Basics of Mechanical Engineering Design

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1.1. Introduction

The subject of machine design or mechanical engineering design involves the knowledge of strength of materials, properties of materials, metallurgy, production techniques, theory of machines, applied mechanics, etc. The fundamental principles of these subjects have to be applied in evolving a design. However, it may be mentioned that mathematical analysis is not always capable of producing practical solutions. Many a times the problems have to be solved by reference to previous experience and by the application of purely empirical rules. This may be because, either the factors involved are too complex for exact analysis, or many of the discoveries of pure science have not yet been found capable of application in the realm of practice. The design problems can be best approached through a combination of theory, modern knowledge of materials, awareness of the limitations, and practicability of various production methods, and a fair measure of common sense. As the success of a design is dependent upon the close cooperation between scientists, designers, and production experts, the designer's role becomes an intermediary between scientific knowledge and the production side. It will be appreciated that the finest workshop facilities with the most up-to-date machine tools enabling economic production will be no good if the designer has not done his work satisfactorily. Similarly even the best salesman cannot do much if the designer has not approached his task with due regard for economic factors and kept down manufacturing costs to render them competitive.

The subject of mechanical engineering design concentrates on developing the basic faculties of mind. The aim is not only to design a mechanical component but to understand the process of design. The main emphasis is on generation of ideas, analysis of needs, collection of information, structure and morphology of design, methods of designing, limitations on account of resources, economics and optimisation techniques etc. The important challenges to a designer like reliability analysis, ergonomics and human factors, maintainability criteria, altertechnics, aesthetics, environmental aspects, recycling of components after designed life, etc. deserve full attention.

While attacking a design problem, one should ask the following questions :

- What device or mechanism is to be used ;
- What material is to be used ;
- What are the loads acting ;
- How the size is to be determined ;
- How will size, space, weight, manufacture, operation, reliability, maintenance, cost, aesthetic appearance, and user's reaction affect the design?

Obviously, a designer is often confronted with innumerable number of factors, so sometimes assumptions have to be made. Machine members have to be so sized that they will withstand the resulting stresses and deformation and at the same time transmit the required motion with constant or variable forces acting on them, keeping in view the criterion of wear and the environmental conditions like temperature, corrosion and other ambient conditions. The velocity and acceleration of the parts must often be considered in order to take care of the resulting vibration and inertia effects; and the forces resulting from static and dynamic forces estimated correctly. The method of fabrication of the part, its cost, provision of its assembly in machine, and the accessibility for repair and replacement must also be given due consideration. Proper selection of material depending upon the availability, cost, manufacturing techniques, physical properties, requirements for finish is also very important.

In design problems, it so happens many times that the size depends upon space limitations, size of mating parts, the housing, wear, rigidity, fabrication, lubrication, weight etc. It is recommended that use of standard sizes should be made as far as possible because standard sized parts are less costly, more readily obtained, and often more easily assembled. Therefore the calculated size should be changed to the nearest standard size, if available. Sometimes no exact analysis of stresses and deformations can be made to size certain members, in which case the past experience should be used to obtain properly proportioned machine members. In many cases, empirical equations based on experimental results must be used. In some cases, slight modifications may be necessary considering the ease of fabrication. The factors like assembly of various parts, replacement of worn parts, allowance for wear, provision for lubrication etc. must always be kept in mind while designing a machine.

Since there are always many ways of attacking the same problem, and no rigid rules are applicable, two designers will design a machine differently to perform the same function. The designer must, therefore, rely upon models and other testing techniques to determine whether or not his machine will perform satisfactorily.

1.2. Engineering and Attributes of an Engineer

Engineering involves innovative and methodical application of scientific knowledge and technology and knowledge of natural sciences and mathematics, gained by study, experience, and practice, with judgment to develop ways to utilise, economically, the materials and forces of nature to produce a device, system or process for the benefit of mankind and to satisfy human needs.

