Kurdistan Region
Salahaddin University-Erbil
College of Engineering
Mechanic & Mechatronics Engineering Department

Fundamentals of Design

For Second Stage Students
In Mechanic & Mechatronics Dept.

Prepared By:
Mr. Abdulbasit Abdulqadir Hamza

Second Semester 2021 - 2022

Introduction

Design

- To formulate a plan for the satisfaction of a specified need.
- Process requires innovation, iteration and decision making.
- Communication-intensive
- Products should be
  - Functional
  - Safe
  - Reliable
  - Competitive
  - Usable
  - Manufacturable
  - Marketable

Functional: The product must perform to fill its intended need and customer expectation.

Safe: The product is not hazardous to the user, bystanders or surrounding property. Hazards which cannot be " designed out " are eliminated by guarding (a protective enclosure); if that is not possible, appropriate directions or warnings are provided.

Reliability: Reliability is a conditional probability, at a given confidence level, that the product will perform its intended function satisfactorily or without failure at a given age.

Competitive: The product is a contender in its market.

Usable: The product is "user-friendly" accommodation to human size, strength posture, reach, force, power and control.

Manufacturable: The product has been reduced to a "minimum" number of parts, suited to mass production, with dimensions, distortions and strength under control.

Marketable: The product can be bought and service (repair) is available.

Classifications of Machine Design

The machine design may be classified as follows:

1. **Adaptive design.** In most cases, the designer's work is concerned with adaptation of existing designs. This type of design needs no special knowledge or skill and can be attempted by designers of ordinary technical training. The designer only makes minor alternation or modification in the existing designs of the product.

2. **Development design.** This type of design needs considerable scientific training and design ability in order to modify the existing designs into a new idea by adopting a new material or different method of manufacture. In this case, though the designer starts from the existing design, but the final product may differ quite markedly from the original product.

3. **New design.** This type of design needs lot of research, technical ability and creative thinking. Only those designers who have personal qualities of a sufficiently high order can take up the work of a new design.

General Considerations in Machine Design

Following are the general considerations in designing a machine component:

1. Type of load and stresses caused by the load. The load, on a machine component, may act in several ways due to which the internal stresses are set up.

2. Motion of the parts or kinematics of the machine. The successful operation of any machine depends largely upon the simplest arrangement of the parts which will give the motion required.

The motion of the parts may be:
(a)) Rectilinear motion which includes unidirectional and reciprocating motions.
(b) Curvilinear motion which includes rotary, oscillatory and simple harmonic.
(c)) Constant velocity.
(d) Constant or variable acceleration.

3. Selection of materials. It is essential that a designer should have a thorough knowledge of the properties of the materials and their behavior under working conditions. Some of the important characteristics of materials are: strength, durability, flexibility, weight, resistance to heat and corrosion, ability to cast, welded or hardened, machinability, electrical conductivity, etc.

4. Form and size of the parts. The form and size are based on judgement. The smallest practicable cross-section may be used, but it may be checked that the stresses induced in the designed cross-section are reasonably safe. In order to design any machine part for form and size, it is necessary to know the forces which the part must sustain.

5. Frictional resistance and lubrication. There is always a loss of power due to frictional resistance and it should be noted that the friction of starting is higher than that of running friction. It is, therefore, essential that a careful attention must be given to the matter of lubrication of all surfaces which move in contact with others, whether in rotating, sliding, or rolling bearings.

6. Convenient and economical features. In designing, the operating features of the machine should be carefully studied. The starting, controlling and stopping levers should be located on the basis of convenient handling. The economical operation of a machine which is to be used for production, or for the processing of material should be studied, in order to learn whether it has the maximum capacity consistent with the production of good work.

7. Use of standard parts. The use of standard parts is closely related to cost, because the cost of standard or stock parts is only a fraction of the cost of similar parts made to order. The standard or stock parts should be used whenever possible; parts for which patterns are already in existence such as gears, pulleys and bearings.

8. Safety of operation. Some machines are dangerous to operate, especially those which are speeded up to insure production at a maximum rate. Therefore, any moving part of a machine which is within the zone of a worker is considered an accident hazard and may be the cause of an injury. It is, therefore, necessary that a designer should always provide safety devices for the safety of the operator.

9. Workshop facilities. A design engineer should be familiar with the limitations of his employer's workshop, in order to avoid the necessity of having work done in some other workshop. It is sometimes necessary to plan and supervise the workshop operations and to draft methods for casting, handling and machining special parts.

