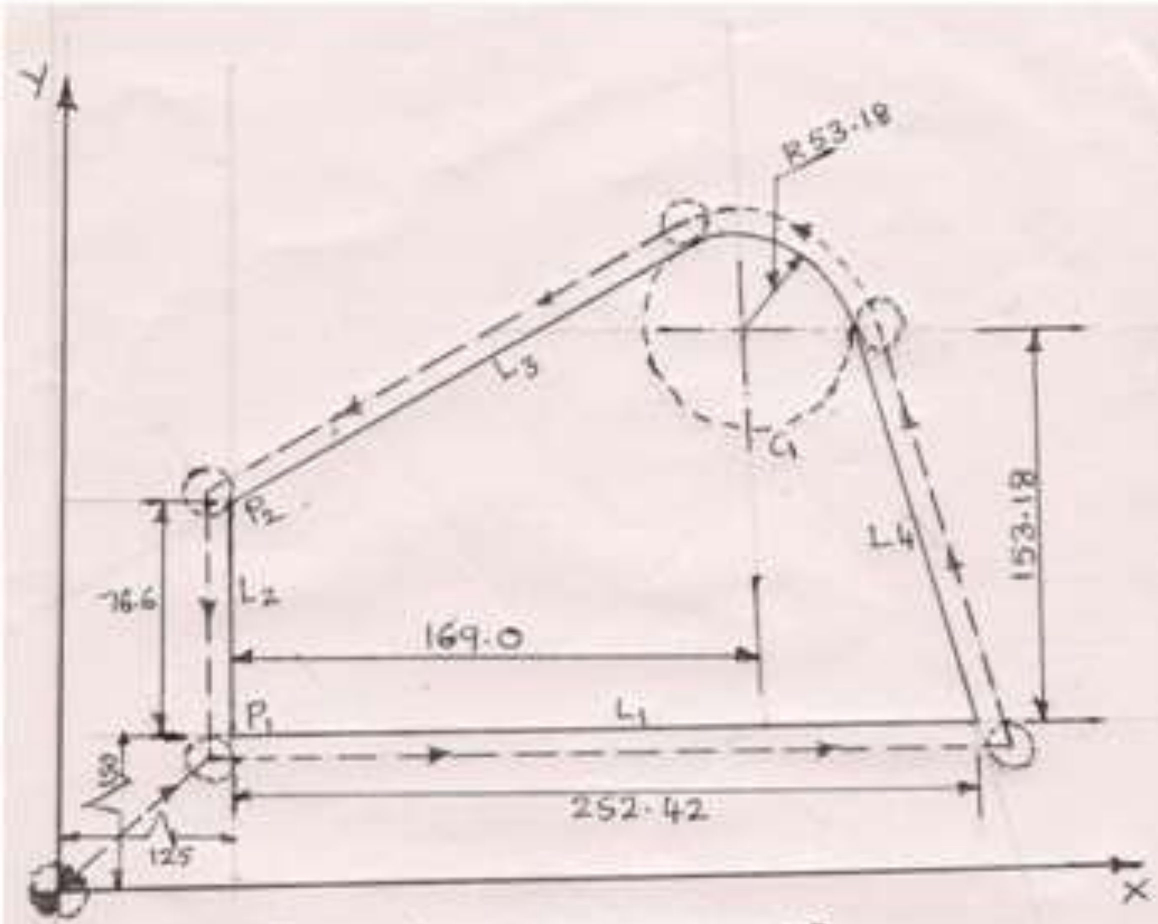
•**Check surface:** This is the surface that stops the forward motion of the tool in the execution of the current command. One might say that the surface "checks" the advance of the tool.

Example 1: APT programming



MACHIN/CNC1 CLPRNT
STPT=POINT/0, 0
L1=LINE/50, 50, 100, 50
L2=LINE/50, 150,100,150
L3=LINE/50, 150, 50,50
C1=CIRCLE/100, 100, RADIUS, 50
P1=POINT/0, 0,-20
P2=POINT/50, 0,-20
P3=POINT/50, 50,-20
PLN=PLANE/P1, P2, P3
CUTTER/10
SPINDL/350

Example 2: APT programming

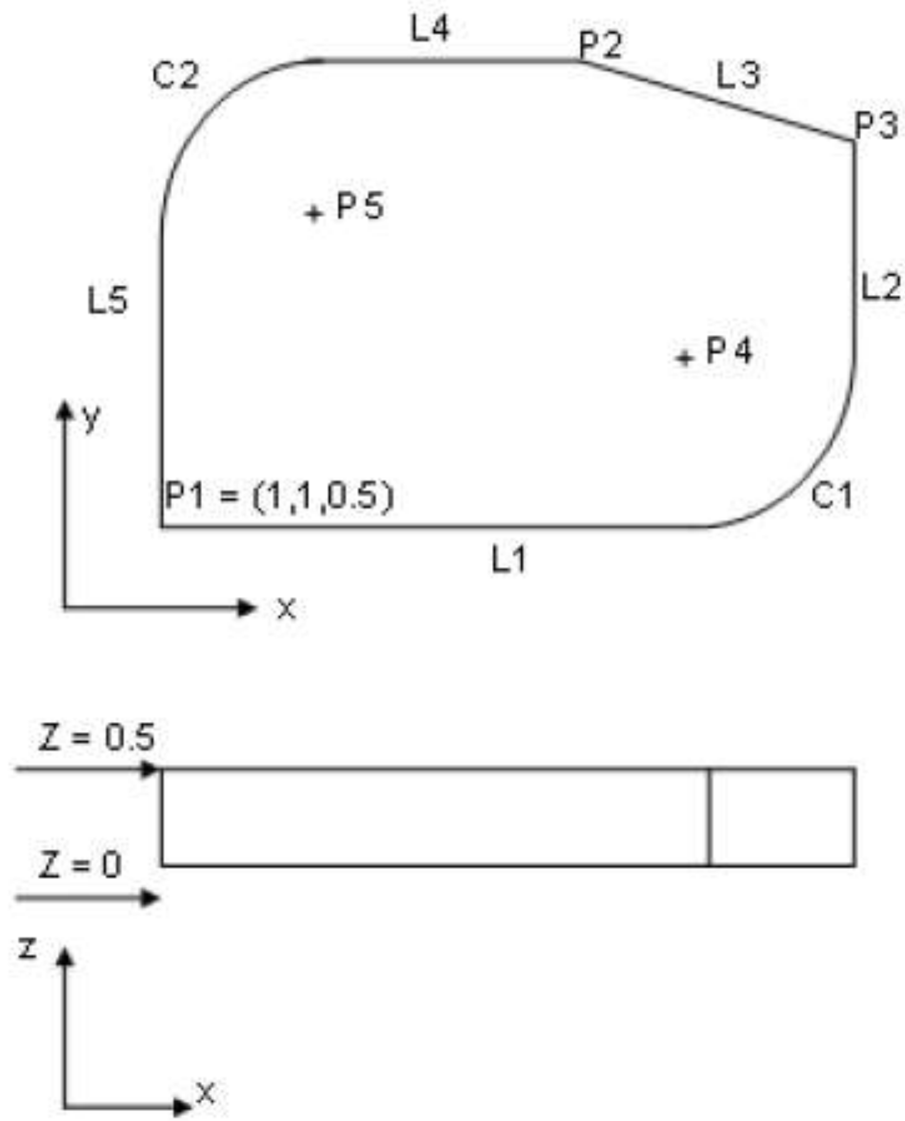


EX2: APT PROGRAMMING
PART THICKNESS → 20mm.

```
MACHIN/TMATIC CLPRNT
NOPOST STPT=POINT/0, 0, 0
P1=POINT/125,150
P2=POINT/125,226.6
P3=POINT/377.42, 150
L1=LINE/P1, P3
L2=LINE/P2, PERPTO, L1
C1=CIRCLE/294,303.18,53.18
L3=LINE/P2, LEFT, TANTO, C1
L4=LINE/P3, RIGHT, TANTO, C1
P4=POINT/0, 0,-25
P5=POINT/50, 0,-25
P6=POINT/50, 25,-25
PL1=PLANE/P4, P5, P6
CUTTER/12
FEDRAT/300
OUTTOL/0.025
SPINDL/800 FROM/STPT
INDIRV/1, 1, 0
GO/TO, L1, TO, L2, TO, PL1
TLRGT, GORGT/L1, PAST, L4
GOLFT/L4, TANTO, C1
GOFWD/C1, TANTO, L3
GOFWD/L3, PAST, L2
GOLFT/L2, PAST, L1
SPINDL/OFF
GOTO/STPT FINI
```

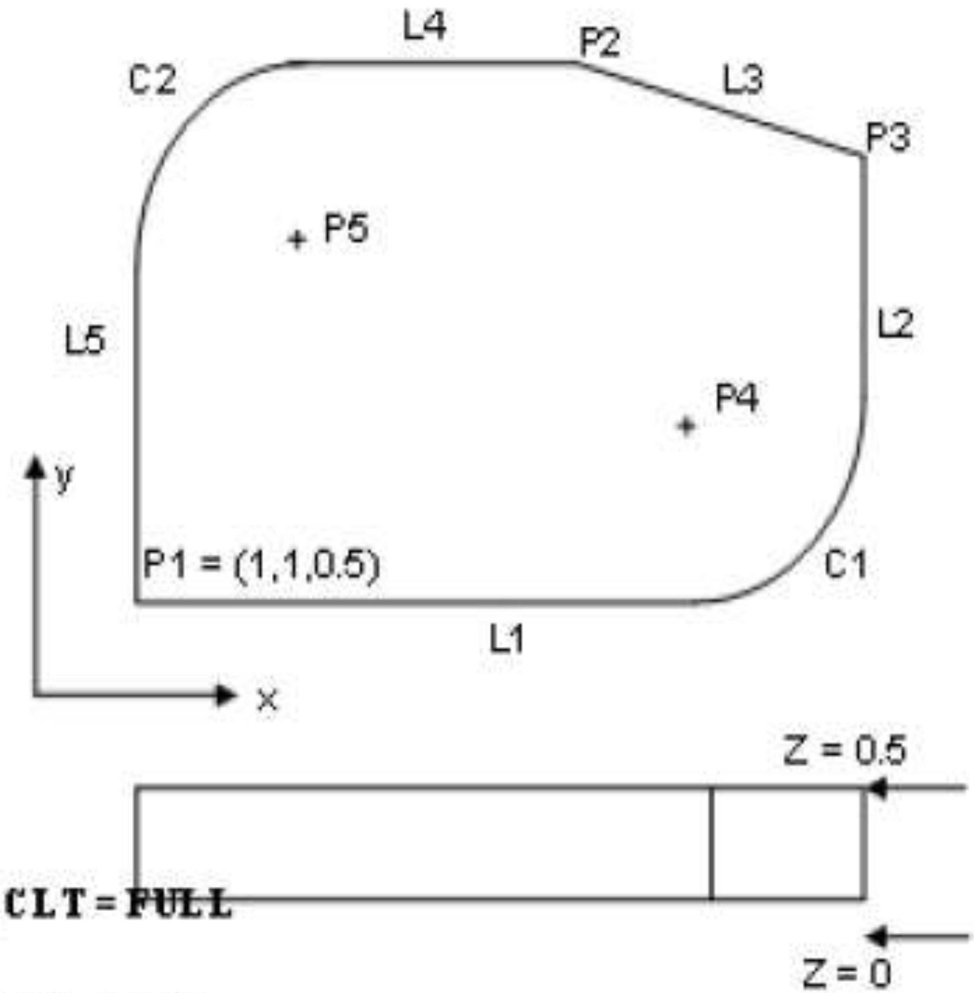
Example 3: APT contouring example

```
PARTNO  P1534
        MACHIN/ MILL, 4
        CLPRINT
        OUTTOL/ 0.0015
P0      = POINT/0, 0, 1.1
P1      = POINT/1, 1, 0.5
P2      = POINT/4, 3.5, 0.5
P3      = POINT/5.85, 2.85, 0.5
PL1     = PLANE/ P1, P2, P3
PL2     = PLANE/ PARLEL, PL1, ZSMALL, 0.5
P4      = POINT/5, 1.85, 0.5
P5      = POINT/2, 2.5, 0.5
C1      = CIRCLE/ CENTER, P4, RADIUS, 0.85
C2      = CIRCLE/ CENTER, P5, RADIUS, 1.0
L1      = LINE/ P1, RIGHT, TANTO, C1
L2      = LINE/ P3, LEFT, TANTO, C1
L3      = LINE/ P2, P3
L4      = LINE/ P2, RIGHT, TANTO, C2
L5      = LINE/ P1, LEFT, TANTO, C2
MILLS   = MACRO/ CUT, SSP, FRT, CLT
        CUTTER/ CUT
```