In order to be a successful designer, an engineer should possess following attributes:

- Should be able to identify and define problem, develop alternative solutions and implement the otpimum solution.
- Be able to convey ideas effectively, logically in a convincing manner both orally and in written form.
- Behave in a highly ethical and professional manner at all times and under all circumstances.
- Be imaginative, open minded, optimistic and have positive attitude.
- Be proficient in mathematical techniques and knowledgeable about sciences and technology.
- Acquire new skills and knowledge in science and technology and the areas of expertise.
- Be familiar with knowledge of business strategies and management practices.
- Familiarity with computer technology.
- Understand cultural differences around the world to be able to work in harmony.
- Work in teams with mutual trust and respect among all members.
- Be patient and diligent in work.

A design engineer uses science and technology, traditional experience and creativity, for the benefit of mankind. The engineering profession is a major contributor to the quality of life, welfare and wealth of the people of the world. Most social and economic activities depend increasingly on engineering applications. Increasingly the standards of engineering knowledge and engineering practice determine the long-term welfare of people and the wealth generation capabilities of nations. In recent years it has become evident that particular engineering skills are required to reduce demand on natural resources, and to restore and safeguard the biophysical environment in which we live. In this era of globalization, engineering is becoming even more global, and global engineering practice will become more important. There are increased needs to harmonize global standards.

As population and economic growth place increasing pressures on our social and bio-physical environment, the task of design engineer becomes more complex and they have to accept increased responsibilities to develop sustainable solutions to meet community needs, overcome extreme poverty and prevent segregation of people. The education of engineers needs to inculcate an understanding of sustainability and cultural and social sensitivities as well. The engineering code of ethics must reflect a strong commitment to principles of sustainable development.

The developed world needs new, efficient and cleaner technologies that do not adversely affect the environment and will help to cut down on the excessive consumption of the resources of the world.

1.3. Ideonomics

Ideonomics is the science concerning generation of ideas, their collection/gathering, analysis and presentation. For solving any problem, an important requisite is collection of as many pertinent ideas as possible. Preliminary ideas may be gathered by individual or group approaches using commonly acceptable methods like brainstorming, market analysis, or research of present designs. Preliminary methods must be as broad as possible to permit unique solutions that could revolutionise existing ways/methods. It is important that all ideas are recorded in written form or on rough sketches. Ideas recorded in the form of sketches help in retention of original ideas and stimulate the design process. A designer must get a feel of the problem and form several ideas for possible solutions as more and more problem requirements are listed. He should not allow himself to narrow his efforts to any preliminary ideas that might preclude other possible solutions. The qualities of creativity and imagination help a designer to gather more ideas concerning a problem to be solved. A good designer must develop the habit of cultivating his ideas even if they appear to be ridiculous or irrelevant initially. He must not evaluate the ideas as they are generated but must record as many ideas as possible with sketches and notes which always have high effective communication power. If several ideas come rapidly, they must be written on the work sheets without hesitating to develop each idea individually lest they be forgotten. Ideas can be converted from notes to sketches and graphical representation later.

1.3.1. Method of Accumulating Ideas

Four methods of gathering preliminary ideas in common use are :

(*a*) **Individual approach.** An individual designer working independently communicates with himself through the ideas gathered and jotted down in the form of rough sketches and notes. He tries to gather as many pertinent ideas as possible. He moves with the assumption that the better ideas will come out more likely from a long list rather than a short list. Any temptation to become involved with ideas at initial stage must be avoided and attempts should be made to gather as many alternative solutions as possible. For better and effective communication with himself and others subsequently, these must be recorded in the form of freehand sketches or graphs and notes. All the ideas form basis for possible adaptations and modifications.

Some preliminary ideas may not appear at first glance to have sufficient merit to provide possible solution but often these get converted into more valuable solutions when modified later.

After listing all possible ideas, the designer must ask following questions to enable him improve upon his preliminary ideas and expand his initial concepts.

- Whether new ways of use can be considered with some modification or introducing new concept.
- Whether modifications are possible by changing meaning, colour, motion, sound, odour, form, shape, etc.
- Whether it is possible to make it stronger, longer/thicker, have extra value or plus ingredient, etc. Think of many ways of magnifying/exaggerating as many features as possible.
- Whether it is possible to miniaturise/condense it, make it shorter/lighter, etc. Think of as many ways of minifying and understanding as possible.

