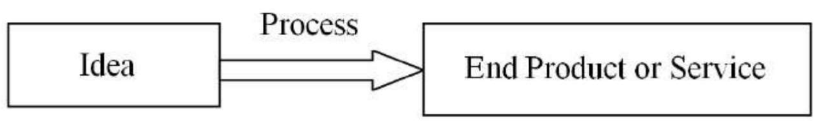
**Week 01 [CO:1] [PO:1]:**

**Explain Product Development**

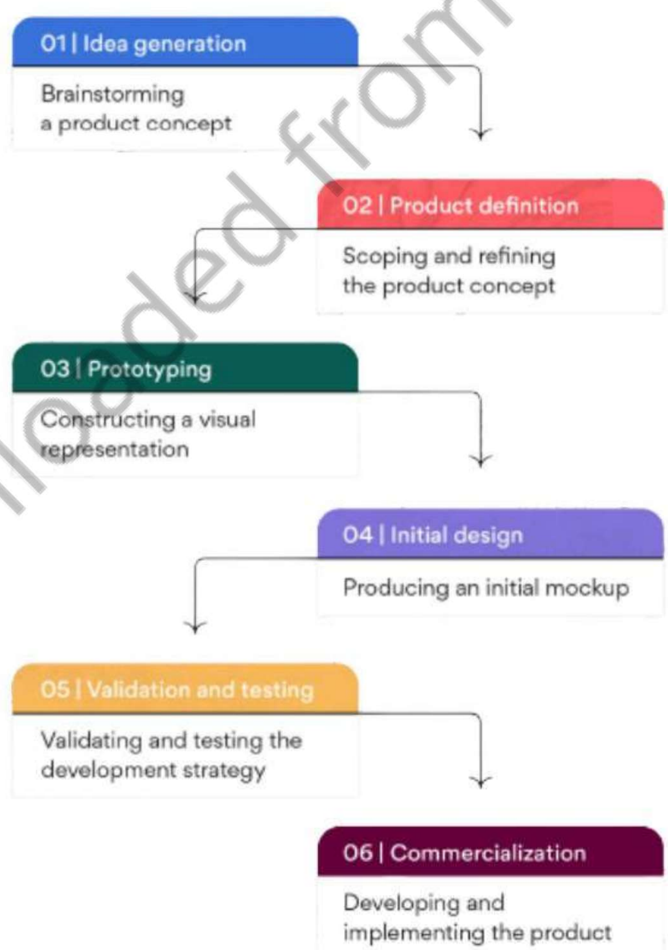
Product development is a comprehensive process that involves the creation, design, and introduction of new or improved products into the market.




This process involves various stages, i.e. idea generation, Product definition, Prototyping, Initial design, validation & Testing and Commercialization.

Here's an overview of the key stages involved in product development:

**Stages of Product Development:**



**Need and Feasibility study:**

A Need and Feasibility Study is a critical phase in product development, helping businesses assess the viability of a new product or an enhancement to an existing one. This study aims to answer two fundamental questions:

**1. Need Analysis:**

a) ***Market Demand:*** Identify if there is a market need or demand for the proposed product. Understand the target audience, their preferences, and pain points that the new product aims to address.

b) ***Competitor Analysis:*** Evaluate existing products in the market, their strengths and weaknesses. Identify opportunities for differentiation and areas where the new product can offer a competitive advantage.

c) ***Customer Feedback:*** Conduct surveys, interviews, or focus groups to gather insights directly from potential customers. Understand their expectations, preferences, and whether they would be interested in the proposed product.

**2. Feasibility Analysis:**

a) ***Technical Feasibility:*** Assess the technical capabilities and resources required to develop and produce the product. Consider whether the technology needed is available, and if not, evaluate the feasibility of acquiring or developing it.

b) ***Financial Feasibility:*** Conduct a thorough financial analysis, including cost estimation for development, production, marketing, and distribution. Determine potential revenue streams and profitability projections.

c) ***Resource Feasibility:*** Evaluate the availability of skilled personnel, raw materials, and other resources needed for product development. Ensure that the necessary expertise is either in-house or can be sourced effectively.

d) ***Legal and Regulatory Feasibility:*** Investigate the legal and regulatory requirements that the product may need to comply with. This includes patents, trademarks, industry standards, and any potential obstacles or restrictions.

e) ***Operational Feasibility:*** Analyze whether the existing operational infrastructure can support the product development and subsequent production. Consider the impact on existing processes and workflows.

*By conducting a comprehensive Need and Feasibility Study, businesses can minimize risks associated with product development and make informed decisions about whether to proceed with the project.*

*This study provides a solid foundation for creating a business case and securing support from stakeholders, investors, or management.*

*If the study reveals that the market demand is high, technical and financial feasibility are favorable, and potential risks are manageable, it indicates a strong case for moving forward with the product development initiative.*

**Explain Development of design, Selection of Materials and Process:**

The development of design, selection of materials, and process in product development are crucial aspects that significantly influence the final product's performance, appearance, and manufacturability. Here's an overview of each stage:

**1. Development of Design:**

a) ***Conceptualization:*** After identifying the need for a product, the design process begins with conceptualizing its form, features, and functionality. This involves creating sketches, outlines, or using design software to visualize the product's appearance and structure.

b) ***Detailed Design:*** Once the initial concept is approved, detailed design work follows. This includes specifying dimensions, materials, tolerances, and other critical aspects. Computer-Aided Design (CAD) tools are commonly used during this phase to create detailed 3D models and technical drawings.

c) ***Prototyping:*** Physical prototypes are often created to test the design's feasibility and functionality. Prototyping helps identify any design flaws, improve ergonomics, and allows for user testing and feedback.

**2. Selection of Materials:**

a) ***Material Properties:*** The choice of materials is a critical decision that affects the product's performance, durability, and cost. Different materials have varying mechanical, thermal, and electrical properties. Understanding these properties is crucial for selecting the most suitable materials for each component.

b) ***Cost Considerations:*** The cost of materials is a significant factor in product development. Balancing performance requirements with cost constraints is essential. Sometimes, alternative materials or composite materials may be considered to achieve the desired balance.

c) ***Sustainability:*** With increasing emphasis on sustainable practices, the environmental impact of materials is a growing consideration. The selection of recyclable or environmentally friendly materials is becoming an important aspect of material selection.

**3. Process Selection:**

a) ***Manufacturability:*** The chosen manufacturing process must align with the design and material specifications. Some products may require specific manufacturing processes, such as injection molding, CNC machining, 3D printing, or casting. The selected process should be capable of producing the desired geometry and meeting quality standards.

b) ***Efficiency and Cost-effectiveness:*** The manufacturing process should be efficient and cost-effective. Factors such as production volume, cycle time, labor requirements, and waste generation are considered in the selection of manufacturing processes.

c) ***Quality Assurance:*** The chosen manufacturing process should allow for effective quality control and assurance. This involves implementing measures to ensure that the final product meets the specified standards and tolerances.

*Successful product development requires a seamless integration of design, material selection, and manufacturing processes.*

*Collaboration between designers, engineers, and manufacturing experts is crucial to ensure that the final product not only meets design and performance requirements but is also feasible to produce at scale within cost constraints.*

*Iterative testing and refinement are common during these stages to optimize the product for both functionality and manufacturability.*

Case studies of Product development by using Video: **https://youtu.be/oe6vd23kr0i?Si=Mgd9iIAmjID6uyhR**

## Explain Prototype, launching of product and Product life cycle

**1. Prototype:** Prototype is earlier sample, model or release of a product, build to test a concept or process. The main reason for prototype is to validate the idea and this is step in converting an idea to a real product.

a) ***Purpose:*** Prototypes are early models of a product, either physical or digital, created to test and validate design concepts.
b) ***Development:*** Prototypes help in identifying design flaws, refining functionality, and receiving feedback from users before mass production.
c) ***Types:*** Prototypes can be low-fidelity (basic representation) or high-fidelity (closer to the final product), depending on the development stage.

**2. Launching of Product:**

A product launch is a planned effort to bring a new product to market. The goal is to make sure that everyone inside the company, partners, stake-holders, target customers know about the product.

a) ***Purpose:*** Launching marks the introduction of the product to the market, making it available for purchase by consumers.
b) ***Components:*** Launch strategies involve marketing, distribution, and sales efforts to create awareness and generate initial sales.
c) ***Considerations:*** A successful launch considers target audience, pricing, promotion, and distribution channels.

**3. Product Life Cycle:**

A product life cycle is the amount of the time a product undergoes from being introduced into the market until it is taken off the production.

***There are four stages in a product life cycle:***

i. ***Introduction:*** The product is launched, and sales begin.
ii. ***Growth:*** Sales increase as the product gains market acceptance.
iii. ***Maturity:*** Sales plateau, and competition may intensify. Marketing focuses on differentiation and retaining market share.
iv. ***Decline:*** Sales decrease due to market saturation, changing preferences, or technological advancements.

**Week 02 [CO:1] [PO:1]:**

**General consideration in design based on various aspects:**

Designing a product or system involves considering a variety of factors to ensure its success, functionality, and sustainability. Here are general considerations based on the following aspects:

**1. Functional Requirements:**
Clearly define and understand the purpose and functionality of the product or system.
Ensure that the design meets all specified functional requirements.

**2. Effect on Environment:**
Consider environmental impact and strive for eco-friendly designs.
Opt for sustainable materials and processes to minimize the carbon footprint.

**3. Life:**
Design for durability and longevity.
Consider the product life cycle, including disposal and recycling options.

**4. Reliability:**
Ensure the product's consistency and dependability under various conditions.
Conduct reliability testing to identify and address potential failure points.

**5. Safety:**
Prioritize user safety in all design aspects.
Comply with safety standards and regulations relevant to the product.

**6. Principles of Standardization:**
Adhere to industry standards to enhance compatibility and interoperability.
Promote consistency in design elements to facilitate user understanding.

**7. Assembly Feasibility:**
Design components for easy assembly and disassembly.
Minimize the number of parts to simplify the assembly process.

**8. Maintenance:**
Consider ease of maintenance and repair.
Design for accessibility to critical components that may require regular servicing.

**9. Cost:**
Strive for cost-effectiveness without compromising quality.
Evaluate and optimize manufacturing processes to reduce production costs.

**10. Quantity:**
Consider production volume and scalability in the design.
Optimize the design for both small-scale and mass production.

**11. Legal Issues and Patents:**
Ensure compliance with intellectual property laws.
Conduct thorough patent searches to avoid infringement issues.

**12. Aesthetic and Ergonomic Factors:**
Consider the visual appeal and aesthetics of the product.
Prioritize user comfort and usability through ergonomic design.

**13. Choice of Materials:**
Select materials based on their properties, sustainability, and cost.
Consider the environmental impact of material choices.

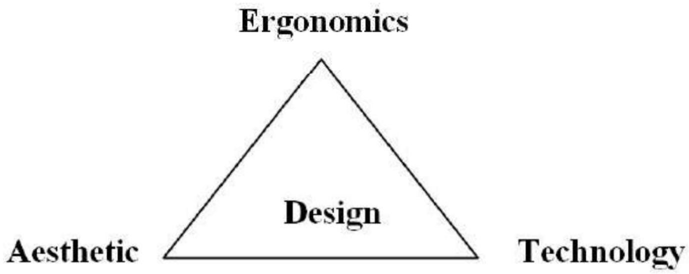
**14. Feasibility of Manufacturing Processes:**
Evaluate the feasibility of manufacturing methods.
Optimize the design to align with efficient and cost-effective production processes.

*These considerations collectively contribute to the overall success of a design, ensuring that the end product not only meets functional requirements but also aligns with sustainability, safety, and economic considerations. Additionally, keeping up with technological advancements and market trends is essential for creating innovative and competitive designs.*

**Week 03 [CO:1] [PO:1]:**

**Main Component of Product Design:**

*The main component of product design is as follows:*




**Aesthetic:**

- It deals with appearance
- It is a core design principle that defines designs pleasing qualities.
- In visual terms aesthetics includes factors such as balance, color, movement, pattern, scale, shape and visual weight
- Designers use aesthetics to complement their design and enhance functionality with attractive layouts

**Ergonomics:**

- Ergonomics is considered as the scientific study of man-machine-working
- The ergonomics consideration is as follows: The control should be easy and logically positioned (Example: Automobile gear system)
- The shape of the control component which comes in contact with the hands should confirm (match) with the anatomy of human hands (Example: gear lever knob)
- Proper coloring or paint

**Basic types of product forms:** *There are six major product and type forms*

**Type 1: The differentiated product**

- The differentiated product differ from other similar products or brands in the market
- Example: mobile phone, TV (flat and curve)

**Type 2: The Customized Product**

- Customer specific requirement are taken into account while developing the product
- Example: building plan

**Type 3: The Potential Products**

- The potential product means product for future
- It carries all the improvements and possibilities under the given Technology, economical and other conditions
- Examples: electrical vehicles

**Type 4: The core products**

- It is not a tangible physical product
- It cannot be touched
- The benefit of product makes it valuable to the buyers
- For example in case of car the benefit is ease at which one can drive the car and another core benefit is the speed of the car
- Other examples internet service software or application broadband mobile networks etc.

