Cambridge University Press & Assessment
978-1-316-63040-2 — Fundamentals of Machine Design
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Excerpt
More Information

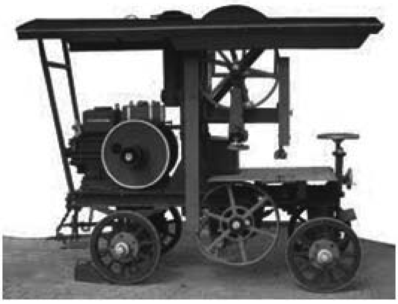
CHAPTER 1

Introduction to Machine Design

Outcomes

- Know stages in design, right from conception to final product after production
- Factors to be considered while designing
- Various types of designs
- Know about fundamental and derived units used in engineering design
- Importance of standardization, its advantages and use in design
- International standards and designation of standard mechanical components
- Preferred numbers, their advantages, and use of various series for selection

1.1 Introduction



Machine is a device, which facilitates the working for which it is designed. For example, sewing machine facilitates stitching, automobiles facilitate travelling. Machines could be of many types, as given below, but here the scope is limited to mechanical machines only. A machine, unless specified, is a Mechanical machine. Input to this machine could be mechanical, electric, or any other type of power.

- Electric machine, which uses electric energy;
- Pneumatic machine, which uses compressed air; and
- Hydraulic machine, which uses any fluid like water (turbines) or oil, etc.

A machine comprises of many machine elements, like shafts to accommodate the machine elements like pulleys, gears, etc., to transmit power; bearings to support the shaft; frame to support and keep all the parts in the required position.

Machine Design is a subject, which deals with the design of machine elements and other aspects like shape, colour, etc. The design is mainly from the strength point of view. The size is calculated so that under the given conditions of loading, the part will not break or deform beyond accepted allowable limit.

1.2 Stages in Design

The design of a machine which is seen today is not the original design. Rather, it is being modified every year. For example, models of cars are changing every year. The design is modified as new materials are developed, which could be stronger than the existing ones. Aesthetic sense of users changes with time, which forces the design to change. Following are the stages in design:

1. **Conceptual design** When a new machine is designed, the idea is first conceived in the mind as to how a machine will work. This idea is jotted down in the form of a rough sketch of the machine on a paper. A list of all the parts it will have is prepared and then each part is sketched.
2. **Design for strength** Material is selected for each part and its properties, like tensile strength, shear strength, etc., are noted from a data book. Then, the size of each part is calculated based on its strength and allowable deformation limits.
3. **Part and assembly drawings** Finished drawings are made for each part. An assembly drawing is also made showing the relative position of each part.
4. **Manufacturing processes** For each part, a manufacturing process is selected as to how that part will be made: in one process or in many processes, one after the other. Any special treatment of hardening, etc., if required, is mentioned.
5. **Production drawings** Manufacturing tolerances are also considered for the various processes and are mentioned on the production drawings. Such drawings also contain the fits for the mating parts, geometric tolerances such as squareness, flatness, circularity, etc., and surface roughness expected from the various processes.
6. **Manufacturing** The machine is manufactured as per the drawings and assembled.
7. **Testing** The machine is tested for the function it is designed for. If it works satisfactorily, it is manufactured in mass as per the requirement. If any malfunctioning appears, the whole cycle from Stage 1 to Stage 7 is repeated.
8. **Sales feedback** If the machine functions satisfactorily, it is mass produced and sent to the market. Any feedback from the customer is sent to the design section, which works mainly for stages 2 and 3. Thus, design is final only for a short period, like six months or 1 year, and is always updated from the information received. Modification is a dynamic process and is done for a machine.

1.3 Design Considerations

Following parameters are considered while finalizing a design:

