MINISTRY OF EDUCATION

Manufacturing Engineering

For Senior High Schools

TEACHER MANUAL

YEAR 1 - BOOK 2

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MINISTRY OF EDUCATION

REPUBLIC OF GHANA

Manufacturing Engineering

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Teacher Manual

Year One - Book Two

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MANUFACTURING ENGINEERING TEACHER MANUAL

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INTRODUCTION

The National Council for Curriculum and Assessment (NaCCA) has developed a new Senior High School (SHS), Senior High Technical School (SHTS) and Science, Technology, Engineering and Mathematics (STEM) Curriculum. It aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, competencies, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, further their education and enter the world of work.

This is the first time that Ghana has developed an SHS Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

This Book Two of the Teacher Manual for Manufacturing Engineering covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively teach Year One of the new curriculum. It contains information for the second 12 weeks of Year One. Teachers are therefore to use this Teacher Manual to develop their weekly Learning Plans as required by Ghana Education Service.

Some of the key features of the new curriculum are set out below.

Learner-Centred Curriculum

The SHS, SHTS, and STEM curriculum places the learner at the center of teaching and learning by building on their existing life experiences, knowledge and understanding. Learners are actively involved in the knowledge-creation process, with the teacher acting as a facilitator. This involves using interactive and practical teaching and learning methods, as well as the learner's environment to make learning exciting and relatable. As an example, the new curriculum focuses on Ghanaian culture, Ghanaian history, and Ghanaian geography so that learners first understand their home and surroundings before extending their knowledge globally.

Promoting Ghanaian Values

Shared Ghanaian values have been integrated into the curriculum to ensure that all young people understand what it means to be a responsible Ghanaian citizen. These values include truth, integrity, diversity, equity, self-directed learning, self-confidence, adaptability and resourcefulness, leadership and responsible citizenship.

Integrating 21st Century Skills and Competencies

The SHS, SHTS, and STEM curriculum integrates 21st Century skills and competencies. These are:

- Foundational Knowledge: Literacy, Numeracy, Scientific Literacy, Information Communication and Digital Literacy, Financial Literacy and Entrepreneurship, Cultural Identity, Civic Literacy and Global Citizenship
- Competencies: Critical Thinking and Problem Solving, Innovation and Creativity, Collaboration and Communication
- Character Qualities: Discipline and Integrity, Self-Directed Learning, Self-Confidence, Adaptability and Resourcefulness, Leadership and Responsible Citizenship

Balanced Approach to Assessment - not just Final External Examinations

The SHS, SHTS, and STEM curriculum promotes a balanced approach to assessment. It encourages varied and differentiated assessments such as project work, practical demonstration, performance assessment, skills-based assessment, class exercises, portfolios as well as end-of-term examinations and final external assessment examinations. Two levels of assessment are used. These are:

- o Internal Assessment (30%) – Comprises formative (portfolios, performance and project work) and summative (end-of-term examinations) which will be recorded in a school-based transcript.
- o External Assessment (70%) – Comprehensive summative assessment will be conducted by the West African Examinations Council (WAEC) through the WASSCE. The questions posed by WAEC will test critical thinking, communication and problem solving as well as knowledge, understanding and factual recall.

The split of external and internal assessment will remain at 70/30 as is currently the case. However, there will be far greater transparency and quality assurance of the 30% of marks which are school-based. This will be achieved through the introduction of a school-based transcript, setting out all marks which learners achieve from SHS 1 to SHS 3. This transcript will be presented to universities alongside the WASSCE certificate for tertiary admissions.

An Inclusive and Responsive Curriculum

The SHS, SHTS, and STEM curriculum ensures no learner is left behind, and this is achieved through the following:

- Addressing the needs of all learners, including those requiring additional support or with special needs. The SHS, SHTS, and STEM curriculum includes learners with disabilities by adapting teaching and learning materials into accessible formats through technology and other measures to meet the needs of learners with disabilities.
- Incorporating strategies and measures, such as differentiation and adaptative pedagogies ensuring equitable access to resources and opportunities for all learners.
- Challenging traditional gender, cultural, or social stereotypes and encouraging all learners to achieve their true potential.
- Making provision for the needs of gifted and talented learners in schools.

Social and Emotional Learning

Social and emotional learning skills have also been integrated into the curriculum to help learners to develop and acquire skills, attitudes, and knowledge essential for understanding and managing their emotions, building healthy relationships and making responsible decisions.

Philosophy and vision for each subject

Each subject now has its own philosophy and vision, which sets out why the subject is being taught and how it will contribute to national development. The Philosophy and Vision for Manufacturing Engineering is:

> **Philosophy:** An effective education in Manufacturing Engineering needed for sustainable industrialisation and economic growth should provide learners with opportunities and hands-on experiences to expand, change, enhance and modify the ways in which they view the world. This can be achieved when skilled facilitators provide the enabling environment that promotes the construction of learners' own knowledge, based on their prior experiences leading to the development of critical thinkers, problem solvers and innovators equipped with 21st century skills and competencies.
>
> **Vision:** Equip graduates with the relevant knowledge and skills to design, analyse and control local and global manufacturing processes.

SUMMARY SCOPE AND SEQUENCE

S/N	STRAND	SUB-STRAND	YEAR 1			YEAR 2			YEAR 3		
			CS	LO	LI	CS	LO	LI	CS	LO	LI
1	Materials for Manufacturing	Classification of Materials	2	1	4	2	1	6	2	1	5
		Properties of Materials	2	1	4	2	1	4	2	1	4
2	Design and Prototyping	Design and Drawing for Manufacturing	2	1	4	3	1	6	2	1	4
		Rapid Prototyping	2	1	4	1	1	2	2	1	4
3	Manufacturing Tools, Equipment and Processes	Manufacturing Tools and Equipment	2	1	4	2	2	4	2	2	4
		Manufacturing Processes	2	1	2	2	1	4	2	1	4
		Safety, Quality and the Environment	2	2	2	2	1	5	2	2	5
Total			**14**	**8**	**24**	**14**	**8**	**31**	**14**	**9**	**30**

Overall Totals (SHS 1 – 3)

Content Standards	**42**
Learning Outcomes	**25**
Learning Indicators	**85**

SECTION 4: RAPID PROTOTYPING

Strand: **Design and Prototyping**

Sub-Strand: Rapid Prototyping

Learning Outcome: *Explain the principles and essence of rapid prototyping for product development.*

Content Standard: Demonstrate that prototyping is essential for product development

INTRODUCTION AND SECTION SUMMARY

Section four (4) introduces learners to rapid prototyping as a form of prototyping technique used for product development. Learners will be briefly introduced to conventional prototyping techniques to give them a good basis to understand rapid prototyping. Learners will understand the principles behind rapid prototyping, the rapid prototyping process, the advantages and disadvantages of rapid prototyping and the applications of rapid prototyping in product development. The section has hands-on activities to help learners practice how to make prototypes using rapid prototyping techniques such as 3D printing. At the end of the section, learners will be equipped with practical skills that will enable them to make prototypes of their design ideas. Therefore, learners will use the knowledge gained in Section Three (3) on the design process in this section to help them make prototypes.

The section covers the following weeks:

- Week 13: **Conventional prototyping and rapid prototyping**
- Week 14: **Principles and process of rapid prototyping**
- Week 15: **Advantages and disadvantages of rapid prototyping**
- Week 16: **Applications of rapid prototyping in manufacturing**

SUMMARY OF PEDAGOGICAL EXEMPLARS

Being mindful of the different backgrounds, learning styles and learning capacities of the learners, varying pedagogical approaches should be used to ensure that all learners benefit from the lessons. Pedagogical exemplars such as project-based learning, research-based learning, collaborative learning, diamond-nine, experiential learning and talk-for-learning approaches should be adopted to meet the different learning capacities and styles of learners. Consider providing learners the opportunity to practice the development of prototypes using rapid prototyping techniques such as 3D printing.

ASSESSMENT SUMMARY

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions; written responses of various levels of difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Projects that allow learners to develop prototypes using rapid prototyping techniques should be encouraged. At the end, learners should be able to demonstrate understanding of the principles of rapid prototyping and use rapid prototyping techniques such as 3D printing to make physical models. These should contribute to learners' formative assessment.

Week 13

Learning Indicator: *Explain the fundamental difference between conventional prototyping and rapid prototyping.*

Theme or Focal Area: Difference Between Conventional Prototyping and Rapid Prototyping

Introduction

Prototyping is an essential part of the manufacturing process. Prototypes are smaller versions of actual designs that allow manufacturers to test the performance of their designs, correct design flaws and redesign before producing in full scale. Prototypes of products can be made using conventional or rapid prototyping techniques. This lesson discusses the major differences between conventional prototyping and rapid prototyping techniques.

Conventional Prototyping

Over the years, manufacturers have used conventional prototyping methods to create models of their designs for performance assessment. Conventional prototyping refers to the process of creating physical models or prototypes using established, non-digital manufacturing techniques and tools such as machining, injection moulding, sheet metal fabrication, woodworking, handcrafting and many more. These processes can be labour-intensive, time-consuming and expensive, prompting the need for easier, faster and cheaper prototyping techniques to enhance the work of manufacturers.

Rapid Prototyping

In recent years, rapid prototyping techniques have been proposed to enhance the manufacturing process. Rapid prototyping is a modern and innovative approach to creating prototypes and physical models quickly and cost-effectively using computer-aided design (CAD) software and additive manufacturing approaches. Examples of rapid prototyping techniques include but are not limited to fused deposition modelling, stereolithography, selective laser sintering, poljes technology, 3D printing and bioprinting.

Differences between Conventional Prototyping and Rapid Prototyping

Conventional prototyping and rapid prototyping are two distinct approaches to developing prototypes in the product design and development process. They differ in various aspects, including their processes, speed, cost and application. The key differences between conventional prototyping and rapid prototyping are presented in Table 13.1.

Table 13.1 Differences between conventional prototyping and rapid prototyping

Item	Conventional Prototyping	Rapid Prototyping
Process and Technique	Uses traditional manufacturing methods such as machining, milling, or handcrafting. This process is time-consuming and may require skilled artisans or machinists to produce detailed models.	Involves creating prototypes layer by layer using computer-aided design (CAD) data. It relies on digital models and specialised machines to build physical prototypes quickly.
Speed	Takes a considerable amount of time, especially for complex and intricate designs.	Significantly faster.
Cost	Can be costly, primarily due to labour, material and machine costs. Skilled machinists and artisans are often required, which adds to the expense.	Initial investment is relatively high. However, it can be cost-effective in the long run. It reduces labour costs, minimises material wastage, and enables quicker design iterations.
Complexity	Better suited for certain types of materials and complex, large-scale prototypes. They are versatile but may have limitations in intricate and highly detailed designs.	Well-suited for creating complex, intricate and detailed prototypes. It excels in producing prototypes with intricate geometries that would be challenging or impossible to create using traditional methods.
Iterative designs	Due to the time and cost involved, conventional prototyping may limit the number of design iterations possible during the development process.	Facilitates iterative design, allowing designers to quickly modify and test multiple design variations. This accelerates the product development cycle.
Materials	Offers a wide range of material choices, including metals, plastics and composites, depending on the machining or manufacturing process.	Material selection may be more limited compared to conventional methods. It primarily uses various types of plastics and resins.

Learning Tasks

1. Learners make prototypes of a miniature shaft, nameplate or signage using available conventional and rapid prototyping techniques.
2. Learners discuss and make presentations on the major differences associated with the use of conventional and rapid prototyping techniques, with emphasis on the processes, complexities, production speed, time involved, needed skill sets and cost implications.

Pedagogical Exemplars

1. **Experiential learning:** Let learners in mixed-ability groups make prototypes of a miniature shaft, nameplate or signage using available conventional prototyping techniques (such as machining, sheet metal working or hand-crafting) and rapid prototyping techniques (such as 3D printing, fused deposition modelling, stereolithography, selective laser sintering. Assign learners with prior technical skills and experience to work on conventional prototyping techniques and learners with computer and digital skills to use rapid prototyping techniques. This will ensure that all learners participate in the activity. Offer guidelines to learners who are not proficient in the use of conventional or rapid prototyping techniques to build their confidence in the use of the prototyping techniques. Be intentional when pairing learners to ensure that learners with difficulties executing tasks get help from proficient peers.
2. **Talk for learning:** Let learners, through presentations, discuss the differences between conventional prototyping techniques such as machining, sheet metal working, welding, etc., and rapid prototyping techniques such as fused deposition modelling, stereolithography, selective laser sintering, poljes technology, 3D printing and bioprinting, considering the technologies used, cost and how quick the workpieces are produced. Provide learners with resources or direct them to sources where they can find more information. Provide a safe, supportive and all-inclusive environment where students feel comfortable asking questions and expressing their thoughts. Encourage curiosity and critical thinking by prompting students to ask clarifying questions and provide evidence to support their arguments. Encourage learners to consider and accept what others say. Allow learners who are not vocal to contribute through writing. Proficient and highly proficient learners should be encouraged to make their presentations through a detailed report or PowerPoint presentations. Accept oral presentations and webbings or mappings from learners approaching proficiency.

Key Assessment

Assessment Level 1

1. Which of the following is not a primary difference between conventional prototyping and rapid prototyping?
   a. The speed of production
   b. The complexity of designs
   c. The cost involved
   d. The materials used
   e. The product designed
2. What is the major difference between rapid prototyping and conventional prototyping?
3. List the two types of prototyping methods.
4. Why is prototyping necessary in product manufacturing?

Assessment Level 2

1. Describe one primary difference between conventional prototyping and rapid prototyping.
2. Compare and contrast the cost implications of conventional prototyping and rapid prototyping techniques.
3. How do the technologies used in conventional prototyping differ from those used in rapid prototyping?
4. How has technological advancement influenced traditional prototyping and rapid prototyping processes?

Assessment Level 3

1. Justify the relevance of using rapid prototyping in manufacturing.
2. How does the use of conventional or rapid prototyping techniques affect the duration of the development of a product?
3. Propose a case where the use of conventional prototyping will be preferred to rapid prototyping in the manufacturing of a product.
4. Evaluate the advantages and disadvantages of applying conventional and rapid prototyping techniques to design different products, such as medical equipment, automobile components, etc.

Assessment Level 4

1. How can conventional and rapid prototyping techniques be improved to address emerging challenges in product development?
2. How have the differences between conventional and rapid prototyping informed your understanding of the use of the right prototyping technique in product manufacturing?
3. How is the advancement of material science influencing prototyping techniques in manufacturing?

Week 14

Learning Indicator: *Discuss the principles and processes of rapid prototyping*

Theme or Focal Area: Principles and Process of Rapid Prototyping

Introduction

Rapid prototyping in its basic form can be described as the production of three-dimensional (3D) parts from computer-aided design (CAD) data in a decreased time scale. It involves the automated fabrication of intricate shapes from CAD data using a layer-by-layer principle. These "three-dimensional printers" allow designers to quickly create tangible prototypes of their designs, which can be modified at any point in time, rather than just two-dimensional pictures.

The Principles of Rapid Prototyping

In rapid prototyping (RP), a solid object with a prescribed shape, dimension and finish can be directly produced from data for a CAD-based geometric model stored in a computer without human intervention. The parts obtained by RP technology can be used directly as the prototype or as a mould for casting the prototype component. The principle of RP technology is based on speed, efficiency and the layer-by-layer construction of physical models from digital designs.

The Process of Rapid Prototyping

The rapid prototyping process is described in Fig. 14.1, and can be summarised below:

1. **Creation of the CAD model of the (part) design:** A component is modelled on a Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) system.
2. **Conversion of CAD model into Standard Tessellation Language (STL) Format:** The solid or surface model to be built is next converted into a format called the "STL" (Stereolithography) file format which originates from 3D systems. The STL file format approximates the surface of the model using polygons. Highly curved surfaces must employ many polygons, which means that STL files for curved parts can be very large.
3. **Slicing of STL file into thin sections:** A computer programme analyses an STL file that defines the model to be fabricated and "slices" the model into cross sections.
4. **Building part layer by layer:** The software that operates RP systems generates laser-scanning paths or material deposition paths. Information computed here is used to deposit the part layer-by-layer on an RP system platform. This step is different for different RP processes and depends on the basic deposition principle used in the rapid prototyping machine.
5. **Post processing/finishing/joining:** At this stage, some manual operations are generally performed to give the model a good surface finish. The post-processing and surface finishing process can be done by sanding, polishing or painting. Also, excess elements adhered to the part or support structures are removed when cleaning the surface. A skilled operator is, therefore, required during the post-processing and surface-finishing stage.