**Type 5: Actual Product**

- It is the tangible physical product that can be seen and touched by the user
- The actual product is what the average person would think as a product
- For example if your person tests drive a car then purchases it, and smartphone buildings etc.

**Type 6: The Augmented Product**

- It refers to the known feasible part of product
- It usually consist of added value for which premium may or may not be paid
- For example if you are buying a car the augmented product will be its warranty customer service support offered by the manufacturer and after sale services

**Explain Designing consideration based on:**

**1. Shape:** The external form or outline of an object.
Consideration: The shape of a product can influence its visual impact. Geometric shapes, curves, and contours can be used to evoke specific feelings or convey a particular aesthetic.

**2. Design Features:** Distinctive characteristics or elements that contribute to the overall design.
Consideration: Unique design features can set a product apart from competitors and enhance its visual interest. This may include innovative shapes, patterns, or functional elements.

**3. Materials:** The substances used to construct a product.
Consideration: The choice of materials affects both the visual and tactile aspects of a design. Consider factors like texture, color, and transparency when selecting materials.

**4. Finishes:** Surface treatments applied to materials to enhance their appearance.
Consideration: Finishes such as gloss, matte, or textured surfaces can impact the perceived quality and style of a product. Proper finishing contributes to the overall aesthetics.

**5. Proportions:** The comparative relationship between different parts of a design.
Consideration: Balanced proportions create a harmonious and visually pleasing design. Consider how different elements relate to each other in terms of size and scale.

**6. Symmetry:** A balanced arrangement of parts on either side of a central point or axis.
Consideration: Symmetry can create a sense of order and formality. However, asymmetry can be used for a more dynamic and modern appearance.

**7. Contrast:** The juxtaposition of different elements to create visual interest.

Consideration: Contrast in color, shape, or texture can highlight specific features and make a design more dynamic. It adds visual intrigue and helps guide attention.

**8. Color:** The visual perception resulting from different wavelengths of light.
Consideration: Color choices evoke emotions and contribute to the overall mood of a design. Consider color harmony and contrast for a balanced and visually appealing result.

**9. Texture:** The tactile quality of a surface or the visual representation of it.
Consideration: Texture adds depth and interest to a design. It can be achieved through material choices, finishes, or patterns.

**Relation between man, machine and environmental factors:**

The connection between people, machines, and the environment is important for making things work well and caring for the Earth. Here are the main points:

**1. Using Machines:**
- Make buttons and screens easy for people to use.
- Design machines so they're comfortable for people.

**2. Helpful Machines:**
- Machines can help people do their work better.
- We need to make sure machines work well with people.

**3. Taking Care of the Environment:**
- Machines should use energy wisely and not create too much waste.
- We should make sure machines don't hurt the air, water, or land.

**4. Safety and Health:**
- Machines should not be dangerous.
- People need to watch over machines to keep everyone safe.

**5. Workplace Design:**
- Make workplaces comfortable with good lighting and less noise.
- Machines can help people work together better.

**6. Social and Economic Impact:**
- Machines might change jobs, so we need to learn new things.

- Machines can help make more things and grow the economy.

**7. Rules and Being Fair:**
- There are rules for using machines, and we need to follow them.
- We should treat everyone fairly when using machines.

**8. Adaptability and Flexibility:**
- Make machines that can change and adapt to new things.
- Teach people how to use new machines.

**9. Resource Efficiency:**
- Make machines that use energy wisely.
- Use materials that don't harm the Earth too much.

**10. Working Together:**
- Everyone involved in making and using machines should work together.
- We want technology to help people and be good for the Earth.

**Design of displays and controls:**

Designing displays and controls means planning how things look and work on devices like phones or machines. Here's what it involves:

**1. Displays:**
- Show Information: Decide how information appears on screens.
- Important Stuff First: Make sure important things stand out.
- Look Good: Make the screen visually appealing.
- Give Feedback: Show visual signs when you do something on the device.

**2. Controls:**
- Buttons and Touch Areas: Design buttons and touch areas that you can interact with.
- Where to Put Them: Decide where these buttons should be for easy use.
- Understandable: Make sure buttons show what they do.
- Stay the Same: Keep buttons looking and working the same way throughout.

**Week 04 [CO:2] [PO:3,4]:**

**Torsion of Shaft the Design of Shaft:**

**Assumptions made in shear stress in a shaft subjected to torsion:**

1. The material is homogeneous, i.e. of uniform elastic properties throughout.
2. The material is elastic, following Hooke's law with shear stress proportional to shear strain
3. The stress does not exceed the elastic limit or limit of proportionality.
4. Circular sections remain circular.
5. Cross-sections remain plane. (This is certainly not the case with the torsion of non-circular sections)
6. Cross-sections rotate as if rigid, i.e. every diameter rotates through the same angle
7. Practical tests carried out on circular shafts have shown that the theory developed below on the basis of these assumptions shows excellent correlation with experimental results.

**Strength and Rigidity of Solid and Hollow shaft:**

The strength and rigidity of solid and hollow shafts depend on their geometry and material properties. Let's explore these aspects for both types:

**1] Solid Shaft:**

***Strength:***

- ***Material:*** The strength of a solid shaft is primarily determined by the material it's made of. Strong materials like steel are commonly used for solid shafts.
- ***Cross-sectional Area:*** The larger the cross-sectional area of the solid shaft, the higher its strength. Strength is directly proportional to the cross-sectional area.

***Rigidity:***

- ***Torsional Rigidity:*** Solid shafts typically exhibit high torsional rigidity, making them resistant to twisting or deformation when subjected to torque.

- ***Bending Rigidity:*** Solid shafts also have good resistance to bending, but their resistance to bending is generally lower than that of hollow shafts of the same material and outer diameter.

**2] Hollow Shaft:**

***Strength:***

- ***Material:*** Similar to solid shafts, the strength of a hollow shaft depends on the material used. Common materials include steel and aluminum.
- ***Outer Diameter and Wall Thickness:*** The strength of a hollow shaft depends on both its outer diameter and wall thickness. Increasing the outer diameter generally increases strength, while increasing the wall thickness enhances strength as well.

***Rigidity:***

- ***Torsional Rigidity:*** Hollow shafts can have excellent torsional rigidity, especially when the outer diameter is large compared to the inner diameter. This makes them suitable for applications requiring resistance to torsional forces.
- ***Bending Rigidity:*** Hollow shafts generally exhibit higher bending rigidity compared to solid shafts of the same material and outer diameter. The distribution of material toward the outer edges contributes to increased resistance to bending.

**Comparison:**

a) ***Weight:*** Hollow shafts are often lighter than solid shafts, making them advantageous in applications where weight is a critical factor.
b) ***Material Utilization:*** Hollow shafts can be more material-efficient, as material is strategically placed towards the outer edges where it contributes more to strength and rigidity.
c) ***Cost:*** Depending on the material and manufacturing process, the cost of hollow shafts may be higher due to additional complexities.

*In summary, both solid and hollow shafts have their advantages and are suitable for different applications. The choice between them depends on specific engineering requirements, such as the need for strength, rigidity, weight, and cost considerations.*

**Power transmitted by solid and hollow shafts:**

- The power transmitted by solid and hollow shafts can be calculated using relevant engineering formulas.
- The American Society of Mechanical Engineers (ASME) and the Bureau of Indian Standards (BIS) provide guidelines and standards for designing mechanical components, including shafts.
- However, specific calculations for power transmission are generally part of broader design codes or handbooks rather than explicitly outlined in the codes themselves.

**Power Transmission Formulas:**

**Solid Shaft:**

The power transmitted by a solid shaft can be calculated using the following torsional formula:

| Particular | Equation | Eqn. No. |
|---|---|---|
| ***Torsion of circular shafts:*** | | |
| The maximum torsional shear stress due to torsional loading | $\tau = \frac{Tc}{J} = \frac{16T}{\pi d^3}$ for solid shafts | 3.1 |
| | $= \frac{16T}{\pi d_o^3}\left(\frac{1}{1-K^4}\right)$ for hollow shafts | |
| The angular deformation | $\theta = \frac{TL}{JG}$ rad $= \frac{584TL}{Gd^4}$ deg., for solid shaft | 3.2 |
| | $= \frac{584TL}{G(d_o^4 - d_i^4)}$ deg., for hollow shafts | |
| The torque to be transmitted by the shaft N-mm | $\left.\begin{aligned} T &= \frac{10^6 P}{\omega} \\ T &= \frac{9.55 \times 10^6 (P)}{n} \end{aligned}\right\}$ SI Units | 3.3(a) |
| The torque transmitted by the shaft, kgf mm | $\left.\begin{aligned} T &= \frac{75 \times 10^3 (MHP)}{\omega} \\ &= \frac{7.16 \times 10^5 (MHP)}{n} \\ &= \frac{9.74 \times 10^5 (P)}{n} \end{aligned}\right\}$ Metric Units | 3.3(b) |

**Hollow Shaft:**

For a hollow shaft, the power transmission formula is similar, but it considers the difference between the outer and inner diameters:

| ***Hollow shaft:**** | | |
|---|---|---|
| The outside diameter of hollow shaft subjected to simple torsion | $d_o = \left[\frac{16T}{\pi\tau_d}\left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}}$ | 3.4(a) |
| Out side diameter of hollow shaft subjected to simple bending | $d_o = \left[\frac{32M}{\pi\sigma_d}\left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}}$ | 3.4(b) |
| | where $\tau_d = \frac{\tau_e B}{RK_s}$ and $\sigma_d = \frac{\sigma_e B}{RK_t}$ | |
| **The outside diameter of hollow shaft subjected to combined bending and torsion.** | $R$ is reliability factor Table 2.7<br>$B$ is the size factor (Eqn. 2.9(b)) | |
| a) According to maximum normal stress theory | $d_o = \left[\frac{16}{\pi\sigma_{\max}}\left(M+\sqrt{M^2+T^2}\right)\times\left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}}$ | 3.5(a) |
| b) According to maximum shear stress theory | $d_o = \left[\frac{16}{\pi\tau_{max}}\left(\sqrt{M^2+T^2}\right)\times\left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}}$ | 3.5(b) |

*For solid shafts, substitute $K = 0$ and $d_0 = d$ in the above equaitons.

**Symbol description and units:**

| Symbols | Description and Units |
|---|---|
| $c$ | distance from neutral axis to outer most fiber, mm |
| $C_m, C_t$ | the numerical combined shock and fatigue factors to be applied to the computed bending moment and torsional moment respectively (Table 3.1) |
| $d$ | diameter of solid shaft, mm (Table 3.5) |
| $d_i, d_0$ | inside and outside diameters of the hollow shaft respectively, mm |
| $F_c$ | Force on the connecting rod, $N$ (kgf) |
| $F_p$ | Force on the piston, $N$ (kgf) |
| $F_r$ | radial force along the crank, $N$ (kgf) |
| $F_t$ | tangential force perpendicular to the crank, $N$ (kgf) |
| $J$ | polar moment of inertia of cross-sectional area about axis of rotation, $mm^4$ |
| $K$ | ratio of inside to outside diameter of hollow shaft |
| $L$ | length of the shaft, mm |
| $M$ | bending moment, $N$ mm (kgf-mm) |
| $n$ | speed of the shaft, rpm |
| $P$ | power, kW |

| | |
|---|---|
| $p_{bc}$ | allowable crank pin bearing pressure, MN/m$^2$ (kgf/mm$^2$) (Table 3.6) |
| $p_{bs}$ | main bearing pressure, MN/m$^2$ (kgf/mm$^2$) (Table 3.6) |
| $T$ | torsional moment, $N$ mm (kgf-mm) |
| $\sigma_b$ | stress due to bending, MN/m$^2$ (kgf/mm$^2$) |
| $\sigma_d$ | design stress, MN/m$^2$ (kgf/mm$^2$) (Table 3.5(b)) |
| $\sigma_e$ | stress at the elastic limit, MN/m$^2$ (kgf/mm$^2$) |
| $\tau$ | torsional shear stress, MN/m$^2$ (kgf/mm$^2$) |
| $\tau_d$ | design shear stress, MN/m$^2$ (kgf/mm$^2$) (Table 3.5(b)) |
| $\tau_e$ | shear stress at the elastic limit, MN/m$^2$ (kgf/mm$^2$) |
| $\omega$ | angular velocity, rad/s |
| $\theta$ | angle of twist, deg |

**Standards and Codes:**

**1. ASME Standards:**

- ❑ ASME BTH-1: Design of Below-the-Hook Lifting Devices
- ❑ ASME B31.1: Power Piping
- ❑ ASME B31.3: Process Piping

**2. BIS Codes:**

- ❑ IS 456: Code of Practice for Plain and Reinforced Concrete
- ❑ IS 3370 Part 1, 2, 3: Code of Practice for Concrete Structures for Storage of Liquids.
- ❑ IS 456: Code of Practice for Design and Construction of Reinforced Concrete Retaining Walls

**Important Notes:**

***1. Material Properties***: The material properties of the shaft, including shear modulus, are crucial for accurate calculations. These properties are often specified in material standards or handbooks.

