1

Introduction

1.1. Machine Design

Engineering design is a decision making process to create plans for making a component which would satisfy the requirements of the customer. Economic considerations are usually of prime importance when the design of new components is undertaken. In general, the lowest overall cost of parts designed is desired.

It is thus a creative process which starts from a requirement and defines a system and the methods of its realisation or implementation so as to satisfy the requirement. The common aim of design is to encourage originality.

The success of a new product is often critically dependent on the excellence of its design.

Design by inference is a creative activity. There is a need for flair and originality in design, this being the hall mark of a good designer.

A machine is a combination of stationary and moving parts constructed for the useful purpose of generating, transforming, or utilising mechanical energy. Machine design acquaints the reader with the fundamentals of designing the most commonly used parts, elements and units of various machines. The design may lead to an entirely new machine or an improvement of existing machine. The objective is to produce a machine which is not only sufficiently rugged to function properly for a reasonable life but is also cheap enough.

The design engineer should possess the knowledge of the following subjects :

(*i*) Mechanics of materials
(*ii*) Mechanisms
(*iii*) Strength of materials
(*iv*) Metallurgy
(*v*) Workshop processes
(*vi*) Workshop organisation.

Design process is very complex and iterative. It requires not only a detailed knowledge of the specific field but also principles of

(*i*) CAD
(*ii*) CAM
(*iii*) CIM
(*iv*) Concurrent engineering
(*v*) DFM (Design for manufacture)
(*vi*) DFA (Design for assembly)
(*vii*) Group Technology
(*viii*) Value engineering etc.

The overall design should not only be functionally sound but also cost effective and economically viable.

The design engineer should be a man of sound judgement and wide experience, and qualities which are usually acquired only after considerable time has been spent in actual professional work.

Design lay outs require both empirical and scientific design. Empirical design involves the use of tables, charts, and formulas which have been established from the experimental studies and scientific computations. Scientific design which requires a broad knowledge of the subjects like mechanics, mathematic, strength of materials, metallurgy etc. is used when a new component is to be designed to operate under special specified conditions for which data are not available.

For the economy of performance correct mechanical, hydraulic, thermodynamic and other principles must be applied.

1.1.1 Classification of Machine Design

Machine design can be classified as follows :

(*a*) Rational design

(*b*) Empirical design

(*c*) Combined rational and empirical design

(*d*) Design by experience.

In rational design mathematics is used to determine the size of the element whereas in empirical design data derived from machines and designs in actual use are used. Such data is tabulated in various hand books for ready reference. In combined rational and empirical design both mathematics and standard data are used in design whereas some parts are designed based on number of informations derived from careful observation and experience.

Design of a machine may proceed along the following lines :

(*i*) Machine is visualised which will satisfy functional requirements. It is profitable to analyse the various possible designs and to select the best possible design.

(*ii*) Preliminary analyses of forces which will act on various parts of the machine.

(*iii*) Determination of general proportions of the parts of machine.

(*iv*) Selection of materials for making different parts.

(*v*) To decide the manufacturing processes.

(*vi*) Preparation of production drawings.

(*vii*) Modifications based on :

(*a*) practical experience

(*b*) cost

(*c*) requirements for quantity production.

It is desirable that the machine designed should be cheaper. Some of the factors for making a cheaper product are as follows :

(*i*) Use of castings in place of forgings and machined parts.

(*ii*) Adoption of fabrication by welding.

(*iii*) In corporation of standard parts.

(*iv*) A reduction to the minimum of the amount of costly materials used.

(*v*) Allowing proper tolerances on the various dimensions.

1.2 Design Process

While designing a component or machine the following procedure (Fig. 1.1) may be adopted :

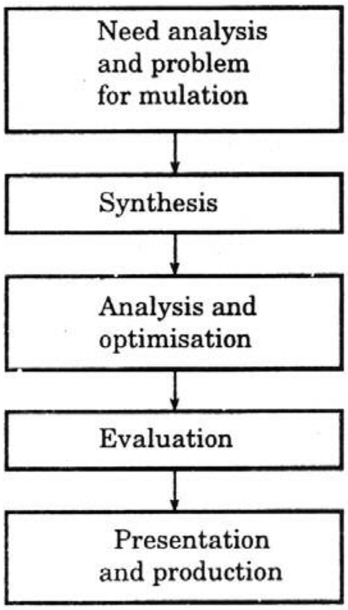

Fig. 1.1. Design process.