- Think of substituting other material, other process, other mode of powering, etc.
- Whether it is possible to interchange components, layout, sequence, etc. Think of as many ways of rearranging as possible.
- Whether it is possible to reverse shape, put it upside down, reversing positive, and negative, and any other ways of reversing some of the possible features.
- Whether it is possible to combine units. Think of combining/blending/ensembling existing features.

(*b*) **Team approach.** Team approach is necessary for complex equipment/devices. Many specialists in a variety of fields work together toward a common goal. The interaction between team members can be useful when they work together to overcome personality differences and personal ambitions. A slight variation of approach could be that each team member prepares individually a series of preliminary ideas which can be discussed with the entire team. A group leader of the team is made responsible to make assignment and moderate all discussions and to ensure that progress is maintained throughout the design problem.

A unique approach to the team effort is the brainstorming session which permits spontaneous interchange of ideas. An individual works independently but this method utilises to advantage the special talents of the team members. Team assignments are made by the group leader to exploit the unique abilities of each member.

(*c*) **Brainstorming.** Brainstorming is defined as a method to practice a conference technique by which a group attempts to find a solution for a specific problem by amassing all the ideas spontaneously contributed by its members. This technique is basically used for ideation (gathering ideas) for further study. It is used to take advantage of the combined ideas of a group of experts. No attempt is made to evaluate or analyse any of the ideas expressed during the session. Discussion regarding merit of any idea is not permitted initially during brainstorming session. The various rules of brainstorming session to be strictly observed by all team members are :

Criticism is not allowed, free wheeling (*i.e.*, wild ideas) is welcomed, as many ideas as possible should be gathered, participants are permitted to seek ways of combining and improving the ideas of others.

The number of participants may vary from 2-3 to 100 or more. Generally optimum is considered around 12. Group should be composed of both persons with experience in the area of problem and persons with limited experience. All persons should preferably be of same status to avoid restriction of flow of ideas. Members should feel free to give any idea without fear of being judged. Group leader prepares a one page outline of the general information pertaining to the brainstorming session and clearly defining the problem, and provides copies to all members 2 days in advance to allow incubation of ideas. The session is held in an informal and comfortable atmosphere. The leader begins by briefly reviewing the problem, leading to question-and-answer session. Only the person allowed by leader expresses his views in few words. All the ideas generated during session are recorded and distributed to participants afterwards. About 100 ideas are gathered in a 20-30 minutes session. The ideas are reviewed and screened to limit to 10-12 ideas which can be developed any analysed for their suitability.

It may be stressed again that brainstorming technique is supplement to the individual's thinking process and can't be considered as a means of solving problems.

(*d*) **Research Methods.** Preliminary ideas about a project/product can be obtained through research methods attempted for similar situation earlier. These ideas can be modified to meet the needs of problem at hand. The process of applying known principles to new applications is called *synthesis*. Various sources of references that provide comparative design solutions for further analysis are technical magazines, manufacturer's brochures, periodicals, patents, and professional consultants.

(*e*) **Survey Methods.** These are used to gather opinions and reactions concerning a completed design, or sample opinions toward a preliminary design during the early stages of the design process. Survey methods can also be used to gather consumer's reaction to a specific solution or proposed design. A designer should be interested in knowing the consumer's attitude and his opinion toward the new design project/product.

1.4. Needs—The Starting Point

Needs, whether factual or fancied, present or future, important or unimportant, are the starting points in design. A designer must remember that it is the ultimate consumer who pays for the product and as such his needs must be fully satisfied and taken into consideration at all stages of design.

A designer thus can start his project with the simplest statement of ultimate need of consumer. He must use all reasonable types of information to validate and clarify this need. He must check the past, the current needs, and the likely future. Since time is involved between start and completion stages, he must project some realistic expectations of future demand, or of stimulated demand if product does not exist now. He must examine whether similar product exists now, what are its costs, the limitations, and the details of competitive products. He must understand why the user wants it. What could he better use? Each bit of information must be tested and evaluated before it is given a place in the logically built-up-case for the project. Questionable or redundant data must be appropriately discarded or shelved.