***2. Safety Factors:*** Design factors, including safety factors, are essential to ensure that the shaft can safely handle the transmitted power without failure.

***3. Dynamic Loading:*** For shafts subjected to dynamic loading, additional considerations and factors might be needed.

***4. Consulting Design Handbooks:*** Design engineers often refer to mechanical engineering handbooks, for comprehensive guidance on power transmission components.

*Always consult the specific design codes, standards, and handbooks relevant to your application and location, as they provide detailed information and considerations for safe and effective power transmission component design.*

**Standard Shaft size in mm:**

Table 3.5 *(a) Standard shaft sizes in mm*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 25 | 28 | 32 |
| 36 | 40 | 45 | 50 | 56 | 63 | 71 | 80 | 90 | 100 | 110 | 125 |
| 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 |
| 380 | 400 | 420 | 440 | 450 | 480 | 500 | 530 | 560 | 600 | – | – |

**Maximum allowable working stresses for shafts:**

Table 3.5 *(b) Maximum Permissible Working Stresses for Shafts*

| Grade of shafting | Simple bending $MN/m^2$ ($kgf/mm^2$) | Simple torsion $MN/m^2$ ($kgf/mm^2$) | Combined stress $MN/m^2$ ($kgf/mm^2$) |
|---|---|---|---|
| "Commercial Steel" shafting without allowance for keyways | 110 (11.2) | 55(5.6) | 55(5.6) |
| "Commercial Steel" shafting with allowance for keyways | 83 (8.5) | 41 (4.2) | 41(4.2) |
| Steel purchased under definite specification (without keyways)* | 60% of the elastic limit but not over 36% of the ultimate in tension. | 30% of the elastic limit but not over 18% of the ultimate in tension. | 30% of the elastic limit but not over 18% of the ultimate in tension. |

*The values are to be reduced by 25% if keyways are present.

**Week 05 [CO:2] [PO:3,4]:**

**Problems on Shafts subjected to only Shear based on Rigidity and Strength:**

1] A shaft is transmitting 100 kW at 180 rpm. If the allowable shear stress is 60 N/mm². Find the suitable diameter of shaft. The shaft is not to twist more than 1° in a length of 3m. Take modulus of rigidity as 80 kN/mm².

Given data

Power, $P = 100$ kW

Speed, $n = 180$ rpm

Allowable shear stress, $\tau = 60 \frac{N}{mm^2}$

To find diameter of shaft, $d = ?$

Angle of twist, $\theta = 1^\circ$

Length of shaft, $L = 3m = 3000\ mm$

Modulus of rigidity, $G = 80 \frac{kN}{mm^2} = 80 \times 10^3 \frac{N}{mm^2}$

Solution :-

The torque transmitted by the shaft in Nmm

$$T = \frac{9.55 \times 10^6 \times P}{n} \quad - \quad \left[\frac{E - 3.3(a)}{50}\right]$$

$$T = \frac{9.55 \times 10^6 \times 100}{180}$$

$$T = 5305555.55 \text{ Nmm} = 5305.55 \times 10^3 \text{ Nmm}$$

Diameter of shaft based on strength :-

$$\tau = \frac{16 \times T}{\pi \times d^3} \quad - \left[\frac{E - 3.1}{50}\right]$$

$$d^3 = \frac{16 \times T}{\pi \times \tau}$$

$$d = \left[\frac{16 \times T}{\pi \times \tau}\right]^{1/3}$$

$$d = \left[\frac{16 \times 5305.55 \times 10^3}{\pi \times 60}\right]^{\frac{1}{3}}$$

$$d = \underline{\underline{76.65}} \text{ mm}$$

Diameter of shaft based on Rigidity :-

$$\theta = \frac{584 \times T \times L}{G \times d^4} \quad - \left[\frac{E - 3.2}{50}\right]$$

$$d^4 = \frac{584 \times T \times L}{G \times \theta}$$

$$d = \left[\frac{584 \times T \times L}{G \times \theta}\right]^{\frac{1}{4}}$$

$$d = \left[\frac{584 \times 5305555.55 \times 3000}{80 \times 10^3 \times 1^\circ}\right]^{\frac{1}{4}}$$

$$d = \underline{\underline{103.823}} \text{ mm}$$

∴ From standard shaft sizes in mm from table – $\frac{3.5(a)}{57}$, considering larger value (103.823mm)

$\boxed{d = 110 \text{ mm}}$ — $\left[\frac{T-3.5(a)}{57}\right]$

2] Design a MS shaft transmitting 80 kW at 500 rpm. The allowable shear stress in the shaft is 50 N/mm² and the angle of twist is not to exceed 1 degree in a length of 1m.
Take modulus of rigidity as $8 \times 10^4$ N/mm².

Given data:-

Power, P = 80 kW

speed, n = 500 rpm

allowable shear stress, $\tau = 50 \frac{N}{mm^2}$

Angle of twist, $\theta = 1^\circ$

Length of shaft, L = 1m = $\underline{\underline{1000 \text{ mm}}}$

Modulus of rigidity, $G = 8 \times 10^4 \frac{N}{mm^2}$

Diameter of shaft, d = ?

Solution :-

Torque transmitted by the shaft in Nmm.

$$T = \frac{9.55 \times 10^6 \times P}{n} \quad - \left[\frac{E - 3.3(a)}{50}\right]$$

$$T = \frac{9.55 \times 10^6 \times 80}{500}$$

$$T = 1528000 \text{ Nmm} \quad \text{or } T = 1528 \times 10^3 \text{ Nmm}$$

Diameter of shaft based on strength :-

$$\tau = \frac{16 \times T}{\pi \times d^3} \quad - \left[\frac{E - 3.1}{50}\right]$$

$$d^3 = \frac{16 \times T}{\pi \times \tau}$$

$$d = \left[\frac{16 \times T}{\pi \times \tau}\right]^{\frac{1}{3}}$$

$$d = \left[\frac{16 \times 1528 \times 10^3}{\pi \times 50}\right]^{\frac{1}{3}}$$

$$d = 53.79 \text{ mm}$$

Diameter of shaft based on Rigidity :-

$$\theta = \frac{584 \times T \times L}{G \times d^4} \quad - \left[\frac{E-3.2}{50}\right]$$

$$d^4 = \frac{584 \times T \times L}{G \times \theta}$$

$$d = \left[\frac{584 \times T \times L}{G \times \theta}\right]^{\frac{1}{4}}$$

$$d = \left[\frac{584 \times 1528 \times 10^3 \times 1000}{8 \times 10^4 \times 1^\circ}\right]^{\frac{1}{4}}$$

$$d = \underline{\underline{57.791\ mm}}$$

$\therefore$ From standard shaft sizes in mm.
Considering larger value (57.791 mm)

$$\boxed{d = 63\ mm} \quad - \left[\frac{T-3.5(a)}{57}\right]$$

## DDHB – REFERENCE PAGE No. 50 & 57



| Particular | Equation | Eqn. No. |
|---|---|---|
| ***Torsion of circular shafts:*** | | |
| The maximum torsional shear stress due to torsional loading | $\tau = \frac{Tc}{J} = \frac{16T}{\pi d^3}$ for solid shafts | 3.1 |
| | $= \frac{16T}{\pi d_o^3}\left(\frac{1}{1-K^4}\right)$ for hollow shafts | |
| The angular deformation | $\theta = \frac{TL}{JG}$ rad $= \frac{584TL}{Gd^4}$ deg., for solid shaft | 3.2 |
| | $= \frac{584TL}{G(d_o^4 - d_i^4)}$ deg., for hollow shafts | |
| The torque to be transmitted by the shaft N-mm | $\left.\begin{array}{l} T = \frac{10^6 P}{\omega} \\ T = \frac{9.55 \times 10^6 (P)}{n} \end{array}\right\}$ SI Units | 3.3(a) |
| The torque transmitted by the shaft, kgf mm | $\left.\begin{array}{l} T = \frac{75 \times 10^3 (MHP)}{\omega} \\ = \frac{7.16 \times 10^5 (MHP)}{n} \\ = \frac{9.74 \times 10^5 (P)}{n} \end{array}\right\}$ Metric Units | 3.3(b) |

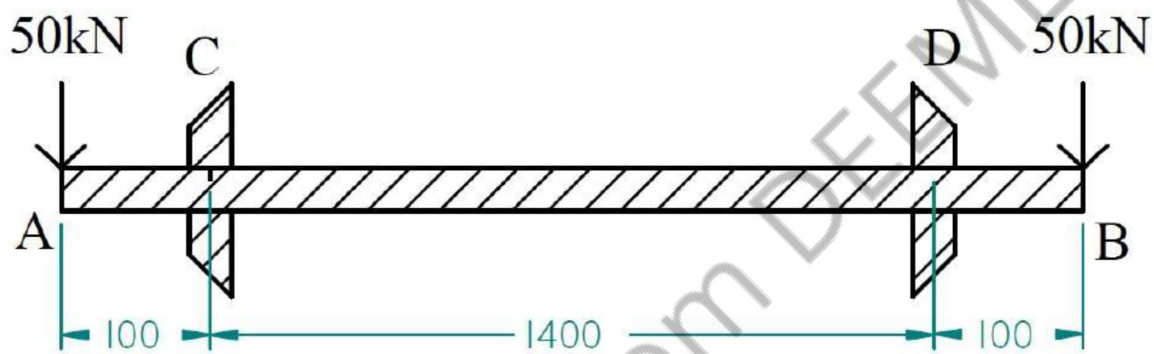


### Table 3.5 *(a) Standard shaft sizes in mm*

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 25 | 28 | 32 |
| 36 | 40 | 45 | 50 | 56 | 63 | 71 | 80 | 90 | 100 | 110 | 125 |
| 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 |
| 380 | 400 | 420 | 440 | 450 | 480 | 500 | 530 | 560 | 600 | – | – |

**Problems on Shaft subjected to only Bending.**

1] A pair of wheels of a railway wagon carries a load of 50 kN on each axle box acting at a distance of 100 mm outside the base. The gauge of rails is 1.4 m. Find the diameter of axle between the wheels, if the stress is not to exceed 100 MPa.