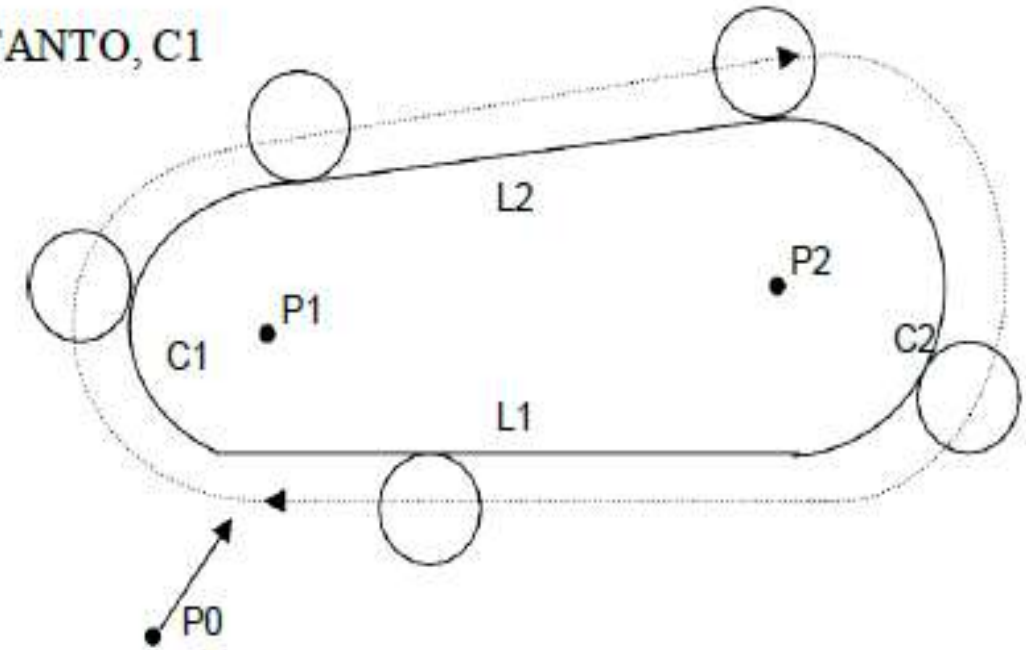
Example 4: APT contouring example

```
FEDRAT/FRT
SPINDL/ SSP
COOLNT/ CLT
FROM / P0
GO/ TO, L1, TO, PL2, ON, L5
GORGT/ L1, TANTO, C1
GOFWD/ C1, TANTO, L2
GOFWD/ L2, PAST, L3
GOLFT/ L3, PAST, L4
GOFWD/ L4, TANTO, C2
GOFWD/ C2, TANTO, L5
GOFWD/ L5, PAST, L1
COOLNT/ OFF
GOTO/ P0
TERMAC
TURRET 4
CALL/ MILLS, CUT= 0.52, SSP = 600, FRT= 3.0, CLT = FULL
TURRET/ 6
CALL/ MILLS, CUT= 0.5, SSP = 900, FRT= 2.0, CLT= FULL
SPINDL/ 0
END
FINI
```



Example 5: APT programming

```
P0   = POINT/ 0, -2, 0
P1   = POINT/ 0.312, 0.312, 0
P2   = POINT/ 4, 1, 0
C1   = CIRCLE/ CENTER, P1, RADIUS, 0.312
C2   = CIRCLE/ CENTER, P2, RADIUS, 1
L2    = LINE/ RIGHT, TANTO, C2, RIGHT,
     TANTO,C1
L1   = LINE/ LEFT, TANTO, C2, LEFT, TANTO, C1
PL1 = PLANE/ P0, P1, P2
MILL = MACRO/ DIA
       FROM/ P0
       GO/TO, L1, TO, PL1,  TO, C2
       GOLFT/ L1, PAST, C1
       GOFWD/ C1, PAST, L2
       GOFWD/ L2, PAST, C2
       GOFWD/ C2, PAST, L1
       GOTO/ P0
       TERMAC
       CALL MILL / DIA = 0.70
       END
       FINI
```



PART-C
AUTOMATION

Automation can be defined as the technology by which a process or procedure is accomplished without human assistance. It is implemented using a program of instructions combined with a control system that executes the instructions. To automate a process, power is required, both to drive the process itself and to operate the program and control system. Although automation is applied in a wide variety of areas, it is most closely associated with the manufacturing industries.

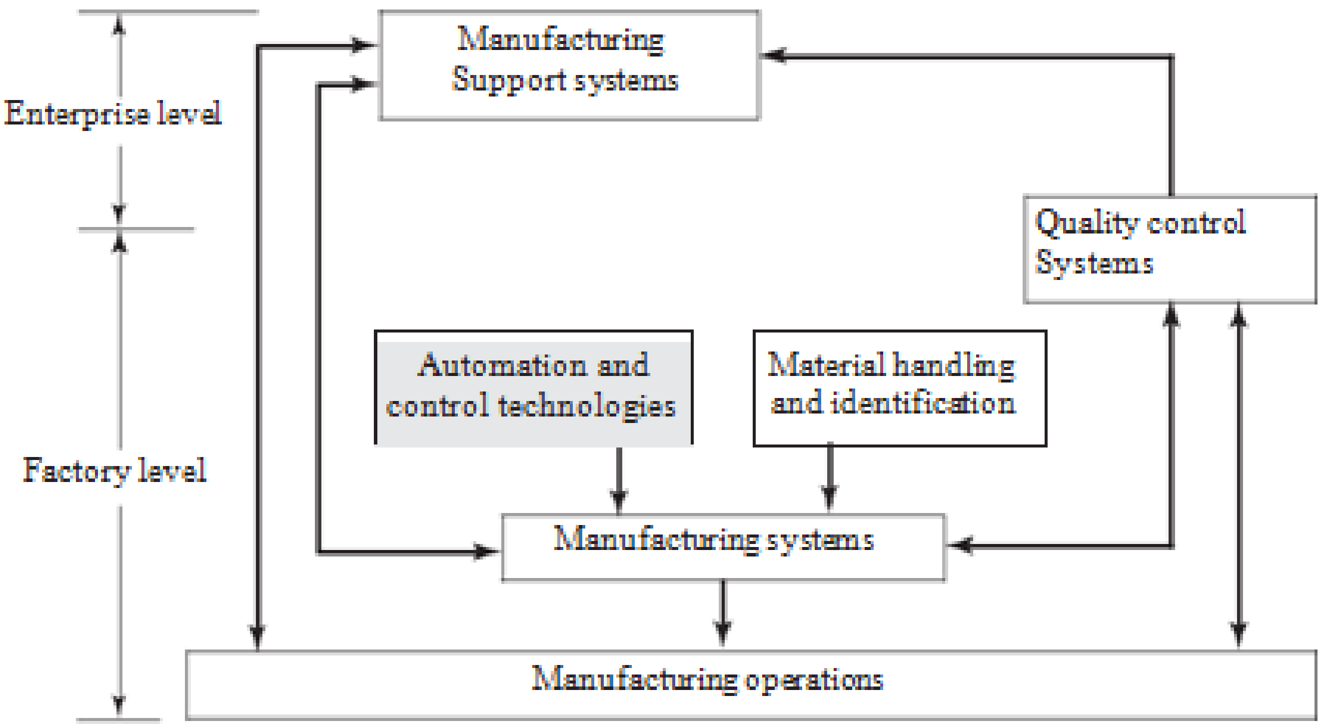


Figure: Automation and control technologies in the production system.

The terms *automation* and *mechanization* are often compared and sometimes confused. ***Mechanization*** refers to the use of machinery (usually powered) to assist or replace human workers in performing physical tasks, but human workers are still required to accomplish the cognitive and sensory elements of the tasks. By contrast, ***automation*** refers to the use of mechanized equipment that performs the physical tasks without the need for oversight by a human worker.

BASIC ELEMENTS OF AN AUTOMATED SYSTEM

An automated system consists of three basic elements:

1. Power to accomplish the process and operate the system,
2. A program of instructions to direct the process,
3. A control system to actuate the instructions.

All systems that qualify as being automated include these three basic elements in one form or another. They are present in the three basic types of automated manufacturing systems: fixed automation, programmable automation, and flexible automation.

•**Power to accomplish the automated process**

An automated system is used to operate some process, and power is required to drive the process as well as the controls. The principal source of power in automated systems is electricity. Electric power has many advantages in automated as well as nonautomated processes:

•Electric power is widely available at moderate cost.

•Electric power can be readily converted to alternative energy forms: Mechanical, Thermal, Light, Acoustic, Hydraulic, and Pneumatic.

•Electric power at low levels can be used to accomplish functions such as Signal Transmission, Information Processing, Data Storage, and Communication.

•Electric energy can be stored in long-life batteries for use in locations where an external source of electrical power is not conveniently available.

Alternative power sources include Fossil Fuels, Atomic, Solar, Water, and Wind. However, their exclusive use is rare in automated systems. In many cases when alternative power sources are used to drive the process itself, electrical power is used for the controls that automate the operation. For example, in casting or heat treatment, the furnace may be heated by fossil fuels, but the control system to regulate temperature and time cycle is electrical. In other cases, the energy from these alternative sources is converted to electric power to operate both the process and its automation.

Power for the process. In production, the term *process* refers to the manufacturing operation that is performed on a work unit.

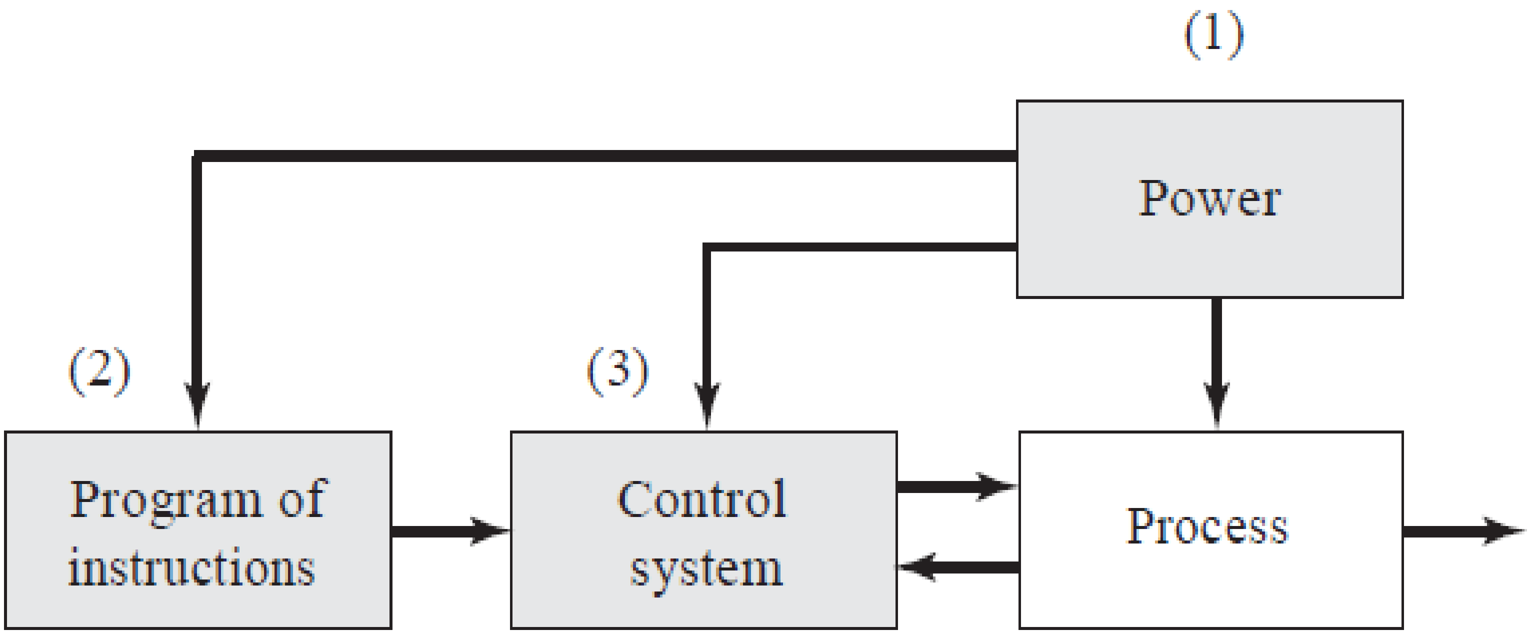


Figure: Elements of an automated system:
(1) power, (2) program of instructions, and (3) control systems.

Process	Power Form	Action Accomplished
Casting	Thermal	Melting the metal before pouring into a mold cavity where solidification occurs.
Electric discharge machining	Electrical	Metal removal is accomplished by a series of discrete electrical discharges between electrode (tool) and work piece. The electric discharges cause very high localized temperatures that melt the metal.
Forging	Mechanical	Metal work part is deformed by opposing dies. Work parts are often heated in advance of deformation, thus thermal power is also required.
Heat-treating	Thermal	Metallic work unit is heated to temperature below melting point to effect micro structural changes.
Injection molding	Thermal and Mechanical	Heat is used to raise temperature of polymer to highly plastic consistency, and mechanical force is used to inject the polymer melt into a mold cavity.
Laser beam cutting Machining	Light and thermal Mechanical	A highly coherent light beam is used to cut material by vaporization and melting. Cutting of metal is accomplished by relative motion between tool and work piece.
Sheet metal punching and blanking	Mechanical	Mechanical power is used to shear metal sheets and plates.
Welding	Thermal (maybe mechanical)	Most welding processes use heat to cause fusion and coalescence of two (or more) metal parts at their contacting surfaces. Some welding processes also apply mechanical pressure.

In addition to driving the manufacturing process itself, power is also required for the following material handling functions:

Loading and unloading the work unit. All of the processes listed in Table are accomplished on discrete parts. These parts must be moved into the proper position and orientation for the process to be performed, and power is required for this transport and placement function. At the conclusion of the process, the work unit must be removed. If the process is completely automated, then some form of mechanized power is used. If the **power for automation.** Above and beyond the basic power requirements for the manufacturing operation, additional power is required for automation. The additional power is used for the following functions:

•***Controller unit.*** Modern industrial controllers are based on digital computers, which require electrical power to read the program of instructions, perform the control calculations, and execute the instructions by transmitting the proper commands to actuating devices.

•***Power to actuate the control signals.*** The commands sent by the controller unit are carried out by means of electromechanical devices, such as switches and motors, called *actuators*. The commands are generally transmitted by means of low-voltage control signals. To accomplish the commands, the actuators require more power, and so the control signals must be amplified to provide the proper power level for the actuating device.

•***Data acquisition and information processing.*** In most control systems, data must be collected from the process and used as input to the control algorithms. In addition, for some processes, it is a legal requirement that records be kept of process performance and/or product quality. These data acquisition and record-keeping functions require power, although in modest amounts.

•**program of Instructions**

The actions performed by an automated process are defined by a program of instructions. Whether the manufacturing operation involves low, medium, or high production, each part or product requires one or more processing steps that are unique to that part or product. These processing steps are performed during a work cycle. A new part is completed at the end of each work cycle. The particular processing steps for the work cycle are specified in a work cycle program, called *part programs* in numerical control. Other process control applications use different names for this type of program.

Work Cycle programs. In the simplest automated processes, the work cycle consists of essentially one step, which is to maintain a single process parameter at a defined level, for example, maintain the temperature of a furnace at a designated value for the duration of a heat treatment cycle. In this case, programming simply involves setting the temperature dial on the furnace.

