Chapter one / Section two

1.8- A Problem-Solving Methodology

Designing can be approached as a problem to be solved. A problem-solving methodology that is useful in design consists of the following steps.

1. *Definition of the problem*
2. *Gathering of information*
3. *Generation of alternative solutions*
4. *Evaluation of alternatives and decision making*
5. *Communication of the results*

This problem-solving method can be used at any point in the design process, whether at the conception of a product or the design of a component.

1.9- CONSIDERATIONS OF A GOOD DESIGN

Design is a multifaceted process. To gain a broader understanding of engineering design, we group various considerations of good design into three categories: (1) achievement of performance requirements, (2) life-cycle issues, and (3) social and regulatory issues.

1.9.1- Achievement of Performance Requirements

It is obvious that to be feasible the design must demonstrate the required performance. *Performance measures both the function and the behavior of the design,* that is, how well the device does what it is designed to do. Performance requirements can be divided into *primary performance requirements and complementary performance requirements.* A major element of a design is its function. The function of a design is how it is expected to behave. For example, the design may be required to grasp an object of a certain mass and move it 50 feet in one minute. *Functional requirements are usually expressed in capacity measures such as forces, strength, deflection, or energy or power output or consumption.* *Complementary performance requirements* are concerns *such as the useful life of the design, its robustness to factors occurring in the service environment its reliability, and ease, economy, and safety of maintenance*. Issues such as built-in safety features and the noise level in operation must be considered. Finally, the design must conform to all legal requirements and design codes.

A product is usually made up of a collection of parts, sometimes called piece parts. A part is a single piece requiring no assembly. When two or more parts are joined it is called an assembly. Often large assemblies are composed of a collection of smaller assemblies called subassemblies. A similar term for part is component. The two terms are used interchangeably, but in the design literature the word component sometimes is used to describe a subassembly with a small number of parts.

Consider an ordinary ball bearing. It consists of an outer ring, inner ring, 10 or more balls depending on size, and a retainer to keep the balls from rubbing together. A ball bearing is often called a component, even though it consists of a number of parts.

Closely related to the function of a component in a design is its form. *Form* is *what the component looks like, and encompasses its shape, size, and surface finish. These, in turn, depend upon the material it is made from and the manufacturing processes that are used to make it.*

A variety of analysis techniques must be employed in arriving at the features of a component in the design. By feature we *mean specific physical attributes, such as the fine details of geometry, dimensions, and tolerances on the dimensions.*

Typical geometrical features *would be fillets, holes, walls, and ribs*. The computer has had a major impact in this area by providing powerful analytical tools based on finite element analysis. Calculations of stress, temperature, and other field-dependent variables can be made rather handily for complex geometry and loading conditions. When these analytical methods are coupled with interactive computer graphics, we have the exciting capability known as computer-aided engineering (CAE). Note that with enhanced capability for analysis comes greater responsibility for providing better understanding of product performance at early stages of the design process.

Environmental requirements for performance deal with two separate aspects. The first concerns *the service conditions* under which the product must operate. The extremes of temperature, humidity, corrosive conditions, dirt, vibration, and noise, must be predicted and allowed for in the design. The second aspect of environmental requirements *pertains to how the product will behave with regard to maintaining a safe and clean environment*, that is, ***green design.*** Often governmental regulations force these considerations in design, but over time they become standard design practice. Among these issues is the *disposal of the product* when it reaches its useful life. ***For more information on design for environment (DFE).***

Aesthetic requirements ***refer to "the sense of the beautiful.*** " They are concerned with how the product is perceived by a customer because of its shape, color, surface texture, and also such factors as balance, unity, and interest. This aspect of design usually is the responsibility of the industrial designer, as opposed to the engineering designer. *The industrial designer is an applied artist*. Decisions about the appearance of the product should *be an integral part of the initial design concept.* An important design consideration is adequate ***attention to human factors engineering,*** which *uses the sciences of biomechanics, ergonomics, and engineering psychology to assure that the design can be operated efficiently by humans.* It applies physiological and anthropometric data to such design features as visual and auditory display of instruments and control systems. It is also concerned with human muscle power and response times. The industrial designer often is responsible for considering the human factors.

Manufacturing technology must be closely integrated with product design. There may be restrictions on the manufacturing processes that can be used, because of either selection of material or availability of equipment within the company.

The final major design requirement is cost. Every design has requirements of an economic nature. These include such issues as product development cost, initial product cost, life cycle product cost, tooling cost, and return on investment. In many cases cost is the most important design requirement. If preliminary estimates of product cost look unfavorable, the design project may never be initiated. Cost enters into every aspect of the design process.