***All dimensions are in mm***



Given data:-

The distance of gauge of rails $= 1.4\,m = \underline{1400\,mm}$

Allowable stress, $\sigma = 100\,MPa = 100 \times 10^6\,Pa$

$M = mega = 10^6$

$Pa = \frac{N}{m^2}$ (Pascal)

$1m = 1000\,mm$

$1m^2 = (1000)^2 mm^2$

$= 100 \times 10^6 \frac{N}{m^2}$

$= 100 \times 10^6 \frac{N}{(1000)^2 mm^2}$

$= 100 \times \cancel{10^6} \frac{N}{\cancel{10^6}\, mm^2}$

$\boxed{\sigma = 100 \frac{N}{mm^2}}$

Solution :-

Let us name downward reactions as $R_A$ and $R_B$

i.e $R_A = R_B = 50$ kN

Let us name upward reactions as $R_C$ and $R_D$

To find $R_C$ and $R_D$, let us take bending moment at point C.

$$BM \text{ at LHS} = BM \text{ at RHS}$$

$$-(R_A \times 100) = -(R_B \times 1500) + (R_D \times 1400)$$

$$-(50 \times 100) = -(50 \times 1500) + 1400\,R_D$$

$$-5000 = -75000 + 1400\,R_D$$

$$-5000 + 75000 = 1400\,R_D$$

$$70000 = 1400\,R_D$$

or

$$1400\,R_D = 70000$$

$$\text{i.e } R_D = \frac{70000}{1400}$$

$$R_D = \underline{\underline{50 \text{ kN}}}$$

W.K.T Downward Reactions = upward Reactions

$$\text{ie} \quad R_A + R_B = R_C + R_D$$

$$50 + 50 = R_C + 50$$

$$R_C = 100 - 50$$

$$R_C = 50\ kN$$

$\therefore$ Reaction at point C, $R_C = 50\ kN$

Reaction at point D, $R_D = 50\ kN$

Shear Force Calculations :-

SF at A :- $LHS = 0$

$RHS = R_B - R_C - R_D$

$= 50 - 50 - 50$

$= -50\ kN$

SF at C :- $LHS = -50\ kN$

$RHS = R_B - R_D$

$= 50 - 50$

$= 0\ kN$

SF at D :- $LHS = R_C - R_A$

$= 50 - 50$

$= 0\ kN$

$RHS = R_B = 50\ kN$

SF at B :- $LHS = R_C + R_D - R_A$

$= 50 + 50 - 50$

$= 50\ kN$

$RHS = 0\ kN$

Bending Moment Calculations:-

BM at A :-

LHS = 0

RHS = $(R_C \times 100) + (R_D \times 1500) - (R_B \times 1600)$

$= (50 \times 100) + (50 \times 1500) - (50 \times 1600)$

$= 5000 + 75000 - 80000$

$= 0$

$\therefore$ LHS = RHS = 00 kN mm

BM at C :-

LHS = $-(R_A \times 100) = -(50 \times 100) = -5000$ kN mm

RHS = $(R_D \times 1400) - (R_B \times 1500)$

$= (50 \times 1400) - (50 \times 1500)$

$= 70000 - 75000$

$= -5000$ kN mm

BM at D :-

LHS = $(R_C \times 1400) - (R_A \times 1500)$

$= (50 \times 1400) - (50 \times 1500)$

$= 70000 - 75000$

$= -5000$ kN mm

RHS = $-(R_B \times 100) = -(50 \times 100) = -5000$ kN mm

BM at B :-

$$LHS = (R_C \times 1500) + (R_D \times 100) - (R_A \times 1600)$$

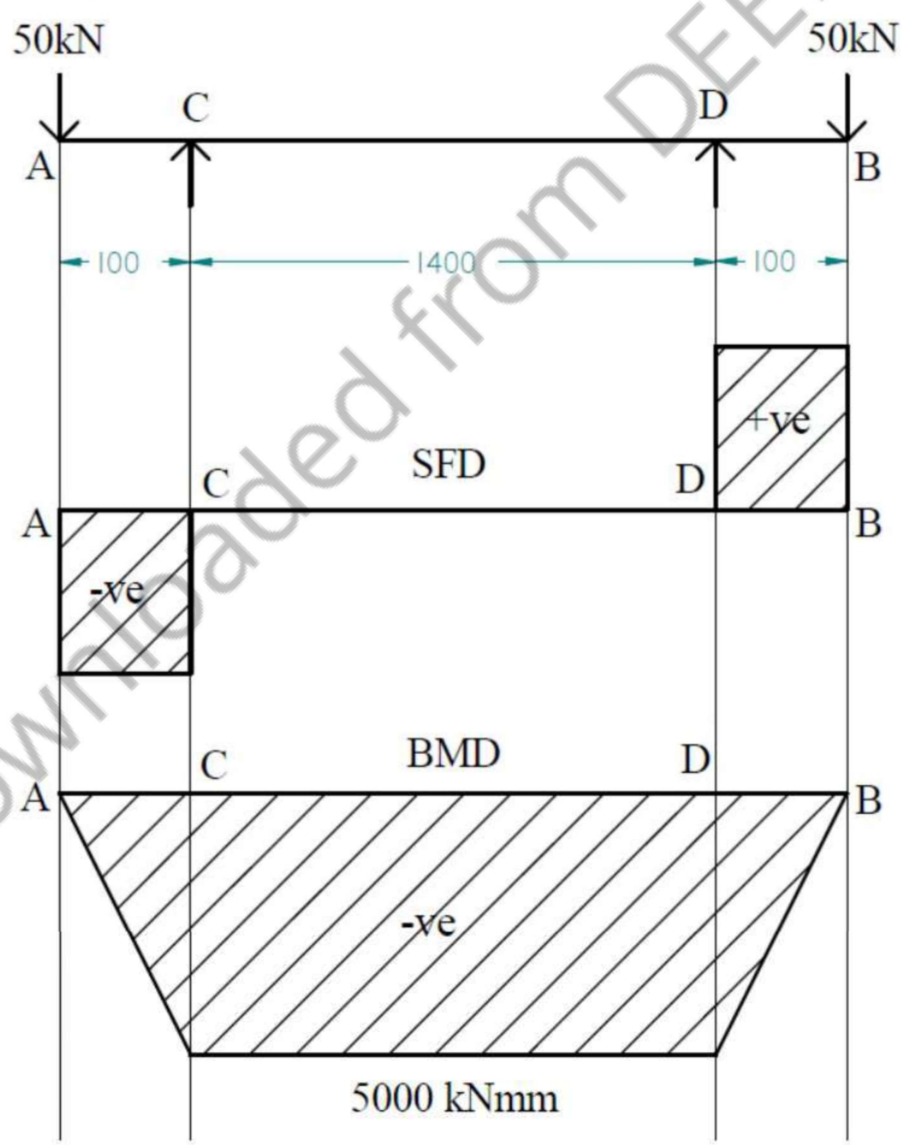
$$= (50 \times 1500) + (50 \times 100) - (50 \times 1600)$$

$$= 75000 + 5000 - 80000$$

$$= \underline{\underline{0}}$$

$$RHS = \underline{\underline{0}}$$

**SFD & BMD Diagram:**



From Bending Moment Diagram, Maximum Bending Moment, $M = 5000$ kNmm

i.e $M = 5000 \times 10^3$ Nmm

∴ Diameter of shaft subjected to simple benging is given by :-

$$d_o = \left[\frac{32 \times M}{\pi \times \sigma_d} \times \left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}} \quad \text{---} \quad \left[\frac{E - 3.4(b)}{50}\right]$$

But for a solid shaft, $K = 0$ and $d_o = d$

∴ the above equation can be written as

$$d = \left[\frac{32 \times M}{\pi \times \sigma}\right]^{\frac{1}{3}} \quad (\sigma_d = \sigma)$$

$$d = \left[\frac{32 \times 5000 \times 10^3}{\pi \times 100}\right]^{\frac{1}{3}}$$

$d = 79.85$ mm

∴ $d = 80$ mm standard shaft size $\left[\frac{T - 3.5(a)}{57}\right]$

**Week 06 [CO:2] [PO:3,4]:**
**Problems on Shaft subjected to combined Shear and Bending.**

① A solid circular shaft is subjected to a bending moment of 3000 Nm and a torque of 10000 Nm. The shaft is made of 45C8 steel having ultimate tensile stress of 700 MPa and a ultimate shear stress of 500 MPa. Assuming a factor of safety as 6. Determine the diameter of the shaft.

Given data:-

Bending moment, $M = 3000\ Nm = 3 \times 10^6\ Nmm$

Torque, $T = 10000\ Nm = 10 \times 10^6\ Nmm$

Ultimate tensile stress, $\sigma_u = 700\ MPa = 700 \times 10^6 \frac{N}{m^2}$

$= 700 \times 10^6 \frac{N}{10^6\ mm^2}$

$\sigma_u = 700 \frac{N}{mm^2}$

Ultimate shear stress, $\tau_u = 500\ MPa = 500 \frac{N}{mm^2}$

Factor of Safety, $FOS = 6$

Diameter of shaft, $d = ?$

Solution :-

$$\text{Allowable Tensile stress } (\sigma) = \frac{\sigma_u}{FoS} = \frac{700 \text{ N/mm}^2}{6}$$

$$\text{i.e } \sigma = 116.66 \frac{N}{mm^2}$$

$$\text{Allowable shear stress}, \tau = \frac{\tau_u}{FoS} = \frac{500 \text{N/mm}^2}{6}$$

$$\tau = 83.33 \frac{N}{mm^2}$$

From the maximum torsional shear stress formula

$$\tau = \frac{16 \times T}{\pi \times d^3} \quad \text{—} \quad \left[\frac{E - 3.1}{50}\right]$$

$$\text{i.e } d^3 = \frac{16 \times T}{\pi \times \tau}$$

$$d = \left[\frac{16 \times T}{\pi \times \tau}\right]^{\frac{1}{3}}$$

$$d = \left[\frac{16 \times 10 \times 10^6}{\pi \times 83.33}\right]^{\frac{1}{3}}$$

$$d = 84.863 \text{ mm}$$

According to maximum normal stress Theory

$$d_o = \left[\frac{16}{\pi \times \sigma_{max}} \left(M + \sqrt{M^2 + T^2}\right) \times \left(\frac{1}{1-K^4}\right)\right]^{\frac{1}{3}}$$

$$- \left[\frac{E - 3.5(a)}{50}\right]$$

For solid shaft , $K=0$ and $d_o = d$

$\sigma_{max} = \sigma$

$\therefore$ above equation can be written as follows

$$d = \left[\frac{16}{\pi \times \sigma} \left(M + \sqrt{M^2 + T^2}\right)\right]^{\frac{1}{3}}$$

$$d = \left[\frac{16}{\pi \times 116.66} \times \left(3\times10^6 + \sqrt{(3\times10^6)^2 + (10\times10^6)^2}\right)\right]^{\frac{1}{3}}$$

$$d = \underline{\underline{83.718 \text{ mm}}}$$

Considering maximum value of diameter (84.863 mm)

Standard shaft size $d = 90$ mm $- \left[\frac{T - 3.5(a)}{57}\right]$

**Week 07 [CO:2,3] [PO:3,4]:**

**Classification of springs:**

- Springs are mechanical components that store and release mechanical energy.
- They find extensive use in various engineering applications to provide elasticity and flexibility.
- Springs are classified based on different criteria, including their shape, material, and application.

**Here are some common classifications of springs in design:**

**Based on Shape:**

- Coil Springs
- Leaf Springs
- Torsion Springs
- Compression Springs
- Extension Springs
- Spiral Springs
- Constant Force Springs

**Based on Material:**

- Steel Springs
- Stainless Steel Springs
- Alloy Springs
- Non-Metallic Springs

**Based on Application:**

- Automotive springs
- Industrial Springs
- Valve Springs
- Electrical Contact Springs
- Aerospace Springs
- Medical Springs

**Based on Load and Deflection Characteristics:**

- Linear Springs
- Non-Linear Springs
- Variable Rate Springs
- Progressive Rate Springs
- Regressive Rate Springs

**Other Classifications:**

- Closed-Coil Springs vs. Open-Coil Springs
- Ground Ends vs. Squared Ends

**Application of springs:**

- Springs find widespread applications in various engineering fields due to their ability to store and release mechanical energy.
- Their elasticity and flexibility make them valuable components in different systems.
- Here are some common applications of springs in engineering:

**1. Automotive Industry:**

- ***Vehicle Suspension Systems:*** Coil springs and leaf springs are used to absorb shocks and provide a smooth ride by supporting the vehicle's weight.
- ***Valve Springs:*** Springs are employed in internal combustion engines to open and close valves.

**2. Mechanical Engineering:**

- ***Mechanical Watches:*** Springs power the movement of mechanical watches, storing energy when wound and releasing it to drive the watch mechanism.
- ***Clutches and Brakes:*** Springs assist in engaging and disengaging clutches and brakes.

**3. Manufacturing and Machinery:**

- ***Press Machines:*** Springs are used in the design of press machines to control the force applied during metal forming processes.
- ***Conveyor Systems:*** Springs are used to provide tension and absorb shocks in conveyor systems.

**4. Aerospace Industry:**

- ***Landing Gear Systems:*** Springs are utilized in the shock-absorbing systems of landing gear.
- ***Aircraft Seating:*** Springs contribute to the design of seats to provide comfort and shock absorption.

**5. Electronics and Electrical Engineering:**

- ***Switches and Connectors:*** Springs are used in switches and connectors to maintain electrical contact.

- ***Printers:*** Springs assist in the movement of printer components like rollers and trays.

**6. Medical Devices:**
- ***Surgical Instruments:*** Springs are used in various medical instruments, ensuring proper functioning and ease of use.
- ***Prosthetics:*** Springs contribute to the flexibility and movement of prosthetic limbs.

**7. Civil Engineering and Construction:**
- ***Vibration Isolators:*** Springs are used to reduce vibrations in buildings and structures.
- ***Bridge Bearings:*** Springs assist in providing flexibility and absorbing movements in bridge structures.

**8. Robotics:**
- ***Robot Joints:*** Springs are employed in robotic joints to provide flexibility and control movement.
- ***Force Sensors:*** Springs can be part of force sensors to measure and respond to external forces.

**9. Energy Storage Systems:**
- ***Mechanical Energy Storage:*** Springs are used in some mechanical energy storage systems, such as those found in some types of flywheels.