Work cycle programs are usually much more complicated than in the furnace example described. Following are five categories of work cycle programs, arranged in approximate order of increasing complexity and allowing for more than one process parameter in the program:

•***Set-point control***, in which the process parameter value is constant during the work cycle

•***Logic control***, in which the process parameter value depends on the values of other variables in the process.

•***Sequence control***, in which the value of the process parameter changes as a function of time. The process parameter values can be either discrete or continuously variable. Sequence control, also called *sequencing*,

•***Interactive program***, in which interaction occurs between a human operator and the control system during the work cycle.

•***Intelligent program***, in which the control system exhibits aspects of human intelligence (e.g., logic, decision making, cognition, learning) as a result of the work cycle program.

Most processes involve a work cycle consisting of multiple steps that are repeated with no deviation from one cycle to the next. Most discrete part manufacturing operations are in this category. A typical sequence of steps (simplified) is the following: (1) load the part into the production machine, (2) perform the process, and (3) unload the part. During each step, there are one or more activities that involve changes in one or more process parameters.

A work cycle may include manual steps, in which the operator performs certain activities during the work cycle, and the automated system performs the rest. These are referred to as *semi automated* work cycles. A common example is the loading and unloading of parts by an operator into and from a numerical control machine between machining cycles, while the machine performs the cutting operation under part program control. Initiation of the cutting operation in each cycle is triggered by the operator activating a “start” button after the part has been loaded.

Decision making in the programmed Work Cycle. Each work cycle consisted of the same steps and associated process parameter changes with no variation from one cycle to the next. The program of instructions is repeated each work cycle without deviation. In fact, many automated manufacturing operations require decisions to be made during the programmed work cycle to cope with variations in the cycle. The following summarizes the features of work cycle programs (part programs) used to direct the operations of an automated system:

•***Process parameters.*** How many process parameters must be controlled during each step? Are the process parameters continuous or discrete? Do they change during the step, for example, a positioning system whose axis values change during the processing step?
•***Number of steps in work cycle***. How many distinct steps or work elements are included in the work cycle? A general sequence in discrete production operations is (1) load, (2), process, (3) unload, but the process may include multiple steps.
•***Manual participation in the work cycle***. Is a human worker required to perform certain steps in the work cycle, such as loading and unloading a production machine, or is the work cycle fully automated?
•***Operator interaction.*** For example, is the operator required to enter processing data for each work cycle?
•***Variations in part or product styles***. Are the work units identical each cycle, as in mass production (fixed automation) or batch production (programmable automation), or are different part or product styles processed each cycle (flexible automation)?
•***Variations in starting work units***. Variations can occur in starting dimensions or materials. If the variations are significant, some adjustments may be required during the work cycle.

•A control system to actuate the instructions

The control element of the automated system executes the program of instructions. The control system causes the process to accomplish its defined function, which is to perform some manufacturing operation. The controls in an automated system can be either closed loop or open loop.

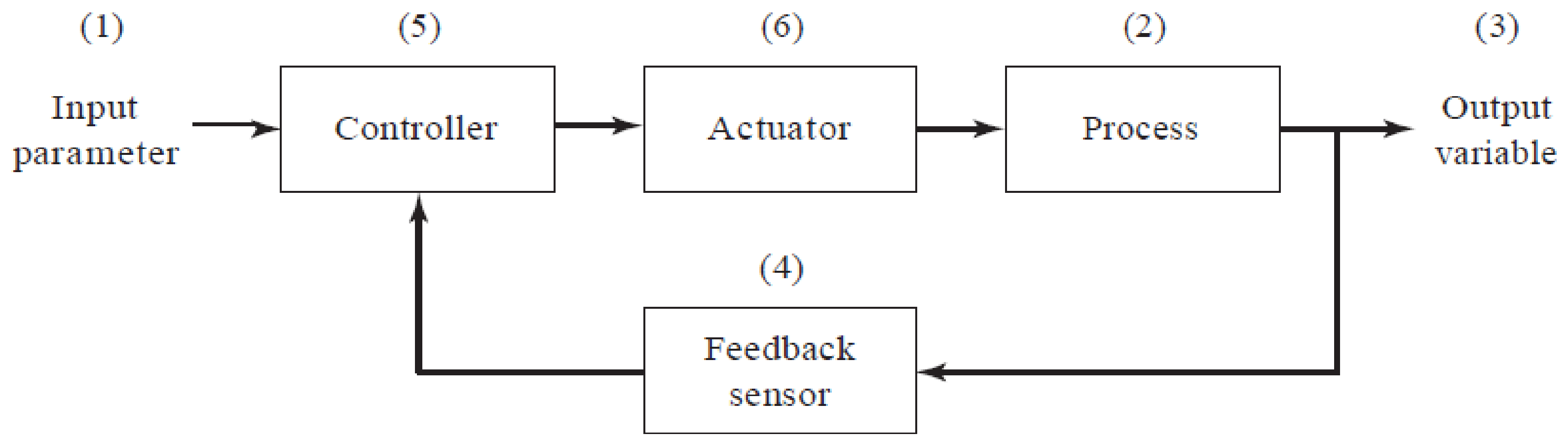


Figure: A feedback control system.

A ***closed-loop control system***, also known as a *feedback control system*, is one in which the output variable is compared with an input parameter, and any difference between the two is used to drive the output into agreement with the input.

As shown in Figure, a closed-loop control system consists of six basic elements: (1) input parameter, (2) process, (3) output variable, (4) feedback sensor, (5) controller, and (6) actuator. The input parameter (i.e., set point) represents the desired value of the output. In a home temperature control system, the set point is the desired thermostat setting. The process is the operation or function being controlled. In particular, it is the output variable that is being controlled in the loop.

In the process of interest is usually a manufacturing operation, and the output variable is some process variable, perhaps a critical performance measure in the process, such as temperature or force or flow rate. A sensor is used to measure the output variable and close the loop between input and output. Sensors perform the feedback function in a closed-loop control system. The controller compares the output with the input and makes the required adjustment in the process to reduce the difference between them. The adjustment is accomplished using one or more actuators, which are the hardware devices that physically carry out the control actions, such as electric motors or flow valves. It should be mentioned that Figure shows only one loop. Most industrial processes require multiple loops, one for each process variable that must be controlled.

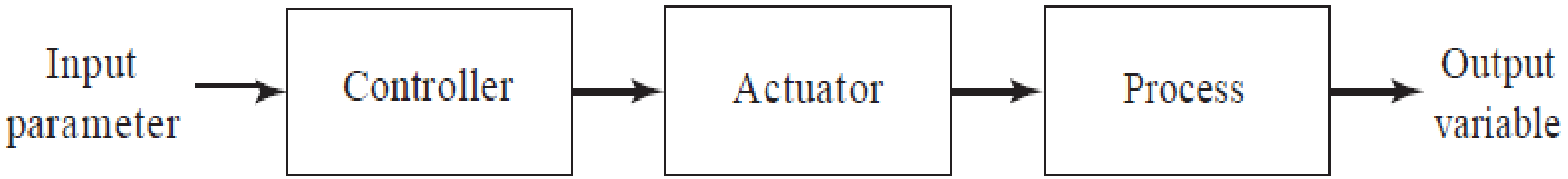


Figure: An open-loop control system.

In contrast to a closed-loop control system, an ***open-loop control system*** operates without the feedback loop, as in Figure. In this case, the controls operate without measuring the output variable, so no comparison is made between the actual value of the output and the desired input parameter. The controller relies on an accurate model of the effect of its actuator on the process variable. With an open-loop system, there is always the risk that the actuator will not have the intended effect on the process, and that is the disadvantage of an open-loop system. Its advantage is that it is generally simpler and less expensive than a closed-loop system. Open-loop systems are usually appropriate when the following conditions apply: (1) the actions performed by the control system are simple, (2) the actuating function is very reliable, and (3) any reaction forces opposing the actuator are small enough to have no effect on the actuation. If these characteristics are not applicable, then a closed-loop control system may be more appropriate.

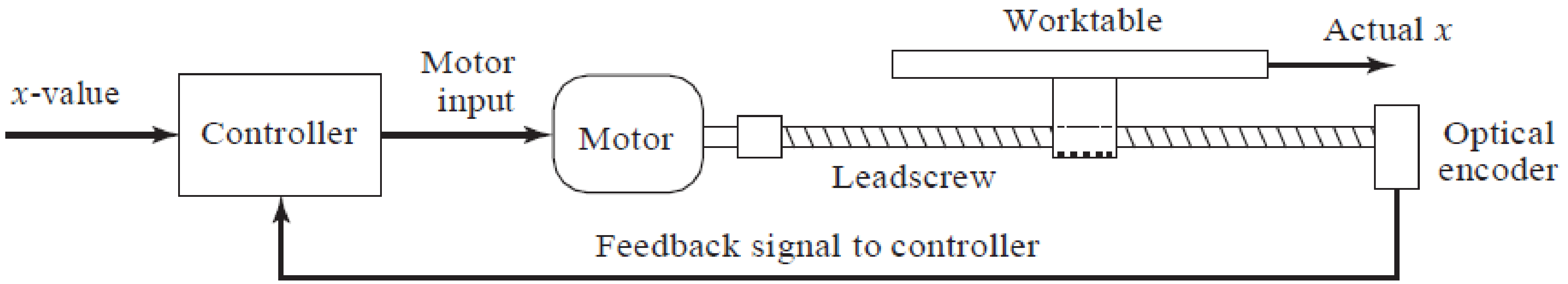


Figure: positioning system consisting of a lead screw driven by a dc servomotor.

Figure illustrates the case of a closed-loop positioning system. In operation, the system is directed to move the worktable to a specified location as defined by a coordinate value in a Cartesian (or other) coordinate system. Most positioning systems have at least two axes (e.g., an *x–y* positioning table) with a control system for each axis, but the diagram only illustrates one of these axes. A DC servomotor connected to a lead screw is a common actuator for each axis. A signal indicating the coordinate value (e.g., *x*-value) is sent from the controller to the motor that drives the lead screw, whose rotation is converted into linear motion of the positioning table. The actual *x*-position is measured by a feedback sensor (e.g., an optical encoder). As the table moves closer to the desired *x*-coordinate value, the difference between the actual *x*-position and the input *x*-value decreases. The controller continues to drive the motor until the actual table position corresponds to the input position value.

For the open-loop case, the diagram for the positioning system would be similar to the preceding, except that no feedback loop is present and a **stepper motor would be used in place of the dc servomotor**. A stepper motor is designed to rotate a precise fraction of a turn for each pulse received from the controller. Since the motor shaft is connected to the lead screw, and the lead screw drives the worktable, each pulse converts into a small constant linear movement of the table. To move the table a desired distance, the number of pulses corresponding to that distance is sent to the motor. Given the proper application, whose characteristics match the preceding list of operating conditions, an open-loop positioning system works with high reliability.

ADVANCED AUTOMATION FUNCTIONS

In addition to executing work cycle programs, an automated system may be capable of executing advanced functions that are not specific to a particular work unit. In general, the functions are concerned with enhancing the safety and performance of the equipment. Advanced automation functions include the following: (1) safety monitoring, (2) maintenance and repair diagnostics, and (3) error detection and recovery.

(a) Safety Monitoring

It is important that the automated system be designed to operate safely when workers are in attendance. In addition, it is essential that the automated system carry out its process in a way that is not self-destructive. Thus, there are two reasons for providing an automated system with a safety monitoring capability: (1) to protect human workers in the vicinity of the system, and (2) to protect the equipment comprising the system.

Safety monitoring means more than the conventional safety measures taken in a manufacturing operation, such as protective shields around the operation or the kinds of manual devices that might be utilized by human workers, such as emergency stop buttons. Safety monitoring in an automated system involves the use of sensors to track the system's operation and identify conditions and events that are unsafe or potentially unsafe. The safety monitoring system is programmed to respond to unsafe conditions in some appropriate way. Possible responses to various hazards include one or more of the following: (1) completely stopping the automated system, (2) sounding an alarm, (3) reducing the operating speed of the process, and (4) taking corrective actions to recover from the safety violation.

The following list suggests some of the possible sensors and their applications for safety monitoring:

(1)Limit switches to detect proper positioning of a part in a work holding device so that the processing cycle can begin.

(2)Photoelectric sensors triggered by the interruption of a light beam; this could be used to indicate that a part is in the proper position or to detect the presence of a human intruder in the work cell.

(3)Temperature sensors to indicate that a metal work part is hot enough to proceed with a hot forging operation. If the work part is not sufficiently heated, then the metal's ductility might be too low, and the forging dies might be damaged during the operation.

(4)Heat or smoke detectors to sense fire hazards.

(5)Pressure-sensitive floor pads to detect human intruders in the work cell.

(6)Machine vision systems to perform surveillance of the automated system and its surroundings.

(b) Maintenance and repair Diagnostics

Modern automated production systems are becoming increasingly complex and sophisticated, complicating the problem of maintaining and repairing them. Maintenance and repair diagnostics refers to the capabilities of an automated system to assist in identifying the source of potential or actual malfunctions and failures of the system. Three modes of operation are typical of a modern maintenance and repair diagnostics subsystem:

•***Status monitoring***. In the status monitoring mode, the diagnostic subsystem monitors and records the status of key sensors and parameters of the system during normal operation. On request, the diagnostics subsystem can display any of these values and provide an interpretation of current system status, perhaps warning of an imminent failure.

•***Failure diagnostics***. The failure diagnostics mode is bring into notification when a malfunction or failure occurs. Its purpose is to interpret the current values of the monitored variables and to analyze the recorded values preceding the failure so that its cause can be identified.

•***Recommendation of repair procedure***. In the third mode of operation, the subsystem recommends to the repair crew the steps that should be taken to effect repairs. Methods for developing the recommendations are sometimes based on the use of expert systems in which the collective judgments of many repair experts are pooled and incorporated into a computer program that uses artificial intelligence techniques.