Modern tools for market survey (like depth interviews, testing of psychological reactions, careful sampling methods, correlations, etc.) must be followed. Such careful consumer analysis is important for products of both sophisticated technical nature as well as the mass-produced products of low technical sophistication.

l.4.l. Variety of Needs

There are two types of human drives :

(*i*) **Biological.** It teems from tissue hunger. The biological needs and drives of the race give the engineering designer his basic work areas, *viz.* food, shelter, clothing, transportation, employment, etc.

(*ii*) **Psychological—Social.** This could be either in-born or acquired from the culture since infancy. Psychological needs have a way of continually intruding into all personal and public relations and must be faced and dealt with by the designer. The psychological needs motivate people to seek :

(*a*) security ;
(*b*) response to and from others ;
(*c*) group approval and status ; and
(*d*) new experience and knowledge.

Other apparent motivation (neurotic drives) such as power-hunger or certain fears, are believed relatable to one or more of above attributes.

One should realise that the root cause for all consumer needs is a variety of above drives or motivations which may or may not be visible or even acknowledged, but they are still there.

A designer in searching for the basic needs should not project his own needs into the picture. Many a times it can be a fallacy to assume the interests of other people as coincident with those of own. It must be realised that social behaviours are different, there are different economic levels, and personalities involved are different. In projecting future needs, many factors, including time changes, competitors, legislation, and political situations all enter into consideration. It must be analysed whether the need is of temporary nature or permanent, or whether the need is of imaginative type attractive to people now but which is really the expression of another momentarily unsatisfied want. A designer must seek to get maximum assurance from or about the customer, concerning those needs at the time when the product will finally appear in the market.

1.4.2. Analysis of Statements of Need

It is important that the early statements of needs be translated into statements of goals. It would be realised during this process that sometimes a bonafide need may suddenly transform itself into another one. The apparent need simply becomes different as the designer tries to understand it better. For instance in the design of generators, as its size increases, more heat has to be removed, for which bigger blower is required. But instead of increasing size of blower, actual size gets reduced due to use of hydrogen as cooling medium with higher heat conductivity. Another instance of reverse requirement is spring steel which was customarily given a very high polish to avoid cracks to reduce the fatigue—cycling strength. But subsequently it was observed that much higher fatigue strength is achieved with shotpeening *i.e.*, pebbled surface. Another example of change of need is in case of supersonic fighter. It is generally thought that decreased flight resistance is obtained by smoothing the fuselage and pointing the nose for streamline action. But analysis proved that better results are achieved with bulging the nose and narrowing the fuselage waist in case of supersonic fighter plane. It would be appreciated from above that the initial needs may change when attempts are made to prepare statement of the goals of needs and with increased understanding.

The initial statement of the goals of need should :

(*a*) start with rather well defined needs ;

(*b*) identify the resources required and those available ;

(*c*) quantify the constraints clearly ; and

(*d*) present some criteria or methods, by which the results can be judged.

It must be realised that while analysing a need, each engineering question (investigation) probes toward a satisfactory meeting of the original need.

A need can be analysed thoroughly by surveying the past, present and future market, concentrating on the needs of end user directly, eliminating the prejudices or misconceptions of the analysis about the need as far as possible, measuring the needs against expected ability to satisfy them, and finally translating the needs into a statement of project goals.

l.4.3. Needs Analysis

The information about needs from various phases is of crucial importance to the design engineer. Different persons involved in the product's design, *viz*. manufacturer, distributor, user have different needs from their own point of view and, very often of conflicting nature. The designer has to understand and weigh them properly. For instance customer wants goods to be functional, goodlooking, long-lasting, and inexpensive. The distributor wants them with sales appeal, with no service problems, safely transported, and with lots of profit. The manufacturer wants them easily made by low-cost labour and easily procured material, with no seasonality, and with high demand.

These extremes of particular preferences may seem incompatible, but they represent strong feelings and desires on the part of those who must be considered in a needs analysis. These varieties of view points apply equally to all engineering projects.