10. Number of machines to be manufactured. The number of articles or machines to be manufactured affects the design in a number of ways. The engineering and shop costs which are called fixed charges or overhead expenses are distributed over the number of articles to be manufactured.

11. Cost of construction. The cost of construction of an article is the most important consideration involved in design. In some cases, it is quite possible that the high cost of an article may immediately bar it from further considerations. The aim of design engineer under all conditions, m

\should be to reduce the manufacturing cost to the minimum.

12. Assembling. Every machine or structure must be assembled as a unit before it can function. Large units must often be assembled in the shop, tested and then taken to be transported to their place of service. The final location of any machine is important and the design engineer must anticipate the exact location and the local facilities for erection.

Computational Tools

- Computer – Aided Engineering (CAE)

Any use of the computer and software to aid in the engineering process, includes:

- √ Computer – Aided Design (CAD). Like, Drafting, 3-D solid modeling, AutoCAD and etc.
- √ Computer – Aided Manufacturing (CAM). Like CNC toolpath, rapid prototyping, etc.
- √ Engineering analysis and simulation. Like Finite element, dynamic analysis, etc.
- √ Math Solvers. Like Spreadsheet, Procedural Programming Language, equation solver, etc.

Standards and Codes

- Standard
  - A set of specifications for parts, materials, or processes
  - Intended to achieve uniformity, efficiency, and a specified quality.
  - Limits the multitude of variations

- Code
  - A set of specifications for the analysis, design, manufacture, and construction of something.
  - To achieve a specified degree of safety, efficiency, and performance or quality
  - Does not imply absolute safety
  - Various organizations establish and publish standards and codes for common and/or critical industries.

Some organizations that establish standards and codes of particular interest to mechanical engineers:

Aluminum Association (AA)

American Iron and Steel Institute (AISI)

American Society of Mechanical Engineers (ASME)

American Society of Testing and Materials (ASTM)

International Standards Organization (ISO)

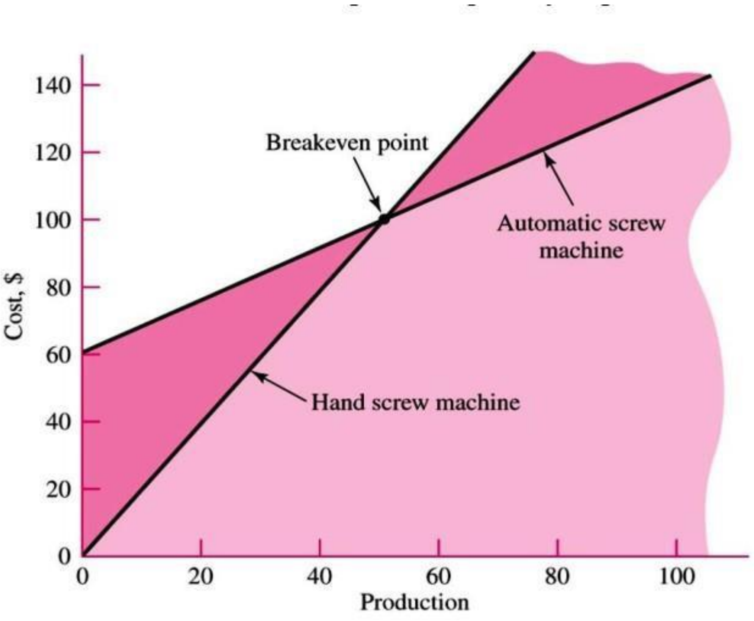
Society of Automotive Engineers (SAE)

Economics

- Cost is almost always an important factor in engineering design.
- Use of standard sizes is a first principale of cost reduction.
- Certain common components may be less expensive in stocked sizes.

Breakeven Points

- A cost comparison between two possible production methodes
- Often there is a breakeven point on quantity of production



EXAMPLE
Automatic screw machine
25 parts/hr
3 hr setup
$20/hr labor cost
Hand screw machine
10 parts/hr
Minimal setup
$20/hr labor cost
Breakeven at 50 units