**10. Sporting Goods:**
- ***Bicycles:*** Springs are used in various bicycle components, such as suspension systems.
- ***Firearms:*** Springs are used in the design of triggers and recoil mechanisms in firearms.

**11. Consumer Products:**
- ***Toys:*** Springs are commonly used in various toys to provide motion and play features.
- ***Doors and Latches:*** Springs contribute to the opening and closing mechanisms of doors and latches.

**Leaf spring and its applications:**

- A leaf spring is a type of suspension spring commonly used in vehicles, especially in older or heavy-duty designs.
- It consists of multiple layers of flexible, curved strips or leaves of spring steel bound together to form a single unit.
- Leaf springs provide support and stability to the vehicle while allowing for controlled movement.
- Here are some applications of leaf springs:

**Applications of Leaf Springs:**

**1. Automotive Suspension Systems:**

- ***Trucks and Commercial Vehicles:*** Leaf springs have been traditionally used in the rear suspension of many trucks, buses, and commercial vehicles. They provide durability and load-carrying capacity, making them suitable for heavy-duty applications.
- ***Trailers:*** Leaf springs are common in the suspension systems of trailers, providing support for cargo loads.
- ***Off-Road Vehicles:*** Some off-road vehicles and utility vehicles use leaf springs for their simplicity and robustness.

**2. Railway Cars:**

- ***Wagons and Freight Cars:*** Leaf springs have been historically used in the suspension systems of railway wagons and freight cars.

**3. Industrial and Agricultural Equipment:**

- ***Tractors and Agricultural Machinery:*** Leaf springs are employed in the suspension systems of tractors and agricultural equipment due to their ability to handle heavy loads.
- ***Construction Equipment:*** Leaf springs may be found in the suspension systems of construction machinery.

**4. Military Vehicles:**

- ***Military Trucks and Vehicles:*** Leaf springs have been utilized in various military vehicles for their ruggedness and ability to handle challenging terrains.

**5. Vintage and Classic Cars:**

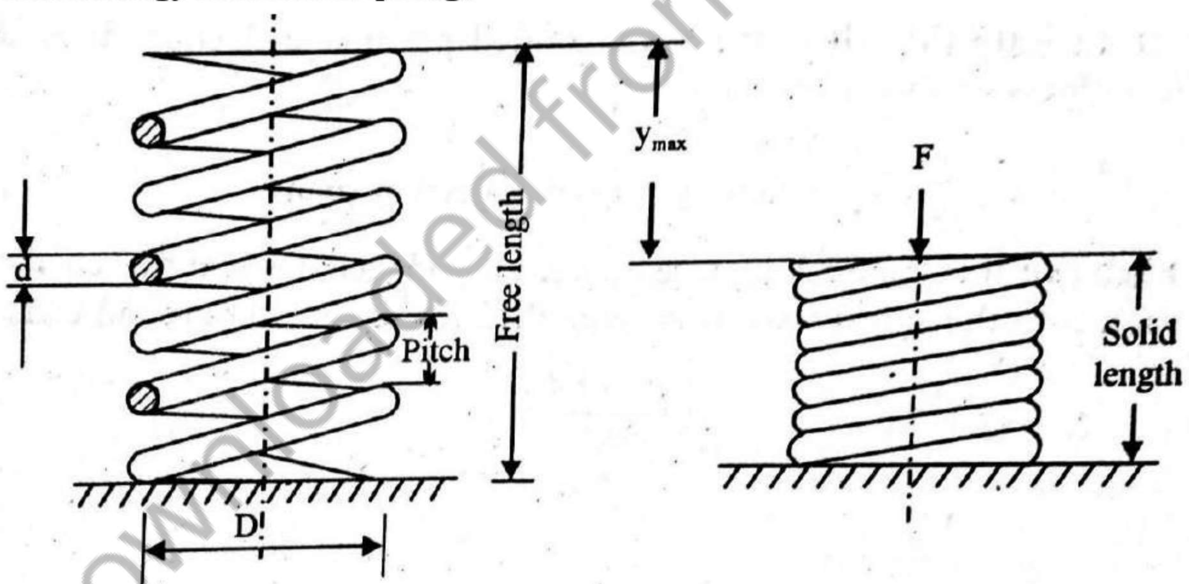
- ***Historical and Classic Vehicles:*** Leaf springs were commonly used in the suspension systems of vintage and classic cars.

**6. Aftermarket Suspension Upgrades:**

- ***Off-Road Enthusiasts:*** Some off-road enthusiasts choose to use leaf springs in aftermarket suspension setups for their simplicity and durability.

*Leaf springs offer several advantages, including simplicity of design, durability, and cost-effectiveness. However, modern vehicles often use more complex suspension systems, such as coil springs or air springs, to achieve better ride comfort and handling characteristics. Despite this, leaf springs continue to have applications in specific vehicle types and industrial settings where their characteristics are well-suited to the requirements.*

**Terminology of Helical spring:**




- Helical springs, commonly known as coil springs, are mechanical devices used to store and release energy.
- Understanding the terminology associated with helical springs is essential for designing and specifying these components.

**Here are key terms related to helical springs:**

**1. Wire Diameter (d):** The diameter of the wire from which the spring is formed. It is measured across the width of the wire.

**2. Mean Coil Diameter (D):** The average diameter of the coil, calculated by adding the outside diameter to the inside diameter and dividing by 2.

**3. Outside Diameter ($D_o$):** The maximum diameter of the coil, including the diameter of the wire.

**4. Inside Diameter ($D_i$):** The minimum diameter of the coil, excluding the diameter of the wire.

**5. Pitch (p):** The axial distance between adjacent coils, measured parallel to the axis of the spring.

**6. Total Coils (i):** The total number of active coils in the spring. This includes both the active coils and the end coils.

**7. Active Coils ($i_a$):** The coils that are free to deflect under load. It excludes the end coils, which are usually flattened or closed.

**8. Free Length ($L_f$):** The overall length of the spring when no external force is applied.

**9. Solid Length ($L_s$):** The length of the spring when it is compressed to the point where all coils touch and no further compression is possible.

**10. Spring Rate (k):** The amount of force required to compress or extend the spring by a certain distance. It is expressed in force per unit of deflection (N/m).

**11. Deflection (y):** The distance the spring is compressed or extended from its free length.

**12. Shear Stress (τ):** The internal force per unit area acting tangentially across a section of the wire in the spring.

**13. Buckling:** A phenomenon where the spring may buckle or deform laterally if the compressive load exceeds a critical value. Proper design and choice of materials help prevent buckling.

**14. Spring Index (C):** The ratio of mean coil diameter to wire diameter. It provides information about the shape and behaviour of the spring.

**15. Coil Helix Angle (α):** The angle formed by the helix of the spring coil with respect to its axis.

**16. Load (W):** The force applied to the spring, causing it to compress or extend.

**17. Hooke's Law:** A principle stating that the force needed to extend or compress a spring by some distance is proportional to that distance.

**Materials of springs:**

- Springs are made from a variety of materials, each chosen based on the specific requirements of the application.
- The selection of spring material depends on factors such as the type of load, environmental conditions, temperature range, and desired spring characteristics.
- Here are common materials used for springs:

**1. High Carbon Steel:**

- ***Properties:*** High carbon steel is known for its high strength and durability. It is cost-effective and widely used in industrial applications.
- ***Applications:*** Heavy-duty coil springs, automotive suspension systems.

**2. Alloy Steel:**

- ***Properties:*** Alloy steel combines strength with improved resistance to corrosion and fatigue. Alloying elements like chromium, vanadium, or silicon enhance performance.
- ***Applications:*** Automotive, machinery, industrial springs.

**3. Stainless Steel:**

- ***Properties:*** Stainless steel is corrosion-resistant and maintains its strength at high temperatures. It is often chosen for applications requiring cleanliness and hygiene.
- ***Applications:*** Medical devices, marine equipment, food processing machinery.

**4. Music Wire (Spring Wire):**

- ***Properties:*** Music wire is a high-carbon steel wire with uniform wire diameter, high tensile strength, and good surface finish.
- ***Applications:*** Small springs, precision instruments, musical instruments.

**5. Phosphor Bronze:**

- ***Properties:*** Phosphor bronze offers good corrosion resistance and electrical conductivity. It is also known for its fatigue resistance.
- ***Applications:*** Electrical contacts, springs in precision instruments.

**6. Titanium Alloy:**

- ***Properties:*** Titanium alloys are lightweight, corrosion-resistant, and have high strength. They are suitable for applications where weight is a critical factor.
- ***Applications:*** Aerospace components, medical implants.

**7. Inconel Alloy:**

- ***Properties:*** Inconel alloys are known for their high-temperature resistance, corrosion resistance, and excellent mechanical properties.
- ***Applications:*** Aerospace components, chemical processing equipment.

**8. Beryllium Copper:**

- ***Properties:*** Beryllium copper combines high electrical conductivity with good spring properties. It is non-magnetic and resists sparking.
- ***Applications:*** Electronic connectors, switches, non-sparking tools.

**9. Chrome Silicon:**

- ***Properties:*** Chrome silicon is a heat-treated alloy known for its high strength, fatigue resistance, and stability.

- ***Applications:*** Firearms, automotive suspension systems, industrial springs.

**10. Nitinol (Nickel Titanium):**

- ***Properties:*** Nitinol is a shape memory alloy that exhibits unique properties, such as superelasticity and the ability to return to a predefined shape after deformation.
- ***Applications:*** Medical devices (stents, guidewires), actuators.

**11. Plastics (for Light-Duty Applications):**

- ***Properties:*** Some plastics, such as fiberglass-reinforced composites or high-performance polymers, may be used for light-duty springs where corrosion resistance and non-metallic properties are essential.
- ***Applications:*** Medical devices, lightweight mechanisms.

*The choice of spring material depends on factors such as strength requirements, environmental conditions, cost considerations, and specific application needs. It's important to consider the material's properties in relation to the intended use to ensure optimal performance and durability.*

**Week 08 [CO:2,3] [PO:3,4]:**

## Design of helical spring

Q Design a helical compression spring for a maximum load of 1000 N for a deflection of 25 mm using the valve of spring index as 5. The maximum permissible shear stress for spring wire is 420 MPa and the modulus of rigidity 84 kN/mm² with considering Wahl's stress factor as 1.3105

given data :-

Load, $F = 1000\,N$

Deflection, $y = 25\,mm$

Spring Index, $C = 5$

Spring index $C = \frac{D}{d} = 5$

$\therefore \frac{D}{d} = 5$ or $\underline{\underline{D = 5d}}$

Shear stress, $\tau = 420\,MPa = 420 \times 10^6 \frac{N}{m^2} = \frac{420 \times 10^6\,N}{(1000)^2\,mm^2}$

$= \frac{420 \times \cancel{10^6}\,N}{\cancel{10^6}\,mm^2}$

$\therefore \underline{\underline{\tau = 420 \frac{N}{mm^2}}}$

Modulus of Rigidity, $G = 84 \frac{kN}{mm^2} = 84 \times 10^3 \frac{N}{mm^2}$

Wahl's stress factor, $K = 1.3105$

<u>Solution</u> :-

To find Diameter of wire (d) and Coil (D)

W.K.T $\tau = \frac{8FDK}{\pi \times d^3}$ - - - $\boxed{\frac{11.1\,(d)}{169}}$ (DDHB)

But $D = 5d$

$\therefore \tau = \frac{8 \times F \times 5 \times \cancel{d} \times K}{\pi \times d^{\cancel{3}2}}$

$$\tau = \frac{8 \times F \times 5 \times K}{\pi \times d^2}$$

$$\therefore d^2 = \frac{8 \times F \times 5 \times K}{\pi \times \tau}$$

$$d = \left[\frac{8 \times F \times 5 \times K}{\pi \times \tau}\right]^{\left(\frac{1}{2}\right)}$$

$$d = \left[\frac{8 \times 1000 \times 5 \times 1.3105}{\pi \times 420}\right]^{\left(\frac{1}{2}\right)}$$