(*i*) Problem formulation
(*ii*) Problem analysis
(*iii*) Problem synthesis
(*iv*) Evaluation of alternatives and decision making
(*v*) Presentation and production.

1.2.1 Need analysis and problem formulation. While designing a new component it should be ensured that need exists for such a component. This can be done by gathering as much information as possible by surveying the market and by studying the similar components already available in the market. Once it is established that need exists for the component being designed then the problem should be stated as clearly as possible. The problem should be studied in greater details. The broader the definition the greater will be possibility of creative solutions.

1.2.2 Synthesis. In this stage of design making process a number of possible solutions are suggested including the previous solutions available (if any). The design engineer should have up to date knowledge keeping in view the various developments that have taken place regarding the part to be designed.

1.2.3 Analysis and optimisation

In this stage the criteria to be used in selecting the best design are identified taking into consideration the following factors :

(*a*) Manufacturing cost
(*b*) Reliability
(*c*) Safety
(*d*) Ease of maintenance
(*e*) Repairs
(*f*) Ease of operation
(*g*) Sales appeal.

1.2.4 Evaluation of alternatives and decision taking

In this phase all the alternative solutions are evaluated on the basis of overall cost and salability and the best possible solution is finally chosen.

1.2.5 Presentation and production

The solution finalised is documented in details. Detailed and dimensional drawings of the solution should be made available. Tolerances wherever needed should be clearly stated. Tolerances should be as large as possible to reduce the manufacturing cost. The materials out of which the designed parts are to be made, should be specified.

1.3 To Prepare Final Drawing

Working drawings are prepared after assembly drawing has been made and all possible revisions have been taken into account. The working drawing should possess the following information.

(*i*) It should be clear, concise and complete. All dimensions that are needed for manufacturing and assembly should be mentioned clearly.
(*ii*) Type of finish to be used should be given.
(*iii*) Standard symbols should be used.
(*iv*) Bill of materials should be prepared in tabular form.
(*v*) If the manufacturing process involves any special method such as lapping, heat treatment etc., then such process should be indicated in a foot note.

1.4 Design Procedure

When a new machine or an element of the machine is to be designed the various considerations involved are as follows.

(*i*) To state the problem completed and clearly.

(*ii*) To decide the kinematic arrangement of parts of the machine and to carry out detailed analysis of their motion.

(*iii*) To determine the nature of the forces and their magnitude acting on different elements of the machine.

(*iv*) To select proper materials for each elements of the machine and to determine the allowable stresses in the different materials.

(*v*) To determine the size of each element.

(*vi*) To prepare detailed drawings of the various elements of the machine designed.

(*vii*) To select the economical manufacturing processes by which various elements are to be manufactured.

(*viii*) To fabricate prototypes and to test the prototypes for acceptable performance. Any flaws revealed during testing should be removed by making alterations in the preliminary design of the component.

The design should be such that

(*a*) It is easier to manufacture the various parts

(*b*) It is easier to assemble the various parts

(*c*) As far as possible standard parts should be used

(*d*) There should be safety of operation and adjustment for wear.

1.5 Design Requirements

The machine designed should comply with the requirements of the standards set up by the state standards institute. The basic requirements of an engineering component designed are as follows.

(*i*) Its overall cost should be minimum.

(*ii*) It should be of good quality. Although it is difficult to define quality in absolute terms however the essential characteristics of quality may be grouped as under :

(*a*) Specificational quality

(*b*) Functional quality

(*c*) Aesthetical quality

(*d*) Usage quality.

Specificational quality includes conformance to basic design specifications based on standards. The component designed should function properly. Aesthetic quality of the product refers to the quality characteristics to provide for the aesthetic value demanded by users whereas usage quality may consist of simplity, economy and higher trouble-free working life of the component.

(*iii*) It should function properly. The element designed should be reliable in working and should have higher working efficiency.

(*iv*) It should be lighter in weight.

(*v*) It should be sufficiently strong, rigid and wear resistant.

(*vi*) The design should conform to the safety codes.