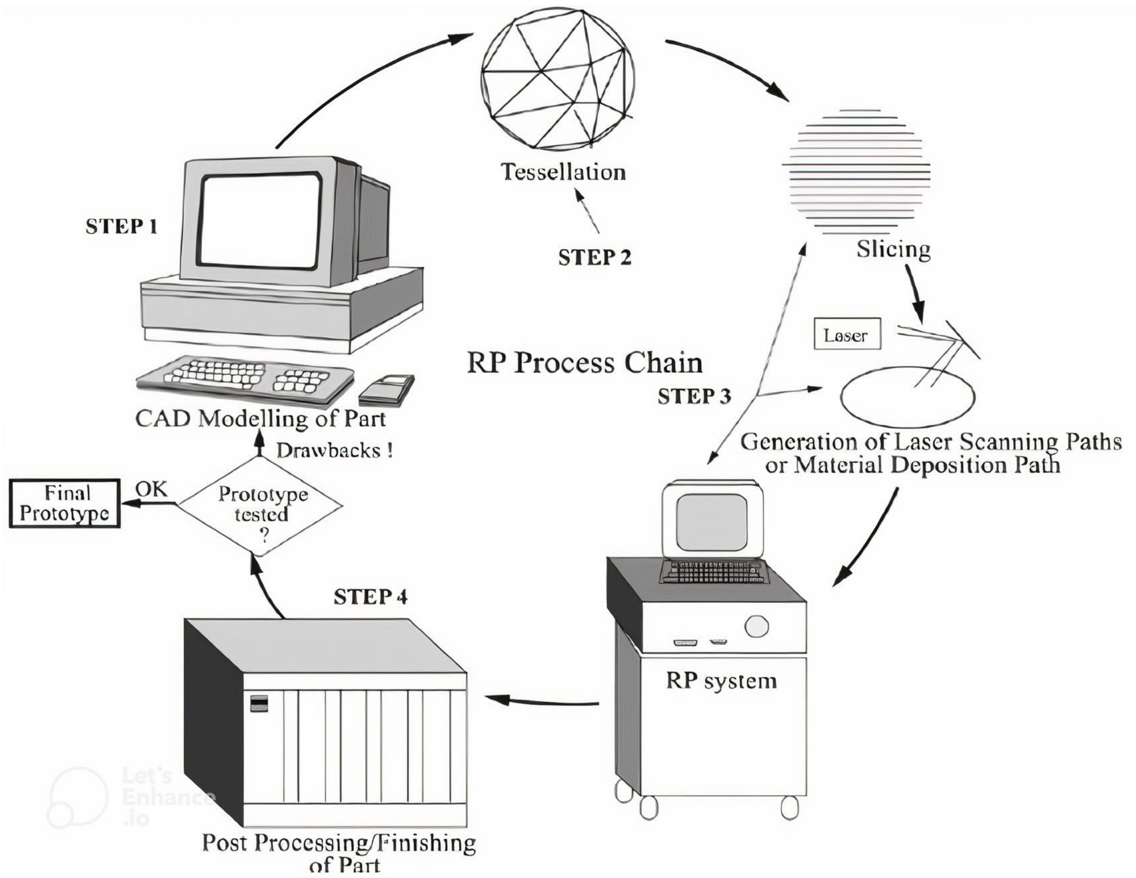

Fig. 14.1:*The rapid prototyping process (Source: Gibson et al., 2014)*

Learning Tasks

1. Learners design a 3D model of any object of their choice and print it using a 3D printing process.
2. Learners make presentations of the RP prototyping process using the 3D printing process as a case study.

Pedagogical Exemplars

1. **Experiential learning:** Demonstrate a typical rapid prototyping process to the learners using a physical 3D printer or by showing learners a video of a typical 3D printing process from start to finish. Afterwards, let learners in mixed-ability groups develop a prototype of any object of their choice using a 3D printer. Be intentional to enhance peer-to-peer teaching when forming the groups by ensuring that each group has learners with varying abilities. Use a rotating station model where students move through different prototyping stations, each focusing on a different aspect of the rapid prototyping process such as design, modelling, printing and post-processing. This will allow learners to engage with the material at their own pace and practice each rapid prototyping process. Encourage learners with higher skill sets to design and print a complex object.
2. **Collaborative learning:** After the demonstration of rapid prototyping process and using a physical 3D printer or videos and the subsequent development of a prototype using 3D printers, let learners in mixed-ability groups discuss the principles and process of rapid prototyping and make presentations on the principles and process of rapid prototyping. Provide learners

with additional resources such as articles, textbooks or internet sites to help them understand the concept. Assign specific roles (for example researcher, team leader, timekeeper, organiser, writer, etc.) to learners to ensure that each learner contributes to the activities of the group. Encourage learners to tolerate and accept the views of others. Allow learners to use different presentation formats such as webbings, mind maps, oral presentations, written reports, video presentations or PowerPoint presentations. Encourage talented learners to present written reports and make PowerPoint presentations.

Key Assessment

Assessment Level 1

1. Which of the following technologies is commonly used in rapid prototyping?
   a. Injection moulding
   b. CNC machining
   c. 3D printing
   d. Laser cutting
2. List the steps involved in the rapid prototyping process.
3. What are the fundamental principles of rapid prototyping, and why are they important in product development?
4. What are the steps involved in the rapid prototyping process?

Assessment Level 2

1. Explain the principle of the prototyping process.
2. Briefly describe the rapid prototyping process.
3. Explain the essence of the post-processing activities in rapid prototyping
4. How important is the conversion of a CAD model into Standard Tessellation Language (STL) Format during rapid prototyping?

Assessment Level 3

1. How do the principles of rapid prototyping align with broader trends in manufacturing and the rise of digital manufacturing?
2. Discuss the possibilities of integrating rapid prototyping with other emerging technologies, such as artificial intelligence and the Internet of Things (IoT), to enhance the design and manufacturing process.
3. What is the justification for slicing the STL file into thin layers for the design of the models?

Assessment Level 4

1. How does rapid prototyping differ from the traditional prototyping process?
2. How can the rapid prototyping process be adopted to enhance the conventional prototyping processes in the local industry?
3. Propose a necessary improvement that can be made in the rapid prototyping process to enhance the capabilities of the technology.

Week 15

Learning Indicator: *Explain the advantages and disadvantages of rapid prototyping.*

Theme or Focal Area: Advantages and Disadvantages of Rapid Prototyping

Introduction

Innovation has become an integral part of the manufacturing process. Rapid prototyping provides a faster and cost-effective means of innovatively making physical prototypes during product development. However, rapid prototyping has several disadvantages that need to be understood to help in making decisions when selecting a prototyping technique. This lesson provides insights into the advantages and disadvantages of rapid prototyping to help learners gain valuable insights into the technology.

Advantages of Rapid Prototyping

Rapid prototyping has many advantages including:

1. **Faster Product Development:** Rapid prototyping significantly speeds up the product development process by allowing teams to iterate on designs and concepts quickly.
2. **Reduced Costs:** Rapid prototyping allows designers to detect and address design flaws early in the development cycle. This helps to save substantial costs compared to making changes later in the process or after production has begun.
3. **Improved Communication:** Prototypes made using rapid prototyping techniques provide a tangible representation of the product. This makes it easier for stakeholders, including clients, engineers and designers, to understand and discuss the design and functionality.
4. **User Feedback:** Rapid prototypes can be tested with end-users, providing valuable feedback that helps refine the design and align it with user needs and expectations.
5. **Elimination or Reduction of risk:** Rapid prototyping helps identify potential issues and risks early, enabling designers and manufacturers to address them before they become critical problems.
6. **Enhanced Creativity:** Rapid prototyping provides the freedom to quickly experiment with ideas. This can stimulate creativity and innovation among designers.
7. **Improvement in Iterations:** Rapid prototyping allows for multiple iterations, enabling continuous improvement until the final product meets the desired standards.
8. **Customisation:** Prototypes made with rapid prototyping techniques can be customised to focus on specific aspects of a product, allowing for the testing of individual features or components.

Disadvantages of Rapid Prototyping

Rapid prototyping has several disadvantages, including:

1. **Limited Functionality:** Prototypes may lack full functionality, which can lead to misconceptions about the final product's capabilities.
2. **Time and Resource Intensive:** Creating prototypes requires time and resources, and the rapid iteration process can be demanding for the team.
3. **Potential for Scope Creep:** Frequent changes during the prototyping phase can lead to scope creep, causing delays and increased costs.

4. **Quality Concerns:** Rapid prototyping may prioritise speed over quality, potentially leading to the development of unstable or inefficient solutions.
5. **Overemphasis on Aesthetics:** Prototypes can sometimes focus too much on visual design, neglecting underlying functionality and performance.
6. **Resistance to Change:** Teams or stakeholders may resist making significant changes based on prototype feedback, especially if they are attached to a particular design or concept.
7. **Risk of Misinterpretation:** Stakeholders may misinterpret the purpose of a prototype, thinking it represents the final product, which can lead to unrealistic expectations.
8. **Cost of Tools and Equipment:** Utilising advanced prototyping tools and equipment can be expensive, especially for small businesses or start-ups.
9. **Material Problems:** Most rapid prototyping techniques have a limited material range. Prototypes may also exhibit reduced material properties like surface finish and strength.
10. **Skilled labour:** Rapid prototyping requires skilled labour.

Learning Tasks

1. Learners make a diamond-nine arrangement of the advantages and disadvantages of rapid prototyping.
2. Learners debate on the advantages and disadvantages of rapid prototyping.
3. Learners make presentations on the advantages and disadvantages of rapid prototyping. create rapid prototypes of simple products using 3D printers.

Pedagogical Exemplars

1. **Diamond-nine activity:** Provide learners in mixed-ability groups with cards having varying levels of complexities (for instance, some cards can have straightforward advantages or disadvantages while others may present more technical advantages and disadvantages) on the advantages and disadvantages of rapid prototyping. Let learners with difficulties in understanding the concept choose straightforward cards and encourage proficient learners to choose more technical cards. Groups should be formed to have learners of different proficiency levels and provide specific tasks, such as leader, recorder, presenter etc., to learners in each group to ensure that all learners are participating in the activity. Furthermore, make room for groups to select their preferred diamond-nine presentation format such as oral presentations, poster displays or digital slide presentations.
2. **Talk for learning:** Divide the class into two main groups with one group supporting rapid prototyping and the other group as critics of rapid prototyping. Facilitate a structured debate where students in each group present arguments to support their stand. Encourage learners to support their arguments with examples and engage in respectful discussions. Assign and rotate roles such as timekeepers, researchers and debaters to learners in each group to ensure that all learners participate in the debate. Encourage learners who are not good with public speaking to play active roles in writing their views and sharing with their groups. Provide learners with resources or direct them to sources where they can find more information to help in the debate. Provide a safe, supportive and all-inclusive environment where students feel comfortable to contribute to the debate.
3. **Research-based learning:** Learners in mixed-ability groups read from the library on the advantages and disadvantages of rapid prototyping and present their findings in class to receive feedback from their colleagues. Consider different abilities of learners when forming the groups

to ensure that learners with difficulties understanding concepts benefit from their colleagues who are more proficient. Provide learners with additional learning resources such as articles, videos and internet sources to help them in their search. Accept oral reports or webbings from learners approaching proficiency. Encourage proficient and highly proficient learners to present detailed written reports, blogs, video or PowerPoint presentations.

Key Assessment

Assessment Level 1

1. Which of the following is a disadvantage of rapid prototyping?
   a. Reduced time-to-market
   b. Lower prototyping costs
   c. Limited material options
   d. Higher surface quality in prototypes
2. List three (3) benefits of rapid prototyping.
3. Mention four (4) disadvantages of rapid prototyping.

Assessment Level 2

1. State one advantage of rapid prototyping and explain why it is beneficial to project development.
2. Explain why not using any tools in rapid prototyping is an advantage.
3. Describe how one disadvantage of rapid prototyping can be addressed to reduce its impact on product development.

Assessment Level 3

1. Explain the reasons for the rough surface finish of products designed using rapid prototyping.
2. Discuss how advancements in rapid prototyping have helped address the limitations of traditional prototyping techniques.
3. Discuss the impacts of rapid prototyping on product development, considering its advantages.
4. Discuss the suitability of using rapid prototyping in the development of products for different industrial applications such as medical devices, electronic devices and automotive components.

Assessment Level 4

1. Evaluate the role of rapid prototyping in promoting innovation and competitiveness in the manufacturing industry.
2. Assess the potential problems and benefits associated with the integration of rapid prototyping into conventional manufacturing processes.

Week 16

Learning Indicator: *Discuss the applications of rapid prototyping in manufacturing.*

Theme or Focal Area: Applications of Rapid Prototyping in Manufacturing

Introduction

Rapid prototyping helps validate the feasibility of a design and verify that a design meets the desired requirements and specifications. It is essential in product development, customisation, concept modelling, production of end-use parts, reverse engineering and rapid manufacturing. This lesson discusses the application of rapid prototyping in product development.

Applications of Rapid Prototyping

Concept models and validation

Rapid prototyping allows for the development of physical concept models of future products. These concept models allow engineers and designers to test and validate their ideas. It also provides the opportunity for engineers and designers to explore the functionality of their initial concepts and demonstrate their validity to stakeholders for the approval of the development of the product.

Functional Prototyping

Engineers use rapid prototyping to produce prototypes of various designs. These prototypes, which are closely related to the final products, help engineers and designers to accelerate their product development cycle through testing and evaluation. This allows designers and engineers to refine their designs based on real-life performance data to ensure better product performance. For example, automobile manufacturing companies use rapid prototyping to create concept cars and test new designs and features before going into full production; components like engine parts, interior features and exterior panels can be rapidly prototyped to evaluate their performance and fit.

Customisation and Personalisation of Products

Rapid prototyping helps in the production of customised and personalised products specific to individual preferences and requirements. This is extremely important in the medical, footwear and consumer goods industries where products need to be designed specifically for an individual. For instance, surgeons use rapid prototyping to create patient-specific implants for bone reconstruction, craniofacial surgeries, dental procedures, prosthetic limbs and other medical devices that fit patients perfectly; shoe manufacturing companies can create prototypes of different sole designs to evaluate comfort, support and performance and also create footwear tailored to an individual's foot shape and preferences.

Tooling and Jigs

Rapid prototyping is used to create specialised tools, jigs and fixtures that aid in the manufacturing process. These tools can be produced quickly and cost-effectively, enhancing production efficiency.

Iterative Design

Rapid prototyping helps designers to easily iterate and refine their designs multiple times in a shorter span, leading to faster innovation and improvement of products.

Creation of Complex Geometries

Rapid prototyping allows for the creation of intricate and complex geometries that would be challenging or impossible to produce using traditional methods. This is particularly beneficial in industries like aerospace and medical devices.

Spare Parts Production

Maintenance and service industries such as the automotive and aerospace industries use rapid prototyping to quickly and efficiently produce spare parts for their maintenance and repair services.

Education and Training

Rapid prototyping is used in educational institutions and training programmes to teach students about product design, manufacturing processes and hands-on problem-solving.

Learning Tasks

1. Learners make presentations on the industrial applications of rapid prototyping.
2. Learners develop prototypes using 3D printing.