- **Strength** The machine member is considered under various stresses which may arise in the part. It has to be safe in all respects.
- **Material selection** Selection of the material depends on many parameters like type of application, weight, durability, temperature conditions, type of environment (corrosive or non corrosive), machinability, weldability, etc.
- **Safe operation** Moving parts have to be specially protected to avoid any unwanted accident. Sharp corners, which could cause injury, are to be avoided.
- **Kinematics** A machine will work satisfactorily only if its moving parts are arranged such that they give the required motion.
- **Cost** The cost of the part has to be suitable, so that it can sustain the competition in the market.
- **Number of items** The design of a machine, required for producing a component, depends on as to how many parts are to be produced. For a small number of items to be produced, one would not like to spend on a machine meant for large production and, hence, its design should be suitable according to production.
- **Aesthetic aspects** While the product is basically designed for its function, the customers are attracted more by its appearance. It has to be to the liking of the people. This aspect changes with time and the type of population, where it is to be used. The parameters which affect the appearance are: shape, surface finish, type of material, colour, etc. The shape of an aeroplane is based on its aerodynamic design so that it offers minimum resistance to the wind. Various surface finishes like Nickel plating on the rims of the wheel of a two wheeler or anodizing on some parts are used. Various colours and colour combinations on the body of the car attract people.
- **Ergonomics aspects** This word is derived from two Greek words: *Ergo*, meaning work, and *nomos*, meaning natural laws. A product is designed so that it causes minimum fatigue to the user and offers maximum possible comfort. For example, shape of an easy chair should provide maximum comfort to the body. Size of parts, like levers, hand wheels, and foot pedals should be such that they are easy to operate with the amount of force which a person can apply without much fatigue. For example, a too big or too small steering wheel of a car will not be comfortable, if its size is much different than the shoulder width of the driver. The size of display instruments should be such that these are easily readable without much strain on the eyes. Proper lighting for night use has to be provided with indicators of contrast colour, for example, instruments on the panel of a car. The size of the letters should be about 1 / 200 times the distance from where they are read to avoid strain to the eyes.
- **Easy maintenance** Every machine requires some maintenance. The design should be such that parts are easily accessible for repair or replacement.

- **Easy lubrication** To decrease friction between the moving parts, lubrication is done. The places where it is needed should be easy accessible.
- **Assembly** Big machines are assembled in small sub-assemblies and then the final assembly is done. The design has to be modular so that each sub-assembly can be easily taken out.
- **Light weight** For portable machines, this is an important consideration. The weight of the machine has to be as minimum as possible, with the usual desired strength.
- **Reliability** A machine has to be reliable enough to provide the type of service for which it is designed.
- **Rigid** The machine should be strong and rigid to bear all loads and vibrations generated in it. This can be done by using rolled sections, welding, etc.
- **Wear resistance** The parts that are prone to wearing should exhibit considerable life before replacement. Selection of suitable materials and lubrication can solve this problem.
- **Use of standard parts** Wherever parts are to be purchased from the market, these have to be adapted to the size of standard parts for easy changeability.
- **Efficiency** It is defined as the ratio of output to input. Losses should be low to achieve maximum efficiency.

1.4 Types of Design

Design is done in many ways. The type of design selected depends on the type of product and requirement.

1. **Empirical design** This type of design is done on the basis of knowledge available for that product for existing practices. The main dimensions are found just by applying empirical formulae and not by strength calculations. These formulae have been tested for years. Generally, only small components can be designed by this method.
2. **Design for strength** Size of the components is calculated by doing stress analysis. All the loads and other service conditions are considered. A factor of safety is assumed to arrive at a safe allowable stress and then the size is found.
3. **Design by evolution** Technology has been in use for the last many years. A safe working design is assumed as the basis and then slight modifications are done in the existing design.
4. **New design** These designs start from scratch, that is, right from conceptual design and across all the stages in design as described in Section 1.2. These designs are also called inventive or creative designs.
5. **Adaptive design** In some fields, the design has been so much tested and proven that there is hardly any major change in the design, for example, bicycle. Slight

modifications are made from aesthetic or functional point of view only, but the major design remains the same.

6. **Functional design** A machine has to function properly for which it is designed. So, in addition to strength calculations, the mechanics part is also considered for its proper working.
7. **Process design** It is done by the production engineers mainly for the tools, machines to be used, processes to be done, heat treatment if required, surface finishing processes, etc.
8. **Industrial design** It is an effort in styling a product keeping into considerations the tool design, die design, etc., so that it can be easily manufactured in an industry.
9. **Optimum design** An engineer always likes to design a machine which gives maximum efficiency at minimum cost. Now, with the help of computers many numerical analysis solutions are available to optimize a size for minimum weight or minimum cost, etc. For example, a helical spring for the same stiffness can be of some wire size, some coil diameter, and some suitable material. A combination, which gives minimum weight or minimum cost, can be selected.
10. **Computer aided design** With the development of high speed computers, Computer Aided Design (CAD) softwares are available, which are capable of doing three dimensional geometric modelling, stress analysis, etc., and final drawings can be prepared from the same model. This modelling can be used not only for design, but even for manufacturing also, which is called Computer Aided Manufacturing (CAM).

1.5 Units

All physical quantities are measured in units, which are arbitrary, but internationally accepted. Each country adapts a system of units. There are four systems of units, which are commonly used and accepted universally. These are:

- Foot, Pound, Second (**FPS**) units
- Centimetres, Grams, Seconds (**CGS**) units
- Meter, Kilogram, Second (**MKS**) units
- System International (**SI**) units. Since SI units are being followed now, only these will be described and mostly followed in this book.