The various items that the designer should consider in designing equipment for operator safety are as follows.

(*a*) Covers or enclosures should be provided for moving components that are in close proximity to the operator.

(*b*) Parts which may cause injury to the operator should not project from the equipment.

(*c*) Sharp corners and edges should be avoided.

(*vii*) It should be easier to make the adjustments and to lubricate the parts designed.

1.6 Design Factors Relating to Customer's Requirements for Economic Design

While designing a component the following factors from customer's requirement point of view should be considered.

(*i*) The size and weight should be kept as small as possible.

(*ii*) The component should be free from noise.

(*iii*) It should be easier to transport the component.

(*iv*) It should be reliable, durable, and strong.

(*v*) Its energy consumption should be low.

(*vi*) It should have operational safety.

(*vii*) Manufacturing cost and maintenance cost should be low.

(*viii*) The component should be reliable and should have more service life.

(*ix*) The component should have good appearance.

(*x*) The overall cost of the component should be low.

(*xi*) The component should have good appearance.

1.7 Design Factors Relating to Manufacturing Requirements for Economic Design

While designing a component/machine the designer should decide about the following factors from manufacturing point of view:

(*i*) Materials to be used.

(*ii*) Manufacturing processes to be used.

(*iii*) Equipment required to manufacture the component.

(*iv*) Tooling required for manufacturing the components.

(*v*) Inspection and testing stages.

(*vi*) Manufacturing cost.

As far as possible standard materials available should be used. The manufacturing of components designed should be easier and minimum inspection should be needed to check the accuracy of the components. The overall manufacturing cost should be low.

1.7.1 Standardisation

Standardisation is defined as the adoption of prescribed regulations and specifications as they pertain to materials, methods and equipment. Standardisation of design helps in reducing cost, simplifying replacement and elimination of unnecessary variation in sizes.

A standard is a set of specifications for parts, materials or processes intended to achieve uniformity, efficiency and a specified quality. One of the important purpose of a standard is to place a limit on the number of items in the specifications so as to provide a reasonable inventory of tooling sizes, shapes and varieties.

The advantages of standardisation are in reducing cost, simplifying replacement and reducing the quantities of material in stock. The designer should be always on the alert to use parts for which patterns and dies are available instead of making new designs which serve the purpose no better.

Standardisation has got the following uses :

1. It makes the mass production possible, thereby, reducing the manufacturing costs and labour requirements.
2. The standardisation of specifications and methods of testing the machine elements helps in improving their quality and hence the service life.
3. The repair and maintenance of the machines is simplified since the worn out or damaged parts can easily be replaced by the standard ones.
4. It reduces the time and efforts needed to create and manufacture new machines since the standard elements and units can be used to assemble a new machine.

1.8 Computer Aided Design (C.A.D.)

Computer aided design (C.A.D.) can be defined as the use of computer systems to assist in the creation, modification, analysis and optimisation of a design. The computer systems consist of hardware and software to perform the specialised design functions. The C.A.D. hardware consists of the following :

(*i*) Computer.

(*ii*) Graphics display terminals.

(*iii*) Key boards.

C.A.D. software consists of the computer programme to implement computer graphics on the system.

A C.A.D. system permits a more thorough engineering analysis and a large number of design alternatives can be investigated. Design errors are also reduced through the greater accuracy provided by the system. Computer aided design systems provide the designer with the first promising relief from the repetitive drudgery. Computers work at high speeds and are very accurate. In C.A.D. system the parameters of a design can be changed and the calculations quickly repeated until the combination for optimum result is obtained.

Use of a C.A.D. system provides better engineering drawings, more standardisation in drawings, better documentation of design, fewer drawing errors and greater legibility. The greater is the quantity of modification of drawings or repetition of parts of the drawing. The greater will be the improvement of productivity of the C.A.D. system. Unless this occurs the time of preparing drawing on the C.A.D. system is comparable to that for ordinary drafting.

1.8.1 Functions of C.A.D.

The various mechanical engineering design related tasks which are performed by a computer as follows :

(*i*) Geometric modelling.

(*ii*) Engineering analysis.

(*iii*) Design review and valuation.

(*iv*) Automated drafting.

(*v*) Parts classification and coding.

(*vi*) Manufacturing data base.