Pedagogical Exemplars

1. **Talk for learning:** Provide learners with articles, textbooks or videos on the applications of rapid prototyping. Place learners in groups, with each group representing an industry (such as the automobile, engineering, manufacturing, building, food and clothing industries) and let each group make a presentation on the applications of rapid prototyping in their representative industries. The groups should be formed such that each group has learners of different skills and abilities. Also, assign tasks (such as researcher, recorder, leader, organiser, etc.) to learners in each group to ensure that all learners contribute to the tasks. Encourage peer-to-peer teaching and cooperative learning to help learners with varying levels of understanding. Allow learners to select their preferred mode of presentation, such as oral presentation, webbings, mind maps, written reports, video presentations, PowerPoint presentations, etc. However, encourage learners who are proficient to make individual reports. Further, create a conducive environment to ensure that all learners contribute to the discussions. Encourage learners who are not vocal to write their comments.
2. **Project-based learning:** Provide learners with components used in varying industries such as the automobile, engineering, manufacturing, building, food and clothing industries.
3. Let learners in groups select a component from the given components and make prototypes of their choice using 3D printing. Allow learners present their prototypes through written reports, PowerPoint presentations, video presentations or oral presentations, indicating the process used and the challenges encountered during the prototyping process. Groups should be formed such that others will help learners who have difficulties understanding and performing the task. Further, challenge highly proficient learners to perform tasks individually.

Key Assessment

Assessment Level 1

1. List four (4) industries that apply rapid prototyping in their work.
2. Mention two (2) applications of rapid prototyping in the automobile industry.
3. Describe one of the ways rapid prototyping is used in the medical industry.
4. In which of the following industries is rapid prototyping mostly used?
   a) Automotive
   b) Retail
   c) Banking
   d) Fishing

Assessment Level 2

1. Explain how rapid prototyping can be used to enhance the work of a manufacturing engineer.
2. Describe one typical application of rapid prototyping in the automotive industry.
3. Explain the role of rapid prototyping in the architectural industry.

Assessment Level 3

1. Discuss the benefits the local automotive and manufacturing industries can derive from using rapid prototyping.
2. Discuss how rapid prototyping can positively impact the local clothing industry.
3. Analyse the ethical problems associated with the application of rapid prototyping in the medical industry.

Assessment Level 4

1. How can rapid prototyping be applied in the local manufacturing and automobile industries?
2. Evaluate the economic impact of rapid prototyping on the local manufacturing industry.
3. Evaluate the potential effects of the widespread applications of rapid prototyping on the society.

Section Review

This section introduced learners to the rapid prototyping process. The section discussed the similarities and differences between conventional and rapid prototyping processes. The principles, processes, advantages, disadvantages and application of rapid prototyping processes were also discussed. The lessons learnt from the section can be summarised as below:

1. Conventional prototyping relies on traditional manufacturing techniques and can be time-consuming and costly. However, it offers a wide range of materials and versatility.
2. Rapid prototyping leverages technology to create prototypes quickly and cost-effectively, making it ideal for iterative design and complex geometries.
3. The process of rapid prototyping includes the creation of a 3D (CAD) model of the part to be designed, conversion of the CAD model into a Standard Tessellation Language (STL) file format, slicing of the STL file into thin layers and sections, construction of the part layer by layer and post-processing of the part (cleaning, joining, finishing etc.).
4. Rapid prototyping offers many benefits, such as speed, cost savings and improved communication.
5. It also has drawbacks related to functionality limitations, resource demands and potential for misinterpretation.
6. Successful implementation of rapid prototyping requires careful planning, clear communication and a focus on balancing speed with quality.
7. Rapid prototyping has wide industrial applications including the automotive, medical, footwear, educational industries, etc. for the validation of a design's feasibility to ensure that the design meets the desired requirements and specifications.
8. Rapid prototyping is essential in product development, customisation, concept modelling, production of end-use parts, reverse engineering and rapid manufacturing.

Additional Reading Materials

1. Kalpakjian, S., & Schmid, S. (2020). Manufacturing Engineering & Technology (8th ed.). Pearson.
2. Gibson, I., Rosen, D.W., & Stucker, B. (2014). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing (2nd ed.). Springer.
3. Simpson, T.W., Yu, J., & Jiao, J. (2020). Design for Additive Manufacturing: Guidelines and Applications for Industrial 3D Printing. CRC Press.
4. Chua, C. K., Leong, K. F., & Lim, C. S. (2010). Rapid Prototyping: Principles and Applications (2nd Edition). World Scientific Publishing.
5. Jacobs, C. S., & Rosen, D. W. (2007). Practical Guide to Rapid Prototyping. Society of Manufacturing Engineers (SME).

References

1. Kalpakjian, S., & Schmid, S. (2020). Manufacturing Engineering & Technology (8th ed.). Pearson.
2. Gibson, I., Rosen, D.W., & Stucker, B. (2014). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing (2nd ed.). Springer.
3. Simpson, T.W., Yu, J., & Jiao, J. (2020). Design for Additive Manufacturing: Guidelines and Applications for Industrial 3D Printing. CRC Press.
4. Chua, C. K., Leong, K. F., & Lim, C. S. (2010). Rapid Prototyping: Principles and Applications (2nd Edition). World Scientific Publishing.
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SECTION 5: PRINCIPLES OF MARKING OUT, MEASUREMENT AND GAUGING

Strand: **Manufacturing Tools, Equipment and Processes**

Sub-Strand: Manufacturing Tools and Equipment

Learning Outcome: *Apply the principles of marking out, measurement and gauging; and accurately use industry standards in manufacturing a product*

Content Standard: Demonstrate knowledge and understanding of standards, measurement and gauging in the manufacturing process

INTRODUCTION AND SECTION SUMMARY

Section five (5) introduces learners to the principles of marking out, measurement and gauging, which is a precursor and an integral part of the product development process.

Learners will be introduced to the principles of setting datums for workpieces and the selection of coordinate systems when dimensioning objects. Learners will understand the processes involved in marking out workpieces, the standard units of measurement and their applications. The section has hands-on activities to help learners practice how to make a workpiece, standard units of measurement conversions and the use of measuring instruments and gauges. At the end of the section, learners will be equipped with practical skills that will enable them to appreciate the relevance of setting up datums on workpieces, marking out workpieces, measurement and gauging in manufacturing engineering.

The section covers the following weeks:

Week 17: **Setting datum for a workpiece and selecting coordinate systems when dimensioning objects**

Week 18: **Mark out a workpiece**

Week 19: **Standard units of measurement**

Week 20: **Measuring dimensions using gauges**

SUMMARY OF PEDAGOGICAL EXEMPLARS

Being mindful of the different backgrounds, learning styles and learning capacities of learners, varying pedagogical approaches should be used to ensure that all learners benefit from the lessons. Pedagogical exemplars such as talk for learning, project-based learning, research-based learning, collaborative learning, the diamond-nine and experiential learning approaches should be adopted to meet the different learning capacities and styles of learners. Consider providing learners with the opportunity to practice setting datums on workpieces, marking out workpieces, standard units of measurement conversions, measurement reading using instruments and gauges.

ASSESSMENT SUMMARY

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions; written responses of various difficulty levels appropriate for the class can also be requested from learners relative to the major concepts in this section. Projects that allow learners to develop prototypes using rapid prototyping techniques should be encouraged. At the end, learners should be able to demonstrate understanding of the principles of setting up datums on workpieces, marking out on workpieces, measurement and gauging in manufacturing engineering. These should contribute to learners’ formative assessment.

Week 17

Learning Indicator: *Set the datum for a workpiece and select coordinate systems for dimensioning an object.*

Theme or Focal Area: Setting Datum for a Workpiece and Selecting Coordinate Systems When Dimensioning Objects

Introduction

A datum is used to establish a reference position from which all dimensions are taken on a workpiece. It helps to set the reference point used to establish the coordinate system for measurement and tolerance. Datum and coordinate systems are necessary for ensuring accurate design and production of objects. This lesson discusses how to set the datum for a workpiece and select coordinate systems when dimensioning objects.

Datum

A datum helps to establish a reference position from which all dimensions are taken and all measurements made. A datum may be a point, an edge or a centreline, depending on the shape of the workpiece. For any plane surface, two datums are required to position a point and these are usually at right angles to each other. The selection of a datum depends on the part's function and intended use and can be influenced by the functional requirement of the product, features of the parts, stability, and the manufacturing process. A chosen datum should accurately represent the part's orientation. Point datum, edge datum and centreline datum are commonly used in most manufacturing processes.

Point Datum

A point datum is a fixed and predetermined location on the workpiece that is established when setting up a workpiece for a machining operation. The datum is fixed and serves as the reference point for all measurements and dimensioning during the manufacturing process. In many applications, such as in CNC machining and metrology, a point datum is used as the origin (0,0,0) of a coordinate system from which other measurements and dimensions are defined to ensure precision during the manufacturing process. An example of a point datum is shown in Fig, 17.1. Point datums are often marked using standard symbols on engineering drawings and workpiece surfaces. These markings help technicians to locate and reference the point datum during setup and machining processes.

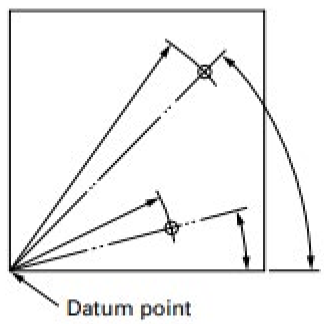


Fig. 17. 1: *An example of a point datum*

Edge Datum

An edge datum refers to a specific edge or surface on a workpiece that serves as a reference for measurement, alignment or machining operations to ensure accuracy and repeatability in machining operations as shown in Fig. 17.2. An edge datum can also be used as a reference plane in a coordinate system to help define the orientation and position of the workpiece or features relative to the axes of the machine. Standard symbols and markings are made on engineering drawings and the surfaces of workpieces to denote edge datum. These help machinists to locate the edge datum that serves as a guide when setting up the machine tool or workpiece and performing machining operations. Edge datum is also used in assembly and alignment processes to ensure proper fit and functionality of machine components.

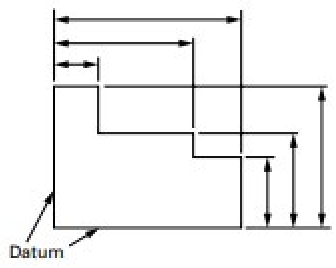


Fig. 17.2: *An example of edge datum*

Centreline Datum

A centreline datum is an imaginary line or axis that runs through the centre of a cylindrical or symmetrical workpiece as shown in Fig, 17.3. It serves as a reference for measurement, alignment and machining operations, especially when machining symmetrical components such as shafts, cylinders and rotational parts. It defines the central axis around which these components are symmetrically balanced. The centerline datum serves as a reference for aligning and orienting the workpiece or tooling during the setup and machining operations. An accurate establishment of the centreline datum is significant for achieving dimensional accuracy and consistency in manufacturing processes.

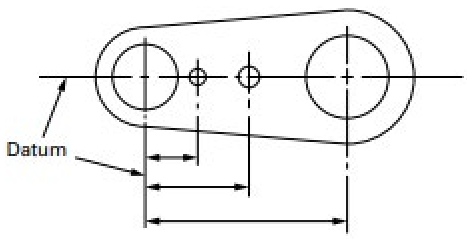


Fig. 17.3: *An example of a centre line datum*

Coordinate System and Dimensioning

Coordinate systems are used to define the position and orientation of the workpiece. The Cartesian coordinate or rectangular coordinate system, with X, Y, and Z axes, is commonly used when dimensioning a workpiece. In this case, the dimensions are taken relative to the datums at right angles to each other. Other coordinate systems, such as polar cylindrical or spherical coordinates, can be used in special cases.

Origin Point: The origin is the intersection point of the axes (0,0,0). This is the starting point for all measurements and dimensioning on the workpiece.

Learning Tasks

1. Learners dimension a workpiece using the Cartesian coordinate system.
2. Learners set up suitable point, edge and centreline datum for different workpieces.

Pedagogical Exemplars

1. **Talk for learning:** Provide learners with resources (such as videos, textbooks, physical workpieces or internet sites) on setting out a datum and selecting coordinate systems. Provide additional resources, such as simplified notes, to learners who will need help, and advanced textbooks to proficient learners. Facilitate a class discussion on the concept of datum setting and coordinate systems based on students' understanding after going through the resources provided. Ensure that a friendly environment is created for all learners participate in the discussion. Allow learners who are not vocal to contribute by writing, and ensure that few learners do not hijack the discussion session. Provide leading questions to proficient learners. After the discussion, place learners in mixed groups to make presentations on the setting out of datum and selection of coordinate systems when manufacturing a product. Assign specific roles to learners in each group to ensure that all learners participate in the process. Allow each group to select their mode of presentation such as oral presentation, written reports, video presentation, or PowerPoint presentation. Encourage proficient and highly proficient learners to provide individual written reports.
2. **Project-based learning:** Divide students into mixed-ability groups and assign each group a specific engineering task or component to design. Provide guidelines and resources for project planning, such as templates, timelines and research materials. Also, encourage each group to assign specific roles to each learner to ensure that all learners participate in the project. Encourage each group to develop a plan for selecting a datum and coordinate systems based on the project requirements. Also, provide opportunities for hands-on experimentation with different datum and coordinate system configurations using physical models. Plan a project presentation session where each team presents their design project and explains their approach to setting the datum and coordinate systems. Allow each group to select their mode of presentation through engineering drawings, CAD models, written reports, video presentations or PowerPoint presentations.

Key Assessment

Assessment Level 1

1. List the different ways to set out a datum on a workpiece.
2. What is the primary purpose of establishing a datum on a workpiece in engineering and manufacturing processes?
3. Write down the fundamental principle guiding the setting out of a datum on a workpiece.
4. Briefly explain the importance of applying the Cartesian coordinate system in product manufacturing and development.

Assessment level 2

1. What is the primary purpose of establishing a datum on a workpiece when manufacturing a product?
2. Describe the process of setting out datums on a workpiece, ensuring their alignment with design specifications and tolerance requirements.
3. List the different ways to set out a datum on a workpiece.

4. Describe the key considerations for selecting datum features based on their geometric characteristics and functional requirements.

Assessment Level 3

1. Explain how coordinate systems contribute to the dimensioning of workpieces.
2. Explain how the setting out of a datum on a workpiece affects the drawing of points on a graph sheet.
3. How can you verify the accuracy of a selected coordinate system and reference datum before undertaking a machining operation?
4. How relevant is the setting out of a datum on a workpiece to the fabrication of products?

Assessment level 4

1. Explain how to set out a datum to mark out a rectangular shape on a workpiece using the centreline method and polar coordinate system of dimensioning
2. In what scenarios would you employ Cartesian coordinate systems or polar coordinate systems for dimensioning objects, and why?
3. What are the advantages and disadvantages of using Cartesian coordinate systems compared to other coordinate systems in precision engineering?
4. How do you handle situations where there are conflicting requirements for datum selection based on different manufacturing processes or inspection methodologies?

Week 18

Learning Indicator: *Produce a mark out on a workpiece.*

Theme or Focal Area: Design Mark Out on a Workpiece

Introduction

Marking out is the process of accurately and precisely transferring design information onto the surface of a workpiece before any machining or fabrication takes place. This is made possible using measuring and marking out tools. This lesson discusses the tools that are used when marking out and the marking out process.

Marking-out tools

Marking-out tools generally comprise measuring tools and scribers. The measuring tools are used to provide guidelines and accurate measurements for the marking-out process. Some measuring tools include straight edges, dividers, callipers, steel squares, combination squares and many more. These measuring tools are used together with scribers to mark out design geometries on a workpiece.

Straight edge

It is used when marking out a straight line between two points. It is also used together with squares to draw lines at right angles.

Fig. 18.1: *Straight edge tool*

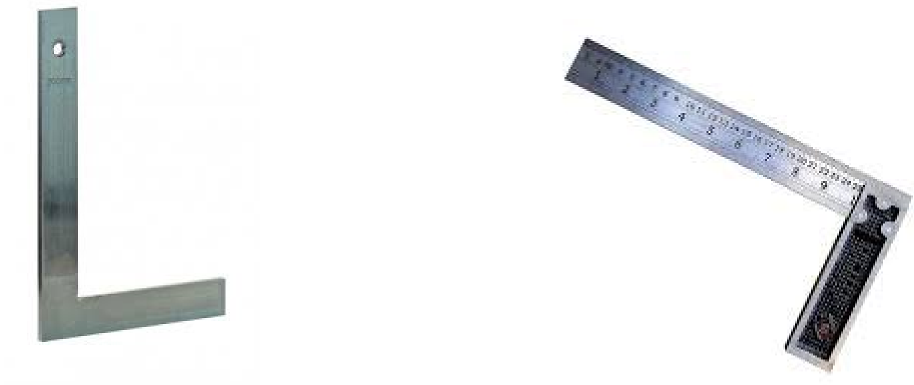
Divider

Dividers are used to mark out shapes onto sheet metals. They work best if a small indent is placed on the sheet metal using a centre punch for one of the legs to rest in.