(c) Error Detection and recovery

In the operation of any automated system, there are hardware malfunctions and unexpected events. These events can result in costly delays and loss of production until the problem has been corrected and regular operation is restored. Traditionally, equipment malfunctions are corrected by human workers, perhaps with the aid of maintenance and repair diagnostics subroutine. With the increased use of computer control for manufacturing processes, there is a trend toward using the control computer not only to diagnose the malfunctions but also to automatically take the necessary corrective action to restore the system to normal operation. The term *error detection and recovery* is used when the computer performs these functions.

Error Detection: The error detection step uses the automated system's available sensors to determine when a deviation or malfunction has occurred, interpret the sensor signal(s), and classify the error. Design of the error detection subsystem must begin with a systematic listing of all possible errors that can occur during system operation. The errors in a manufacturing process tend to be very application-specific. They must be anticipated in advance in order to select sensors that will enable their detection.

In analyzing a given production operation, the possible errors can be classified into one of three general categories:

Random errors: Random errors occur as a result of the normal stochastic nature of the process. These errors occur when the process is in statistical control. Large variations in part dimensions, even when the production process is in statistical control, can cause problems in downstream operations. By detecting these deviations on a part-by-part basis, corrective action can be taken in subsequent operations.

Systematic errors: Systematic errors are those that result from some assignable cause such as a change in raw material or drift in an equipment setting. These errors usually cause the product to deviate from specifications so as to be of unacceptable quality.

Aberrations: Results from either an equipment failure or a human mistake. Examples of equipment failures include fracture of a mechanical shear pin, burst in a hydraulic line, rupture of a pressure vessel, and sudden failure of a cutting tool. Examples of human mistakes include errors in the control program, improper fixture setups, and substitution of the wrong raw materials.

The two main design problems in error detection are (1) anticipating all of the possible errors that can occur in a given process, and (2) specifying the appropriate sensor systems and associated interpretive software so that the system is capable of recognizing each error. Solving the first problem requires a systematic evaluation of the possibilities under each of the three error classifications. If the error has not been anticipated, then the error detection subsystem cannot detect and identify it.

Error recovery: Error recovery is concerned with applying the necessary corrective action to overcome the error and bring the system back to normal operation. The problem of designing an error recovery system focuses on devising appropriate strategies and procedures that will either correct or compensate for the errors that can occur in the process. Generally, a specific recovery strategy and procedure must be designed for each different error. The types of strategies can be classified as follows:

Make adjustments at the end of the current work cycle. When the current work cycle is completed, the part program branches to a corrective action subroutine specifically designed for the detected error, executes the subroutine, and then returns to the work cycle program. This action reflects a low level of urgency and is most commonly associated with random errors in the process.

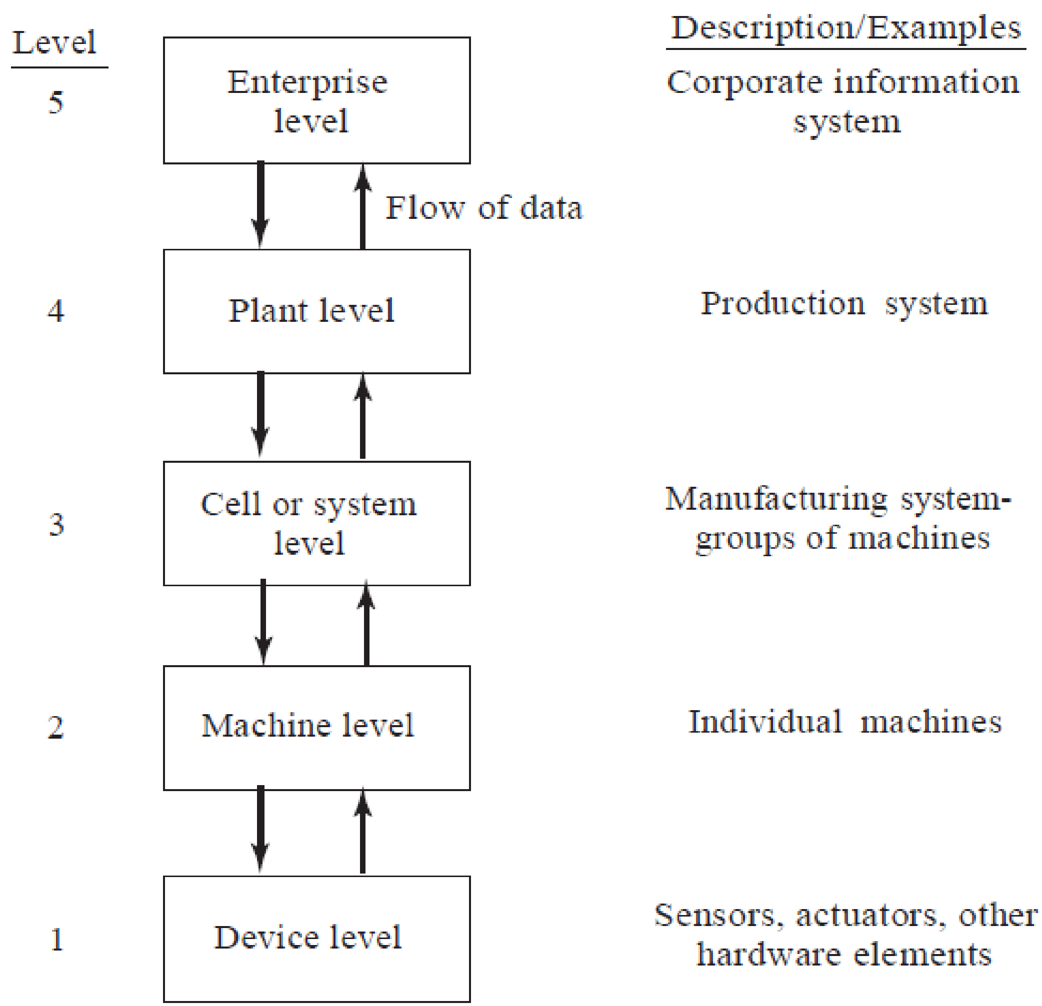
Make adjustments during the current cycle. This generally indicates a higher level of urgency than the preceding type. In this case, the action to correct or compensate for the detected error is initiated as soon as it is detected. However, the designated corrective action must be possible to accomplish while the work cycle is still being executed. If that is not possible, then the process must be stopped.

Stop the process to invoke corrective action. In this case, the deviation or malfunction requires that the work cycle be suspended during corrective action. It is assumed that the system is capable of automatically recovering from the error without human assistance. At the end of the corrective action, the regular work cycle is continued.

Stop the process and call for help. In this case, the error cannot be resolved through automated recovery procedures. This situation arises because (1) the automated cell is not enabled to correct the problem or (2) the error cannot be classified into the predefined list of errors. In either case, human assistance is required to correct the problem and restore the system to fully automated operation.

LEVELS OF AUTOMATION

Automated systems can be applied to various levels of factory operations. One normally associates automation with the individual production machines. However, the production machine itself is made up of subsystems that may themselves be automated. For the purposes of this, five levels of automation can be identified, and their ladder is represented in Figure.



•***Device level.*** This is the lowest level in the automation hierarchy. It includes the actuators, sensors, and other hardware components that comprise the machine level. The devices are combined into the individual control loops of the machine, for example, the feedback control loop for one axis of a CNC machine or one joint of an industrial robot.

•***Machine level.*** Hardware at the device level is assembled into individual machines. Examples include CNC machine tools and similar production equipment, industrial robots, powered conveyors, and automated guided vehicles. Control functions at this level include performing the sequence of steps in the program of instructions in the correct order and making sure that each step is properly executed.

•***Cell or system level.*** This is the manufacturing cell or system level, which operates under instructions from the plant level. A manufacturing cell or system is a group of machines or workstations connected and supported by a material handling system, computer, and other equipment appropriate to the manufacturing process. Production lines are included in this level. Functions include part dispatching and machine loading, coordination among machines and material handling system, and collecting and evaluating inspection data.

•***Plant level.*** This is the factory or production systems level. It receives instructions from the corporate information system and translates them into operational plans for production. Likely functions include order processing, process planning, inventory control, purchasing, material requirements planning, shop floor control, and quality control.

•***Enterprise level.*** This is the highest level, consisting of the corporate information system. It is concerned with all of the functions necessary to manage the company: marketing and sales, accounting, design, research, aggregate planning, and master production scheduling. The corporate information system is usually managed using Enterprise Resource Planning.

Part-d

CONTROL TECHNOLOGIES IN AUTOMATION

Industrial control is defined as the automatic regulation of unit operations and their associated equipment, as well as the integration and coordination of the unit operations in the larger production system.

LEVELS OF AUTOMATION IN THE TWO INDUSTRIES

The levels of automation seen in the low and intermediate levels. At the device level, there are differences in the types of **actuators and sensors** used industries are in the two industry categories, simply because the processes and equipment are different. In the **process industries**, the devices are used mostly for the control loops in chemical, thermal, or similar processing operations, whereas in **discrete manufacturing**, the devices control the mechanical actions of machines.

At level 2, the difference is that **unit operations** are controlled in the process industries, and **machines** are controlled in discrete manufacturing operations.

At level 3, the difference is between control of interconnected unit processing operations and interconnected machines. At the upper levels (plant and enterprise), the control issues are similar, allowing for the fact that the products and processes are different.

VARIABLES AND PARAMETERS IN THE TWO INDUSTRIES

The distinction between process industries and discrete manufacturing industries extends to the variables and parameters that characterize their respective production operations. The **variables** are defined as outputs of the process and **parameters** are defined as inputs to the process.

In the process industries, the variables and parameters of interest tend to be continuous, whereas in discrete manufacturing, they tend to be discrete. The differences are explained with reference to Figure.

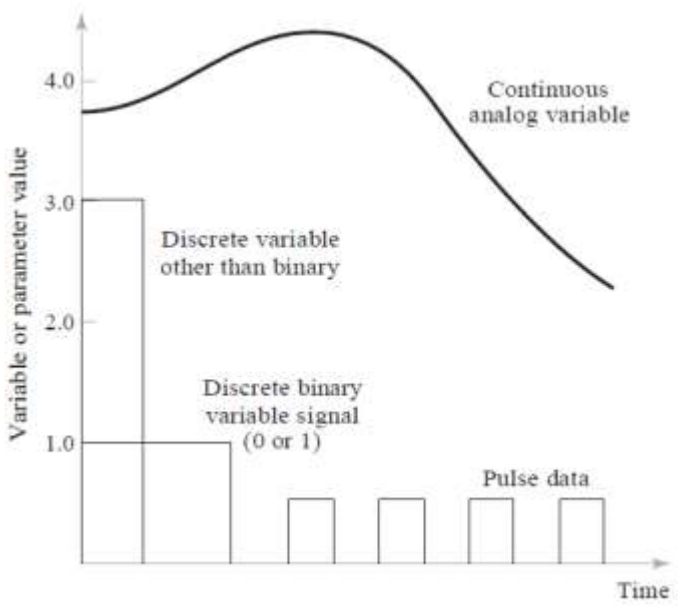


Figure: Continuous and discrete variables and parameters in manufacturing operations.

A ***continuous variable*** (or parameter) is one that is uninterrupted as time proceeds, at least during the manufacturing operation. A continuous variable is generally considered to be ***analog***, which means it can take on any value within a certain range. The variable is not restricted to a discrete set of values. Production operations in both the process industries and discrete parts manufacturing are characterized by continuous variables. Examples include force, temperature, flow rate, pressure, and velocity. All of these variables are continuous over time during the process, and they can take on any of an infinite number of possible values within a certain practical range.

A ***discrete variable*** (or parameter) is one that can take on only certain values within a given range. The most common type of discrete variable is ***binary***, meaning it can take on either of two possible values, ON or OFF, open or closed, and so on. Examples of discrete binary variables and parameters in manufacturing include limit switch open or closed, motor on or off, and work part present or not present in a fixture. Not all discrete variables (and parameters) are binary. Other possibilities are variables that can take on more than two possible values but less than an infinite number, that is, ***discrete other than binary***. Examples include daily piece counts in a production operation and the display of a digital tachometer. A special form of discrete variable is ***pulse data***, which consist of a series of pulses (called a *pulse train*) as shown in Figure. As a discrete variable, a pulse train might be used to indicate piece counts, for example, parts passing on a conveyor activate a photocell to produce a pulse for each part detected. As a process parameter, a pulse train might be used to drive a stepper motor.

PROCESS INDUSTRIES VERSUS DISCRETE MANUFACTURING INDUSTRIES

Industries and their production operations were divided into two basic categories: (1) process industries and (2) discrete manufacturing industries. Process industries perform their production operations on amounts of materials, because the materials tend to be liquids, gases, powders, and similar materials, whereas discrete manufacturing industries perform their operations on quantities of materials, because the materials tend to be discrete parts and products. The kinds of unit operations performed on the materials are different in the two industry categories.

Table: Typical Unit Operations in the Process Industries and Discrete Manufacturing Industries

Process Industries	Discrete Manufacturing Industries
Chemical reactions	Casting
Comminution	Forging
Chemical vapor deposition	Extrusion
Distillation	Machining
Mixing and blending of ingredients	Plastic molding
Separation of ingredients	Sheet metal stamping

Table: Levels of Automation in the Process Industries and Discrete Manufacturing Industries

Level	Process Industries	Discrete Manufacturing Industries
5	Enterprise level management information system, strategic planning, high-level management of enterprise	Enterprise level management information system, strategic planning, high-level management of enterprise
4	Plant level scheduling, tracking materials, equipment monitoring	Plant or factory level scheduling, tracking work-in-process, routing parts through machines, machine utilization
3	Supervisory control level control and coordination of several interconnected unit operations that make up the total process	Manufacturing cell or system level control and coordination of groups of machines and supporting equipment working in coordination, including material handling equipment
2	Regulatory control level control of unit operations	Machine level production machines and workstations for discrete product manufacture
1	Device level sensors and actuators comprising the basic control loops for unit operations	Device level sensors and actuators to accomplish control of machine actions

Continuous Versus discrete control

Industrial control systems used in the process industries tend to emphasize the control of continuous variables and parameters. By contrast, the manufacturing industries produce discrete parts and products, and their controllers tend to emphasize discrete variables and parameters. Just as there are two basic types of variables and parameters that characterize production operations, there are also two basic types of control: (1) ***continuous control***, in which the variables and parameters are continuous and analog; and (2) ***discrete control***, in which the variables and parameters are discrete, mostly binary discrete. Some of the differences between continuous control and discrete control are summarized in Table.