1. **Geometric modelling.** It deals with computer compatible mathematical description of the geometry of an object. Mathematical description allows the image of the object to be displayed and manipulated on a graphics terminal through signals from a CAD computer system.

2. **Engineering analysis.** This is concerned with stress-strain calculations, heat transfer computations and use of differential equations to describe the dynamic behaviour of the system being designed.

3. **Design Review and Evaluation.** Design accuracy can be checked conveniently on graphics terminal, semi-automatic dimensioning and tolerancing routines. A procedure called layering is often useful in design review. Generally layering involves over laying the geometric image of the final shape of the machined part on the top of the image of the rough costing. Another procedure is interference checking. This is particularly useful in the design of the assembled structures.

Kinematics is one of the most important evaluation features available on C.A.D. systems. The available kinematic packages provide the capability to estimate the motion of simple designed mechanisms. This helps in visualisation of the operation of the mechanisms and helps to ensure against interference with other components.

4. **Automated Drafting.** It is used for the creation of a hard copy engineering drawing directly from C.A.D. data base.

5. **Part classification and coding.** C.A.D. can be used to develop a part classification and coding.

6. **Manufacturing database.** C.A.D. helps in preparing manufacturing data base for the component to be designed and manufactured.

The four phases of CAD are shown in Fig. 1.1 (*a*).

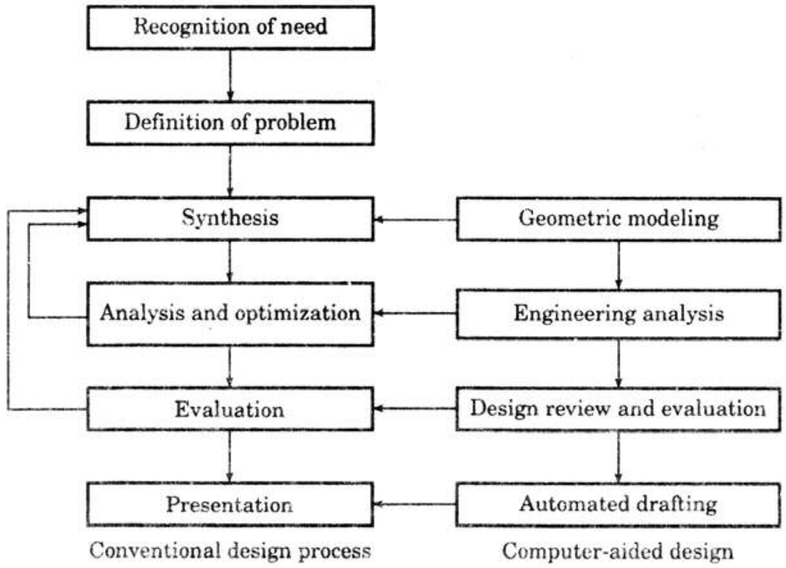

Fig. 1.1 (a)

1.9. Product Cycle

Fig. 1.2 shows the various steps in the product cycle (design and manufacturing). The product cycle begins with a concept, an idea for a product. The concept is cultivated, refined analysed improved and translated into a plan for the product through the design engineering process. Then a set of engineering drawings is prepared showing how the product will be manufactured. Manufacturing is followed by quality control, testing and delivery to the customer.

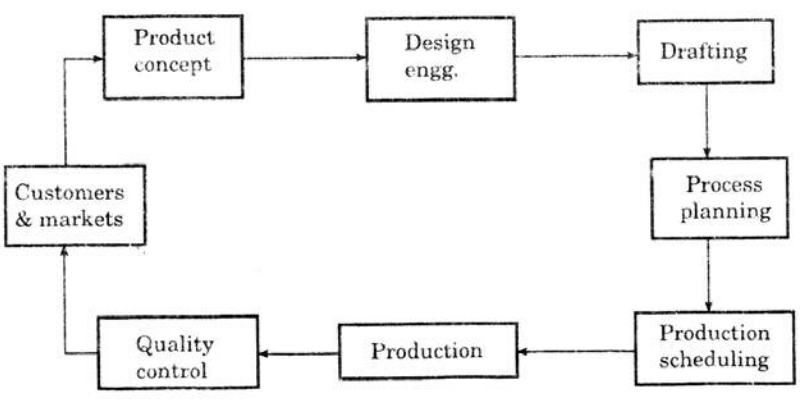

Fig. 1.2

1.10 Units

All physical quantities are measured in certain units. There are two types of units :

(*i*) Fundamental units. (*ii*) Derived Units.