Fig. 18.2: *Divider*

Steel square

The flat steel square and steel try square are used to lay out right angles (90°) and can also be used as a scale. They are important tools for accurate layout work in pattern drafting and come in various sizes.



(a) (b)

Fig. 18.3: *(a) Flat steel square and (b) Steel try square*

Callipers

Callipers can be inside or outside callipers. Inside callipers are used to measure the diameter of holes or widths of keyways and slots. Outside callipers are used to measure the outside dimensions of either a flat or round stock. It may also be used to check the parallelism of surfaces.

(a) (b)

Fig. 18.3 (a) Inside calliper and (b) Outside calliper)

Scriber

Scribers are used together with steel squares and straight edges to mark lines on a worksheet. They are generally made of steel with one end straight and the other end bent at right angles.

Fig. 18.4: *Scriber*

Combination set

The combination set is important when making and taking measurements on a workpiece. It has four main parts namely: the steel rule, square head, protractor head and centre head. The steel rule is used in measuring lengths, widths and depths of workpieces; the square head is used for measuring and marking out perpendicular lines and right angles on a workpiece; the protractor head is used for measuring and marking angles; the centre head is used to locate the centre of cylindrical and circular workpieces.

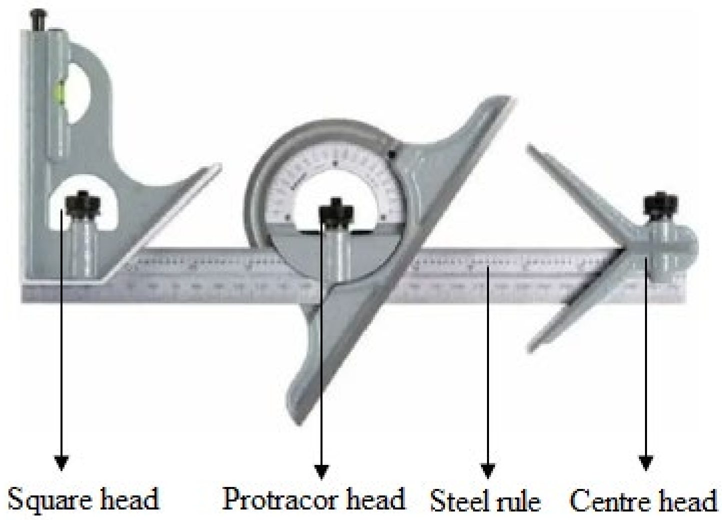


Fig. 18.5: *Combination set*

Steps for marking out on a workpiece

1. Understand the engineering drawing or design specifications of the workpiece. This will help you understand the dimensions, tolerances and features that need to be marked on the workpiece.
2. Select the appropriate marking-out tools based on the material of the workpiece and the required precision. Always ensure that marking tools are clean and properly calibrated.
3. Clean the surface of the workpiece to remove any dirt, debris or oil to ensure proper adhesion of the markings and prevent errors.
4. Identify the reference points or features that need to be marked. These might include hole centres, edges, corners, curves and intersections.
5. Accurately transfer measurements from the engineering drawing to the workpiece using the selected marking tools.
6. Double-check all measurements and reference points to avoid mistakes before continuing the marking-out process.
7. Mark out areas of the workpiece that require cutting, machining or drilling. Clearly indicate all dimensions and locations where material needs to be removed.
8. Mark out the necessary points that need alignment or symmetry to ensure accurate assembly or fitting.
9. Inspect all mark-out areas to ensure clarity and accuracy. Make changes where necessary.
10. Consider protecting your markings with marking pens or tapes to ensure durability and avoid the markings being erased.

Tolerance

Tolerance refers to the permissible deviation from a specified dimension in manufacturing processes. There are two main types of tolerance: dimensional tolerance and geometric tolerance. Dimensional tolerance specifies the allowable difference in linear dimensions, such as length, width and thickness, while geometric tolerance specifies the allowable difference in geometric features, such as form, profile, orientation and location.

In a marking-out operation in the workshop, tolerance plays a crucial role in ensuring that components fit together correctly, meeting functional requirements and dimensional constraints. Tolerance impacts the standardisation of parts or assemblies, affecting manufacturing costs significantly. Proper tolerance allocation is essential to control the accumulation of deviations across multiple machining operations called tolerance stack-up. It is essential to measure and verify dimensions against the specified tolerances using precision measuring tools such as callipers, micrometres or height gauges during a marking out process. Checking dimensions and tolerances at various stages of marking out helps identify any discrepancies early on, allowing adjustments to be made before machining or fabrication begins.

Information on tolerance is mostly provided on engineering drawings using standardised symbols, abbreviations and tolerancing methods. Specifications of tolerance must be accurately interpreted and applied during marking out to achieve the desired level of precision and quality in the final product. It is important to consider how individual tolerances stack up during marking out, to ensure that the cumulative variation remains within acceptable limits for the overall assembly. Effective tolerance management ensures product quality, functional capability, manufacturability and cost-effectiveness in the production process.

Learning Tasks

1. Learners make presentations on marking out tools and their uses in product manufacturing.
2. Learners mark out and cut rectangular, cylindrical and conical shapes from metal sheets using the necessary marking-out tools.

Pedagogical Exemplars

1. **Talk for learning:** Perform a live demonstration of a marking out process on a workpiece and invite learners to observe. Introduce learners to the marking-out tools used and explain each marking-out process to the learners. Encourage learners to ask questions as the demonstration progresses and invite learners to try their hands on the marking out process. Afterwards, put learners in groups to make presentations on marking out tools and their uses in the manufacturing industry. Be intentional when forming groups to ensure peer-to-peer learning. Provide additional resources such as videos, textbooks, posters or an internet resource to help learners who have difficulties understanding the concept. Encourage groups to assign roles to ensure that each learner participates in the process. Allow learners to select their presentation format such as webbing, posters, mind maps, oral presentations or written reports. Encourage proficient learners to mark out a rectangular, cylindrical or circular shape on a workpiece and include that in their presentation.
2. **Experiential learning:** Set up multiple marking stations in the classroom or workshop, each equipped with different types of workpieces (e.g., wooden blocks, metal plates), marking tools and geometries (rectangular, cylindrical or conical) to be cut. Put learners in mixed-ability groups and let each group rotate among the marking stations to mark out and cut the necessary geometry in each station using the workpiece and the right marking tool at each station. Provide help and guidance to learners as they rotate among the stations and perform the marking out

process. Encourage learners in each group to collaborate with peers, share insights and solve problems together as they explore different marking challenges. After the activity, allow learners to select a mode of presentation that suits their interest to present their marked-out workpieces to the class, explaining the tools and processes used to mark out each geometry. Encourage non-vocal learners to present their results in writing. Encourage proficient learners to mark out complex shapes and provide written reports on the marking out tools and processes used.

Key Assessment

Assessment Level 1

1. Name two common methods used for marking out on a workpiece.
2. List the parts of a product that can be marked out on a worksheet.
3. What tools are commonly used for marking out on metal workpieces?
4. Briefly describe how an incorrect marking out on a workpiece can lead to errors in a machining process.

Assessment Level 2

1. What factors should be considered when selecting an appropriate marking-out tool for a metal sheet workpiece?
2. In what situations would a marking gauge be used instead of a ruler or tape measure for marking out on a workpiece?
3. Explain the importance of using a datum during the marking out process.
4. How will you ensure consistency and accuracy when transferring dimensions from a technical drawing to a workpiece during marking out?

Assessment Level 3

1. Explain the importance of marking out in the manufacturing industry.
2. How does the choice of marking technique vary based on the material properties and machining processes involved?
3. Discuss the strategies that can be used to minimise human error and variability in manual marking-out processes.
4. Propose an innovative marking-out methodology that can ensure precision manufacturing in the local manufacturing industry.

Assessment Level 4

1. How can markings made with pens or tapes on a workpiece be protected to ensure that the markings are not erased during the manufacturing process?
2. How can the principle of marking out help avoid mistakes and wastage of materials in manufacturing?
3. Evaluate the effectiveness of different marking tools in achieving precise and accurate marking-out results on different workpieces, such as wood, metal or plastic.
4. Analyse the importance of precision and accuracy in marking out on a workpiece, considering its impact on the overall quality of a finished product.

Week 19

Learning Indicator: *Understand standard units of measurement for workpieces.*

Theme or Focal Area: Standard Units of Measurement

Introduction

Standard units of measurement serve as the foundation for quantifying and comparing physical quantities across various fields and disciplines. These standardised units provide a common language for expressing measurements, enabling precision, consistency and accuracy in scientific, industrial and everyday applications. From the length of a ruler to the weight of a package, standard units provide a universal framework for communication and understanding. In this lesson, we delve into the significance and practical applications of standard units of measurement, examining their role in facilitating commerce, engineering, science, manufacturing and everyday life. The common standard units used in measuring workpieces include those for measuring the length, diameter and angle of workpieces.

Systems of Measurements

The systems of measurement are groups of units of measurement and conventions (rules) relating to each other. Systems of measurement are important in science, commerce, industry and everyday life. There are several systems of measurement used around the world. Some of the most common systems of measurement used in manufacturing include the metric system/ international system of units (SI), US customary systems and imperial system. Table 19.1 shows some basic units of measurement for imperial and metric systems.

a) Metric System/ International System of Units (SI): This is the most widely used system of measurement globally. It's a decimal-based system, meaning all units relate to each other by factors of 10. This makes it incredibly convenient for calculations and conversions. It is a coherent system based on seven fundamental units: metre (length), kilogramme (mass), second (time), ampere (electric current), kelvin (temperature), mole (amount of substance) and candela (luminous intensity). All other units in the SI system are derived from these fundamental units.

b) US Customary System: This system is primarily used in the United States and to a lesser extent in Liberia and Myanmar. It uses units like inches, feet, miles, pounds, ounces, gallons and Fahrenheit for temperature.

c) Imperial System: This system is historically based on the British Imperial System and is still used in some countries formerly part of the British Empire, such as Ghana (commonly used in most industries but rarely used in educational institutions), Canada and historically in the United Kingdom. It has units similar to the US Customary System but with some variations.

The imperial system has a single set of units for fluid ounces, pints, quarts and gallons whereas the US system has two sets of volume units: one for dry goods (cups, pints, quarts, gallons) and another for liquids (fluid ounces, pints, quarts, gallons). The size of a US fluid ounce is slightly larger than an imperial fluid ounce.

Table 19.1: *Basic units of measurement for imperial and metric systems*

Unit of Measurement	System of Measurement	
	Metric System (SI Units)	**Imperial System**
Length	Millimetre (mm)	Inch (in)
	Centimetre (cm)	Foot (ft)
	Meter (cm)	Yard (yd)
	Kilometre (km)	Mile (mi)
Mass	Milligramme (mg)	Ounce (oz)
	Gramme (g)	Pound (lb)
	Kilogramme (kg)	Stone (st)
	Tonne (t)	Ton (short ton)
Volume	Millilitre (ml)	Fluid ounce (fl oz)
	Litre (l)	Pint (pt)
	Cubic centimetre (cc or cm^3)	Quart (qt)
	Cubic metre (m^3)	Gallon (gal)

Line and End Measurements

Sometimes, distances must be measured between two lines, two surfaces, between a line and a surface or between two points. When the distance between two engraved lines is used to measure the length, it is called line standard or line measurement. An example of standard line measurement is the use of a ruler or a tape measure to determine the length of an object in inches, centimetres or millimetres. The rule with divisions marked with lines is widely used. When the distance between two flat parallel surfaces is considered a measure of length, it is known as end standard or end measurement. The end standards are extensively used for precision measurement in workshops. The most common examples are measurements using slip gauges, end bars, ends of micrometre anvils, Vernier callipers, etc. For an accurate measurement, it is necessary to select a measuring device that suits a particular measuring situation. For example, for a direct measurement of the distances between two edges, a rule is not suitable because it is a line-measuring device. Table 19.2 compares line measurements and end measurements.

Table 19.2: *Comparison between line and end measurements*

Characteristics	Line standard	End standard
Principle of measurement	Distance between two engraved lines is used as a measure of length	Distance between two flat and parallel surfaces is used as a measure of length
Accuracy of measurement	Limited accuracy of ±0.2 mm; magnifying lens or microscope is required for high accuracy	High accuracy of measurement; close tolerances up to ±0.0005 mm can be obtained
Ease and time of measurement	Measurements made using a scale are quick and easy	Measurements made depend on the skill of the operator and are time-consuming

Characteristics	Line standard	End standard
Wear Markings on the scale are not subjected to wear.	Wear may occur on leading ends, which results in under-sizing	Measuring surfaces are subjected to wear
Alignment	Alignment with the axis of measurement is not easy, as they do not contain a built-in datum	Alignment with the axis of measurement is easy, as they possess a built-in datum
Manufacture	The manufacturing process is simple	The manufacturing process is complex
Cost	Cost is low	Cost is high
Parallax effect	Subjected to parallax effect	No parallax error; their use depends on the feel of the operator
Wringing	Does not exist	Slip gauges are wrung together to build the required size
Examples	Scale	Slip gauges, end bars, ends of micrometre anvils, and Vernier callipers

Measurement of Length

Length is used to measure the dimensions of a workpiece, including its width, height and depth. It is fundamental for defining the size and shape of a part involving quantifying the distance between two points or the extent of an object along a straight line. The universal standard unit of length is the metre. However, the millimetre is used in most workshops due to the sizes of workpieces handled in the workshop. Steel rule, Vernier callipers, micrometres, tape measures and dial indicators are examples of instruments used to measure the length of a workpiece in the workshop. However, the selection of a specific measuring instrument for a given measurement task is contingent upon the requisite accuracy of the measurement. For example, the rule is not applicable for measuring a linear distance of 20.55 mm, given that its minimum measurable increment is 0.5 mm rather than 0.55 mm. Hence, in this case, the rule can accurately measure 20.5 and not 20.55 mm. Table 19.3 shows the conversion of length measurement between different units.

Table 19.3: *Length unit conversion*

Millimetre (mm)	1
Centimetres (cm)	0.1
Meters (m)	0.001
Kilometres (km)	0.000001
Inches (In)	0.03937
Feet (ft)	0.003281
Yards (yd)	0.001094
Miles (ml)	6.21e-07

Measurement of Diameter

Measurement of diameter involves calculating the distance across the widest part of a circular or cylindrical object. This concept represents a fundamental component of metrology, which finds application across a broad spectrum of disciplines such as engineering, manufacturing and scientific research. Diameter measurement is fundamental for assessing the size, shape and alignment of cylindrical components, such as pipes, shafts, bearings and cylinders. The instruments that are commonly used for measuring diameter include callipers, micrometres, dial indicators and specialised tools such as diameter tapes and bore gauges. These instruments allow for accurate and precise measurement of diameter, ensuring proper fit, alignment and functionality of cylindrical objects. In manufacturing, measurement of diameter is essential for quality control and process optimisation. This ensures that machined parts and components meet design specifications and tolerances.

Measurement of Angle

Measurement of angle involves quantifying the rotation or inclination between two intersecting lines or surfaces. Understanding and measuring angles is essential for design and manufacturing tasks. Angles are typically measured in degrees (°), radians (rad) or other units, depending on the application. A full circle is divided into 360 degrees, with each degree representing 1/360th of the circle's circumference. Radians, on the other hand, are based on the ratio of the arc length to the radius of a circle and are commonly used in trigonometry and calculus. Common instruments used for measuring angles include protractors, bevel protractors, combination squares, sine bars, angle blocks, goniometers, theodolites and digital angle finders. These instruments allow for accurate and precise measurement of angles, enabling tasks such as layout, alignment and geometric calculations. Proper calibration, technique and instrument selection are essential to ensure reliable and accurate angle measurements.