1.5. Role of Information in Design Process

An important part of engineer's job is to organise, improve and transmit information. An engineer transmits pertinent, useable and reliable information in the form of

(*i*) drawings (*ii*) specifications

(*iii*) performance predictions (*iv*) bills of material

(*v*) technical advice.

The engineer thus has to collect the information in any form and from any source available and convert the same to the desired form. It is only based on information that the engineer uniquely creates systems and products. In any organisation an engineer has great role of generating and controlling the flow and conversion or transformation of the information.

It is the responsibility of a designer (engineer) to transform nebulous and incomplete inputs of information into useful, specific and complete information outputs. An engineer needs a great deal of information for designing any product/project. The information may be available in his mind or he may have to obtain it from other sources.

The real problems about collecting information can be

- The sources of information and their location, its availability, and nature of sources.
- How to get it, *i.e.*, accessibility and cost of obtaining, whether available directly or indirectly.
- Credibility, authenticity, relevance and accuracy of information. This can be very important and has to be thoroughly analysed and judged.
- Sometimes information has to be properly interpreted and examined whether same is applicable for given requirement.
- It has to be seen whether the information collected is sufficient.

An information may comprise of facts, data, unorganised knowledge, or intelligence. It may be verbal, graphic, or symbolic. Information covers all aspects of the problem situation, the materials, the principles, the economics, government laws and regulations. An efficient engineering office must therefore be well equipped with catalogs, reports, files, data books, operating manuals, handbooks to enable designer to access the desired information.

Important Facts about Information

(*i*) A small amount of information is always available and can be found at the outset. But it is never complete and much more is required. Many times, it is not known or clear as to how much information is really required.

(*ii*) It takes time to search information.

(*iii*) Sometimes information items may be conflicting and much of it may not be necessary.

(*iv*) It costs time and money to obtain information.

Categories of Information

Information can be classified based on its reliability and usefulness. Uncertainty in information will lead to uncertainty in design. The broad classification on above basis can be

(*i*) hard information (*ii*) soft information.

Hard information is verifiable, unambiguous, permanent, documentable, numerical, checked by several sources, or it has some combination of these attributes. It has maximum reliability when properly transmitted. An engineer can depend upon it most confidently. It includes such matters as : Principles, laws, quantities, standards, data on present systems. Contracts, physical relations, drawings/photographs.

Soft information may be equally or more important, but it is generally nebulous, qualitative, verbal, transient, not necessarily verifiable, or it has some combinations of these characteristics. Such information must be doubly verified. It includes : Opinions, market surveys, recommendations, ideas, proposals, situations, hearsay, one-run statistics, projected data on future systems.

Rationality of Information

It is generally observed that all information has a basically statistical nature. For example, information about strength of materials, other mechanical and electrical properties etc. have some variability, the range of variation may be wide or narrow. No dimension, measure, or characteristic required by designer is exact or fixed. No “one number” can be depended on absolutely. The problem of the designer is thus whether to use average value or median, or range, or maximum or minimum value or combination of these. Each problem case determines which option will give the desired results and designer has to use caution and judgement in this regard.

In the real situation, the complexity grows further by the interaction of several given numbers with each other. This interplay forces the designer to attempt a more basic understanding of the situation he is working with and only then he can select the best number among those available.

Sources for Information

As a designer/engineer learns more about his project, he realises that he does not know many things. One should appreciate that engineer's life is one of continual self education. He never knows in advance all he must know on a project. The engineer has to continually look for sources of information which must be collected and assimilated. Usually new information has to be developed bit by bit by selection from a wide variety of sources.

The various sources of information a designer has to look for are :

- Vendors of components, materials, etc.
- Regulating agencies of the government.
- Trade associations in the field of the project.
- Testing/research institutes.
- Standardisation organisations.
- Professional specialists.
- Financial, insurance and taxation sources.
- Organisation management, and
- Client or customer himself.

Obtaining information costs time and money. Each decision taken comes as a balance between the risk of proceeding versus the cost of verifying. If a manufacturer guarantees a life of a product, there is no need to collect data for verification. All engineering information thus has an economic base. If the risk is small, the information is relatively not important. According to one theory of probability, the information is that which reduces uncertainty and this statement leads to a quantification of the value of information.