$d = \underline{6.303}$ mm is the wire diameter

$$\therefore D = 5 \times d$$

$$D = 5 \times 6.303$$

$D = \underline{31.515}$ mm is the coil diameter

To find number of turns of the coil

W.K.T $\quad y = \dfrac{8 F D^3 i}{G \times d^4} \quad - \left(\dfrac{11.5\ (a)}{170}\right)$ DDHB

$$\therefore i = \frac{y \times G \times d^4}{8 \times F \times D^3}$$

$$i = \frac{25 \times 84 \times 10^3 \times (6.303)^4}{8 \times 1000 \times (31.515)^3}$$

$$i = 13.23 \simeq 14 \text{ turns}$$

Free length of the spring

$$L_f = (i \times d) + y + (0.15 \times y)$$

$$L_f = (14 \times 6.303) + 25 + (0.15 \times 25)$$

$$L_f = 116.992 \text{ mm}$$

Pitch of the coil

$$p = \frac{L_f - 2d}{i}$$

$$p = \frac{116.992 - (2 \times 6.303)}{14}$$

$$p = 7.45 \text{ mm}$$

Solid length

$$L_s = i \times d$$

$$L_s = 14 \times 6.303$$

$$L_s = 88.242 \text{ mm}$$

OR

$$L_s = L_f - y$$

$$L_s = 116.992 - 25$$

$$L_s = 91.99 \text{ mm}$$

**DDHB – REFERENCE PAGE No. : 167, 168, 169, 170, 171 & 189**

# Springs

| Symbols | Description and Units |
|---|---|
| $B$ | size factor |
| $C$ | spring index |
| $d$ | diameter of the wire, mm |
| $D$ | pitch diameter or mean diameter of spring, mm |
| $f$ | natural frequency of the spring, $H_2$ |
| $F$ | load on the spring, N (kgf) |
| $F_a$ | variable load, N (kgf) |
| $F_m$ | average or mean load, N (kgf) |
| $F_o$ | spring scale or rate, N/mm (kgf/mm) |
| $F_{cr}$ | critical axial load on the spring, N (kgf) |
| $F_{max}$ | maximum load on the spring, N (kgf) |
| $F_{min}$ | minimum load on the spring, N (kgf) |
| $i$ | the number of active coils in the spring |
| $K$ | stress correction factor |
| $K_t$ | stress concentration factor |
| $K_{tf}$ | fatigue stress concentration factor |
| $R$ | reliability factor |
| $U$ | resilence of the spring, N mm (kgf-mm) |
| $V$ | volume of the spring, $mm^3$ |
| $y$ | axial deflection of the spring, mm |
| $\tau$ | maximum stress in the helical spring, $MN/m^2$ ($kgf/mm^2$) |
| $\tau_d$ | design stress for static loading, $MN/m^2$ ($kgf/mm^2$) |
| $\tau_{dr}$ | design stress for completely reversed loads, $MN/m^2$ ($kgf/mm^2$) |
| $\tau_e$ | Elastic limit stress in shear, $MN/m^2$ ($kgf/mm^2$) |
| $\sigma$ | maximum stress in the leaf spring, $MN/m^2$ ($kgf/mm^2$) |
| $\sigma_f$ | stress in the full length leaves, $M/Nm^2$ ($kgf/mm^2$) |
| $\sigma_g$ | stress in the graduated leaves, $MN/m^2$ ($kgf/mm^2$) |

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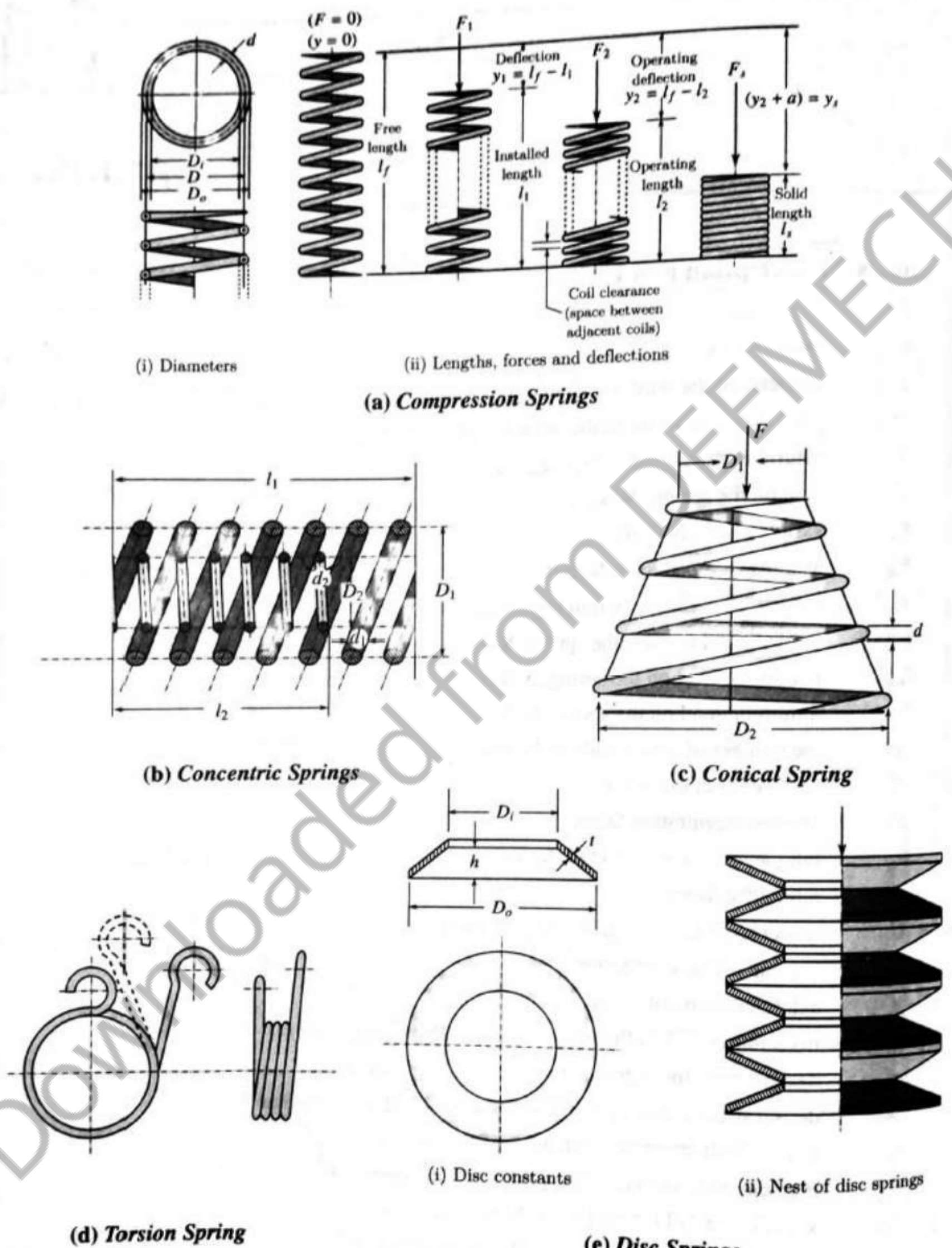
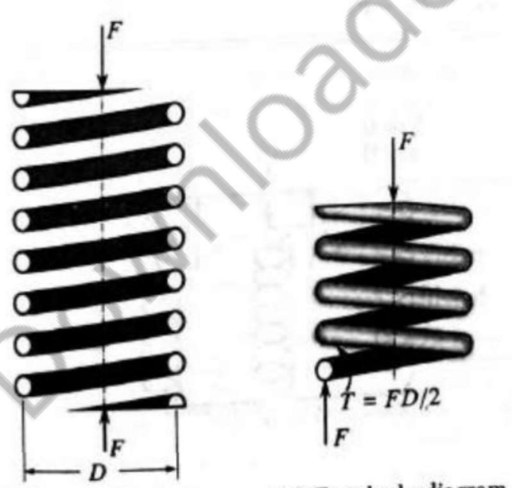



**Fig. 11.1:** ***Notations for different types of springs***

| Particular | Equation | Eqn. No. |
|---|---|---|
| ***Cylindrical compression spring:*** | | |
| ***(a) Round section springs:*** | | |
| Torsional moment produced in the spring (Fig. 11.2) | $T = \frac{1}{2}FD$ | 11.1(a) |
| The internal resisting moment | $T = Z_p\tau = \left(\frac{\pi d^3}{16}\right)\tau$ | 11.1(b) |
| The shear stress due to torque only | $\tau = \frac{8FD}{\pi d^3}$ | 11.1(c) |
| The shear stress in the helical spring (considering compressive stress acting along the coil and also direct shear stress) | $\tau = \frac{8FDK}{\pi d^3} = \frac{yGdK}{\pi iD^2}$ | 11.1(d) |
| The wire diameter, (Table 11.1 and 11.2) | $d = \sqrt[3]{\left(\frac{8FDK}{\pi\tau}\right)}$ | 11.1(e) |
| | where $K$ is the stress correction factor | |
| According to Wahl, the stress correction factor (Fig. 11.3) | $K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$ | 11.2(a) |
| The stress correction factor (*Bergstroessar*) | $K = \frac{4C+2}{4C-3}$ | 11.2(b) |
| | where $C = (D/d)$, the spring index | 11.2(c) |
| Very close approximate equation for the stress factor ($2 \geq C \leq 12$) | $K = \frac{2}{C^{0.25}} = 2\left(\frac{d}{D}\right)^{0.25}$ | 11.2(d) |




(a) Axially loaded (b) Free-body diagram

**Fig. 11.2: *Helical Compression Spring***

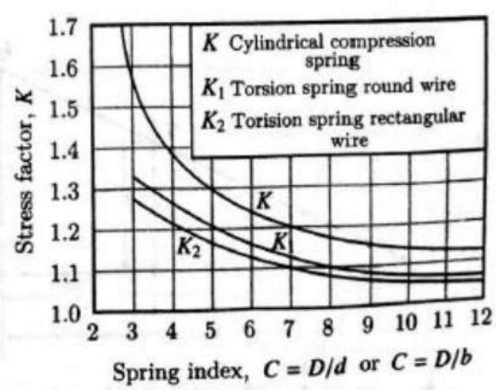
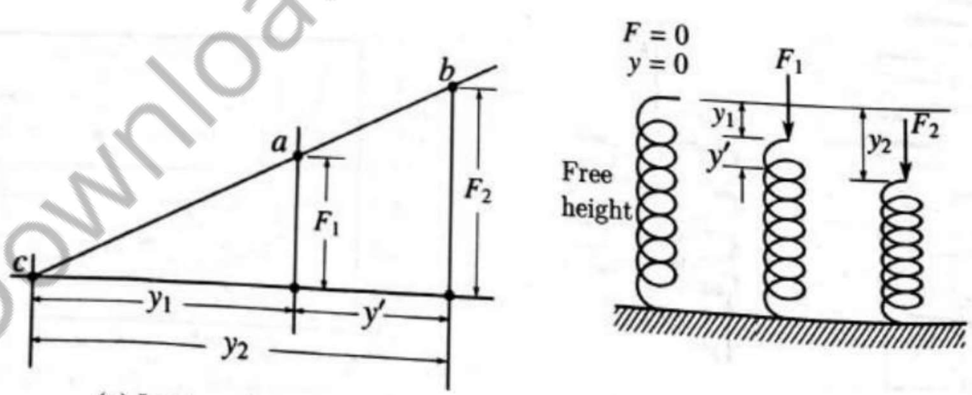



**Fig. 11.3: *Stress factors for helical springs***

| Particular | Equation | Eqn. No. |
|---|---|---|
| Taking the stress factor from Equation 11.2(d), the shear stress in the spring | $\tau = \frac{16FD^{0.75}}{\pi d^{2.75}} = \frac{5.1FC^{0.75}}{d^2}$ | 11.3 |
| The angular deflection | $\theta = \frac{16FDl}{\pi Gd^4} = \frac{16FD^2 i}{Gd^4}$ where $l = \pi Di$, length of the spring bar, mm | 11.4 |
| The axial deflection of the spring | $y = \frac{8FD^3 i}{Gd^4} = \frac{8FC^3 i}{Gd}$ | 11.5(a) |
| The axial deflection of the spring in terms of the shear stress | $y = \frac{\pi i \tau D^2}{KGd} = \frac{\pi i \tau D^{2.25}}{2Gd^{1.25}}$ | 11.5(b) |
| The load acting along the axis of the spring | $F = \frac{yGd^4}{8D^3 i}$ | 11.5(c) |
| The shear stress in terms of deflection ($y$) | $\tau = \frac{yGdK}{\pi i D^2}$ | 11.5(d) |
| The number of active coils required | $i = \frac{yGd^4}{8FD^3} = \frac{yGd}{8FC^3} = \frac{yKGd}{\pi D^2 \tau}$ | 11.6 |
| Spring scale or rate or stiffness | $F_o = F/y = \frac{d^4 G}{8iD^3}$ | 11.7(a) |
| Spring scale (Fig. 11.4) | $F_o = \frac{F_2 - F_1}{y'}$ | 11.7(b) |

where deflections $y_1$ and $y_2$ are due to forces $F_1$ and $F_2$ respectively

$y^1 = y_2 - y_1$ and the total deflection $y_2 = \frac{F_2}{F_0} = \frac{y^1 F_2}{F_2 - F_1}$