Measurement of Volume

Measurement of volume plays an essential role in various scientific, industrial and everyday applications. Volume refers to the amount of space occupied by a three-dimensional object or substance, and accurate measurement is essential for tasks ranging from scientific research and engineering design to manufacturing and commerce.

a) **Definition and Units:** Volume is typically measured in cubic units, such as cubic metres (m^3), cubic centimetres (cm^3), cubic inches (in^3) or litres (L). The choice of unit depends on the scale of the object or substance being measured and the desired level of precision.

b) **Direct Measurement:** The most straightforward method of measuring volume involves direct measurement using physical instruments such as graduated cylinders, beakers or volumetric flasks. These containers are marked with calibrated volume graduations, allowing the volume of liquids or bulk solids to be read directly from the scale.

c) **Displacement Method:** The displacement method is commonly used to measure the volume of irregularly shaped objects or substances. It involves immersing the object in a known volume of liquid (often water) and measuring the change in volume caused by the displacement of the liquid. The volume of the object is then calculated based on the difference in the initial and final volumes of the liquid.

d) **Geometric Formulas:** For regular geometric shapes such as cubes, spheres, cylinders and cones, volume can be calculated using specific geometric formulas derived from their dimensions. These formulas express volume as a function of length, width, height or radius, depending on the shape of the object.

Measurement of Mass

The measurement of mass is a fundamental aspect of metrology that plays a crucial role in scientific research, industrial processes, commerce and everyday life. Mass refers to the quantity of matter contained in an object, and accurate measurement is essential for tasks ranging from scientific experiments and manufacturing processes to trade and compliance with regulatory standards.

a) **Definition and Units:** Mass is typically measured in units such as grammes (g), kilogrammes (kg), ounces (oz), or pounds (lb). The choice of unit depends on the scale of the object being measured and the desired level of precision. The International System of Units (SI) defines kilogramme as the base unit of mass.

b) **Direct Measurement:** The most common method of measuring mass involves direct measurement using a balance or scale. Balances are calibrated instruments that compare the mass of an object to a standard mass, such as weights or calibration masses. The mass of the object is determined by achieving equilibrium between the unknown mass and the standard mass.

c) **Electronic Scales:** Modern electronic scales use load cells or strain gauges to measure the force exerted by an object due to gravity. This force is then converted into mass using calibration factors and displayed digitally. Electronic scales offer high precision and accuracy and are widely used in laboratory, industrial and commercial settings.

d) **Weighing Methods:** Different weighing methods are employed depending on the nature of the object being measured. For example, analytical balances are used for precise measurements of small masses in laboratory settings while platform scales are suitable for larger masses such as industrial materials or produce.

e) **Calibration and Traceability:** Calibration of weighing instruments is essential for ensuring accuracy and traceability in mass measurements. Calibration involves comparing the performance of a weighing instrument to a known standard and adjusting it if necessary to minimise measurement errors. Calibration procedures are typically conducted according to established standards and guidelines to maintain consistency and reliability.

f) **Density and Volume Relationships:** Mass measurements are often related to volume measurements through the concept of density, which is the mass of a substance per unit volume. By measuring both mass and volume, density can be calculated, providing valuable information about the composition and properties of materials.

Errors in Measurements

Errors in measurements refer to discrepancies between the measured value and the true value of a quantity being measured. These errors can arise from a variety of sources and can affect the accuracy, precision and reliability of measurement results. Understanding the different types of errors is essential for identifying and minimising their impact on measurement outcomes. Here's an overview of the types of errors in measurements:

a) **Systematic Errors**: Systematic errors are consistent and repeatable deviations from the true values that occur consistently in the same direction. These errors can result from flaws in measurement instruments, calibration issues, environmental factors or systematic biases in the measurement process. Systematic errors can lead to inaccuracies in measurement results that persist across multiple measurements and are not reduced by averaging.

b) **Random Errors:** Random errors are unpredictable fluctuations in measurement values that occur randomly and vary in magnitude and direction. These errors can result from factors such as fluctuations in environmental conditions, inherent variability in measurement instruments, or human factors such as inconsistent technique or observation. Random errors can be reduced by taking multiple measurements and averaging the results to minimise the effect of individual fluctuations.

c) **Instrumental Errors:** Instrumental errors are caused by deficiencies in the measurement instrument itself, such as inaccuracies in the scale readings, zero errors or miscalibrations. These errors can lead to systematic deviations from the true value and can be minimised through regular calibration and maintenance of measurement instruments.

d) **Observational Errors:** Observational errors occur due to limitations in human perception, judgment or interpretation during the measurement process. These errors can result from factors such as parallax, misreading of scale markings or subjective bias in recording measurement values. Observational errors can be minimised by ensuring proper training, standardising measurement procedures and using appropriate observational techniques.

e) **Environmental Errors:** Environmental errors are caused by fluctuations or variations in environmental conditions, such as temperature, humidity, pressure or electromagnetic interference. These factors can affect the performance of measurement instruments and lead to inaccuracies in measurement results. Environmental errors can be minimised by controlling environmental conditions, using temperature-stabilised measurement environments or applying correction factors based on environmental monitoring.

f) **Human Errors:** Human errors result from mistakes or oversights made by individuals involved in the measurement process, such as incorrect data entry, calculation errors or procedural mistakes. These errors can introduce inaccuracies and inconsistencies in measurement results and can be minimised through proper training, adherence to standard operating procedures and double-checking of measurements.

g) **Gross Errors:** Gross errors are large and obvious mistakes in measurement values that are often caused by equipment malfunction, procedural errors or human mistakes. These errors can be identified and corrected through careful inspection and validation of measurement data.

Learning Tasks

1. Learners make presentations on the standard units of measurement, explaining why these units of measurement are used in the manufacturing industry.
2. Learners measure the length, diameter, volume and mass of objects using respective measuring instruments and present their results in class.
3. Learners discuss the importance of using standard measurements (standardisation) in the manufacturing industry.

Pedagogical Exemplars

1. **Collaborative learning:** Provide learners with videos, textbooks, posters or internet resources on standard units of measurement. Assign learners in mixed-ability groups a set of measurement tasks such as measuring the length, diameter, volume and mass of objects. Encourage learners to work together to discuss measurement techniques, select appropriate measurement tools and record their measurements accurately. Foster collaboration by encouraging learners to share ideas, ask questions and help each other. Further, assign collaborative measurement projects that require learners to work together to solve real-world measurement problems. For example, learners could plan and conduct a measurement-based scavenger hunt around the school or community. Encourage learners to divide tasks, allocate responsibilities and collaborate on data collection, analysis and presentation. Let learners make presentations of their measurement results using a presentation model such as maps, webbings, oral presentations, written reports, PowerPoint presentations, etc. that best suits them. Ensure that non-proficient learners get help from colleagues to understand the concept of measurement while challenging proficient

learners to present individual written reports on errors that occurred in their measurements when undertaking the group tasks.

2. **Talk for learning:** Facilitate whole-class discussions where learners can share their thoughts, experiences and questions related to measurement. Pose open-ended questions that prompt students to reflect on the importance of standard units of measurement, discuss real-world applications and explore the challenges and complexities of measurement. Encourage students to listen actively to their peers, respond thoughtfully and build on each other's ideas to construct a deeper understanding collaboratively. Allow non-verbal speakers to contribute through writing and ensure that all learners contribute to the discussion.

Key Assessment

Assessment Level 1

1. List the dimensions of a workpiece that can be measured in the workshop.
2. What is the purpose of standard units of measurement in science and engineering?
3. Mention three commonly used standard units of measurement for length, mass and volume, respectively.
4. What is the standard unit of measurement for length and angles?
5. List five (5) examples of everyday objects or phenomena that can be measured using standard units of measurement.
6. Identify three (3) potential sources of error when using standard units of measurement, and how can they be minimised or corrected.

Assessment Level 2

1. Explain the concept of base units and derived units in the SI system, providing examples of each.
2. Discuss the advantages of using the metric system over other systems of measurement in scientific and engineering applications.
3. How is conversion done between different units within the same system of measurement, such as converting metres to kilometres or grammes to milligrammes?
4. Explain the difference between the metric system and the imperial system of measurement.
5. How important is standardisation in the local manufacturing industry?

Assessment Level 3

1. Explain why standard units of measurement are important in the manufacturing industry.
2. How do standard units of measurement contribute to the efficiency and consistency of manufacturing processes?
3. Explain the role of dimensional tolerances in specifying standard units of measurement for machined components in manufacturing.
4. How important is standardisation in the local manufacturing industry?

Assessment Level 4

1. How does the International System of Units (SI) contribute to the standardisation of measurement practices in global manufacturing industries, and what steps can be taken to ensure its universal adoption?
2. Compare and contrast the precision and accuracy of measurements obtained using analogue instruments (e.g., rulers, balances) versus digital instruments (e.g., digital callipers, electronic scales).

3. Describe the role of significant figures in representing the precision of a measured value and how they are determined in practice.
4. Describe the process of selecting appropriate measurement tools and techniques based on the dimensional characteristics and material properties of the workpiece in manufacturing.

Week 20

Learning Indicator: *Describe and use gauges to measure the dimensions of a workpiece*

Theme or Focal Area: Measuring Dimensions Using Gauges

Introduction

The use of gauges and instruments for the accurate measurement of the dimensions of a workpiece is important in manufacturing and engineering processes. Various types of gauges are designed to measure specific dimensions of a workpiece. Some of these gauges and their uses are discussed in the sections following. In the world of manufacturing and engineering, precision reigns supreme. Every component, assembly and final product must adhere to strict standards to ensure functionality, safety and reliability. Central to achieving these standards is the art and science of measurement. Among the array of tools available for this purpose, gauges stand out as essential instruments for capturing dimensions with unmatched accuracy. Measuring dimensions using gauges goes beyond mere numerical values; it's about ensuring adherence to specifications, identifying deviations and maintaining uniformity throughout the production cycle. Whether utilising basic hand tools or sophisticated electronic systems, gauges are available in diverse forms, each tailored to specific applications and precision requirements.

Micrometre

A micrometre is a precision instrument used to measure dimensions with great accuracy, often to the nearest thousandth of a millimetre or micron (μm). A typical micrometre has parts as shown in Fig. 20.1 and explained below:

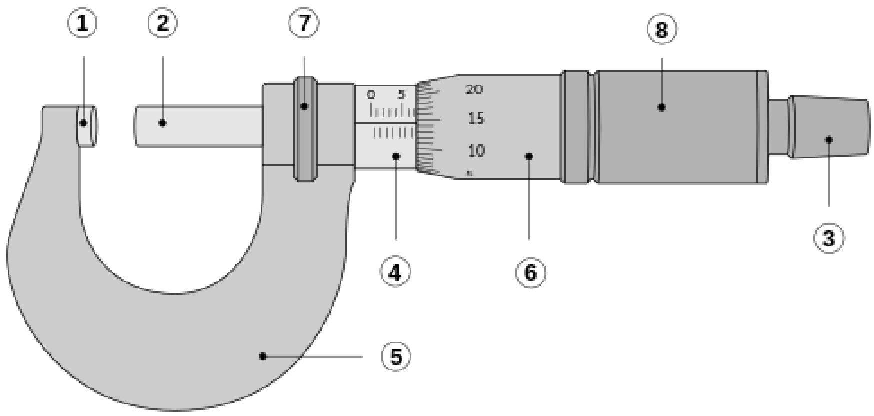


Fig. 20.1: *Parts of a micrometre*

1. **Anvil:** The shiny part that the spindle moves toward, and that the sample rests against.
2. **Spindle:** The shiny cylindrical component that the thimble causes to move toward the anvil.
3. **Ratchet stop:** Device on end of the handle that limits applied pressure by slipping at a calibrated torque.
4. **Sleeve, barrel or stock:** The stationary round component with the linear scale on it. In some instruments, the scale is marked on a tight-fitting but movable cylindrical sleeve fitting over the internal fixed barrel. This allows zeroing to be done by slightly altering the position of the sleeve.

5. **Frame:** The C-shaped body that holds the anvil and barrel in constant relation to each other. It is thick because it needs to minimise flexion, expansion and contraction, which would distort the measurement.
6. **Thimble scale:** Rotating graduated markings.
7. **Lock nut, lock-ring or thimble lock:** The knurled component (or lever) that one can tighten to hold the spindle stationary such as when momentarily holding a measurement.
8. **Thimble:** The component that one's thumb turns.

Steps in using the micrometre

1. Open the micrometre and ensure it's clean and calibrated.
2. Place the workpiece between the anvil (fixed jaw) and the spindle (moveable jaw).
3. Rotate the thimble (or digital display) to move the spindle until it touches the workpiece.
4. Make final adjustment using the Ratchet and tighten the lock nut.
5. Read the measurement from the scale or digital display.
6. To ensure accuracy, make several measurements at different locations and calculate the average.

Vernier Calliper

A Vernier calliper is a versatile measuring tool with both inside and outside jaws and a Vernier scale for high-precision measurements. It can measure external dimensions, internal dimensions and depth. Fig. 20.2 shows a Vernier calliper with labelled parts. The parts labelled are described below:

1. Outside large jaws: used to measure the external diameter of an object (like a hollow cylinder) or width of an object (like a rod) or the diameter of an object (like a sphere).
2. Inside small jaws: used to measure the internal diameter of an object (like a hollow cylinder or pipe).
3. Depth probe/rod: used to measure the depths of an object (like a small beaker) or a hole.
4. Main scale (Metric): marked every millimetre and helps to measure the length correctly up to 1 mm.
5. Main scale
6. (Imperial): marked in inches and fractions.
7. Vernier scale (Metric): gives interpolated measurements to 0.1 mm or better.
8. Vernier scale (Imperial): gives interpolated measurements in fractions of an inch.
9. Retainer: used to block movable part to allow the easy transferring of a measurement.

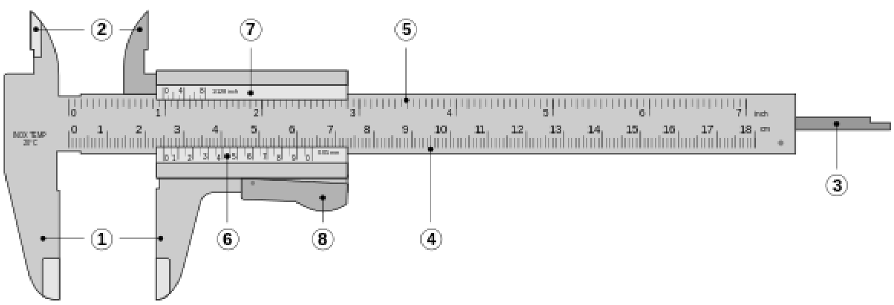


Fig. 20.2: *Parts of a Vernier calliper*

Using the Vernier calliper

1. Open the calliper and ensure it's clean and calibrated.
2. For external measurements, place the workpiece between the jaws, aligning it perpendicular to the jaws' axis.
3. Close the jaws gently until they touch the workpiece.
4. Read the measurement from the Vernier scale and the main scale.
5. For internal measurements, use the inner jaws.
6. For depth measurements, use the depth probe.