Units are of two types and are tabulated in Tables 1.1a and 1.1b.

- Fundamental units are for length, mass, time, temperature, etc. (Table 1.1a).
- Derived units are derived from fundamental units like velocity, acceleration, force, pressure, energy, power, etc. (Table 1.1b).

Table 1.1a S.I. Units Pertaining to Mechanical Engineering: Fundamental Units

Physical quantity	Unit	Abbreviation
Length	Meter	M
Mass	Kilogram	Kg
Time	Second	S
Temperature	Kelvin	K
Angle	Radian	Rad

Table 1.1b S.I. Units Pertaining to Mechanical Engineering: Derived Units

Physical quantity	Unit	Abbreviation
Acceleration	meter/second^2	m/s^2
Angular acceleration	radian/second^2	rad/s^2
Angular velocity	radian/second	rad/s
Area	square meter	m^2
Density	kilogram/meter^3	kg/m^3
Energy, Work	newton meter, Joule	Nm, J
Force, Weight	Newton	N
Mass	Kilogram	Kg
Modulus of elasticity	newton/meter^2	N/m^2 or Pa*
Modulus of section	meter^3	m^3
Moment of inertia	kilogram/meter^2	kg/m^2
Momentum	kilogram meter/s	kgm/s
Power	Watt	W, Nm/s
Pressure, Stress	newton/meter^2	N/m^2 or Pa
Speed	meter/second	m/s
Torque	newton meter	Nm
Velocity	meter/second	m/s
Volume	meter^3	m^3
Work	newton meter	Nm

* Pascal

Notes:

- Plurals are not used with the abbreviation, for example, meters or meter will be abbreviated as 'm'.
- Most of the abbreviations are used in lower case unless derived from names, for example, N for Newton or W for Watt.

- Units for the names should not start with upper case, for example, 50 newton and not 50 Newton.

Very large or very small quantities are prefixed with a letter as given in Table 1.2.

Table 1.2 Prefix to Units

Multiplier	10^{12}	10^{9}	10^{6}	10^{3}	10^{-3}	10^{-6}	10^{-9}	10^{-12}
Name	Tera	Giga	Mega	Kilo	Milli	Micro	Nano	Pico
Prefix letter	T	G	M	K	m	µ	n	p

1. **Mass** It is the amount of material contained in a body and does not change with gravitational force. Its unit is kg.
2. **Weight** It is the pull exerted due to gravitational force of earth over a body. Since the value of acceleration due to gravity g varies with altitude, hence weight also varies. Unit of weight is Newton, if mass is in kg and g is in m/s^2. It is equivalent to kgm/s^2.

   Weight = Mass × Acceleration
3. **Density** It is mass per unit volume. Its unit is kg/m^3.
4. **Momentum** It is the product of mass and velocity. Its unit is kgm/s.

   Momentum = Mass × Velocity
5. **Force** As per Newton's second Law of Motion, force is proportional to change of momentum. Thus,

$$\text{Force} = \frac{\text{Mass} \times (\text{Final velocity} - \text{Initial velocity})}{\text{Time}}$$

   or Force = Mass × Acceleration

   Unit of force is also Newton: $1\ \text{N} = 1\ \text{kg} \times 1\ \text{m/s}^2 = 1\ \text{kg m/s}^2$

6. **Couple** Two equal forces F acting parallel to each other in opposite directions give rise to a couple. Its unit is Nm. The distance X between the forces is called arm of couple. Magnitude of the couple T is given by: $T = F \times X$
7. **Torque** Torque T is the product of force and its perpendicular distance from line of axes. Its unit is also Nm. $T = F \times X$
8. **Work** Work W is product of force and displacement X caused by the force. Its unit is also Nm. $W = F \times X$

   For angular displacement, work done is given by: $W = T \times \theta$

   Where, T is the torque, and θ is the angular displacement
9. **Power** It is the rate of doing work. Unit of power is watt.

   Power = Work done / Time taken

If ω is angular speed in radians per second and N is speed in r.p.m., then,

$$P = T \times \frac{\omega}{t} = T \times \frac{2\pi N}{60}$$

10. Energy It is the capacity to do work. Its unit is Nm. It is of two types:

i. **Potential energy** It is the energy *P.E.* stored in a body for doing work due to its position. It can give work due to its fall.

$P.E.$ = Weight × Height = $W \times h = m \times g \times h$

ii. **Kinetic energy** It is the energy *K.E.* possessed in a body due to its velocity and mass.