Obtaining Information

To obtain information from concerned sources is an art. Important tips in this regard are :

- Set the stage by a brief background so as not to waste time of others. The conversation could be opened by identifying self, his affiliation, the project and the purpose.
- Ask for what is specifically needed.
- Ask question directly with frankness and simplicity.
- Simply phrase the question so it gets passed quickly to the right person to answer it.
- Keep the questions logically related to your project.
- Do not ask for immediate answers if you can wait.

1.6. Description

A designer must have his goal very clear before him, and to achieve his goal he must maintain an organised approach to his work. Any design project involves a countless items which can be given due importance only by following a logical development process. In any project, results are achieved only when all the associated subsystems, components, and parts work properly. For overall success, the engineering work must be broken into smaller units and **a description** of procedures developed to organise the smaller units of engineering work.

Unresolved technical needs are called problems and solutions to problem situations are arrived at by thorough understanding (deep penetration and an encompassing of the many aspects and faceted of the original situation) and not by superficial or fortuitous fitting of a few facts together or by the substituting of some numbers into a formula. Desirable solutions to problems are obtained by application of persistence, care and wisdom. The insight or understanding is realised by deep penetration and an encompassing of the many aspects and facets of the original situation.

A veriety of **description** can be given to a problem—solving process, *i.e.*, the procedures to organise the smaller units of engineering work. This would help designer to understand the processes and steps involved in solving a problem :

(*i*) *Design Process.* The various steps involved can be :

Analysis, Synthesis, Evaluation, Decision, Optimisation Revision, Implementation.

(*ii*) *Thought Process.* It involves :

Preparation, Incubation, Overall consideration and penetration, Elaboration.

(*iii*) *Professional Method.* The various steps are :

Problem definition, Plan treatment, Execute plan, Check as a whole, Learn and generalise.

(*iv*) *Engineering Method.* It analyses the problem by :

Preliminary analysis, Statement of question, Solution, Checking, and Interpretation.

(*v*) *Problem Solving.* The various steps are :

Recognition, Definition, Preparation, Analysis, Synthesis, Evaluation, Presentation.

(*vi*) *Scientific Method.* Various steps involved to define a problem and its solution are :

Collect existing facts, prepare list of missing facts, develop hypothesis, design and conduct experiment, revise hypothesis, develop theories and validate them.

(*vii*) According to some other approaches, various steps can be :

Recognise and gather data, list possible solutions and test them, select best possible solution, application.

1.7. Fundamental Rules of Machine Design

It is necessary to adopt a systematic methodology for finding design solution to machine design problems. The general mechanical design principles adopted are :

- designing for sufficient strength.
- incorporate sufficient provisions for resistance to wear.
- incorporate devices with least friction.
- optimise use of materials.
- be considerate for ease of machining.
- be aware of ease of maintenance.
- pay due attention to aesthetics and ergonoginics
- simple designs are best.
- incorporate safety, environmental friendly and recyclability.
- give due consideration to cost.
- never overspecify.

1.8. Considerations in Design

Usually strength is an important factor that governs the geometry and dimensions of any component. There are several other characteristics which influence the design and entire configuration of system. Some of these are :

—need, —safety, —durability, —reliability, —stiffness, —cost, —distortion, —wear, —creep, —friction, —corrosion, —weight, —noise, —utility, —surface conditions, —lubrication, —manufacturing considerations, — life, —competitiveness, —shape/size, —volume, —control, —thermal properties, —marketability, —styling, —ease of operation, —lack of maintenance, —non-polluting, — recycling, —waste disposal, —codes and standards.

A designer is thus required to possess skills in several fields. Skills are reflected by confronting adequacy statement to judge whether all constraints have been sufficiently examined and optimality realised.