Reading from the Vernier calliper

To read the measurement readings from the Vernier calliper properly, you need to remember two things. For example, if a Vernier calliper outputs a measurement reading of 2.13 cm, this means that:

1. The main scale contributes the main number(s) and one decimal place to the reading (E.g., 2.1 cm, where 2 is the main number and 0.1 is the one decimal place number).
2. The Vernier scale contributes the second decimal place to the reading (E.g. 0.03 cm)

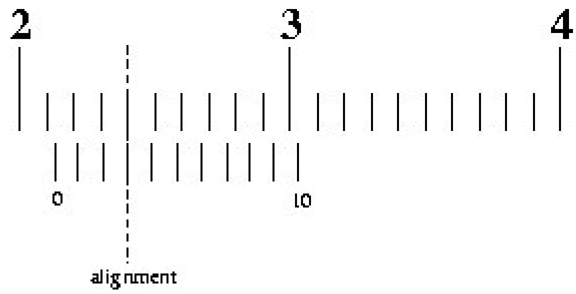


Fig. 20.3: *Sample reading from a Vernier calliper*

Let's examine Fig. 20.3 for the image of the Vernier calliper reading above. A two-step method can be used to get the measurement reading from this:

1. To obtain the main scale reading: Look at the image above. 2.1 cm is to the immediate left of the zero on the Vernier scale. Hence, the main scale reading is 2.1 cm.
2. To obtain the Vernier scale reading: Look at the image above and look closely for an alignment of the scale lines of the main scale and Vernier scale. In the image above, the aligned line corresponds to 3. Hence, the Vernier scale reading is 0.03 cm.
3. To obtain the final measurement reading, we will add the main scale reading and Vernier scale reading together. This will give 2.1 cm + 0.03 cm = 2.13 cm.

Angle gauge

An angle gauge, often referred to as a protractor or bevel protractor, is a tool used to measure angles in a workshop accurately. It is typically a semicircular or full-circle instrument with a calibrated scale, and it can be used for both internal and external angle measurements.

Using the angle gauge

1. Inspect and prepare the angle gauge. Ensure that it is clean.
2. Select the correct type of angle gauge.
3. Position the angle gauge on the workpiece in such a way that the centre point (the pivot point of the gauge) aligns with the vertex of the angle you want to measure.
4. Align one of the gauge's arms or blades with one of the lines forming the angle. Ensure that the blade lies along the line.

5. Read the angle measurement where the other arm or blade intersects the scale. This value represents the angle you are measuring.
6. Lock the gauge if necessary and record the measurement.
7. Double-check measurement to ensure accuracy.

Learning Tasks

1. Learners make presentations on different measuring gauges and their uses in the workshop.
2. Learners read micrometres, Vernier callipers and angle gauges.
3. Learners use micrometres, Vernier callipers and angle gauges to measure the length, diameter and angles of workpieces.

Pedagogical Exemplars

1. Collaborative learning: Make different 'Gauge Stations' in the classroom, with each station having a measuring gauge such as Vernier callipers, micrometre screw gauges and angle gauges. Provide demonstrative videos or charts or textbooks at each station that explain the uses of the measuring gauge in the workshop. Let learners in mixed-ability groups rotate around the stations and familiarise themselves with the measuring gauges and their use at the workshop. Ensure that learners of different capabilities are in each group to ensure peer-to-peer learning. Let learners make presentations on the measuring gauges and their use. Assign specific roles to learners in each group to ensure equal participation in the presentations. Allow learners to choose the mode of presentation that suits them ie. webbings, mappings, oral presentations, posters, written reports, PowerPoint presentations, etc. Encourage proficient learners to individually prepare written reports and PowerPoint presentations.
2. Experiential learning: In mixed-ability groups, let learners go around the 'Gauge Station' and use the measuring gauge in each station to measure the length, diameter and angles of a workpiece in the station. Form the groups to ensure that all learners have access to use the measuring instruments, and that slow learners have the opportunity to learn from other colleagues. Provide demonstrative videos or charts or textbooks at each station that explain how to read the measuring gauges. Let learners make presentations on the use of the measuring gauges to measure the length, diameter and angles of workpieces. Allow learners to use their own presentation format and challenge proficient learners to make individual presentations.

Key Assessment

Assessment Level 1

1. Which gauge is typically used to measure the gap width?
   a) Calliper
   b) Micrometre
   c) Feeler gauge
   d) Ruler
2. Which of the following gauges is NOT typically used to measure the diameter of a round workpiece?
   a) Vernier Calliper
   b) Micrometre
   c) Steel Ruler

d) Dial Gauge

3. A Vernier calliper can measure the internal dimensions of an object. (True/False)
4. What unit of measurement do most gauges use?
5. A Vernier calliper has two scales: a main scale and a Vernier scale. (True/False)
6. List two important things to consider when using a measuring gauge.
7. Matching: Match the following gauges with their descriptions:

Instrument	Instrument description
Vernier calliper	Uses a screw mechanism for precise measurement
Micrometre screw gauge	Has a sliding jaw with a Vernier scale for reading fractions of a millimetre
Dial gauge	Simple tool with a graduated scale for basic measurements
Steel rule	Instrument with a dial indicator for showing small displacements

Assessment Level 2

1. What is the purpose of using gauges for measuring dimensions in engineering and manufacturing?
2. Name two common types of gauges used for measuring dimensions and briefly describe their functions.
3. Explain the basic principles behind the operation of common gauges such as callipers, micrometres and angle gauges.
4. Describe the steps involved in accurately using a calliper to measure the dimensions of a cylindrical object.
5. What factors should be considered when selecting the appropriate gauge for a specific measurement task?
6. Explain the difference between the main scale and the Vernier scale on a Vernier calliper.
7. Describe the steps involved in measuring the diameter of a workpiece using a micrometre.
8. You need to measure the diameter of a metal rod to an accuracy of 0.01 mm. Which gauge would be most appropriate: a steel ruler, a Vernier calliper, or a micrometre? Explain your answer.

Assessment Level 3

1. What precautions should be taken to prevent damage to gauges during use and storage?
2. Describe the steps involved in using a micrometre screw gauge to measure the length of a workpiece in the workshop.
3. How are factors such as temperature variations and material properties accounted for when performing measurements with gauges in environments with dynamic conditions?

Assessment Level 4

1. Describe the principles of gauge measurement accuracy and precision, including factors that can affect measurement uncertainty and strategies for minimising errors.
2. Create a concept map that illustrates different types of measuring gauges, their accuracy and their applications

3. Why are digital measuring tools superior to traditional mechanical gauges in manufacturing?

Section Review

This section introduced learners to the rapid prototyping process. The section discussed the principles of setting datums for workpieces, the selection of coordinate systems when dimensioning objects and marking out on workpieces. The principles and processes of the standard units of measurement and their applications were also discussed. The lessons learnt from the section can be summarised as below:

1. Datum selection and coordinate systems ensure consistent measurement and communication that aids proper dimensioning and accuracy in manufacturing and assembly.
2. Datum can be set out as a point, edge or centre line. The Cartesian coordinate system is commonly used when dimensioning a workpiece. Other coordinate systems can be used in special applications.
3. Marking out requires accurately and precisely transferring design information from an engineering drawing onto a workpiece before any machining or fabrication.
4. Various tools such as steel rules, callipers, scribers, combination sets, etc. are used to ensure that marking outs are done accurately and precisely to avoid mistakes in the manufacturing process.
5. Precision in measurement and adherence to standard units are vital for ensuring the quality and functionality of manufactured workpieces, as well as for facilitating communication between engineers, designers and manufacturers.
6. Gauges such as micrometres, Verniers and angle gauges are used to measure the dimensions of workpieces in the workshop.
7. Knowledge of the reading and right measurement procedure of these gauges is necessary to ensure the accuracy and precision of manufactured products.

Additional Reading Materials

1. Bruce J, Black, 2015. Workshop processes, practices and materials, 5th edition published by Routledge 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN
2. Bewoor, A.K., & Kulkarni, V.A. (2018). Metrology and Measurement. CRC Press.
3. Hocken, R.J., & Walter, D.J. (2015). Coordinate Measuring Machines and Systems, Second Edition. CRC Press
4. Sirohi, R.S., & Juneja, K.L. (2011). Introduction to Engineering Metrology. New Age International

References

1. Bruce J, Black, 2015. Workshop processes, practices and materials, 5th edition published by Routledge 2 Park Square, Milton Park, Abingdon, Oxon OX14 4RN
2. Bewoor, A.K., & Kulkarni, V.A. (2018). Metrology and Measurement. CRC Press.
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4. Sirohi, R.S., & Juneja, K.L. (2011). Introduction to Engineering Metrology. New Age International.

SECTION 6: **PRINCIPLES OF MARKING OUT, MEASUREMENT AND GAUGING**

Strand: **Manufacturing Tools, Equipment and Processes**

Sub-Strands:

1. Manufacturing Tools and Equipment
2. Safety, Quality and the Environment

Learning Outcomes:

1. *Apply the principles of bulk deformation and sheet metal working to roll, forge, cut, bend and draw metal sheets.*
2. *Describe the importance of safety, health and environmental considerations for the manufacturing industry.*

Content Standards:

1. Demonstrate knowledge and understanding of standards, measurement and gauging in the manufacturing process
2. Demonstrate an understanding of the importance of workplace safety and workplace organisation.
3. Demonstrate an understanding of ways in which the manufacturing industry affects society

INTRODUCTION AND SECTION SUMMARY

Section six (6) introduces learners to the fundamentals of basic bulk deformation forming processes and sheet metal work development, which are essential components of the manufacturing industry. Learners will be introduced to the principles of deformation forming, the selection of appropriate forming processes and the development of sheet metal work. The section includes practical activities that allow learners to understand the processes involved in bulk deformation and sheet metal work, the standard procedures and their applications. Next, the section delves into workplace hazards and safety practices. Learners will understand the importance of maintaining a safe working environment and the standard safety practices in the manufacturing industry. They will engage in activities that will help them identify potential hazards and apply safety measures in a manufacturing setting. Lastly, the section explores the social and economic impacts of the manufacturing industry on society. Learners will gain insights into how the manufacturing industry influences economic growth, job creation and societal development. At the end of the section, learners will have a comprehensive understanding of the manufacturing industry, its processes, safety practices and its impact on society.

The section covers the following weeks:

Week 21: **Basic bulk deformation forming processes**

Week 22: **Sheet metal work development**

Week 23: **Workplace hazards and safety practices**

Week 24: **Social and economic impacts of the manufacturing industry on society**

SUMMARY OF PEDAGOGICAL EXEMPLARS

Acknowledging the diverse backgrounds, learning styles and capacities of learners, it is crucial to employ varied pedagogical approaches. Pedagogical exemplars such as experiential learning, research-based learning, project-based learning, talk for learning, collaborative learning, and practice-based learning should be utilised to cater to learners' unique needs. Learners should be given opportunities to practice real-world skills such as metalwork techniques like rolling, forging and extrusion, and stamping drawing of sheet metals. They should also be encouraged to identify workplace hazards and understand the socio-economic contributions of manufacturing industries to society.

ASSESSMENT SUMMARY

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions; written responses of various difficulty levels appropriate for the class can also be requested from learners relative to the major concepts in this section. Projects that allow learners to manufacture components using bulk deformation forming processes should be encouraged. At the end, learners should be able to demonstrate an understanding of the principles of basic bulk deformation forming processes, sheet metal work development, workplace hazards and safety practices, and the social and economic impacts of the manufacturing industry on society in manufacturing engineering. These should contribute to learners' formative assessment.

Week 21

Learning Indicator: *Discuss rolling, forging and extrusion as bulk deformation processes*

Theme or Focal Area: Explain Bulk Deformation Forming Processes and Discuss Rolling, Forging and Extrusion as Basic Bulk Deformation Forming Processes

Introduction to Bulk Deformation Forming Processes

Material forming processes in which the thicknesses or cross-sections are reduced, or shapes are significantly changed, are referred to as Bulk Deformation Forming Processes. Bulk deformation forming processes are a set of metalworking methods that involve substantial plastic deformation of the material to achieve a specific shape while preserving its mass and chemical composition. These techniques are distinguished by their three-dimensional deformation, in contrast to sheet-forming processes, and encompass practices like rolling, extrusion, cold and hot forging, bending, and drawing. The key aspect of these processes is the application of appropriate stresses - tension, compression and shear - to shape metal products into desired dimensions. The importance of bulk deformation processes in the industry is highlighted by their cost efficiency, superior mechanical properties of the end product, operational flexibility, increased productivity and reduced raw material wastage, resulting in accelerated production rates.

Rolling

Rolling operations reduce the thickness or cross-section of a material through compressive forces exerted by rolls. In the basic rolling process, a metal is passed between two rolls that rotate in opposite directions, with the gap between the rolls being somewhat less than the thickness of the metal being rolled. Rolling is used to convert thick materials or metals into blooms, slabs or billets, which are later rolled to produce plates, sheets, strips, rails, wire rods, bars, pipes, etc. The process of rolling involves more than just mechanically reducing material thickness. It also includes intricate interactions between the material's microstructure and the applied stresses, resulting in texture evolution and refinement of the microstructure. In the case of thread rolling, materials experience significant microstructural changes as they are primarily stretched at the top and bottom of the formed thread parts, improving the performance of these parts. The complexity of the rolling process and its influence on material properties highlight its importance in bulk metal forming. Here, rolling not only shapes materials but also boosts their mechanical properties by carefully controlling deformation and microstructural evolution. Figure 21.1 shows the basic metal rolling process and some products produced by the metal rolling process respectively.

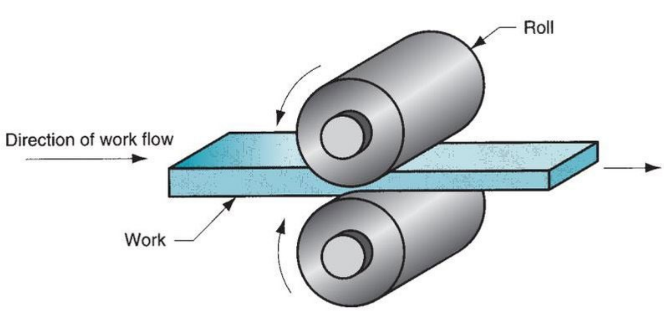

Fig. 21.1: *The basic metal rolling process*

Fig.21.2: *Some products produced by the metal rolling process*

Forging

Forging is a term applied to a family of processes that induce plastic deformation through localised compressive forces applied through dies. The forging equipment can take the form of hammers, presses or special forging machines. Forging is the oldest known metal-working process. Common forging processes include open–die drop-hammer forging, impression-die drop-hammer forging, automatic hot forging and roll forging, etc. This method falls under the category of bulk deformation, encompassing techniques that convert material of basic shapes into specific forms without changing its mass or chemical composition through three-dimensional deformation. Forging methods consist of procedures like closed-die forging, where multiple dies compress a billet into a more intricate shape, often resulting in excess material called flash that needs to be removed, indicating material wastage and additional processing stages. The forging procedure can be complex, involving significant plastic deformation at high temperatures to achieve the desired shape and size. Forging plays a vital role in diverse sectors, such as automotive, military and aerospace, due to its capacity to manufacture consistent, high-quality parts at affordable prices and with high reproducibility. The process entails intricate die designs and demands a thorough comprehension of material flow, die filling and the effects of forging on microstructure and mechanical properties. Figure 21.3 presents an image of open-die and closed-die forging processes.

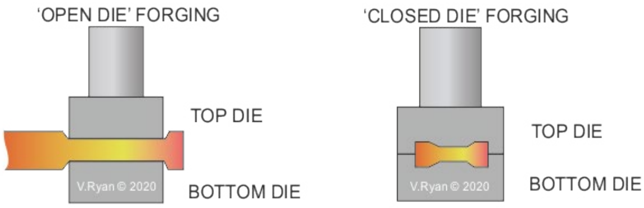

Fig. 21.3: *Open die forging vs Closed die forging processes*

Extrusion

In the extrusion process, the metal is compressed and forced to flow through a suitably shaped die to form a product with a reduced but constant cross-section. Extrusion may be carried out directly or indirectly. In direct extrusion, a solid ram drives an entire billet to and through a stationary die and must provide additional power to overcome the friction between the surface of the moving billet and the confining chamber. In indirect extrusion, a hollow ram pushes the die back through a stationary, confined billet. Extrusion is a versatile method extensively employed in the manufacturing of various long, semi-finished components like bars, tubes, wires and strips, either performed at ambient temperature or elevated temperatures. This technique entails the alteration of materials through the implementation of severe plastic deformation (SPD) methods, which play a pivotal role in the creation of bulk materials with refined microstructures and improved mechanical characteristics. The process of extrusion can be categorised into different approaches, each presenting distinct advantages, drawbacks, and applications, spanning from the fabrication of intricate shapes to the enhancement of material attributes. A notable variation of extrusion is friction extrusion, which leverages heat generated by friction and shear strain to process metallic materials, providing a distinctive means of enhancing material properties by handling powders, chips and bulk materials. Figure 21.4 shows a schematic of a direct extrusion process.