1.9.2 - Total Life Cycle

The total life cycle of a part starts with the conception of a need and ends with the retirement and disposal of the product.

Material selection is a key element in shaping the total life cycle. In selecting materials for a given application, the first step is evaluation of the service conditions. Next, the properties of materials that relate most directly to the service requirements must be determined. Except in almost trivial conditions, there is never a simple relation between service performance and material properties. The design may start with the consideration of static yield strength, but properties that are more difficult to evaluate, such as fatigue, creep, toughness, ductility, and corrosion resistance may have to be considered. We need to know whether the material is stable under the environmental conditions. Does the microstructure change with temperature and therefore change the properties? Does the material corrode slowly or wear at an unacceptable rate?

Material selection cannot be separated from manufacturability. There is an intimate connection between design and material selection and the manufacturing processes. The objective in this area is a trade-off between the opposing factors of minimum cost and maximum durability. Durability is the amount of use one gets from a product before it is no longer useable. Current societal issues of energy conservation, material conservation, and protection of the environment result in new pressures in the selection of materials and manufacturing processes. Energy costs, once nearly ignored in design, are now among the most prominent design considerations. Design for materials recycling also is becoming an important consideration. The life cycle of production and consumption that is characteristic of all products is illustrated by the materials cycle shown in Fig. 1.6. This starts with the mining of a mineral or the drilling for oil or the harvesting of an agricultural fiber such as cotton.

These raw materials must be processed to extract or refine a bulk material (e.g., an aluminum ingot) that is further processed into a finished engineering material (e.g., an aluminum sheet). At this stage an engineer designs a product that is manufactured from the material, and the part is put into service. Eventually the part wears out or becomes obsolete because a better product comes on the market. At this stage, one option is to junk the part and dispose of it in some way that eventually returns the material to the earth. However, society is becoming increasingly concerned with the depletion of natural resources and the haphazard disposal of solid materials. Thus, we look for economical ways to recycle waste materials (e.g., aluminum beverage cans).

1.9.3 - Regulatory and Social Issues

Specifications and standards have an important influence on design practice. The standards produced by such societies as ASTM and ASME represent voluntary agreement among many elements (users and producers) of industry. As such, they often represent minimum or least-common-denominator standards. When good design requires more than that, it may be necessary to develop your own company or agency standards. On the other hand, because of the general nature of most standards, a standard sometimes requires a producer to meet a requirement that is not essential to the particular function of the design.

The codes of ethics of all professional engineering societies require the engineer to protect public health and safety. Increasingly, legislation has been passed to require federal agencies to regulate many aspects of safety and health. The requirements of the Occupational Safety and Health Administration (OSHA), the Consumer Product Safety Commission (CPSC), the Environmental Protection Agency (EPA), and the Department of Homeland Security (DHS) place direct constraints on the designer in the interests of protecting health, safety, and security. Several aspects of the CPSC regulations have far-reaching influence on product design. Although the intended purpose of a product normally is quite clear, the unintended uses of that product are not always obvious. Under the CPSC regulations, the designer has the obligation to fore-see as many unintended uses as possible, then develop the design in such a way as to prevent hazardous use of the product in an unintended but foreseeable manner. When unintended use cannot be prevented by functional design, clear, complete, unambiguous warnings must be permanently attached to the product. In addition, the designer must be cognizant of all advertising material, owner's manuals, and operating instructions that relate to the product to ensure that the contents of the material are consistent with safe operating procedures and do not promise performance characteristics that are beyond the capability of the design. An important design consideration is adequate attention to ***human factors engineering,*** *which uses the sciences of biomechanics, ergonomics, and engineering psychology to assure that the design can be operated efficiently and safely by humans. It applies physiological and anthropometric data to such design features as visual and auditory display of instruments and control systems. It is also concerned with human muscle power and response times.*

1.10- DESCRIPTION OF DESIGN PROCESS:

According to "Morris Asimow" explained his view on design processes into seven steps, as:

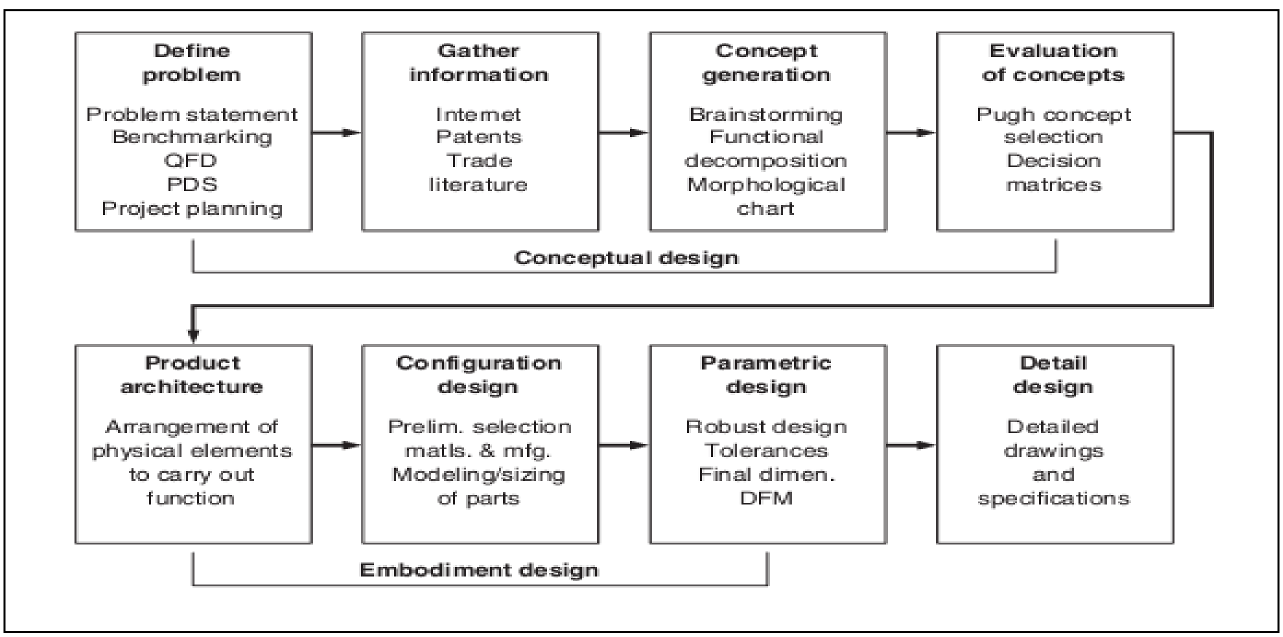

Fig. 1.16- The design activities that make up the i rst three phases of the engineering design process.

1.10.1- Phase I. Conceptual Design

Conceptual design is the process by which the design is initiated, carried to the point of creating a number of possible solutions, and narrowed down to a single best concept. It is sometimes called the *feasibility study*. Conceptual design is the phase that requires *the greatest creativity, involves the most uncertainty, and requires coordination among many functions in the business organization*. The following are the discrete activities that we consider under conceptual design.

● ***Identification of customer needs :*** The goal of this activity is *to completely understand the customers' needs* and to communicate them to the design team.

● ***Problem definition :*** The goal of this activity is *to create a statement that describes what has to be accomplished to satisfy the needs of the customer*. This involves analysis of competitive products, the establishment of target specifications, and the listing of constraints and trade-offs. Quality function deployment (QFD) is a valuable tool for linking customer needs with design requirements. A detailed listing of the product requirements is called a product design specification (PDS).

● ***Gathering information****:* Engineering design presents special requirements over engineering research in the need to acquire a broad spectrum of information.

● ***Conceptualization*** : Concept generation involves *creating a broad set of concepts that potentially satisfy the problem statement*. Team-based creativity methods, combined with efficient information gathering, are the key activities.

● ***Concept selection*** : *Evaluation of the design concepts, modifying and evolving into a single preferred concept, are the activities in this step*. The process usually requires several iterations.

● ***Refinement of the PDS*** : *The product design specification is revisited* after the concept has been selected. The design team must commit to achieving certain critical values of design parameters, usually called critical-to-quality (CTQ) parameters, and to living with trade-offs between cost and performance.

● ***Design review*** : Before committing funds to move to the next design phase, a design review will be held. The design *review will assure that the design is physically realizable and that it is economically worthwhile.* It will also look at a *detailed product development schedule. This is needed to devise a strategy to minimize product cycle time and to identify the resources in people, equipment, and money needed to complete the project*.