(a) Loads and deflections

(b) Loads and deflections

**Fig. 11.4:** ***Loads and deflections in a helical spring***

| Particular | Equation | Eqn. No. |
|---|---|---|
| ***The resilience of the spring or work done by the spring*** | | |
| | $U = \frac{Fy}{2} = \frac{4F^2D^3i}{Gd^4} = \frac{\pi^2 d^2 Di\tau^2}{16K^2G} = \frac{\pi^2 d^{1.5} D^{1.5} i\tau^2}{64G} = \frac{0.155 d^3 C^{1.5} i\tau^2}{G}$ $= \frac{V\tau^2}{4K^2G} = \frac{V\tau^2 C^{0.5}}{16G} = \frac{y^2 d^4 G}{16iD^3}$ | 11.8 |
| Volume of the spring | $V = \pi Di \times \frac{\pi}{4} d^2$ | 11.9 |
| The size factor for sections above 12.5 mm wire diameter in section | $B = \frac{d^{0.25}}{1.885}$ | 11.10(a) |
| *Note:* For rectangular sections, the value of $b$ or $h$ whichever is smaller is used instead of $d$ in the above Equation 11.10 | | |
| Where $b$ is the breadth of spring wire, mm and $h$ is the thickness of spring wire, mm | | |
| Design or permissible shear stress (Table 11.3 and Fig. 11.8) | $\tau_d = \frac{\tau_e}{RB} = \frac{1.885\tau_e}{Rd^{0.25}}$ | 11.10(b) |
| Reliability factor | $R = \frac{F(\text{(compressed)})}{F(\text{working})} = \frac{y+a}{y}$ | 11.11 |

where $\tau_e$ is the elastic limit stress in shear (Table 11.5 to 11.7)

$y$ is the deflaction under the working load

$a$ is the total clearance between the spring coils ($a \approx 25\%$ of $y$ and then $R \approx 1.25$)

| Particular | Equation | Eqn. No. |
|---|---|---|
| wire diameter for static loads | $d = \left(\frac{6RF}{\tau_e}\right)^{0.4} \times D^{0.3}$ | 11.12(a) |
| If there are no space limitations, then the diameter of the wire in terms of the spring index | $d = \left(\frac{6RF}{\tau_e}\right)^{0.57} C^{0.43}$ | 11.12(b) |

*Note:* For good design, values of $C$ between 8 and 10 are preferred

***(b) Rectangular section springs:***

The stress in the rectangular section spring

$$\tau = \frac{KFD(1.5h + 0.9b)}{b^2h^2} = \frac{KFD(1.5 + 0.9m)}{m^2h^3} \quad \text{where } K = \frac{4C-1}{4C-4} + \frac{0.615}{C} \qquad 11.13(a)$$

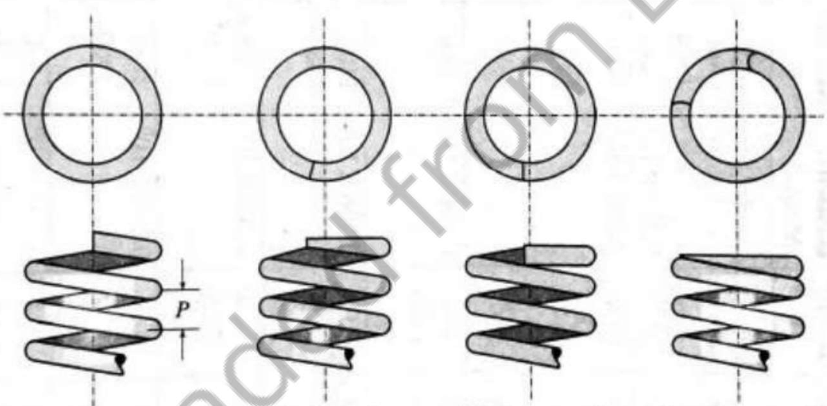
$$= \frac{FD^{0.75}(3h + 1.8b)}{b^{1.75}h^2} = \frac{FD^{0.75}(3 + 1.81m)}{m^{1.75}h^{2.75}}$$

$$\text{where } K = \frac{2}{C^{0.25}} = 2(d/D)^{0.25}, \quad C = \frac{D}{b} \text{ and } m = \frac{b}{h} \le 1$$

**Table 11.3** ***Spring Design stresses***

| Wire diameter (mm) | Design Stress, $MN/m^2$ ($kgf/mm^2$) | | |
|---|---|---|---|
| | Severe service | Average Service | Light service |
| Upto 2.10 | 414 (42.2) | 517 (52.7) | 640 (65.4) |
| 2.10 – 4.50 | 380 (38.7) | 476 (48.5) | 586 (59.8) |
| 4.50 – 8.00 | 330 (33.8) | 414 (42.2) | 510 (52.0) |
| 8.00 – 13.00 | 290 (29.5) | 360 (36.6) | 448 (45.7) |
| 13.00 – 25.00 | 248 (25.3) | 310 (31.6) | 386 (39.4) |
| 25.00 – 38.00 | 220 (22.5) | 276 (28.1) | 345 (35.2) |

**Table 11.4** ***Different types of spring coil ends***




| Type of Spring Coil Ends | Number of Coils | | | Length of Spring | | Pitch ($p$) mm |
|---|---|---|---|---|---|---|
| | End Coils | Active Coils | Total | Solid ($l_s$) (mm) | Free ($l_0$) (mm) | |
| (a) Plain End | 0 | $i$ | $i$ | $(i+1)d$ | $ip + d = ((i+1)d + y + a)$ | $(l_0 - d)/i$ |
| (b) Plain and Ground End | 1 | $i$ | $(i+1)$ | $(i+1)d$ | $(i+1)p = (i+1)d + y + a$ | $l_0/(i+1)$ |
| (c) Square or Close End | 2 | $i$ | $(i+2)$ | $(i+3)d$ | $(ip + 3d) = (i+3)d + y + a$ | $(l_0 - 3d)/i$ |
| (d) Square and Ground End | 2 | $i$ | $(i+2)$ | $(i+2)d$ | $(ip + 2d) = (i+2)d + y + a$ | $(l_0 - 2d)/i$ |

$y$ = axial deflection; $a$ = total clearance between working coils

**Week 09 [CO:2,3] [PO:3,4]:**

**Design of Muff coupling:**

1] Design a muff coupling to connect two shafts transmitting 40 kW at 140 rpm. The permissible shear and crushing stress for the shaft and key material are 30 N/mm² and 80 N/mm² respectively. The material of the muff is CI with permissible shear stress of 15 N/mm². Assume that the maximum torque transmitted is 25% greater than the mean torque.

Given Data :-

Power, $P = 40\ kW$

Speed, $n = 140\ rpm$

Permissible shear stress for shaft and key.

$$\tau_s = \tau_K = 30 \frac{N}{mm^2}$$

Permissible crushing stress for shaft and key.

$$\sigma_s = \sigma_K = 80 \frac{N}{mm^2}$$

Permissible shear stress for muff

$$\tau_{CI} = 15 \frac{N}{mm^2}$$

$T_{max}$ = 25% greater than $T_{mean}$

$$T_{max} = \left[\frac{25}{100} + 1\right] \times T_{mean}$$

$$\boxed{T_{max} = 1.25 \times T_{mean}}$$

Solution :-

Design of Shaft :-

Torque transmitted by shaft :-

$$T = \frac{9.55 \times 10^6 \times P}{n} \quad \left[\frac{E - 3.3(a)}{50}\right]$$

$$T = \frac{9.55 \times 10^6 \times 40}{140}$$

$$T = 2728571.429 \text{ Nmm} = T_{mean}$$

$$\therefore T_{max} = 1.25 \times T_{mean}$$

$$T_{max} = 1.25 \times 2728571.429 \text{ Nmm}$$

$$T_{max} = 3410714.286 \text{ Nmm} \quad \text{— (A)}$$

Maximum shear stress in shaft

$$\tau_s = \frac{16 \times T_{max}}{\pi \times d^3} \quad \text{—} \left[\frac{E-3.1}{50}\right]$$

$$d^3 = \frac{16 \times T_{max}}{\pi \times \tau_s}$$

$$d = \left[\frac{16 \times T_{max}}{\pi \times \tau_s}\right]^{\frac{1}{3}}$$

$$d = \left[\frac{16 \times 3410714.286}{\pi \times 30}\right]^{\frac{1}{3}}$$

$$d = 83.348 \text{ mm}$$

$$\therefore d = 90 \text{ mm} \quad \text{———} \left[\frac{T-3.5(a)}{57}\right]$$

Standard shaft size.

Design of Muff :-

outside diameter of muff, $d_o = 2d + 13$ mm

i.e $d_o = (2 \times 90) + 13$

$d_o = \underline{\underline{193}}$ mm

Length of Muff :- $L = 3.5d$

i.e $L = 3.5 \times 90$

$L = \underline{\underline{315}}$ mm

Now let us check for induced shear stress in muff

$$\tau_{CI} = \frac{16 \times T_{max}}{\pi \times d_o^3} \times \left[\frac{1}{1 - K^4}\right] \rightarrow \left[\frac{E - 3.1}{50}\right]$$

Here $K = \frac{\text{inside diameter}}{\text{outside diameter}}$

$$K = \frac{d}{d_o} = \frac{90}{193}$$

$K = \underline{\underline{0.466}}$

$$\therefore \tau_{cI} = \frac{16 \times T_{max}}{\pi \times d_o^3} \times \left[\frac{1}{1-K^4}\right]$$

$$\tau_{cI} = \frac{16 \times 3410714.286}{\pi \times 193^3} \times \left[\frac{1}{1-(0.466)^4}\right]$$

$$\tau_{cI} = \underline{\underline{2.536}} \ \frac{N}{mm^2}$$ is the induced shear stress in muff.

Since induced shear stress in muff is less than permissible shear stress in muff.

i.e $2.536 \frac{N}{mm^2} < 15 \frac{N}{mm^2}$

$\therefore$ The design of Muff is safe

Design of key :-

From DDHB $\left[\frac{T-4.1}{69}\right]$, for shaft diameter 85 to 95 mm

Width of key, $b = 25$ mm

Height of key, $h = 14$ mm

Length of key, $L_K = \frac{L}{2}$

$$L_K = \frac{315}{2}$$

$$L_K = 157.5 \text{ mm}$$

$\therefore$ Say $L_K = \underline{\underline{158 \text{ mm}}}$

Induced shear stress in the key

$$\tau_K = \frac{T_{max} \times 2}{L_K \times b \times d}$$

$$\tau_K = \frac{3410714.286 \times 2}{158 \times 25 \times 90}$$

$$\tau_K = \underline{\underline{19.188}} \frac{N}{mm^2}$$

Since induced shear stress in key is less than permissible shear stress in key

i.e $19.188 \frac{N}{mm^2} < 30 \frac{N}{mm^2}$

$\therefore$ The design of key based on induced shear stress is safe.

Induced crushing stress in the key

$$\sigma_K = \frac{T_{max} \times 4}{L_K \times h \times d}$$

$$\sigma_K = \frac{3410714.286 \times 4}{158 \times 14 \times 90}$$

$$\sigma_K = \underline{\underline{68.529}} \frac{N}{mm^2}$$

Since induced crushing stress in key is less Than permissible crushing stress in key.

$$\text{i.e } 68.529 \frac{N}{mm^2} < 80 \frac{N}{mm^2}$$

$\therefore$ The design of key based on induced crushing stress is safe.

**Now let us understand, how the formula for Induced shear and crushing stress for key is derived.**

Induced Shear stress in the key.

Maximum Torque transmitted by the shaft = Force × Radius of shaft.

$$\text{i.e } T_{max} = F \times r$$

But w.k.t $r = \frac{d}{2}$, here $d$ = Diameter of shaft

$$\therefore T_{max} = F \times \frac{d}{2} \quad --- (A)$$

Here Force, $F$ = Stress × Area $\quad \because \text{Stress} = \frac{\text{Force}}{\text{Area}}$

$$\text{i.e } F = \tau_K \times A$$

$\tau_K$ = Induced shear stress in key

$A$ = Area of key subjected to shear stress.