1.9. Some Useful Thoughts in Design

- Time is running out. Education is what is left over after one has forgotten every thing learned. One must therefore learn the basic laws of nature and certain essential facts for understanding the problem solving. Emphasis must be upon developing mature minds and educating designers who can think. Imagination is more important than education. Survival of people will depend upon innovation.
- We fear things of whom we are ingnorant.
- Very frequently, we all bind ourselves with constraints of our own making.
- Habit is like making a spider web and we weave a thread of it each day, and at last we find it difficult to come out of it. Do not become victimised by habit.
- Remember that man's continued misuse of natural resource can lead to a depletion of the essentials of life.
- Keep the design as simple as possible. Unnecessary complexity require more effort and time, costly and time consuming manufacturing operations, costly assembly and is more difficult to maintain.
- Today need is for innovative technologies that will function with least possible hazard to ourselves and the environment.
- Every new thing is resisted. It takes long time to get people interested in new ideas.
- Always follow the highest standards of honesty and integrity.
- You can observe a lot just by watching. Observation brings wisdom.
- Communication is complex because different listeners have different ways of seeing things.
- Organisation should evolve methodology to make use of lessons learned so that same mistakes are not repeated.
- Familiarity with the codes and standards pertinent to a particular design project is essential.
- The challenge for designer is to help in the search for truth and happiness—without bringing about some undesirable effects.
- Any design process is iterative in nature. It is initiated with a poorly defined problem and refined by applying systems approach.
- Optimum design is the selection of values of various parameters either to minimise an undesirable effect or to maximise a functional requirement.
- A designer should learn to formulate problem correctly, develop creativity, imagination and analytical skills, work with interdisciplinary teams, make informed ethical decisions, and develop written and oral communication skills.

A designer should acquire good knowledge of modes of failure, relation of appropriate materials, adoption of suitable safety factors and reliability concepts, quality and cost aspects, creating efficient shapes and sizes for components and machines, consider ease of operation and maintenance, safety, environment friendliness and reference to latest applicable codes and standards.

SOLVED PROBLEMS

Problem 1.1. Define the following terms in one sentence.

(*a*) kinematics (*b*) kinetics (*c*) mechanism (*d*) machine

(*e*) Engineering design (*f*) analysis (*g*) iteration.

Sol. (*a*) Kinematics involves study of motion without regard to forces.

(*b*) Kinetics involves study of forces on systems in motion.

(*c*) A mechanism is a system of elements arranged to transmit motion in a predetermined manner.

(*d*) A machine is formed using mechanisms and designed to provide significant forces and transmit significant power.

(*e*) Engineering design is the process of applying various scientific principles and techniques with a view to define a device (process) system in sufficient detail to permit its realisation.

(*f*) Analysis is important process in design and it decomposes, to take apart, to resolve into its constituent parts. Before analysis, the problem must be defined clearly.

(*g*) Iteration is a process in which one proceeds two steps forwards and then returns one step back to learn more about the problem.

Problem 1.2. Engineering design can be defined as an iterative decision-making activity to produce the plans by which resources are converted, preferably optimally, into systems or devices to meet human needs. Explain the terms :

(*a*) iteration (*b*) decision-making

(*c*) conversion of resources (*d*) human need.

Sol. (*a*) *Iteration.* Design is completed in many phases. In each phase, repeated attempts are required to accomplish the aims. The result is practically never complete and acceptable in the first attempt. Information developed in the first study is employed in a second trial, and so on. Only then the satisfactory conclusion is arrived at for a given phase of design.

(*b*) *Decision-making.* One often comes across several equally acceptable alternatives to meet same end. Decision-making is essential for a designer to select one out of several. He has to base his decision upon various working criteria and various ends or values which are exchanged from case to case (trade offs). A designer has only a limited supply or resources to work with, and thus he has to seek to make the best use of them by choosing from among several alternatives.

(*c*) *Conversion of resources.* All the resources (time, money, talent, materials, and other natural resources) are limited. The design has to be performed within the constraints of limited supplied of these resources. Since the resources are finite, their nature and availability varies from situation to situation.

(*d*) *Human needs.* Technological designs have been conceived to satisfy human needs. There are several fundamental needs of a man and many ways of satisfying them. Needs, whether factual or fancied, moral or amoral, present or future, important or unimportant, has been and are the starting points of design.