Work done = Force × Distance = Mass × Acceleration × Distance = $m \times a \times s$

Where, a = Acceleration, s = Distance travelled, u = Initial velocity.

From equation $v^2 - u^2 = 2a \times s$,

If u is zero, then, $s = \dfrac{v^2}{2a}$

Hence, $K.E. = m \times a \times s = \dfrac{1}{2}mv^2$

iii. **Strain energy** It is the energy stored in an elastic body when deformed from its natural position. Its unit is also Nm. For example, if a spring with stiffness $s = W/X$ N per unit deformation is deformed through a distance X by a weight W, then strain energy is given by:

Strain energy = Average force × Deformation $= \dfrac{W}{2} \times X = \dfrac{sX^2}{2}$

1.6 Standardization

Standardization, in general, is defined as the process of formulating rules with the cooperation of all concerned for the benefit and promotion for optimum overall economy. Standardization in technology reduces the number of standard sizes, brands, shapes, and properties characterizing manufactured articles. It can be applied to science, engineering, industry, agriculture, construction, and transportation.

Standardization is used in assembly lines and machine tools, construction, agricultural machinery, and in other technological equipments. It also uses identical components and subassemblies to produce identical equipment with regard to use.

Standardization of the brands of various kinds of products and semi-finished goods makes it possible to reduce the variety to a rational number. It shortens the time needed to reset equipment, and increases the number of units in a production run.

Standardization for production processes, methods of production, control, and testing leads to a significant reduction in the number of types of equipment, tools, instruments, and fixtures.

1.6.1 Objectives of standardization

Standardization plays an active role in the management of the national economy, in the activities of state bodies, enterprises, and organizations. Its objectives are as follows:

- It eliminates diversity among articles that serve the same purpose and helps to attain a high degree of uniformity in the manufacturing, assembly, and testing of articles.
- It establishes quality and technical requirements for manufactured goods, raw materials, semi-finished products, and assembly components.
- It sets norms, requirements, and methods that govern the design and production of manufactured goods and eliminates multiplicity of varieties, brands, and sizes.
- It seeks to develop standardized units and assembly procedures for industrial products.
- It increases interchangeability, efficiency, and reparability of manufactured articles.
- It ensures uniformity and reliability in measurements, and creates and refines state standards for physical units.
- It establishes uniform systems of documentation and systems for the classification and codification of technical and economic information.
- It establishes the terms and designations used in important areas of science and technology.
- It provides a system of labour safety standards.
- It also sets guidelines for environmental protection for improving the use of natural resources.
- It establishes favourable conditions for foreign trade and cultural, scientific, and technical ties.

1.6.2 Advantages of standardization

Standardization has a significant influence on the rate of development and level of production. When standardization is applied to machines, equipment, and instruments it offers benefits that are derived from larger production runs, lower labour inputs, and increased specialization. The advantages of standardization are:

- Reduction in types of components. For example, a bearing manufacturing company will manufacture only those bearings, which are required by most of the industries. Manufacturing a component on large scale reduces the cost of production. Thus, it brings uniformity and minimizes variety.

- It improves interchangeability and makes repair easy, as worn parts can be easily replaced. Spares available in the market fit the standards; otherwise these may not fit properly.
- Reduces volume of design work and length of the design period substantially.
- Reduces the required assortment of spare parts.
- Shortens the time necessary for creating new equipment.
- Lowers the costs incurred in introducing new products.
- Raises the degree of mechanization and automation in production processes.
- Improves quality, reliability, and durability of products due to the attention given to the technological effectiveness of design.

1.7 Use of Standards in Design

Standards and codes are used for design, testing, erection, etc. Standards set specifications for parts, material, and processes to reduce variety and limit the number of items.

In a design office here are three types of standards:

1. **Company standards** These are used in a particular company or its sister concerns only.
2. **National standards** Every country has framed some standards to be used in that country, for example:

AISI	American Iron and Steel Institute
ASA	American Standard Association
ASTM	American Society for Testing Materials
BIS	Bureau of Indian Standards
DIN	Standards of Germany
IS	Indian standards framed by BIS (Bureau of Indian Standard)
ISI	Indian Standard Institution
SAE	Society of Automotive Engineers

3. **International Standards** There are many organizations in the world who establish standard specifications for different products and materials. International Standards are prepared by International Standards Organization (ISO), for example, ISO 8000 for industries and institutions.

Following standards are used in mechanical design offices:

1. **Standards for materials** These standards are for mechanical properties and chemical composition of different materials (see Chapter 2 on 'Engineering Materials'). For example, IS 210 specifies the grades of grey cast iron; IS 1570 (Part 4) specifies chemical composition of alloy steels.