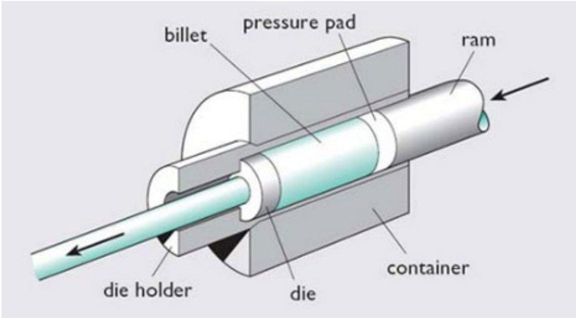

Fig. 21.4: *A schematic of a direct extrusion process*

Learning Tasks

1. Learners make presentations on rolling, forging and extrusion processes, explaining the principles, advantages, disadvantages and applications of each process.
2. Learners perform a metal rolling, forging and extrusion operations at the workshop and present results in class.
3. Learners apply the knowledge gained in rolling, forging and extrusion processes to solve real-life problems.

Pedagogical Exemplars

1. **Experiential learning:** Provide a detailed guide on how to perform a metal rolling, forging and extrusion operation by showing learners a video of these processes in the metal industry, or from textbooks, worksheets and internet resources. This should include safety measures, step-by-step instructions and the expected outcome. Then, under supervision, let learners perform a metal rolling operation at the workshop. Offer different levels of complexity in the task based on learner readiness. For example, beginners could observe and discuss the process while more advanced learners could perform the operation. Consider socio-emotional learners by providing support and encouragement during the process.
2. **Research-based learning:** Provide resources such as textbooks, articles, videos, internet resources, etc. on rolling, forging and extrusion processes. The resources should cover the principles, advantages, disadvantages and applications of each process. Let learners conduct detailed research on these processes and prepare a presentation. They should also be encouraged to find additional resources on their own. Allow learners to choose the format of their presentation (e.g., PowerPoint, poster, report) to cater for different learning styles. Ensure gender equality and social inclusion by promoting equal participation and representation in the research and presentation process.
3. **Project-based learning:** Provide a real-world problem that involves the use of bulk deformation processes that require the application of knowledge about rolling, forging and extrusion, such as the manufacturing of crankshafts, connecting rods, gears, turbine blades, beams, columns, plates, pipelines, valves, fittings, kitchenware, utensils, rail tracks and many more. Let learners work in mixed-ability groups to solve the problem. They should use their research and practical skills to propose, justify a solution and present their solution to the class using any presentation format of their choice. Form groups with diverse skill levels and learning styles. This allows

learners to learn from each other and contribute in different ways. Assign specific tasks to learners in the groups to ensure that all learners participate in the project. Incorporate national core values in the problem-solving process to promote ethical and responsible behaviour.

Key Assessment

Assessment Level 1

1. Which of the following is not a bulk deformation process?

   a) Rolling
   b) Forging
   c) Extrusion
   d) Drilling

2. Rolling, forging and extrusion are all bulk deformation processes. (True/False)
3. What is the definition of rolling, forging and extrusion in the context of bulk deformation processes?
4. Rolling is a type of bulk deformation process. (True/False question)
5. Fill in the blank: ________ is a process where the metal is compressed between two rollers.

Assessment level 2

1. Explain the principle of the rolling process in metal forming.
2. Explain the advantages and disadvantages of using rolling as a bulk deformation process.
3. Given a scenario where a metal needs to be shaped into a long, thin product, which process would be more suitable: rolling or extrusion? Justify your answer.
4. Construct a concept map showing the relationship between rolling, forging and extrusion.
5. What does it mean for a material forming process to be classified as a bulk deformation forming process?

Assessment Level 3

1. Present a case study of a real-world application where rolling, forging and extrusion processes are used. Discuss the reasons for choosing the specific process.
2. Discuss in detail the advantages and disadvantages of rolling, forging and extrusion processes in the manufacturing industry.
3. Prepare a presentation explaining the principles, advantages, disadvantages, and applications of rolling, forging, and extrusion processes.
4. Conduct a debate on the topic: “Forging vs Extrusion: Which is the superior bulk deformation process and why?

Assessment level 4

1. Conduct detailed research on the evolution of bulk deformation processes in the metal industry and their impact on industrial efficiency.
2. Design a creative project demonstrating the working of rolling, forging and extrusion processes.
3. Justify the relevance of bulk deformation forming processes in manufacturing.

Week 22

Learning Indicator:

1. *Recognise and identify dies and presses used for sheet metal working operations*
2. *Discuss cutting, bending and drawing as sheet metal working operations*

Theme or Focal Area: Uses of Dies And Presses in Basic Sheet Metal Working Operations

Introduction

Deformation in metal forming results from the use of a tool known as a die, which applies stresses that exceed the yield strength of the metal. The metal, therefore, deforms to take a shape determined by the geometry of the die. Dies are custom-designed for the part to be produced. High-production dies are referred to as stamping dies. Dies and presses play a vital role in fundamental sheet metal working processes, providing a diverse range of functions to meet the varied demands of the manufacturing sector. The main purpose of dies in sheet metal working is to execute a variety of tasks like punching, blanking, bending and forming, facilitating the efficient and precise mass production of components. For example, a versatile die can carry out punching and blanking simultaneously in one stroke, significantly boosting production efficiency and cutting costs. Likewise, dies are tailored to meet specific operational needs, such as creating sheet-metal parts with semi-circular ends, using theoretical calculations and software tools for design and evaluation. Innovative die configurations, such as interchangeable dies and punches, enable multiple operations to be conducted using a single die set with different stations, streamlining production and reducing labour requirements. Stamping dies, particularly, are integral to the Sheet Metal Forming (SMF) procedure for fabricating car body parts, despite their association with extended lead times and high expenses. Another category of die, bending tools, are indispensable for bending processes on press machines, reshaping components permanently into desired forms.

Components of a Stamping Die

The working components of a stamping die are the punch and the die. These are attached to the upper and lower portions of the die set, respectively called the punch holder (or upper shoe) and die holder (or lower shoe). The die set also includes guide pins and bushings to ensure proper alignment between the die and the punch during the stamping operation. Figure 22.1 shows a schematic of a simple stamping die.

Types of Stamping Dies

Dies (or stamping dies) are classified based on the following criteria:

- Number of separate operations to be performed in each press actuation: A simple die performs a single blanking operation with each stroke of the press; a compound die performs two separate operations at a single station; a combination die performs two operations at two different stations in the die.
- How the die operations are accomplished: A progressive die performs two or more operations on a sheet-metal coil at two or more stations with each press stroke, thus the part is fabricated progressively.

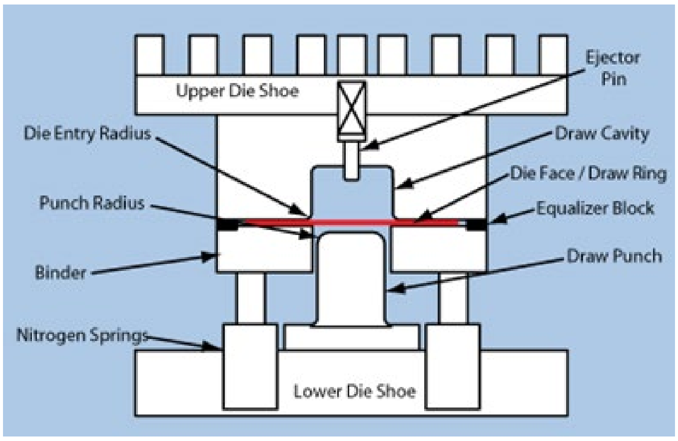

Fig. 22.1 A schematic of a simple stamping die

Presses for Sheet Metal Forming

A press used for sheet metal forming is a machine tool with a stationary bed and a powered ram (or slide) that can be driven towards and away from the bed to perform various cutting and forming operations. It has a frame, which establishes the relative positions of the bed and the ram, with the ram being driven by mechanical or hydraulic power. The frame may be of the gap frame type, the solid gap frame type, the adjustable bed frame type, the straight-sided frame type, etc.

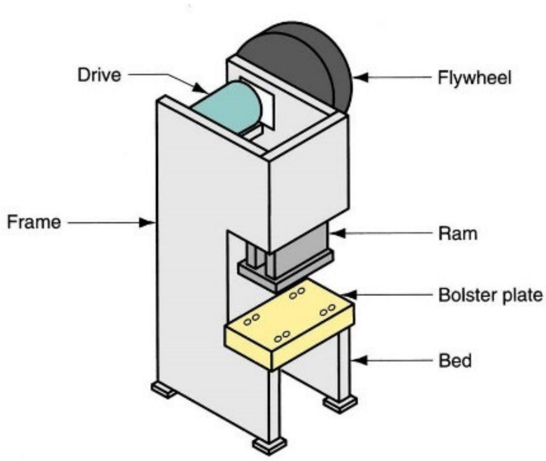

Fig. 22.2: *A schematic of a general gap frame press*

Theme or Focal Area 2: Principles of Cutting, Bending and Drawing in Sheet Metal Working Operations

Introduction

Sheet metal working operations encompass a variety of processes, among which cutting, bending and drawing are fundamental. The principles underlying these operations are critical for achieving desired shapes and geometries in manufacturing, especially in industries such as automotive, where precision and efficiency are paramount.

Cutting in Sheet Metal Working

The cutting of sheet metal is achieved by the shearing action of two sharp cutting edges. The upper cutting edge (the punch) sweeps down past the stationary lower cutting edge (the die). As the punch begins to push into the sheet metal, plastic deformation occurs in the sheet metal surface, and as the punch moves downward, penetration occurs, in which the punch compresses the sheet and cuts into the metal due to the occurrence of fracture in the sheet.

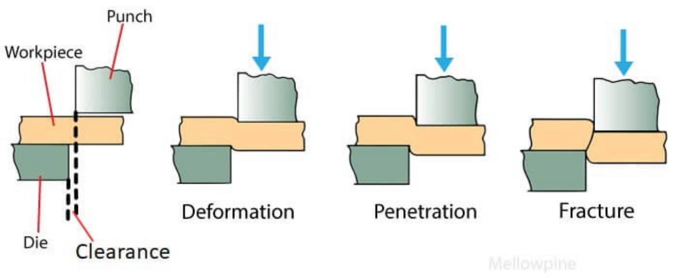

Fig.22.3: *A schematic of the cutting operation in a sheet metal working*

Bending in Sheet Metal Works

Bending in the context of sheet metal operations refers to the straining of the metal around a straight axis. During this operation, the metal on the inside of a neutral plane is compressed while the metal on the outside of the neutral plane is stretched. Bending operations are performed using punch and die tools. V – bending and edge – bending as shown below:

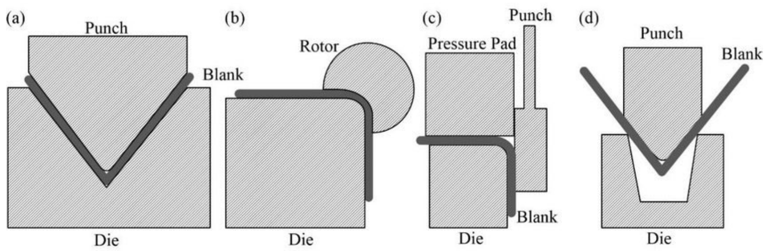

Fig.22.4: *Schematics of (a) a V-bend and (b) an Edge-bend*

Drawing in Metal Sheet Operations

Drawing refers to forming a flat metal sheet into a hollow or a concave shape, by stretching the metal. A blank holder is used to hold down the blank while the punch pushes into the sheet metal.

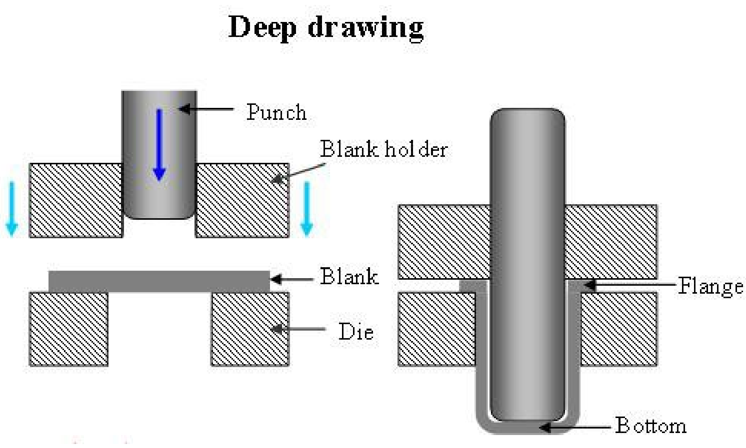

Fig.22.5 A schematic of a deep drawing technique

Learning Tasks

1. Learners identify and name dies and presses used in sheet metal working operations.
2. Learners discuss the operational principles of dies and presses.
3. Learners manufacture components using cutting, bending and drawing of metal sheets at the workshop.
4. Learners make presentations on products manufactured using cutting, bending and drawing processes.

Pedagogical Exemplars

1. Talk for learning: Provide resources such as videos, charts, textbooks, journal articles or internet resources on dies and presses at different stations in the classroom. Let learners go around each station to identify the type of presses or dies in the stations and note their differences and operating principles. Lead a class discussion on the dies and presses presented in class. Let learners discuss the type of dies and presses presented in the classroom, and identify their differences and operating principles as used in sheet metal working. Create a conducive environment to enable all learners to contribute to the discussion. Allow non-vocal learners to write their points to be read during the discussion. Encourage learners to consider what others say and organise contributions through oral presentations, webbings, charts or posters. Encourage proficient learners to organise contributions of the class and present in a written report.
2. Project-based learning: Let learners in mixed-ability groups manufacture simple components of their choice such as metal brackets, hinges, flanges, latches, clips, cover plates etc., using cutting, bending and drawing of metal sheets at the workshop. Assign specific tasks to learners to ensure that all learners participate in the project. Encourage learners to tolerate, accept and critically examine comments from their colleagues during the project execution. Be intentional when forming groups to ensure that learners with difficulties get help from peers, and guide the manufacturing process. Take note of learners with disability and aid them when needed. Allow learners to make presentations of their products using various means that are appropriate to their group.

Key Assessment

Assessment Level 1

1. List any three artefacts made from each of the operations discussed in this section.
2. Bending is a type of sheet metal working operation. (True/False)
3. Fill in the blank: ________ is used to shape the metal in sheet metal working operations.
4. What is the function of a press in sheet metal working operations?

Assessment Level 2

1. Describe the process you would follow to manufacture a component using drawing of metal sheets.
2. Construct a concept map showing the relationship between different sheet metal working operations.
3. Distinguish between drawing, cutting and bending in sheet metal works.

Assessment Level 3

1. How do dies and presses complement each other to achieve a successful metal sheet forming operation?
2. Write an essay discussing the operational principles of sheet metal work equipment.
3. Describe the process of manufacturing metal brackets, hinges and flanges using cutting, bending and drawing of metal sheets.

Assessment Level 4

1. Discuss the basic features and workings of a general gap frame press.
2. Discuss the basic features and workings of a simple stamping die.
3. What precautions must be taken to ensure success in each of the following: cutting, bending and drawing, as sheet metal working operations?
4. Design and create a model demonstrating the use of dies and presses in sheet metal working operations.

Week 23

Learning Indicator: Identify potential hazards in the workspace

Theme or Focal Area: Define Workplace Hazards and Identify Some Potential Workplace Hazards

Introduction

A workplace hazard can be defined as the possibility of harm or danger occurring at the workplace, and it encompasses all aspects of technology and activities that have a certain degree or likelihood of negatively affecting the health and safety of workers at the workplace. A workplace hazard can cause damage to property, injury or death in extreme cases. Hazards in the workplace can arise from various origins, such as being in contact with harmful substances, utilising risky tools and machinery or engaging in activities requiring repetitive motions, strenuous lifting or exposure to severe environmental conditions. The spectrum of hazards present in work settings extend beyond chemical risks to encompass kinetic and potential energy dangers, electrical hazards, geological and meteorological threats, as well as health risks.