In reality, most operations in the process and discrete manufacturing industries include both continuous and discrete variables and parameters. Consequently, many industrial controllers are designed with the capability to receive, operate on, and transmit both types of signals and data.

Table: Comparison between Continuous Control and Discrete Control

Comparison Factor	Continuous Control in Process Industries	Discrete Control in Discrete Manufacturing Industries
Typical measures of product output	Weight measures, liquid volume measures, solid volume measures	Number of parts, number of products
Typical quality measures	Consistency, concentration of solution, absence of contaminants, conformance to specification	Dimensions, surface finish, appearance, absence of defects, product reliability
Typical variables and parameters	Temperature, volume flow rate, pressure	Position, velocity, acceleration, force
Typical sensors	Flow meters, thermocouples, pressure sensors	Limit switches, photoelectric sensors, strain gages, piezoelectric sensors
Typical actuators	Valves, heaters, pumps	Switches, motors, pistons
Typical process time constants	Seconds, minutes, hours	Less than a second

Continuous Control systems

In continuous control, the usual objective is to maintain the value of an output variable at a desired level, similar to the operation of a feedback control system. However, most continuous processes in the practical world consist of many separate feed-back loops, all of which have to be controlled and coordinated to maintain the output variable at the desired value.

There are several ways to achieve the control objective in a continuous process control system. In the following paragraphs, the most prominent categories are surveyed.

Regulatory Control: In regulatory control, the objective is to maintain process performance at a certain level or within a given tolerance band of that level. This is appropriate, for example, when the performance attribute is some measure of product quality, and it is important to keep the quality at the specified level or within a specified range. In many applications, the performance measure of the process, sometimes called the *index of performance*, must be calculated based on several output variables of the process. Except for this feature, regulatory control is to the overall process what feedback control is to an individual control loop in the process, as suggested by Figure.

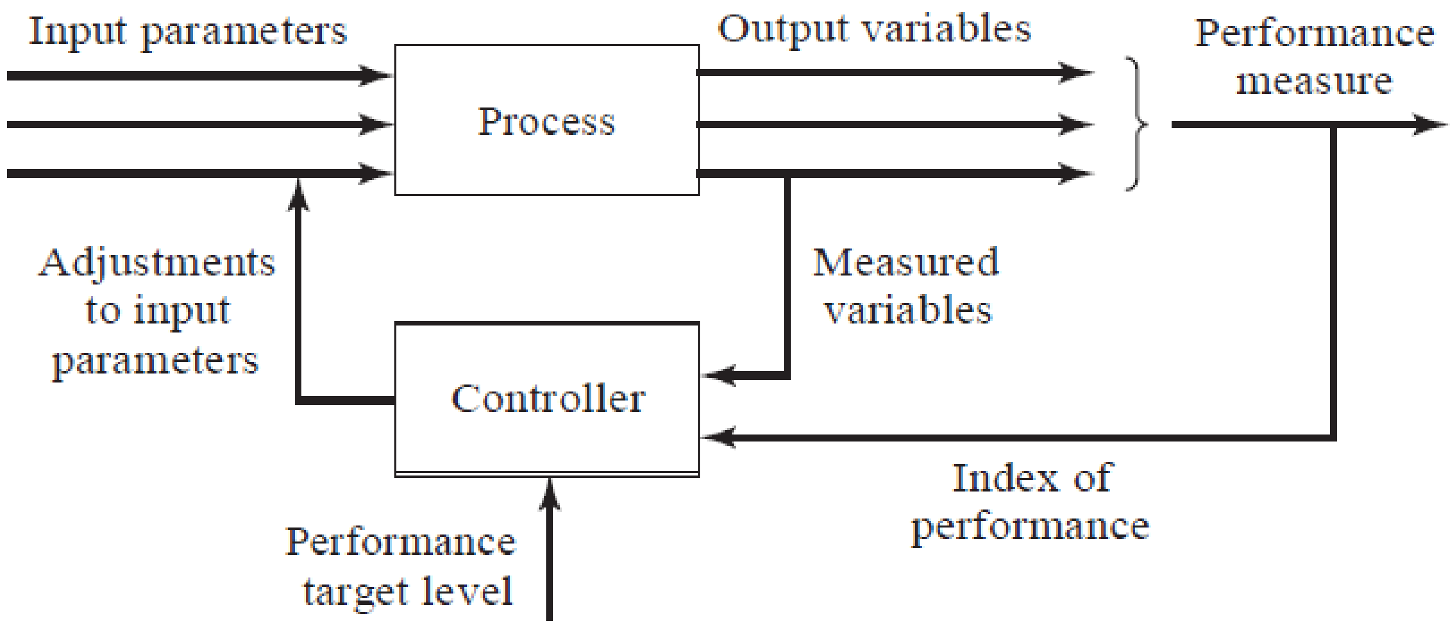


Figure: Regulatory control.

The trouble with regulatory control is that compensating action is taken only after a disturbance has affected the process output. An error must be present for any control action to be taken. The presence of an error means that the output of the process is different from the desired value.

The following control mode, feed forward control, addresses this issue.

Feed forward Control. The strategy in feed forward control is to predict the effect of disturbances that will disturb the process by sensing them and compensating for them before they affect the process. As shown in Figure, the feed forward control elements sense the presence of a disturbance and take corrective action by adjusting a process parameter that compensates for any effect the disturbance will have on the process. In the ideal case, the compensation is completely effective.

However, complete compensation is doubtful because of delays and/or imperfections in the feedback measurements, actuator operations, and control algorithms, so feed forward control is usually combined with feedback control, as shown in the figure. Regulatory and feed-forward control is more closely associated with the process industries than with discrete product manufacturing.

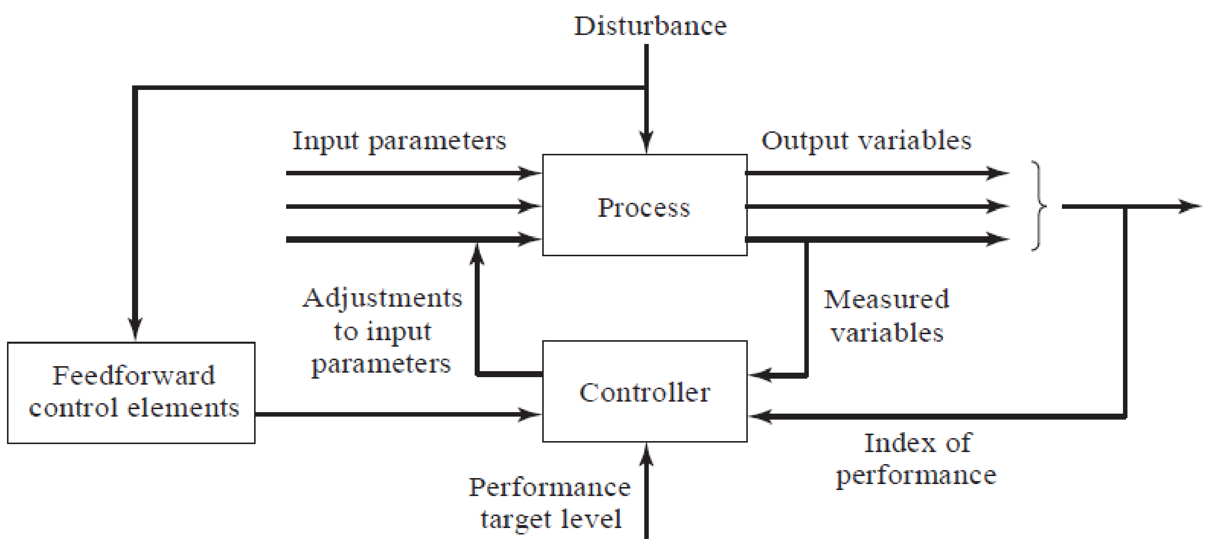


Figure: Feed forward control, combined with feedback control.

Steady-state optimization. This term refers to a class of optimization techniques in which the process exhibits the following characteristics: (1) there is a well -defined index of performance, such as product cost, production rate, or process yield; (2) the relationship between the process variables and the index of performance is known; and (3) the values of the system parameters that optimize the index of performance can be determined mathematically. When these characteristics apply, the control algorithm is designed to make adjustments in the process parameters to drive the process toward the optimal state. The control system is open loop, as seen in Figure. Several mathematical techniques are available for solving steady-state optimal control problems, including differential calculus, calculus of variations, and various mathematical programming methods.

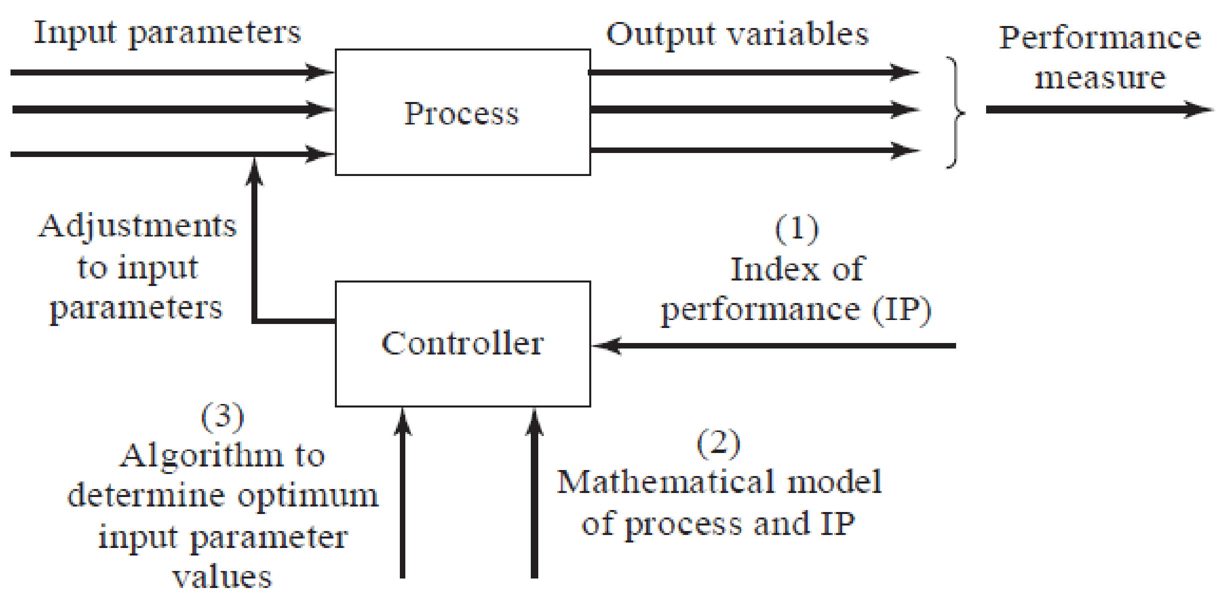


Figure: Steady-state (open loop) optimal control.

Adaptive Control: Steady-state optimal control operates as an open-loop system. It works successfully when there are no disturbances that invalidate the known relation - ship between process parameters and process performance. When such disturbances are present in the application, a self-correcting form of optimal control can be used, called *adaptive control*.

Adaptive control combines feedback control and optimal control by measuring the relevant process variables during operation (as in feedback control) and using a control algorithm that attempts to optimize some index of performance (as in optimal control).

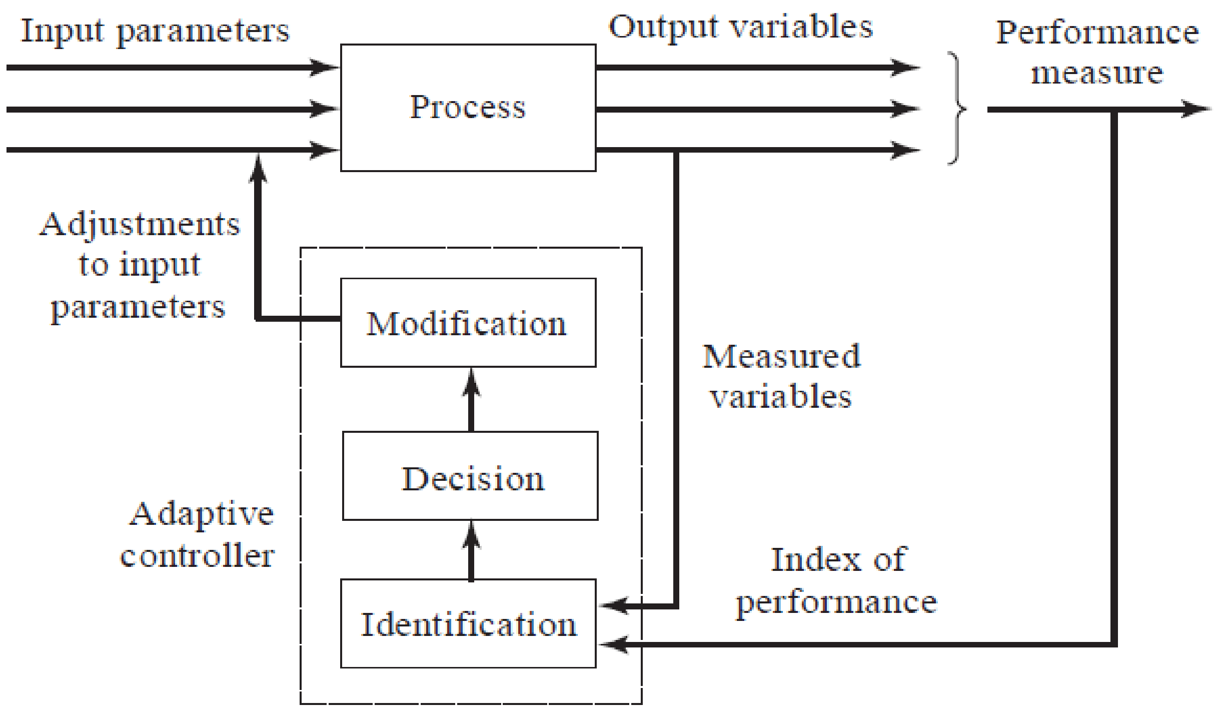


Figure 5.5 Configuration of an adaptive control system.