Needs can be satisfied only by paying the various prices that are exacted. *Function* requires materials and energy. *Safety* usually requires complications in design or operation. *Light weight* is possible with costly materials. *Reliability* is achieved by costly manufacture and costly design. The optimum, or best value for a given situation requires a thoughtful balance between first cost, function, appearance, convenience, maintainability and life. These must be traded off, one for the other, in differing degrees depending upon the assumed priorities.

Problem 1.3. Fill up the blanks, picking best choice from words given at the end.

The engineer starts with a (1) ____________frequently (2) ____________ and nebulous, and proceeds through an identifiable process to plan the (3) ____________ use of resources to meet that need. He decides among available (4) ____________ judging on the basis of accepted (5) ____________, (6) ____________ until a satisfactory solution is reached.

(alternatives, iterating, need, criteria, optimum, vague)

Sol. (1) need, (2) vague, (3) optimum, (4) alternatives, (5) criteria, (6) iterating.

Problem 1.4. List out the real problems likely to be faced about collection of information.

Sol. A designer needs a great deal of information and he will face lot of problems in searching for the same. The real problems likely to be encountered are :

(*i*) Where to find and locate the information? (availability, location of sources, nature of sources, etc.)

(*ii*) Even if located, how to get it? (accessibility, tactness in getting it retrieved, cost, delay, etc.)

(*iii*) Can it be believed ? (authehticity, credibility, relevance, accuracy of information.)

(*iv*) How to interpret the information located ? (meaning, applicability).

(*iv*) Sufficiency of amount and variety (enough, adequate does it serve the purpose).

(*vi*) Decision as a result of information (yes, no, may be, later).

Problem 1.5. If the necessary and desired information were immediately available, the designer's job could be done in fraction of the time. It is for this reason that efficient design office is well equipped with catalogs, reports, files, data book, operating samples, handbooks, etc. What are the real problems regarding information ?

Sol. A designer often feels and experiences following problems/difficulties relating to information.

(*i*) A small amount of information is always available at the outset, but it is never complete. Much more is required for a given job and how to find and where to locate it is not known?

(*ii*) Time is required to decide as to what information is exactly required and more time is required to locate it.

(*iii*) Information items offered are frequently conflicting. Much of the information is not of direct use and not necessary.

(*iv*) Information costs time and money to obtain.

(*v*) Authenticity of information is another serious concern.

Problem 1.6. Information may be classified as hard or soft. What do you mean by hard vs. soft information?

Sol. Hard information is most reliable. It has attributes of verifiable, unambiguous, permanent, documentable, numerical, checked by several sources, etc. Hard information includes principles, laws, standards, data in existing systems, contracts, physical relations, drawings etc. Soft information is generally nebulous, qualitative, verbal, transient, not necessarily verifiable, etc. It may include opinions, market surveys, recommendations, ideas, proposals, situations etc.

Problem 1.7. Elaborate the statement "Good design requires both analysis and synthesis".

Sol. Complex problems can be approached by decomposing it into manageable parts. Next step is analysis, *i.e.*, understand performance of each part in service by using appropriate disciplines of science and engineering. Analysis in effect involves the simplification of the real world through models. Synthesis involves identification of the design elements comprising the products, its decomposition into parts and the combination of the part solutions into a total workable system.

Problem 1.8. What are the important aspects of design process ?

Sol. These are : (*i*) creativity—creating something which did not exist earlier, (*ii*) taking decisions on many variables and parameters (complexity), (*iii*) making choices between many possible solutions starting from the stage of basic concept to smallest detail of shape, & (*iv*) balancing multiple and often conflicting requirements (compromise).

Problem 1.9. Cost of designing is insignificant compared to cost of materials and production. What are' important considerations in design in this respect ?

Sol. (*i*) Though decisions made in design process cost very little in the overall cost of product but it has major effect on cost of product.

(*ii*) True quality is designed into product and it can not be built into a product unless it is designed into it.

(*iii*) The design process should be conducted so as to develop quality cost-competitive products in the shortest possible time.