Categories of Workplace Hazards

Hazards at the workplace can be placed into two (2) broad categories, according to the OSHA (Occupational Safety and Health Administration, USA); Safety Hazards and Health Hazards.

1. Safety Hazards: Safety hazards are situations that can cause immediate injury to or death of a worker. These include machinery, flying materials, fire and explosion hazards and electrical hazards.
2. Health Hazards: These are hazards associated with long-term exposure to certain situations or substances. These hazards can produce acute (immediate) or chronic (long-term) effects. Health hazards include excessive noise, wood dust (carcinogenic), chemicals and vibration from machine operation.

Identifying/Recognising Potential Hazards in a Workplace

Identifying any form of potential hazard in the manufacturing environment can be much easier to carry out by trying to find answers to the following basic questions at any point in the workplace:

- What work is being done? Understanding the kind of work being done is an important step to identifying the potential hazards associated with the work.
- What kind of possible injury, damage or danger can occur? List all the potential hazards that can occur depending on the nature of the work being done.
- What can or has to be done to avoid the potential hazard? After listing all the possible hazards that can occur, write down all the precautions that can be taken to avoid such hazards or to reduce risk if the hazard should occur.

Fig. 23.1: *A workplace with several hazardous situations: what are the various hazards in this picture?*

Theme or Focal Area: Knowing the General Safety Practices in the Manufacturing Environment and the Importance of Following Them

Introduction

Safety is simply a state of being at little or no risk of injury or any form of danger. It is the process of protecting employees from work-related illness and injury. In the manufacturing environment, a wide range of safety practices are implemented to safeguard workers and ensure the production of safe goods. These practices, including compliance with Good Manufacturing Practices (GMP), play a fundamental role in the creation of safe food and healthcare items by coordinating all aspects of the facility to guarantee safety throughout the production process, from sourcing raw materials to distribution. It is imperative to provide training and education to employees in order to enhance the safety culture and behaviour, ultimately fostering a secure environment in the workplace. The manufacturing industry is prone to various hazards such as machine-related risks, musculoskeletal disorders, occupational illnesses stemming from noise and chemical exposure, and incidents of workplace violence, all of which require thorough safety protocols to be put in place.

Who is Responsible for Workplace Safety?

It is very important to understand that safety is a culture and a habit everyone needs to have, irrespective of who/where you find yourself. In the manufacturing environment/workplace:

1. Safety is everyone's responsibility.
2. Management (employer) is responsible for the safety of workers.
3. Workers need to be trained to work safely.
4. All injuries are preventable.
5. Mistakes that lead to accidents can always be prevented.
6. Safety guidelines specific to every site in the workplace must be available all the time, and workers must be obliged to follow them.

Some General Safety Practices at a Manufacturing Workplace:

1. Wear Personal Protective Equipment (PPE).
2. Use equipment and tools properly.
3. Keep work areas and emergency exits clear.
4. Eliminate fire hazards.
5. Take work breaks from time to time (avoid over working).
6. Prevent objects from falling by keeping them in appropriate places.
7. Prevent slips and trips by making sure that spills are cleaned and that aisles are clear.

Identifying Safety Signs and Symbols at the Workplace

Safety signs are essential tools for communicating safety conditions at the workplace. Safety signs serve as visual indicators of potential hazardous situations in the workplace and required precautionary measures to be taken to avoid any accident or harm to employees and visitors. The following are some of the important safety signs to watch out for at the manufacturing workplace:

a. **Exit Sign**
   This safety sign is used to indicate the location of an exit or escape route from a building in an emergency.

Fig. 23.2: *Exit Sign (Source: OSHA, 2023)*

b. Slips, Trips and Falls

This sign in the workplace alerts employees and visitors of the potential dangers of slipping, tripping or falling in a specific area. They are placed in areas where there is a higher risk of falling.

Fig.23.3: *Slip, Trip and Fall Sign*

c. Authorised Personnel Only Sign

This sign is used to restrict access to specific areas or rooms that contain sensitive information, hazardous materials or equipment that could pose a risk to personnel.

Fig.23.4: *Authorised Personnel Only Sign*

d. Personal Protective Equipment (PPE)

The PPE sign indicates areas where PPE is required. It is placed in areas where there is a risk of physical harm.

Fig.23.5: *Personal Protective Equipment (PPE)*

e. Danger Flammable Sign

This is a safety sign used to warn workers and visitors of flammable substances. They are placed in areas where there is a risk of fire explosion.

Fig.23.6 Danger Flammable Sign

Learning Tasks

1. Learners visit any manufacturing workshop in their community and
   a. Make a list of any potential hazards they may identify.
   b. Categorise their list into safety and health hazards.
   c. Make a list of any safety signs they may identify and take note of the specific areas where they have been placed.
   d. Make a list of any personal protective equipment they may identify.
   e. Explain concisely any concerns on the conditions of safety of workers at the workshop you visited.
2. Learners look around their classroom or workshop, identify any condition that could be described as a potential hazard and eliminate any such condition.
3. Learners categorise potential hazards into safety and health hazards.

Pedagogical Exemplars

1. **Collaborative learning:** Show learners a video, textbook, posters, charts, journal articles or internet resources of a manufacturing workplace and let them identify the various potential hazards at the workplace. In a different task, let learners in mixed groups work on various types of workplace hazards and present to the class. Allow learners to use presentation formats that suit them. Encourage learners to respectfully comment on presentations and tolerate criticism. Consider learners' abilities when forming the groups. Encourage proficient learners to provide individual written reports on workplace hazards.
2. **Experiential learning**: Lead learners on a trip to the school's workshop or any local manufacturing workshop, let them list potential hazards at the workshop and identify the various safety practices that need to be followed at vantage locations at the workplace. Encourage all learners to participate in the activity and give additional materials (text, articles, visuals) for diverse preferences. Let learners use mappings, webbings or charts to make a list of the potential hazards identified, categorise their lists into safety and health hazards, make a list of safety signs and protective equipment at the workshop and provide concerns about the safety situation in the workshop. Encourage proficient learners to individually prepare detailed presentations with recommendations that can be shared with the workshop to improve upon their safety situation, where necessary.
3. **Talk for learning:** Lead a class discussion on the safety situation of the classroom. Encourage all learners to participate in the discussion and propose using charts or mappings, to provide safety signs and notes for the classroom. Allow non-vocal learners to contribute to the discussion through writing.
4. **Research-based learning:** Learners in mixed-ability and gender groups, research the general safety practices to be followed in the workplace and present findings to the class to receive feedback. Provide learners with a video, textbook, posters, charts, journal articles or internet resources on hazards to aid their research. Be intentional with the formation of the groups to ensure that all learners benefit from the group. Assign specific roles to learners in each group to ensure equal participation. Allow learners to present their findings using any means possible to them, such as oral presentations, written reports, video presentations, PowerPoint presentations, web blogs, etc.

Key Assessment

Assessment Level 1

1. List the major sources of potential hazards at the workplace.
2. List the most common examples of workplace hazards.
3. What is a workplace hazard?
4. True or False: Personal protective equipment is necessary in a manufacturing environment.
5. Fill in the blank: _______ is a potential health hazard in a manufacturing environment.

Assessment Level 2

1. Explain the meaning of workplace safety practices.
2. How does the adherence to workplace safety practices generally enhance the manufacturing process?
3. You notice a puddle of water near some electrical equipment. What type of hazard is this and what action would you take?
4. Create a concept map of safety practices in a manufacturing environment.

Assessment Level 3

1. Justify the relevance of the knowledge of workplace hazards.
2. Write an essay on the importance of safety practices in a manufacturing environment.
3. Conduct a mini research project on common health hazards in manufacturing workshops in your community.

Assessment Level 4

1. Conduct a practical assessment of a local manufacturing workshop, identifying potential hazards and suggesting improvements.
2. Design a comprehensive safety training programme for new learners or visitors in your school.

Week 24

Learning Indicators:

1. *Describe the social and economic consequences that a manufacturing activity can have or has had on individuals and society*
2. *Explain how the manufacturing industry affects the local and international economy (e.g., with respect to job creation, standards of living, sustainability and conservation of the environment*

Theme or Focal Area 1: Social and Economic Impacts of Manufacturing Activities on Individuals and Society

Introduction

Over the years, manufacturing activities/processes have produced significant impacts, both positive and negative, on the social, economic and environmental dimensions of society, and individuals, whether they are directly or indirectly involved in the operations of the manufacturing sector. This section examines both the negative and positive impacts of manufacturing on the individual and society in the economic and social dimensions.

Positive Social and Economic Impacts on the Individual and Society

- Manufacturing activities have improved the standards of living and financial well-being of individuals and homes through the provision of employment for both skilled and unskilled labour.
- Manufacturing industries promote the development of communities through their corporate social responsibilities (CSRs).
- Manufacturing activities have contributed to the growth of populations and communities due to the surge of migration to industrialised communities.
- Manufacturing activities have enhanced the growth of agricultural communities as agricultural products are the basic raw materials for many manufacturing industries.
- The manufacturing sector contributes greatly to the surge in technological advancement of society, which in turn promotes productivity in other industries. For example, the manufacturing of vehicles, computers and other machinery has led to the growth of transportation networks, digital infrastructure and automation technologies, all of which have revolutionised how goods and services are delivered, information is accessed and tasks are performed across various sectors.

Negative Social and Economic Impacts of Manufacturing Activities on Individuals and Society

- Deaths of individual employees from accidents such as explosions and fire accidents.
- Increase in atmospheric temperature (Global Warming) leading to Climate Change due to an increase in emission of greenhouse gases.
- Destruction of water bodies and viable lands due to improper disposal of wastes from manufacturing activities.
- Release of air pollutants, leading to the contraction of respiratory diseases and skin infections, etc.
- Increased/intensified social problems such as access to housing (because of urbanisation), etc.

Fig.24.1: *Emission of harmful gases into the atmosphere by manufacturing industries (Source: Ahmad, 2023)*

Fig. 24.2: *Deforestation by manufacturing industries (Source: Ahmad, 2023)*

Fig. 24.3: *Discharge of industrial sewage into a water body (Source: Ahmad, 2023)*

Theme or Focal Area: Effects of Manufacturing Activities on Local and Global Economies with Respect to Job Creation, Standards of Living, Sustainability and Environmental Conservation.

Job Creation/Employment

The manufacturing industry creates more jobs/employment (for both skilled and unskilled labour) and enhances the economic growth of the local and global economies, as it adds more value to the primary sector outputs, increasing the national GDP (Gross Domestic Product).

Standards of living

In addition to job creation, people have access to cheap and varied goods. People also have better access to education, health services, etc., due to urbanisation. Households have more income to boost their standards of living.

Sustainability

Most traditional/conventional manufacturing processes are economically and environmentally unsound as they usually result in the depletion of natural resources, hence, demoting both economic and environmental sustainability. Most manufacturing companies are now adopting economically and environmentally–sound processes to promote sustainable manufacturing.

Conservation of Environment

Generally, manufacturing activities are the major cause of the depletion of natural resources and the deterioration of the environment. To protect the environment and guard the fundamental natural resources from exhaustion, manufacturing companies need to be conservation-conscious; the forest, water bodies and wildlife have to be strictly guarded.

Learning Tasks

1. Learners make a list of the various solid, liquid and gaseous pollutants produced by companies.
2. Learners identify and list infrastructures such as roads, school and hospital buildings, donations, etc., in the community that have been provided through the Corporate Social Responsibilities (CSRs) of manufacturing companies.
3. Learners make short notes on how the manufacturing companies in their community have affected the social and economic structure of the community.

Pedagogical Exemplars

1. Research-based learning: Learners research from online and textbooks the social and economic consequences of manufacturing activities on individuals and society, present their findings to the class and receive feedback. Consider learners' abilities when forming mixed-ability groups. Allow learners to demonstrate understanding through various methods (verbal/written). Encourage all learners to participate in the activity and give additional materials (text, articles, visuals) for diverse preferences, etc.
2. Talk for learning: Learners discuss the major social and economic consequences of manufacturing activities on the structure and development of society. Learners add to what others say and organise views using webbings, mappings charts or posters. In different task groups, learners discuss the major effects of the manufacturing industry on the local and international economy with respect to job creation; standards of living; sustainability and conservation. Each group presents to the class for feedback. Consider learners' abilities when forming groups. Allow

learners to choose their presentation method, whether verbal or written. Challenge proficient learners with leading questions during the discussion and encourage them to provide individual written reports.

Key Assessment

Assessment Level 1

1. List the major ways the manufacturing industry influences the local and international economies.
2. Manufacturing activities can have an impact on the environment. (True/False)
3. Fill in the blank: The ________ of a manufacturing company refers to its efforts to give back to the community.
4. What are some examples of infrastructures that a manufacturing company might provide as part of its Corporate Social Responsibilities (CSRs)?
5. Name two types of pollutants that manufacturing activities can produce.

Assessment Level 2

1. Explain the positive impact of the manufacturing industry on the local and international economies.
2. Explain the negative impacts of the manufacturing industry on local and international economies.
3. Describe how the presence of a manufacturing company in a community might affect the standard of living.
4. Explain how manufacturing activities contribute to the socio-economic structure of society.
5. If a manufacturing company employs 100 people from a community of 1000, what percentage of the community is directly employed by the company?

Assessment Level 3

1. Create a concept map showing the relationship between manufacturing activities, economic impact and environmental impact.
2. Given a scenario where a shoe/textile manufacturing company has just been set up in a community, what might be some potential impacts on the local economy?
3. Write an essay on the topic: "The Impact of Manufacturing Activities on Local Communities and the Environment".

Assessment Level 4

1. Explain how the manufacturing industry influences sustainability and environmental conservation.
2. How can the manufacturing industry improve upon the lifestyle of the local community?
3. Write an extended research paper on the topic: "The Long-term Socio-economic Impacts of Manufacturing Activities on Society".
4. Prepare a presentation on the topic: "The Role of Corporate Social Responsibility in Manufacturing".

Section Review

This section introduced learners to the basic bulk deformation processes, sheet metal work development, workplace hazards and safety and social and economic impacts of manufacturing. The lessons learnt from the section can be summarised as below:

1. Rolling, forging and extrusion are important bulk deformation manufacturing processes used in sheet metal working.
2. Rollers and dies are used in performing these processes.
3. Cutting, bending and drawing are essential sheet metal working operations used in manufacturing.
4. Dies and presses help perform various sheet metal operations.
5. Many situations in the workplace could pose some significant level of threat to individuals and properties in the workplace. These situations are identified as hazards.
6. Hazards pose a variety of threats to life and property, from mild threats to severe and even death in extreme situations.
7. Workplace hazards can be classified as safety or health.
8. Safety hazards include fire explosion and electrical hazards, whereas health hazards include excessive noise, flying materials and carcinogenic materials.
9. It is important to act quickly to eliminate any potential hazards and respect safety guidelines in the workplace.
10. Safety signs are important tools used to communicate potential hazards and safety threats in the workplace.
11. It is important to be able to identify various safety signs, understand their meanings and know the specific areas where they are required to be placed at the workplace.
12. Manufacturing activities/processes produce significant impacts, both negative and positive, on individuals and society in general.
13. These impacts influence the various cornerstones of individuals and society: social structure, economic structure and the environment.
14. Among the positive impacts of manufacturing include improvement in the standard of living of individuals via job creation, growth of communities through CSRs, etc.
15. On the other hand, manufacturing companies negatively impact the environment via the release of pollutants; add to the global warming case by releasing greenhouse gases, and pose health threats to individual workers from unsafe manufacturing conditions.

Additional Reading Materials

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ACKNOWLEDGEMENTS

Special thanks to Professor Edward Appiah, Director-General of the National Council for Curriculum and Assessment (NaCCA) and all who contributed to the successful writing of the Teacher Manuals for the new Senior High School (SHS), Senior High Technical School (SHTS) and Science Technology, Engineering and Mathematics (STEM) curriculum.

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