Table A-17 lists some typical preferred sizes

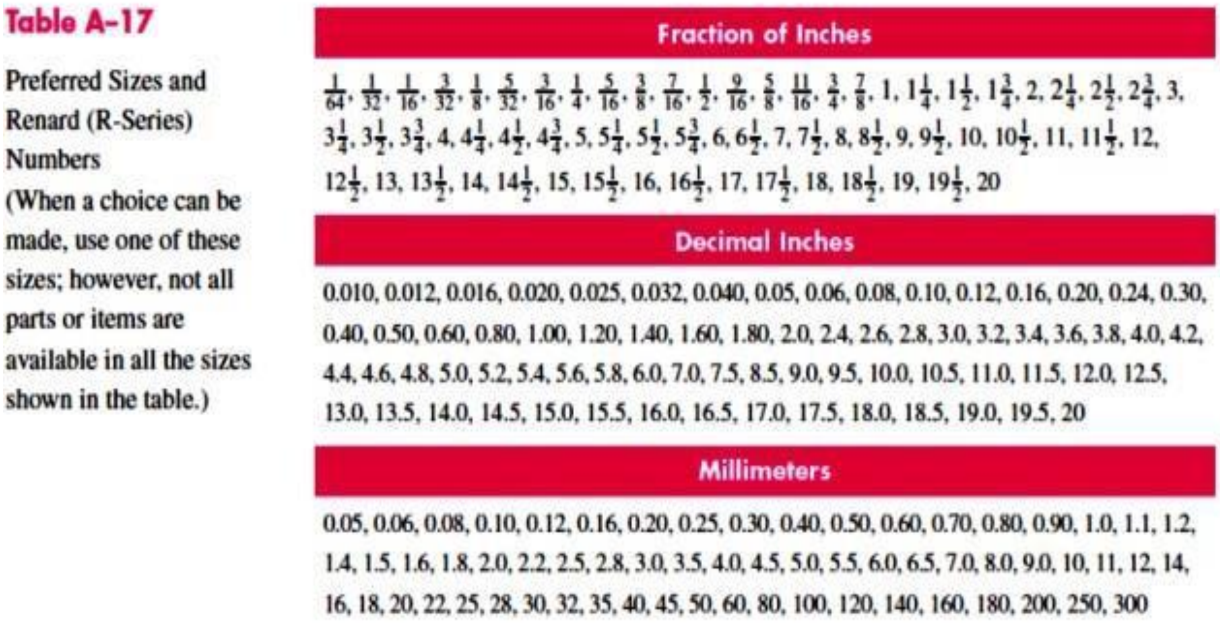


Table A-17

Preferred Sizes and Renard (R-Series) Numbers

(When a choice can be made, use one of these sizes; however, not all parts or items are available in all the sizes shown in the table.)

Fraction of Inches
$\frac{1}{64}, \frac{1}{32}, \frac{1}{16}, \frac{3}{32}, \frac{1}{8}, \frac{5}{32}, \frac{3}{16}, \frac{1}{4}, \frac{5}{16}, \frac{3}{8}, \frac{7}{16}, \frac{1}{2}, \frac{9}{16}, \frac{5}{8}, \frac{11}{16}, \frac{3}{4}, \frac{7}{8}, 1, 1\frac{1}{4}, 1\frac{1}{2}, 1\frac{3}{4}, 2, 2\frac{1}{4}, 2\frac{1}{2}, 2\frac{3}{4}, 3, 3\frac{1}{4}, 3\frac{1}{2}, 3\frac{3}{4}, 4, 4\frac{1}{4}, 4\frac{1}{2}, 4\frac{3}{4}, 5, 5\frac{1}{4}, 5\frac{1}{2}, 5\frac{3}{4}, 6, 6\frac{1}{2}, 7, 7\frac{1}{2}, 8, 8\frac{1}{2}, 9, 9\frac{1}{2}, 10, 10\frac{1}{2}, 11, 11\frac{1}{2}, 12, 12\frac{1}{2}, 13, 13\frac{1}{2}, 14, 14\frac{1}{2}, 15, 15\frac{1}{2}, 16, 16\frac{1}{2}, 17, 17\frac{1}{2}, 18, 18\frac{1}{2}, 19, 19\frac{1}{2}, 20$
Decimal Inches
0.010, 0.012, 0.016, 0.020, 0.025, 0.032, 0.040, 0.05, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.24, 0.30, 0.40, 0.50, 0.60, 0.80, 1.00, 1.20, 1.40, 1.60, 1.80, 2.0, 2.4, 2.6, 2.8, 3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0, 5.2, 5.4, 5.6, 5.8, 6.0, 7.0, 7.5, 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, 12.0, 12.5, 13.0, 13.5, 14.0, 14.5, 15.0, 15.5, 16.0, 16.5, 17.0, 17.5, 18.0, 18.5, 19.0, 19.5, 20
Millimeters
0.05, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.25, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 1.0, 1.1, 1.2, 1.4, 1.5, 1.6, 1.8, 2.0, 2.2, 2.5, 2.8, 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 8.0, 9.0, 10, 11, 12, 14, 16, 18, 20, 22, 25, 28, 30, 32, 35, 40, 45, 50, 60, 80, 100, 120, 140, 160, 180, 200, 250, 300

Acquiring Technical Information

Libraries
Engineering handbooks, textbooks, journals, patents, etc.