Adaptive control is distinguished from feedback control and steady-state optimal control by its unique capability to cope with a time-varying environment. It is not unusual for a system to operate in an environment those changes over time and for the changes to have a potential effect on system performance. If the internal parameters or mechanisms of the system are fixed, as in feedback control or optimal control, the system may perform quite differently in one type of environment than in another. An adaptive control system is designed to compensate for its changing environment by monitoring its own performance and altering some aspect of its control mechanism to achieve optimal or near-optimal performance. In a production process, the "time-varying environment" consists of the variations in processing variables, raw materials, tooling, atmospheric conditions, and the like, any of which may affect performance.

The general configuration of an adaptive control system is illustrated in Figure. To evaluate its performance and respond accordingly, an adaptive control system per-forms three functions, as shown in the figure:

•***Identification.*** In this function, the current value of the index of performance of the system is determined, based on measurements collected from the process. Because the environment changes over time, system performance also changes. Accordingly, the identification function must be accomplished more or less continuously over time during system operation.

•***Decision***. Once system performance is determined, the next function decides what changes should be made to improve performance. The decision function is implemented by means of the adaptive system's programmed algorithm. Depending on this algorithm, the decision may be to change one or more input parameters, alter some of the internal parameters of the controller, or make other changes.

•***Modification.*** The third function is to implement the decision. Whereas decision is a logic function, modification is concerned with physical changes in the system. It involves hardware rather than software. In modification, the system parameters or process inputs are altered using available actuators to drive the system toward a more optimal state.

On-Line search strategies. On-line search strategies can be used to address a special class of adaptive control problem in which the decision function cannot be sufficiently defined; that is, the relationship between the input parameters and the index of performance is not known, or not known well enough to use adaptive control as previously described. Therefore, it is not possible to decide on the changes in the internal parameters of the system to produce the desired performance improvement. Instead, experiments must be performed on the process. Small systematic changes are made in the input parameters of the process to observe the effect of these changes on the output variables. Based on the results of these experiments, larger changes are made in the input parameters to drive the process toward improved performance.

Online search strategies include a variety of schemes to explore the effects of changes in process parameters, ranging from trial-and-error techniques to gradient methods. All of the schemes attempt to determine which input parameters cause the greatest positive effect on the index of performance and then move the process in that direction.

There is little evidence that on-line search techniques are used much in discrete parts manufacturing. Their applications are more common in the continuous process industries.

Other specialized techniques: Other specialized techniques include strategies that are currently evolving in control theory and computer science. Examples include Learning Systems, Expert Systems, neural networks, and other artificial intelligence methods for process control.

Discrete Control systems

In discrete control, the parameters and variables of the system are changed at discrete moments in time, and the changes involve variables and parameters that are also discrete, typically binary (ON/OFF). The changes are defined in advance by means of a program of instructions, for example, a work cycle program. The changes are executed either because the state of the system has changed or because a certain amount of time has elapsed. These two cases can be distinguished as (1) event-driven changes or (2) time-driven changes.

An event-driven change is executed by the controller in response to some event that has caused the state of the system to be altered. The change can be to initiate an operation or terminate an operation, start a motor or stop it, open a valve or close it, and so forth.

An **event-driven** change is executed by the controller in response to some event that has caused the state of the system to be altered. The change can be to initiate an operation or terminate an operation, start a motor or stop it, open a valve or close it, and so forth.

Examples of event-driven changes are the following:

•A robot loads a work part into the fixture, and the part is sensed by a limit switch. Sensing the part's presence is the event that alters the system state. The event-driven change is that the automatic machining cycle can now commence.

•The diminishing level of plastic molding compound in the hopper of an injection molding machine triggers a low-level switch, which in turn opens a valve to start the flow of new plastic into the hopper. When the level of plastic reaches the high-level switch, this triggers the valve to close, thus stopping the flow into the hopper.

•Counting parts moving along a conveyor past an optical sensor is an event-driven system. Each part moving past the sensor is an event that drives the counter.

A **time-driven** change is executed by the control system either at a specific point in time or after a certain time lapse has occurred. As before, the change usually consists of starting something or stopping something, and the time when the change occurs is important.

Examples of time-driven changes include:

•In factories with specific starting times and ending times for the shift and uniform break periods for all workers, the “shop clock” is set to sound a bell at specific moments during the day to indicate this start and stop times.

•Heat-treating operations must be carried out for a certain length of time. An automated heat-treating cycle consists of automatic loading of parts into the furnace (perhaps by a robot) and then unloading after the parts have been heated for the specified length of time.

•In the operation of a washing machine, once the laundry tub has been filled to the present level, the agitation cycle continues for a length of time set on the controls. When this time is up, the timer stops the agitation and initiates draining of the tub.

The two types of change correspond to two different types of discrete control: logic control and sequence control. ***Logic control*** is used to control the execution of event-driven changes, and ***sequence control*** is used to manage time-driven changes.

Discrete control is widely used in discrete manufacturing as well as the process industries. In discrete manufacturing, it is used to control the operation of conveyors and other material transport systems, automated storage systems, stand-alone production machines, automated transfer lines, automated assembly systems, and flexible manufacturing systems. All of these systems operate by following a well-defined sequence of start-and-stop actions, such as powered feed motions, parts transfers between workstations, and on-line automated inspections.

In the process industries, discrete control is associated more with batch processing than with continuous processes. In a typical batch processing operation, each batch of starting ingredients is subjected to a cycle of processing steps that involves changes in process parameters (e.g., temperature and pressure changes), possible flow from one container to another during the cycle, and finally packaging. The packaging step differs depending on the product. For foods, packaging may involve canning or boxing. For chemicals, it means filling containers with the liquid product. And for pharmaceuticals, it may involve filling bottles with medicine tablets. In batch process control, the objective is to manage the sequence and timing of processing steps as well as to regulate the process parameters in each step. Accordingly, batch process control typically includes both continuous control and discrete control.

K.S. INSTITUTE OF TECHNOLOGY, BANGALORE - 560109

Degree : B.E **Semester:** VIII
Branch : MechanicalEngg **CourseCode:** 15ME82
Course Title :ADDITIVE MANUFACTURING

QUESTION BANK

MODULE-I

1. How would you rephrase the meaning of additive manufacturing (AM)?
2. Explain in detail about additive manufacturing and also briefly describing its evolution.
3. Enumerate difference between additive manufacturing and CNC machining process.
4. Can you List and explain different stages of AM?
5. Classify AM Process, explain anyone in each process.
6. What approach would you use to post-processing of AM part?
7. Explain in detail the post-processing of additive manufacturing parts.
8. Can you explain about guideline for process selection?
9. Write in detail about the process chain of additive manufacturing.
10. Write in detail about steps involved in selection methods followed for an additive manufacturing part.
11. Classify different types of additive manufacturing and explain them briefly with neat sketch.
12. With a neat sketch explain the fused deposition modeling process
13. Write a note on a laminated objected manufacturing process with neat sketch along with advantages, disadvantages and applications.
14. Explain how AM techniques used in Rapid tooling and pattern making.
15. Briefly classify AM process and explain Stereo Lithography Apparatus (SLA) process
16. Witn neat sketch explain about stereolithography apparatus including its case study.
17. What dc vou understand by the term selective laser sintering process concerning additive manufacturing?
18. With a neat sketch explain about fused deposition modeling process with case study?
19. Explain with a neat sketch the working principle of the LOM process.
20. Write a note on laminated objected manufacturing (LOM) process with a neat sketch along with advantages, disadvantages and applications.
21. With a neat sketch explain about recent applications of additive manufacturing in medical, mechanical, and engineering field.
22. Briefly explain the application of AM in the field of aerospace and automobile.
23. Explain in detail about applications of additive manufacturing in the field of Aesthetic improvements.
24. What are the different types of support materials?
25. In what way additive manufacturing can be used in the field of thermal technique?
26. Write in detail about steps involved in selection method followed for an AM part.
27. List different post-processing techniques and explain briefly a) support material removal b) Property enhancements using thermal techniques
28. Explain applications of AM in different areas.
29. List applications and advantages of AM.
30. Explain the applications of AM in various fields.
31. Explain in detail about the advantages and disadvantages of additive manufacturing.
32. How would you compare between AM and CNC?

33. How do you compare between AM, CNC and Conventional Technology?

MODULE-II

1. Define system drives, devices, and actuators in the additive manufacturing process.
2. With a neat sketch, what is the function of a balanced vane motor?
3. Explain the following with a neat sketch i) Gear Motor ii) Vane Motor iii) Piston Motor iv) Bent Axis Piston Motor v) Radial Piston Motor.
4. Write a note on the following with a neat sketch: Pneumatic Gear Motor, Piston Motor & Sliding Vane Motors.
5. What do you understand by hydraulic and pneumatic actuators? Classify and explain them briefly.
6. Explain with sketch linear actuators.
7. How pneumatic actuator is different from the hydraulic actuator?
8. Explain the importance of piezoelectric actuators in additive manufacturing.
9. With a neat sketch explain the construction of pneumatic actuator depending on its types i) Single Acting Cylinder ii) Double Acting Cylinder
10. Write the importance of end position cushioning in pneumatic cylinders.
11. With a neat sketch explain the construction of double-acting cylinders.
12. Can you identify the different parts and their operation of swash plate piston motor in the hydraulic system?
13. With a neat Sketch, what are the features of the double-acting cylinder?
14. With a neat sketch explain the construction of a hydraulic cylinder based on its types i) Single Acting ii) Double Acting.
15. With a neat sketch explain solenoid and state its uses.
16. Sketch and explain the working of a stepper motor.
17. Discuss the importance of electrical systems in the additive manufacturing process.
18. Explain the working of a permanent magnet DC motor.
19. Write short notes on diodes and Triacs.
20. Briefly explain the design of the Pneumatic circuit.
21. Write short notes on a) Relays b) Solenoids
22. Write short notes on Mechanical Switch, Relays, Solid State Switches, Thyristors, and Triacs & Solenoids.
23. Explain the working of Relays with a neat sketch.

29. Discuss the design and construction of the diaphragm cylinder and rolling diaphragm cylinder with a neat sketch.
30. Briefly explain the design of the hydraulic circuit.
31. How do you classify motors? Explain AC induction motors in detail.
32. Explain the construction of AC/DC motors with neat sketch.
33. Explain with a neat diagram DC shunt motors.
34. Explain with a neat diagram AC induction motors.

MODULE-III

1. What do you mean by polymer? How polymers are classified?
2. How would you summaries the chemical and thermal properties of Polyester?
3. Explain Polydispersity and molecular weight distribution in polymers.
4. How would you show your understanding of the Concept of functionality?
5. Write short notes on the compression moulding of polymers with a neat sketch.
6. Can you make a distinction between wet spinning and dry spinning?
7. Explain the following processes with neat sketches i) Dry spinning ii) Wet spinning
8. With neat diagram explain a) Dry Spinning b) wet spinning
9. How would you classify the plastic molding techniques? Explain any one of them.
10. Explain with a neat sketch the working principle of Injection Moulding.
11. List various processing techniques of polymers and explain any two.
12. Briefly explain the historical background of powder metallurgy.
13. Explain the different modern sintering techniques concerning powder metallurgy.
14. With a neat diagram explain a) Gas atomization b) Vacuum atomization.
15. Define polymer and briefly explain the different classification of polymers.
16. Define powder metallurgy and explain the steps involved in powder metallurgy.
17. Explain various mechanical powder production techniques.
18. List out the mechanical methods of powder production systems. Explain anyone with a neat sketch.
19. Explain briefly the defect analysis of sintered components
20. What are the stages of liquid phase sintering? Explain any one stage.
21. Define a polymer? What is the different classification of polymers?
22. Write a short note on Polydispersity, molecular weight and molecular weight distribution.
23. What are the methods of spinning for additive manufacturing? Briefly explain them.
24. Draw a neat sketch and explain wet spinning, dry spinning
25. Briefly explain computability issues with polymers
26. With a neat sketch, briefly explain moulding and casting of polymers.
27. Write a short note on polymer processing techniques.
28. What are the different mechanical and chemical methods of powder production?

29. With a neat sketch, briefly explain a particle size and shape distribution.
30. With a neat sketch, briefly explain electron microscopy of powder.
31. Explain briefly the different lubricants used in binders.
32. Explain briefly about the procedure of powder compaction
33. With a neat sketch explain isostatic pressing, injection moulding, and powder extrusion, slip casting and tape casting.
34. Explain briefly about sintering in powder metallurgy.
35. With a neat sketch explain sintering of single and mixed-phase powder.
36. Briefly explain the liquid phase sintering modern sintering techniques.
37. Briefly explain the modern sintering techniques.
38. What are the defects analyses of sintered components?

MODULE-IV

1. With a neat sketch briefly describes Bottom-up and Top-down Approaches.
2. Explain the bottom-up and top-down methods of synthesis.
3. With a neat sketch, briefly explain describe atomic force microscope.
4. Explain briefly the working principle of the Transmission electron microscope.
5. With a neat sketch briefly describes electron probe micro analyzer
6. With a neat sketch, briefly explain X-Ray powder diffraction
7. Explain briefly the working principle of X-Ray diffraction with a neat sketch.
8. Define term Nanotechnology and explain briefly benefits and applications of Nanotechnology
9. With a neat sketch explain briefly Scanning Electron microscope (SEM)
10. With a neat sketch briefly, describes a) Mechanical Grinding b) Sol-gel Process?
11. With a neat sketch briefly describes Gas condensation Process
12. Explain briefly the Gas-phase synthesis of nanomaterials
13. With a neat sketch explain the Flame assisted ultrasonic spray pyrolysis
14. Briefly explain the importance of nanotechnology
15. Briefly explain the emergence of nanotechnology
16. With a neat sketch explain bottom-up and top-down approaches.
17. Briefly explain challenges in nanotechnology.
18. What are the methods required for creating nanostructures?
19. With a neat sketch explain mechanical grinding, wet chemical synthesis of nanomaterials and sol-gel process.
20. With a neat sketch briefly explain, gas-phase synthesis of nanomaterials, flame assisted ultrasonic spray pyrolysis, gas condensation process, and chemical vapor condensation process.
21. Write the principles, image modes, applications, and limitations of optical microscopy.
22. With a neat sketch explain a working principle of a scanning electron microscope.
23. With a neat sketch explain TEM working and image modes.