1.10.1 Fundamental units. All the physical quantities are expressed in terms of the following three fundamental units :

(*i*) Length (L) (*ii*) Mass (M)

(*iii*) Time (T).

1.10.2 Derived units. Some units called derived units are expressed in terms of fundamental units, such as unit of area, velocity acceleration, pressure etc.

1.11 Systems of units

Following four systems of units are internationally accepted :

(*i*) C.G.S. units. (*ii*) F.P.S. units.

(*iii*) M.K.S. units. (*iv*) S.I. units.

C.G.S. units. In this system the fundamental units of length, mass and time are taken as centimetre, gram and second respectively.

F.P.S. units. In this system the fundamental units of length, mass and time are foot, pound and second respectively.

M.K.S. units. In this system the fundamental units of length, mass and time are metre, kilogram and second.

The M.K.S. units are called as gravitational units or engineer's units.

S.I. units (International systems of units). This system has six basic units, two supplementary units and twenty seven derived units.

The six basic units are as follows :

Quantity	*Unit*	*Symbol*
Length	Metre	m
Mass	kilogram	kg
Time	Second	S
Electric current	Ampere	A
Thermodynamic Temperature	Degree kelvin	°K
Luminous intensity	Candala	Cd

There are two supplementary units. One for measure of plane angle called the radian (rad) and other for solid angle called Stearadian (Sr). Some of the derived units are shown in Table 1.1.

Table 1.1

Units	*Symbol*
Volume	m^3
Area	m^2
Density (mass)	kg/m^3
Velocity	m/s
Acceleration	m/s^2
Angular velocity	rad/s
Angular acceleration	rad/s^2
Force	Newton (N)
Torque	Nm
Pressure	N/m^2
Dynamic Viscosity	NS/m^2
Kinematic Viscosity	m^2/s
Power	W
Work, Energy	J
Thermal conductivity	W/mK
Specific heat	J/kg, ^ok
Entropy	J/°k
Frequency	Hertz (Hz)

where N = Newton

m = metre

J = Joule

W = Watt

Pa = Pascal

$1\ N/m^2 = 1\ Pa$

$1\ MPa = 10^6\ Pa = 10^6\ N/m^2 = 10^6\ N/m^2$

$1\ kW = 10^3\ W$

$1kN = 1000N$

$1\ MN = 10^6\ N$

$1\ J = 1\ N\text{–}m$

$1\ W = 1\ J/s$

$1\ Hz = 1$ cycle/s

1.11.1 Comparison of S.I. and M.K.S. system

Table 1.2 indicates the units of some of the quantities in S.I. and M.K.S. system

Table 1.2

Quantity	*S.I. system*	*M.K.S. system*
Length	m	m
Volume	m^3	m^3
Area	m^2	m^2
Force	N	kg
Velocity	m/s	m/s
Angular Velocity	rad/s	rad/s
Torque	Nm	kg-cm
Moment of a force	Nm	kg-cm
Pressure	N/m^2	kg/cm^2
Work, Energy	J	kg-cm
Heat	J	K-cal
Temperature	^oK	^oC
Power	W	kg/s

PROBLEMS

1. What is machine design ?

2. Explain the steps involved while designing a new component.

3. State the design requirements.

4. Write short notes on the following :

(*a*) Design procedure

(*b*) Functional quality

(*c*) Usage quality.

5. Discuss the factors relating to customer's requirement while designing a component.

6. Discuss the factors relating to manufacturing requirements while designing a new component.

7. Discuss the qualities of design engineer.

8. Discuss product cycle.

9. Write short notes on the following :

(*a*) Standardisation of design

(*b*) S.I. Units.

10. Describe the design procedure.

11. What are the requirements of a design engineer ?

12. State the S.I. units of the following in S.I. system :

(*a*) Force (*b*) Power

(*c*) Work (*d*) Temperature

(*e*) Pressure (*f*) Area

(*g*) Volume.