1.10.2 - Phase II. Embodiment Design

Structured development of the design concept occurs in this engineering design phase. It is the place where "flesh is placed on the skeleton" of the design concept. *An embodiment of all the main functions that must be performed by the product must be undertaken.* It is in this design phase that *decisions are made on strength, material selection, size, shape, and spatial compatibility.* Beyond this design phase, major changes become very expensive. This design phase is sometimes called preliminary design. *Embodiment design is concerned with three major tasks:*

● ***Product architecture***: Product architecture is *concerned with dividing the overall design system into subsystems or modules.* In this step we decide how the physical components of the design are to be arranged and combined to carry out the functional duties of the design.

● ***Configuration design of parts and components***: Parts are made up of features like holes, ribs, splines, and curves. *Configuring a part means to determine what features will be present and how those features are to be arranged in space* *relative to each other*. While modeling and simulation may be performed in this stage to check out function and spatial constraints, only approximate sizes are determined o assure that the part satisfies the PDS. Also, *more specificity about materials and manufacturing is given here.* The generation of a physical model of the part with rapid prototyping processes may be appropriate.

●***Parametric design of parts:*** *Parametric design starts with information on the configuration of the part* <u>*and aims to establish its exact dimensions and tolerances*</u>*.*

Final decisions on the material and manufacturing processes are also established if this has not been done previously. *An important aspect of parametric design is to examine the part, assembly, and system for design robustness. Robustness refers to how consistently a component performs under variable conditions in its service environment. The methods developed by Dr. Genichi Taguchi for achieving robustness and establishing the optimum tolerance are discussed. Parametric design also deals with determining the aspects of the design that could lead to failure.* <u>*Another important consideration in parametric design is to design in such a way that manufacturability is enhanced*</u>*.*

1.10.3- Phase III. Detail Design

In this phase the design is brought to the stage of a *complete engineering description of a tested and producible product.* Missing information is added on the arrangement, form, dimensions, and tolerances, surface properties, materials, and manufacturing processes of each part. This results in a specification for each special-purpose part and for each standard part to be purchased from suppliers. In the detail design phase the following activities are completed and documents are prepared:

1. *Detailed engineering drawings suitable for manufacturing. Routinely these are computer-generated drawings, and they often include three-dimensional CAD models.*
2. *Verification testing of prototypes is successfully completed and verification data is submitted. All critical-to-quality parameters are confirmed to be under control. Usually the building and testing of several preproduction versions of the product will be accomplished.*
3. *Assembly drawings and assembly instructions also will be completed. The bill of materials for all assemblies will be completed.*
4. *A detailed product specification, updated with all the changes made since the conceptual design phase, will be prepared.*
5. *Decisions on whether to make each part internally or to buy from an external supplier will be made.*
6. *With the preceding information, a detailed cost estimate for the product will be carried out.*
7. *Finally, detail design concludes with a design review before the decision is made to pass the design information on to manufacturing.*

Phases I, II, and III take the design from the realm of possibility to the real world of practicality. However, the design process is not finished with the delivery of a set of detailed engineering drawings and specifications to the manufacturing organization.

***Many other technical and business decisions must be made that are really part of the design process*.**

A great deal of *thought and planning must go into how the design will be manufactured, how it will be marketed, how it will be maintained during use, and finally, how it will be retired from service and replaced by a new, improved design*.

Generally these phases of design are carried out elsewhere in the organization than in the engineering department or product development department. As the project proceeds into the new phases, the expenditure of money and personnel time increases greatly.

One of the basic decisions that must be made at this point is which parts will be *made by the product developing company and which will be made by an outside vendor or supplier.* This often is called the "***make or buy" decision***. Today, one additional question must be asked: "Will the parts be made and/or assembled in this place or in another country where labor rates are much lower?"

1.10. 4 - Phase IV. Planning for Manufacture

A great deal of detailed planning must be done to provide for the production of the design. *A method of manufacture must be established for each component in the system*. As a usual first step, a process sheet is created; it contains a sequential list of all manufacturing operations that must be performed on the component. Also, it specifies the form and condition of the material and the tooling and production machines that will be used. The information on the process sheet makes possible the estimation of the production cost of the component.

High costs may indicate the need for a change in material or a basic change in the design. Close interaction with manufacturing, industrial, materials, and mechanical engineers is important at this step.

The other important tasks performed in phase IV are the following:

1. ● Designing specialized tools and fixtures
2. ● Specifying the production plant that will be used (or designing a new plant) and laying out the production lines.
3. ●Planning the work schedules and inventory controls (production control)
4. ●Planning the quality assurance system.
5. ● Establishing the standard time and labor costs for each operation.
6. ● Establishing the system of information flow necessary to control the manufacturing operation.

All of these tasks are generally considered to fall within *industrial or manufacturing engineering.*