Government sources
U.S. Patent and Trademark Office; National Technical Information Service; and National Institute for Standards and Technology.

Professional societies
American Society of Mechanical Engineers, Society of Manufacturing Engineers, Society of Automotive Engineers, American Society for Testing and Materials, and American Welding Society.

Commercial vendors
Catalogs, technical literature, test data, samples, and cost information.

Internet
The computer network gateway to websites associated with most of the categories listed above.

Uncertainty

Uncertainties in machinery design abound. Examples of uncertainties concerning stress and strength include

- Composition of material and the effect of variation on properties.
- Variations in properties from place to place within a bar of stock.
- Effect of processing locally, or nearby, on properties.
- Effect of nearby assemblies such as weldments and shrink fits on stress conditions.
- Effect of thermomechanical treatment on properties.
- Intensity and distribution of loading.
- Validity of mathematical models used to represent reality.
- Intensity of stress concentrations.
- Influence of time on strength and geometry.
- Effect of corrosion.
- Effect of wear.
- Uncertainty as to the length of any list of uncertainties.

Stress and Strength

When designing a component, the designer needs to make sure that the maximum stress is less than the strength of the material used for making that component.

- Stress (σ) depends on geometry and load.
- Strength (S) is a materials property; strength is the stress level at which something occurs (such as yield strength or ultimate strength).

When designing mechanical components, the stress level should never reach the yield strength of the material.

Yielding is considered failure; why?

According to AISC, the maximum allowable stress (σ_{all} , τ_{all}) is a reduced value of the yielding strength.

Tension: $0.45S_y \le \sigma_{all} \le 0.6S_y$

Shear: $\tau_{all} = 0.4S_y$

Bending: $0.6S_y \le \sigma_{all} \le 0.75S_y$

Bearing: $\sigma_{all} = 0.9S_y$

Design Factor and Factor of Safety

A design factor is used to:

- Account for uncertainty (material properties, load variability, validity of mathematical models, etc.)
- Ensure safety

By definition
$$n_d = \frac{\text{loss-of-function parameter}}{\text{maximum allowable parameter}}$$

If the parameter is load, then the maximum allowable load can be found from

$$\text{Maximum allowable load} = \frac{\text{loss-of-function load}}{n_d}$$

$$n_d = \frac{\text{loss-of-function strength}}{\text{allowable stress}} = \frac{S}{\sigma(\text{or } \tau)}$$

$$\boxed{n_d = \frac{Strength}{Stress}}$$

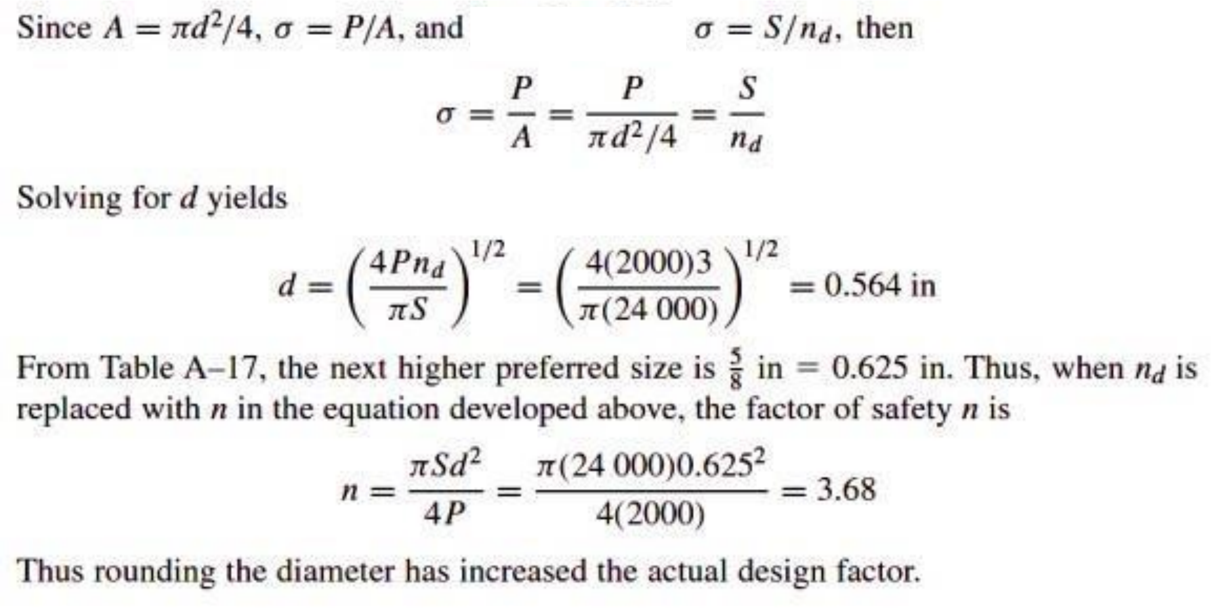
- All loss-of-function modes must be analyzed, and the mode with the smallest design factor governs.