24. With a neat sketch explain the working principle of x-ray Diffraction. Write applications and limitations of the same.
25. With a neat sketch explain the working principle of Scanning probe microscopy. Write applications and limitations of the same.
26. With a neat sketch explain the working principle of atomic force microscopy. Write applications and limitations of the same.
27. With a neat sketch explain the working principle of electron probe micro analyzer. Write applications and limitations of the same.

MODULE-V

1. Explain the role of part programmer's job in computer programming.
2. Classify the CNC machine tools based on control loops with a neat block diagram
3. Briefly explain various numerically controlled part programming languages.
4. Write the Manual part program for machining the profile as shown in fig.
5. Briefly explain levels of automation
6. Explain the different levels of automation with examples
7. Explain the elements of an automated system with a neat sketch.
8. Distinguish between Continuous v/s Discrete Control.
9. Distinguish between Continuous v/s discrete control systems.
10. Distinguish between NC, CNC, and DNC system.
11. Enumerate various advantages and disadvantages of CNC machines
12. Explain a) USA Principal b) Ten strategies
13. Explain various advanced automation functions
14. What are the numerical control systems? Explain in detail the components of an NC system.
15. With a neat sketch explain the NC system and components.
16. With neat sketch explain the CNC system and components.
17. Distinguish between NC and CNC machine tools.
18. Briefly explain the DNC system along with advantages and applications.
19. With block diagram explain the different classification of control loops in CNC machine tools.
20. List the advantages and disadvantages of CNC machines.
21. With a neat sketch explain manual part programming and computer-assisted part programming.
22. What are the different types of NC part programming languages?
23. What do you understand by motion statements and auxiliary statements?
24. Explain the importance of automation in manufacturing.
25. With a block diagram explain elements of automated systems.
26. Write a short note on discrete control systems.

CBCS SCHEME

USN

15ME82

Eighth Semester B.E. Degree Examination, Dec.2019/Jan.2020
Additive Manufacturing

Time: 3 hrs. Max. Marks: 80

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages. 2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. Define Additive Manufacturing process. List out the advantages of AM process in detail. (08 Marks)
b. Explain the process chain (steps) of AM process. (08 Marks)

OR

2 a. List out the post processing techniques of AM parts. Explain any four steps. (08 Marks)
b. Explain use of pattern prepared by AM process for investment casting. (08 Marks)

Module-2

3 a. Explain the applications of AM products in the field of aerospace and biomedical. (08 Marks)
b. With a neat sketch explain the working of Hydraulic Motors:
(i) Gear motor (ii) Unbalanced Vane motor (08 Marks)

OR

4 a. Write a note on the following Electrical Actuators:
(i) Solenoids (ii) Diodes (08 Marks)
b. Write short notes on :
(i) Piezoelectric actuators (ii) Shape memory alloys. (08 Marks)

Module-3

5 a. List out the polymers used for AM process. Explain Dry spinning technique of polymer processing. (08 Marks)
b. Write a note on :
(i) Biopolymer materials (ii) History of powder metallurgy (PM) process. (08 Marks)

OR

6 a. Sketch and explain Powder Extrusion process. (08 Marks)
b. Define Sintering process and explain Microwave Sintering process with neat sketch. (08 Marks)

Module-4

7 a. Explain Bottom-up approach and Top-down approach. (08 Marks)
b. Sketch and explain Flame assisted ultrasonic spray Pyrolysis process. (08 Marks)

OR

8 a. Explain the working of scanning electron microscope with neat sketch. (08 Marks)
b. List out the advantages and limitations of Transmission electron microscope. (08 Marks)

Module-5

9 a. Write a note on classifications of CNC machine tools. (08 Marks)
b. Explain the NC words used in manual part programming. (08 Marks)

OR

10 a. Define automation. Explain the levels of Automation. (08 Marks)
b. Write a note on Continuous and Discrete control. (08 Marks)

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CBCS SCHEME

USN | | | | | | | | | | 15ME82

Eighth Semester B.E. Degree Examination, June/July 2019
Additive Manufacturing

Time: 3 hrs. Max. Marks: 80

Note: Answer any FIVE full questions, choosing ONE full question from each module.

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

Module-1

1 a. Briefly explain the process chain of additive manufacturing. **(08 Marks)**
b. Explain discrete particle system. **(08 Marks)**

OR

2 a. Explain the steps involved in property enhancement using thermal techniques. **(08 Marks)**
b. Write any eight applications of AM in Aerospace, Automobile, Medical and general engineering. **(08 Marks)**

Module-2

3 a. With a neat sketch explain the working of hydraulic piston motors. **(08 Marks)**
b. With a simple pneumatic circuit explain the supply air throttling system. **(08 Marks)**

OR

4 a. Classify Direct Current motors. With a neat sketch, explain the working of a DC motor. **(08 Marks)**
b. Explain the working of diode in a circuit with neat sketches. **(08 Marks)**

Module-3

5 a. How polymers are classified? **(02 Marks)**
b. Explain polydispersity and molecular weight distribution in polymers. **(06 Marks)**
c. Write a short note on compression moulding of polymers with a neat sketch. **(08 Marks)**

OR

6 a. List out the mechanical methods of powder production systems. Explain any one with a neat sketch. **(08 Marks)**
b. What are the stages of liquid phase sintering? Explain any one stage. **(08 Marks)**

Module-4

7 a. Explain the bottom up and top down methods of synthesis. **(08 Marks)**
b. Explain the mechanical grinding methods of creating nano structures. **(08 Marks)**

OR

8 a. With a neat sketch, explain the working of transmission electron microscopy. (08 Marks)
b. Explain the working principles of Atomic force microscopy. (08 Marks)

Module-5

9 a. List out the advantages of CNC machines over NC machines. (08 Marks)
b. Write a part programming for the component shown in the Fig.Q9(b). (08 Marks)

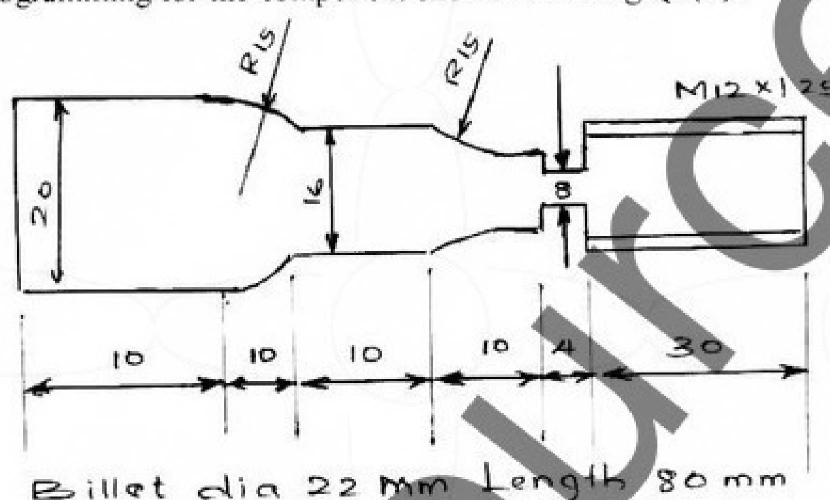

Fig.Q9(b)

OR

10 a. Write down the benefits of automation. (08 Marks)
b. Explain the different levels of automation with examples. (08 Marks)

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CBCS SCHEME

USN

15ME82

Eighth Semester B.E. Degree Examination, November 2020
Additive Manufacturing

Time: 3 hrs. Max. Marks: 80

Note: Answer any FIVE full questions irrespective of modules.

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg. 42+8 = 50, will be treated as malpractice.

Module-1

1 a. Distinguish clearly between Additive Manufacturing and CNC machining. (08 Marks)
b. Sketch and explain solid sheet system process. (08 Marks)

2 a. Discuss post processing of AM parts. (08 Marks)
b. Discuss Additive Manufacturing applications. (08 Marks)

Module-2

3 a. With necessary sketches, discuss the following:
(i) Pulse width modulation.
(ii) Speed control of AC motor. (08 Marks)
b. With, Torque-Speed curve, explain compound motor. (04 Marks)
c. List advantages and disadvantages of DC motors. (04 Marks)

4 With necessary sketches, discuss the following (any four) :
(i) Thyristors (ii) Bipolar transistors (iii) Vane pump.
(iv) Rotary screw compressor. (v) Relay (16 Marks)

Module-3

5 a. Explain clearly classification of polymers. (08 Marks)
b. Explain various powder production techniques. (08 Marks)

6 a. Explain clearly how powder is compacted in Isostatic pressing? (08 Marks)
b. Discuss various stages of liquid phase sintering. (08 Marks)

Module-4

7 a. What are nano materials? Discuss the classification of nonmaterials. (08 Marks)
b. Explain the synthesis of nano-materials by sol-gel process. (08 Marks)

8 a. With a sketch, explain the Transmission Election Microscopy (TEM). (08 Marks)
b. With a sketch, explain the working principle of Atomic Force Microscopy (AFM). (08 Marks)

Module-5

9 a. Explain different types of motion control system in NC process. (08 Marks)
b. With a block diagram, explain the steps involved in the development of a proven part program. (08 Marks)

10 a. List and discuss strategies for automation and production systems. (08 Marks)
b. With a block diagram, explain configuration of an adaptive control system. (08 Marks)

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K S INSTITUTE OF TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

YEAR / SEMESTER	IV / VIII
COURSE TITLE	ADDITTIVE MANUFACTURING
COURSE CODE	15ME82
ACADEMIC YEAR	2019-20 EVEN Sem

CO Attainment Level	Significance
Level 3	60% and above students should have scored >= 60% of Total marks
Level 2	55% to 59% of students should have scored >= 60% of Total marks
Level 1	50% to 54% of students should have scored >= 60% of Total marks

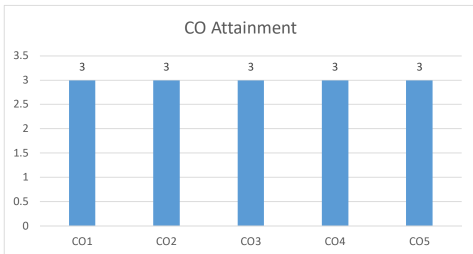
For Direct attainment , 50% of CIE and 50% of SEE marks are considered.
For indirect attainment, Course end survey is considered.
CO attainment is 90%of direct attainment + 10% of Indirect atttainment.
PO attainment = CO-PO mapping strength/3 * CO attainment .