Substitute value of $F$ in (A)

we get,

$$T_{max} = F \times \frac{d}{2} \quad -- (A)$$

i.e $T_{max} = \tau_K \times A \times \frac{d}{2}$ --- (B)

Here Area of key subjected to shear stress = Length of Key × Breadth of Key.

i.e $A = L_K \times b$

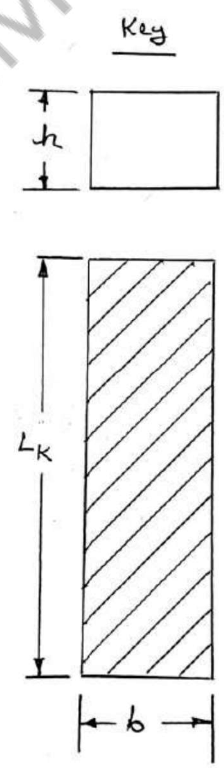
Substitute value of A in (B) we get,

$$T_{max} = \tau_K \times A \times \frac{d}{2} \quad \text{--- (B)}$$

i.e $T_{max} = \tau_K \times L_K \times b \times \frac{d}{2}$

∴ Induced shear stress in Key

$$\boxed{\tau_K = \frac{T_{max} \times 2}{L_K \times b \times d}}$$



Induced crushing stress in the key :-

Maximum Torque Transmitted by the Shaft = Force × Radius of Shaft

i.e $T_{max} = F \times r$

But w.k.t $r = \frac{d}{2}$, here d = Diameter of Shaft

$\therefore T_{max} = F \times \frac{d}{2}$ --- (A)

Here, Force, F = Stress × Area $\because$ Stress = $\frac{\text{Force}}{\text{Area}}$

i.e $F = \sigma_K \times A$

$\sigma_K$ = Induced crushing stress in key

A = Area of key subjected to crushing stress

Substitute value of F in (A)

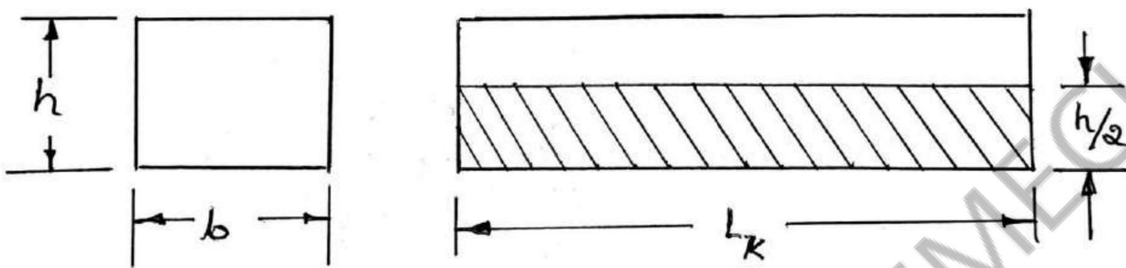
We get

$T_{max} = F \times \frac{d}{2}$ --- (A)

i.e $T_{max} = \sigma_K \times A \times \frac{d}{2}$ --- (B)

Here,

Area of Key subjected to crushing stress = Length of Key × $\frac{\text{Height of Key}}{2}$




i.e $A = L_K \times \frac{h}{2}$

Substitute value of A in (B)

we get,

$$T_{max} = \sigma_K \times A \times \frac{d}{2} \quad --- \quad (B)$$

i.e $T_{max} = \sigma_K \times L_K \times \frac{h}{2} \times \frac{d}{2}$

∴ Induced crushing stress in key

$$\sigma_K = \frac{T_{max} \times 2 \times 2}{L_K \times h \times d}$$

i.e $$\boxed{\sigma_K = \frac{T_{max} \times 4}{L_K \times h \times d}}$$

## DDHB – REFERENCE PAGE No. : 50, 57 & 69



| **Particular** | **Equation** | **Eqn. No.** |
|---|---|---|
| ***Torsion of circular shafts:*** The maximum torsional shear stress due to torsional loading | $\tau = \dfrac{Tc}{J} = \dfrac{16T}{\pi d^3}$ for solid shafts <br> $= \dfrac{16T}{\pi d_o^3}\left(\dfrac{1}{1-K^4}\right)$ for hollow shafts | 3.1 |



**Table 3.5** ***(a) Standard shaft sizes in mm***

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 25 | 28 | 32 |
| 36 | 40 | 45 | 50 | 56 | 63 | 71 | 80 | 90 | 100 | 110 | 125 |
| 140 | 160 | 180 | 200 | 220 | 240 | 260 | 280 | 300 | 320 | 340 | 360 |
| 380 | 400 | 420 | 440 | 450 | 480 | 500 | 530 | 560 | 600 | – | – |



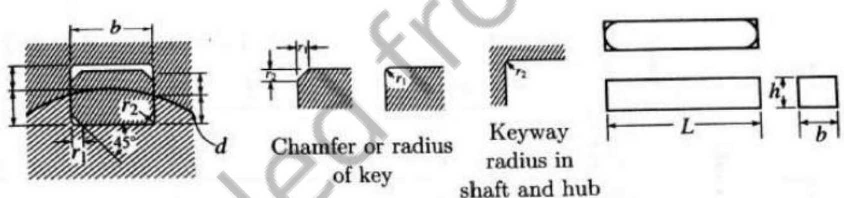
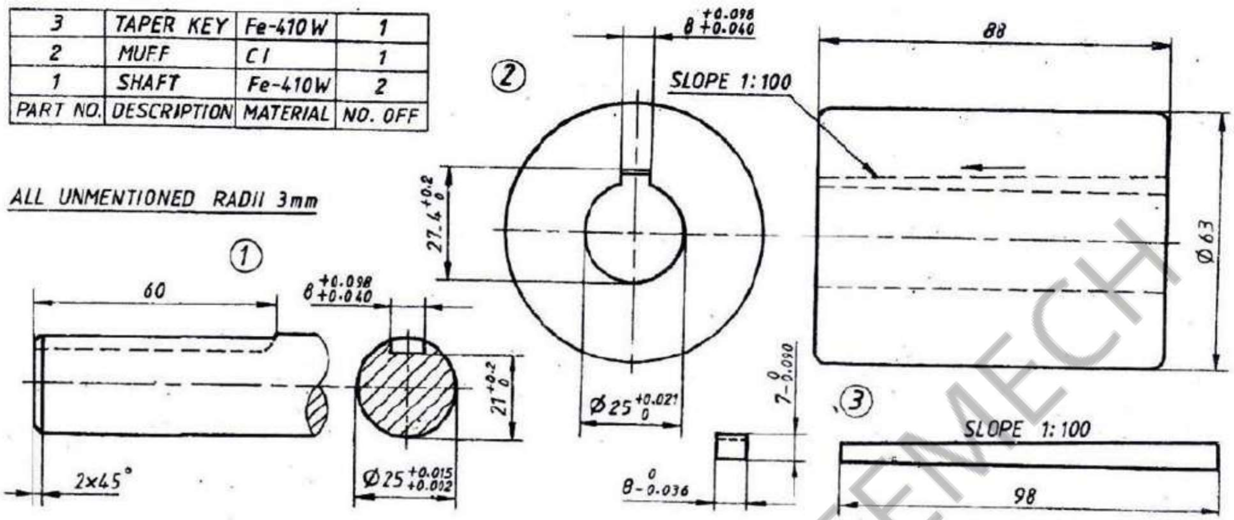



**Table 4.1** ***Dimensions of Parallel keys and keyways (All Dimensions in mm)***

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| For shart diameters | *Above* | 6 | 8 | 10 | 12 | 17 | 22 | 30 | 38 | 44 | 50 | 58 | 65 | 75 | 85 | 95 | 110 | 130 | 150 | 170 | 200 | 230 | 260 | 290 | 330 | 380 | 400 |
| | *Up to* | 8 | 10 | 12 | 17 | 22 | 30 | 38 | 44 | 50 | 58 | 65 | 75 | 85 | 95 | 110 | 130 | 150 | 170 | 200 | 230 | 260 | 290 | 330 | 380 | 400 | 500 |
| Key cross section | *Width b* | 2 | 3 | 4 | 5 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 25 | 28 | 32 | 36 | 40 | 45 | 50 | 56 | 63 | 70 | 80 | 90 | 100 |
| | *Height h* | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8 | 9 | 10 | 11 | 12 | 14 | 14 | 16 | 18 | 20 | 22 | 25 | 28 | 32 | 32 | 36 | 40 | 45 | 50 |
| Keyway depth (nominal) | *in shaft* $t_1$ | 1.2 | 1.8 | 2.5 | 3.0 | 3.5 | 4.0 | 5.0 | 5.0 | 5.5 | 6.0 | 7.0 | 7.5 | 8.5 | 9.0 | 10 | 11 | 12 | 13 | 15 | 17 | 19 | 20 | 22 | 25 | 28 | 31 |
| | *in hub* $t_2$ | 1.0 | 1.4 | 1.8 | 2.3 | 2.8 | 3.3 | 3.3 | 3.3 | 3.8 | 4.3 | 4.4 | 4.9 | 4.9 | 5.4 | 6.4 | 7.4 | 8.4 | 9.4 | 10.4 | 11.4 | 12.4 | 13.4 | 14.4 | 15.4 | 17.4 | 19.5 |
| Tolerance on | $t_1$ | | + 0.1 | | | | | | | + 0.2 | | | | | | | | | | | | | + 0.3 | | | | |
| Keyway depth | $t_2$ | | | | | + 0.1 | | | | | | | | | + 0.2 | | | | | | | | | | | + 0.3 | |
| Chamfer or radius $r_1$ of key | *Max* | | 0.25 | | | 0.35 | | | | 0.55 | | | | | 0.80 | | | | | 1.30 | | | 2.00 | | | 2.95 | |
| | *Min* | | 0.16 | | | 0.25 | | | | 0.40 | | | | | 0.60 | | | | | 1.00 | | | 1.60 | | | 2.50 | |
| keyway radius $r_2$ | *Max* | | 0.16 | | | 0.25 | | | | 0.40 | | | | | 0.60 | | | | | 1.00 | | | 1.60 | | | 2.50 | |
| Length of key L | *Min* | 6 | 6 | 8 | 10 | 14 | 18 | 22 | 28 | 36 | 45 | 50 | 56 | 63 | 70 | 80 | 90 | 100 | 110 | 125 | 140 | 160 | 180 | 200 | 220 | 250 | 280 |
| | *Max* | 20 | 36 | 45 | 56 | 70 | 90 | 110 | 140 | 160 | 180 | 200 | 220 | 250 | 280 | 320 | 360 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |

***Designation:*** A Parallel Key of width 10 mm, height 8 mm, and length 50 mm shall be designated as: Parallel Key 10 × 8 × 50 × LS:2048

**Solid Muff Coupling**




All Dimensions are in mm



**CAD commands – Solid Edge:**

**Part No. 1: Shaft**

Open Solid edge→Solid part→tools→Edgebar→view→toolbars→toolbars→select main and features toolbars→OK.

Protrusion→RRP→required toolbars inside protrusion: main, draw, features and relationship toolbars→OK→circle by centre→smart dimension 25mm→return→distance of protrusion=70mm→enter→click→finish→cancel.

Round→radius 5mm→select edge→accept→preview→finish→cancel.
Chamfer→2mm enter→select edge→accept→finish→cancel.

Tools→material table→Fe-410W→apply to model→Tools→color manager→part: select the required color→ok.

File→save→summary→title:SHAFT→ok→save the file in a particular folder→file name: SHAFT→save.

**Part No. 2 Muff**

Solid edge→solid part→protrusion→RRP→circle by centre→draw 2 circles→smart dimension: 63mm & 25mm→return→symmetric extent→distance:88mm→enter→click→finish→cancel.

Cutout→FRP→visible and hidden edge→line→draw the profile→smart dimension→27.4mm & 27.1mm→shaded with visible edge→return→symmetric extent→distance:8mm→enter→click→finish→cancel.

Round→radius: 3mm→enter→select edges→accept→finish→cancel.

Tools→material table→CI→apply to model→Tools→color manager→part: select the required color→ok.

File→save→summary→title:MUFF→ok→save the file in a particular folder→file name: MUFF→save.

**Part No. 3: Taper Key**

Protrusion→FRP→line→draw the profile→connect→smart dimension: 98mm, 7mm and 6.9mm→return→symmetric extent→distance:8mm→enter→finish→cancel.

Tools→material table→Fe-410W→apply to model→Tools→color manager→part: select the required color→ok.

File→save→summary→title:TAPER KEY→ok→save the file in a particular folder→file name: TAPER KEY →save.

**Assembly of Muff coupling:**

Solid edge→assembly→view→toolbars→toolbars→select main, assembly features and assembly command toolbars→ok

Tool→edge bar→parts library→drag shaft→mirror components→select RRP→select shaft→accept→ok→finish→cancel.

Hide front and top reference planes→drag taper key from parts library→assembly command: flash fit→select tool→assembly path finder→taper key→right→(-98/2)→parts library→drag muff→assembly command: flash fit and axial align→ select tool→assembly path finder→muff→right→(-88/2) →click.

File→save→file name: Solid Muff Coupling→save.