- Stress and strength terms must be of the same type and units.

- Stress and strength must apply to the same critical location in the part.

The factor of safety is the realized design factor of the final design, including rounding up to standard size or available components.

EXAMPLE 1–2 A rod with a cross-sectional area of *A* and loaded in tension with an axial force of *P* 2000 lbf undergoes a stress of σ = *P*/*A*. Using a material strength of 24 kpsi and a *design factor* of 3.0, determine the minimum diameter of a solid circular rod. Using Table, A–17, select a preferred fractional diameter and determine the rod's *factor of safety*.



Since $A = \pi d^2/4$, $\sigma = P/A$, and $\sigma = S/n_d$, then

$$\sigma = \frac{P}{A} = \frac{P}{\pi d^2/4} = \frac{S}{n_d}$$

Solving for d yields

$$d = \left(\frac{4Pn_d}{\pi S}\right)^{1/2} = \left(\frac{4(2000)3}{\pi(24\,000)}\right)^{1/2} = 0.564 \text{ in}$$

From Table A–17, the next higher preferred size is $\frac{5}{8}$ in = 0.625 in. Thus, when n_d is replaced with n in the equation developed above, the factor of safety n is

$$n = \frac{\pi S d^2}{4P} = \frac{\pi(24\,000)0.625^2}{4(2000)} = 3.68$$

Thus rounding the diameter has increased the actual design factor.

Reliability- *R*

Reliability of a component is the probability that the component will not fail during use.

The reliability (R) can be expressed numerically in the range ($0 \leq R \leq 1$)

- ✓ If $R = 0.9$, it means that there is a chance of 90% that the component will perform its function without failure.

Probability of Failure: p_f

where p_f is the probability of failure, given by the number of instances of failures per total number of possible instances.

$$R = 1 - p_f$$

Example: If 1000 parts are manufactured, with 6 of the parts failing, the reliability is**: -**

$$R = 1 - \frac{6}{1000} = 0.994 \qquad \text{or } 99.4\ \%$$

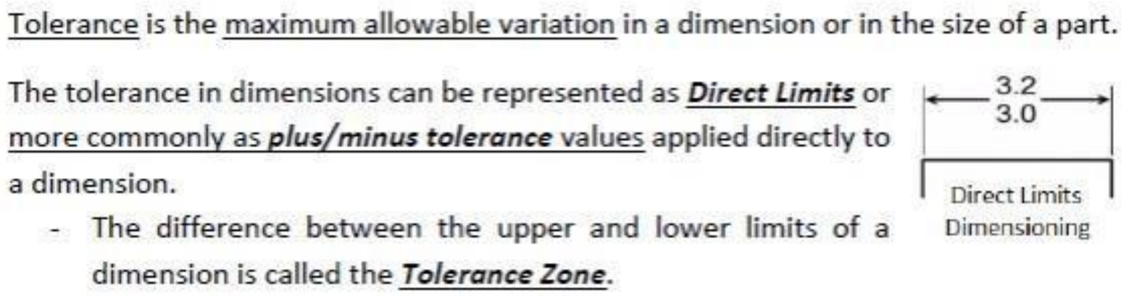
- *Series System* – a system that is deemed to have failed if any component within the system fails
- The overall reliability of a series system is the product of the reliabilities of the individual components.

$$R = \prod_{i=1}^{n} R_i$$

Example: A shaft with two bearings having reliabilities of 95% and 98% has an overall reliability of

$$R = R_1 R_2 = 0.95\ (0.98) = 0.93 \qquad \text{or } 93\%$$

Dimensions and Tolerances



Tolerance is the maximum allowable variation in a dimension or in the size of a part.