Sl. No	USN	Name of the Student	15ME82 IA1					A1					IA2					A2					IA3					A3					SEE
			CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	
			18	12				6	4				6	18	6				2	6	2					12	18				4	6	80
1	1KS16ME002	ABHIJEETH.B.BHAT	17	11				6	4				0	3	6				2	6	2					12	18				4	6	67
2	1KS16ME004	ABHILASH.S	17	10				6	4				3	12	1				2	6	2					12	18				4	6	54
3	1KS16ME006	ABHISHEK PAREEK	AB	AB				6	4				6	5	6				2	6	2					12	18				4	6	45
4	1KS16ME008	AMOGHA.M.KEKUDA	17	11				6	4				6	5	2				2	6	2					12	16				4	6	53
5	1KS16ME009	ASHOK KUMAR KARMALI	15	6				6	4				0	8	5				2	6	2					12	14				4	6	47
6	1KS16ME010	ASHWIN MAIYA.M	17	10				6	4				5	17	4				2	6	2					10	18				4	6	57
7	1KS16ME011	BHARATHKUMAR.P	AB	AB				6	4				1	3	6				2	6	2					12	18				4	6	65
8	1KS16ME012	BHARGAV JOSHI	AB	AB				6	4				5	18	1				2	6	2					12	18				4	6	56
9	1KS16ME013	BHUVAN BHARADWAJ.V.K	18	10				6	4				2	2	5				2	6	2					12	16				4	6	52
10	1KS16ME014	CHANDAN KUMAR.N.P	17	9				6	4				1	3	3				2	6	2					10	18				4	6	52
11	1KS16ME015	CHIRAG.B.P	17	6				6	4				3	7	4				2	6	2					12	18				4	6	58
12	1KS16ME016	DEEPAK.R.GOWDA	AB	AB				6	4				6	14	0				2	6	2					12	16				4	6	41
13	1KS16ME019	HARISH HADIMANI	17	10				6	4				0	8	2				2	6	2					12	16				4	6	56
14	1KS16ME021	HARSHA.S	15	6				6	4				6	15	6				2	6	2					12	18				4	6	43
15	1KS16ME022	HARSHAVARDHAN.N	17	10				6	4				5	4	1				2	6	2					12	18				4	6	71
16	1KS16ME023	HARSHITH.S	17	11				6	4				4	1	4				2	6	2					12	18				4	6	58
17	1KS16ME024	HEMANTH.R	AB	AB				6	4				0	18	6				2	6	2					12	16				4	6	42
18	1KS16ME025	HEMANTH KUMAR.D.L	AB	AB				6	4				5	5	2				2	6	2					10	18				4	6	56
19	1KS16ME026	HITESH.C.S	AB	AB				6	4				1	1	5				2	6	2					12	14				4	6	46
20	1KS16ME027	IMRAN KHAN	17	11				6	4				2	5	3				2	6	2					10	18				4	6	34
21	1KS16ME028	IRANNA CHANABASAPPA TELI	17	11				6	4				6	15	1				2	6	2					12	18				4	6	53
22	1KS16ME029	JAGADISH.P.SHETTI	15	9				6	4				2	8	0				2	6	2					12	18				4	6	54
23	1KS16ME030	JAYANTH.P	16	12				6	4				5	16	1				2	6	2					12	18				4	6	58
24	1KS16ME031	JAYDEEP.B	18	10				6	4				3	10	5				2	6	2					12	18				4	6	51
25	1KS16ME032	JUNAID KHAN	17	11				6	4				1	8	0				2	6	2					12	18				4	6	37
26	1KS16ME033	KANISHKA.P.SHANKAR	AB	AB				6	4				6	13	4				2	6	2					12	18				4	6	33
27	1KS16ME035	KAUSHIK.K.H	17	6				6	4				6	16	4				2	6	2					12	18				4	6	41
28	1KS16ME036	KIRAN PRAKASH AKOLKAR	17	12				6	4				1	4	0				2	6	2					12	18				4	6	50
29	1KS16ME038	M.VENKATESH KASHYAP	AB	AB				6	4				4	0	0				2	6	2					12	18				4	6	51
30	1KS16ME040	MADAN.S	6	10				6	4				6	7	4				2	6	2					12	18				4	6	64
31	1KS16ME044	MANOJ.R	17	12				6	4				2	9	0				2	6	2					12	18				4	6	52
32	1KS16ME045	MOHAMMED YASIR RIAZ	17	11				6	4				1	7	5				2	6	2					12	18				4	6	49
33	1KS16ME046	MOHAN KUMAR.N	AB	AB				6	4				4	8	2				2	6	2					12	18				4	6	50
34	1KS16ME047	NAGARJUN.S	17	11				6	4				6	7	1				2	6	2					12	18				4	6	31
35	1KS16ME048	NAGARJUN.S	AB	AB				6	4				2	3	4				2	6	2					10	14				4	6	42
36	1KS16ME049	NAGESH.T.S	16	9				6	4				0	11	0				2	6	2					12	18				4	6	60
37	1KS16ME052	NAVEEN DESHPANDE	17	10				6	4				2	16	2				2	6	2					12	18				4	6	54
38	1KS16ME053	NITHIN.N	17	9				6	4				3	2	2				2	6	2					12	18				4	6	65
39	1KS16ME054	P.VIGNESH	17	6				6	4				6	4	6				2	6	2					12	18				4	6	46
40	1KS16ME055	PAPPU KUMAR SINGH	17	6				6	4				5	18	1				2	6	2					12	18				4	6	47
41	1KS16ME056	PAVAN KUMAR.L	17	6				6	4				0	9	4				2	6	2					10	18				4	6	50
42	1KS16ME057	PAVITHRA.B	AB	AB				6	4				3	10	6				2	6	2					10	18				4	6	53
43	1KS16ME058	PECHU MUTHU.S	17	11				6	4				0	5	6				2	6	2										4	6	49
44	1KS16ME060	PRAJWAL KRISHNA	AB	AB				6	4				2	18	3				2	6	2					12	14				4	6	46
45	1KS16ME061	PRAKASH RAJU.S	AB	AB				6	4				2	10	4				2	6	2					12	14				4	6	53
46	1KS16ME062	PRAMOD.R	AB	AB				6	4				4	16	5				2	6	2					10	14				4	6	66
47	1KS16ME063	PRAMOD RAJ.K	6	11				6	4				1	5	6				2	6	2					10	18				4	6	55
48	1KS16ME064	PRANAV.J.ATHREY	AB	AB				6	4				6	12	1				2	6	2					12	18				4	6	42
49	1KS16ME067	RAJKUMAR.S.K	6	8				6	4				5	6	3				2	6	2					12	18				4	6	59
50	1KS16ME069	RAMESH PAL.P	17	11				6	4				4	5	5				2	6	2					12	18				4	6	52
51	1KS16ME070	RISHI.R.NAIK	15	6				6	4				3	10	6				2	6	2					12	18				4	6	41
52	1KS16ME073	SAGAR.N	6	7				6	4				6	7	5				2	6	2					12	18				4	6	57
53	1KS16ME075	SHAIK MOINUDDIN	15	9				6	4				4	4	2				2	6	2					9	2				4	6	61
54	1KS16ME076	SHARATH.S.YADAV	14	8				6	4				5	2	5				2	6	2					8	13				4	6	54
55	1KS16ME081	SHIVARAJ.N.S	13	12				6	4				2	12	4				2	6	2					0	8				4	6	50
56	1KS16ME082	SHIVASHANKAR.B.M	8	9				6	4				6	3	4				2	6	2					3	15				4	6	73
57	1KS16ME083	SIRISH GOVARDHAN	12	10				6	4				0	7	5				2	6	2					6	16				4	6	48
58	1KS16ME084	SOWJANYA.D	18	7				6	4				5	15	4				2	6	2					10	7				4	6	56
59	1KS16ME085	SREEKARA.K.B	16	9				6	4				5	7	2				2	6	2					10	4				4	6	61
60	1KS16ME086	SUDARSHAN.T	6	10				6	4				1	0	0				2	6	2					9	3				4	6	33
61	1KS16ME087	SUDHARSHAN.M.D	15	12				6	4				3	10	3				2	6	2					10	14				4	6	65
62	1KS16ME089	SUMESH.R	5	7				6	4				4	8	6				2	6	2					9	2				4	6	56
63	1KS16ME090	SUPREETH.K.R	14	6				6	4				4	18	4				2	6	2					9	7				4	6	51
64	1KS16ME093	VARUN.C	0	8				6	4				1	15	2				2	6	2					9	1				4	6	60
65	1KS16ME094	VASANTH KUMAR.S	18	8				6	4				6	14	1				2	6	2					9	14				4	6	69
66	1KS16ME095	VIJAYA KUMAR.M.S	2	9				6	4				6	17	0				2	6	2					9	4				4	6	68
67	1KS16ME096	VIJAYKUMARNAIK.T.C	16	8				6	4				2	3	1				2	6	2					7	11				4	6	52
68	1KS16ME097	VINAY.B.V	6	3				6	4				2	10	1				2	6	2					8	17				4	6	31
69	1KS16ME098	VINAY.V.P	12	10				6	4				6	11	1				2	6	2					7	1				4	6	60

70	1KS16ME099	VINITH.P	15	0				6	4				6	8	0				2	6	2					1	5				4	6	48
71	1KS16ME100	VITHAN.T.R	3	10				6	4				4	0	2				2	6	2					3	14				4	6	62
72	1KS17ME401	ARUNKUMAR.E	17	12				6	4				3	8	0				2	6	2					10	16				4	6	48
73	1KS17ME402	ARUN KUMAR.R	8	1				6	4				5	12	5				2	6	2					3	13				4	6	48
74	1KS17ME404	CHETHAN.C.R	2	1				6	4				4	2	2				2	6	2					9	12				4	6	62
75	1KS17ME405	DARSHAN.H.R	3	2				6	4				6	10	1				2	6	2					11	11				4	6	44
76	1KS17ME406	DEEPAK.E	17	8				6	4				1	3	3				2	6	2					11	5				4	6	33
77	1KS17ME408	GUHAN BHASKAR	16	2				6	4				1	13	2				2	6	2					7	5				4	6	30
78	1KS17ME409	GURUPRASAD.T.M	14	2				6	4				6	15	1				2	6	2					8	14				4	6	38
79	1KS17ME410	GURUSWAMY.H	13	2				6	4				4	1	5				2	6	2					4	0				4	6	40
80	1KS17ME411	JEEVAN ABHISHEK	13	4				6	4				6	15	5				2	6	2					10	15				4	6	55
81	1KS17ME412	KANTHARAJU.K.N	17	7				6	4				5	1	3				2	6	2					10	16				4	6	56
82	1KS17ME413	KIRAN.S	10	10				6	4				6	4	0				2	6	2					12	7				4	6	36
83	1KS17ME415	LOHITH.R	15	4				6	4				0	15	0				2	6	2					2	4				4	6	50
84	1KS17ME416	MAHADEVA RAJU.H.E	5	5				6	4				6	15	1				2	6	2					0	4				4	6	42
85	1KS17ME417	MAHESH.D	12	10				6	4				2	0	3				2	6	2					10	0				4	6	49
86	1KS17ME418	MANISH.N.D	8	6				6	4				6	16	3				2	6	2					1	17				4	6	56
87	1KS17ME419	MITHUN.S	0	4				6	4				3	4	1				2	6	2					11	13				4	6	34
88	1KS17ME420	MOHAN KUMAR.C	12	2				6	4				2	1	4				2	6	2					11	8				4	6	51
89	1KS17ME421	MOHAN KUMAR.K	14	1				6	4				4	13	6				2	6	2					3	15				4	6	47
90	1KS17ME422	NAGESH.S	15	8				6	4				2	11	4				2	6	2					11	6				4	6	66
91	1KS17ME423	NIKHIL GOWDA.N.S	5	11				6	4				6	4	1				2	6	2					6	10				4	6	57
92	1KS17ME425	PRATAP.L	5	7				6	4				1	12	2				2	6	2					12	2				4	6	58
93	1KS17ME426	PRATHEEK.P	11	10				6	4				0	17	5				2	6	2					5	0				4	6	48
94	1KS17ME430	RAKESH.B.R	13	7				6	4				3	13	6				2	6	2					12	5				4	6	33
95	1KS17ME431	RAKSHITH.L	18	11				6	4				3	12	1				2	6	2					12	11				4	6	55
96	1KS17ME432	RAVI.K.R	4	7				6	4				4	17	0				2	6	2					9	0				4	6	48
97	1KS17ME434	SHASHANK.Y.K	9	4				6	4				0	9	6				2	6	2					9	2				4	6	57
98	1KS17ME435	SHASHIKUMAR.C.R	12	12				6	4				2	16	3				2	6	2					8	1				4	6	53
99	1KS17ME437	SRINIVASA.B.V	15	5				6	4				0	9	6				2	6	2					9	18				4	6	35
100	1KS17ME439	SURABHI.N	11	5				6	4				5	8	4				2	6	2					4	7				4	6	45
101	1KS17ME440	SUSHMA.Y.S	4	12				6	4				6	1	6				2	6	2					5	11				4	6	54
102	1KS17ME441	TEJAS.P.N	2	0				6	4				4	18	2				2	6	2					2	9				4	6	70
103	1KS17ME442	THRIVENI.M	14	11				6	4				1	3	3				2	6	2					5	11				4	6	52
104	1KS17ME444	VINAY.S	2	7				6	4				3	7	0				2	6	2					5	4				4	6	48
60% of Maximum marks (X)			11	07	00	00	00	04	02	00	00	00	04	11	04	00	00	00	01	04	01	00	00	00	00	07	11	00	00	00	02	04	48
No. of students above X			63	52	00	00	00	104	104	00	00	00	52	39	46	00	00	00	104	104	104	00	00	00	00	82	73	00	00	00	104	104	73
Total number of students (Y)			88	88	00	00	00	104	104	00	00	00	104	104	104	00	00	00	104	104	104	00	00	00	00	103	103	00	00	00	104	104	104
CO Percentage			71.59	59.09	#DIV/0!	#DIV/0!	#DIV/0!	100.00	100.00	#DIV/0!	#DIV/0!	#DIV/0!	50.00	37.50	44.23	#DIV/0!	#DIV/0!	#DIV/0!	100.00	100.00	100.00	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	79.61	70.87	#DIV/0!	#DIV/0!	#DIV/0!	100.00	100.00	70.19
			CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	CO1	CO2	CO3	CO4	CO5	SEE
LEVEL			3	2	#DIV/0!	#DIV/0!	#DIV/0!	3	3	#DIV/0!	#DIV/0!	#DIV/0!	1	0	0	#DIV/0!	#DIV/0!	#DIV/0!	3	3	3	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	3	3	#DIV/0!	#DIV/0!	#DIV/0!	3	3	3

Method 1

CO	CIE	SEE	DIRECT ATTAINMENT	Level	COURSE EXIT SURVEY	LEVEL	ATTAINMENT
CO1	73.86	70.19	72.03	3.00	60.00	3.00	3
CO2	74.15	70.19	72.17	3.00	60.00	3.00	3
CO3	72.12	70.19	71.15	3.00	60.00	3.00	3
CO4	93.20	70.19	81.70	3.00	60.00	3.00	3
CO5	85.44	70.19	77.81	3.00	60.00	3.00	3
AVERAGE							3.00



	IA1	A1	IA2	A2	IA3	A3	AVG
CO1	71.59	100.00	50.00	#DIV/0!	#DIV/0!	#DIV/0!	73.86
CO2	59.09	100.00	37.50	100.00	#DIV/0!	#DIV/0!	74.15
CO3	#DIV/0!	#DIV/0!	44.23	100.00	#DIV/0!	#DIV/0!	72.12
CO4	#DIV/0!	#DIV/0!	#DIV/0!	100.00	79.61	100.00	93.20
CO5	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	70.87	100.00	85.44

79.59

Co-Po Mapping Table

CO'S	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PS01	PSO2
CO1	3	2	1	1	_	_	_	_	_	_	_	_	3	2
CO2	3	2	1	2	_	_	_	_	_	_	_	_	3	2
CO3	3	2	1	_	_	_	_	_	_	_	_	_	3	2
CO4	3	2	1	_	_	_	_	_	_	_	_	_	3	2
CO5	3	2	1	1.5	_	_	_	_	_	_	_	_	3	2
AVG	3.00	2.00	1.00	1.50	_	_	_	_	_	_	_	_	3.00	2.00

PO ATTAINMENT TABLE

CO'S	CO Attainment in %	CO RESULT	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PS02
CO1	3.00	Y	3.00	2.00	1.00	1.00	_	_	_	_	_	_	_	_	3.00	2.00
CO2	3.00	Y	3.00	2.00	1.00	2.00	_	_	_	_	_	_	_	_	3.00	2.00
CO3	3.00	Y	3.00	2.00	1.00	_	_	_	_	_	_	_	_	_	3.00	2.00
CO4	3.00	Y	3.00	2.00	1.00	_	_	_	_	_	_	_	_	_	3.00	2.00
CO5	3.00	Y	3.00	2.00	1.00	1.50	_	_	_	_	_	_	_	_	3.00	2.00
Average			3.00	2.00	1.00	1.50	_	_	_	_	_	_	_	_	3.00	2.00