The tolerance in dimensions can be represented as ***Direct Limits*** or more commonly as ***plus/minus tolerance*** values applied directly to a dimension.

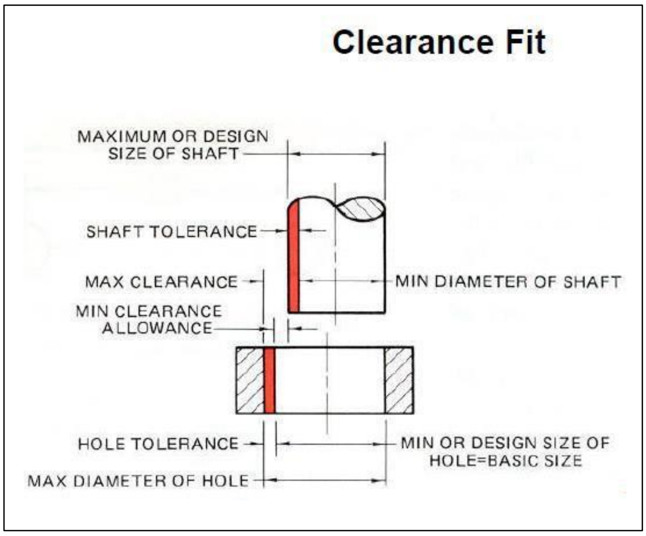
- The difference between the upper and lower limits of a dimension is called the ***Tolerance Zone***.

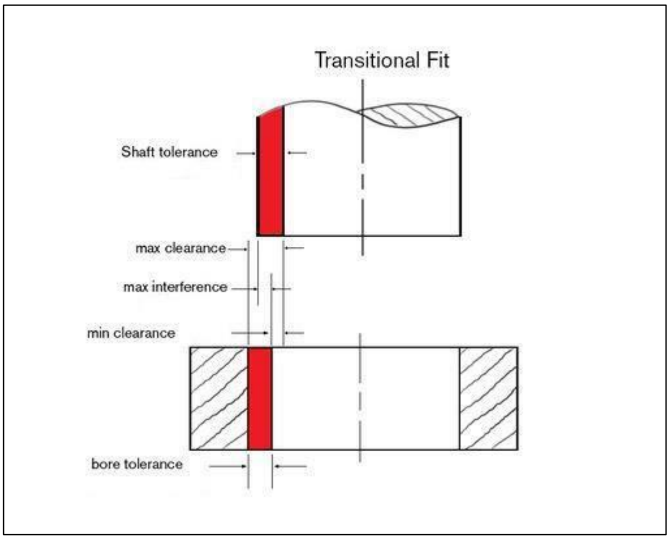
There are three types of tolerances

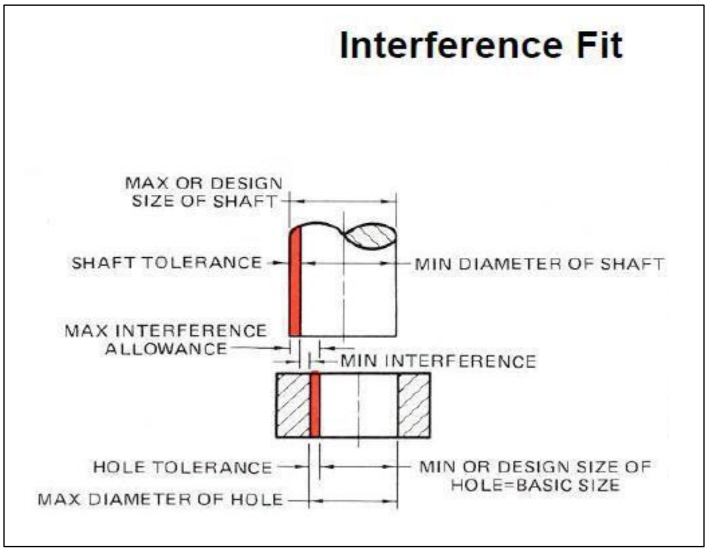
A. **Clearance fit**
It is a fit that always enables a clearance between the hole and shaft in the coupling. The lower limit size of the hole is greater or at least equal to the upper limit size of the shaft.

B. **Transition fit**
It is a fit where (depending on the actual sizes of the hole and shaft) both clearance and interference may occur in the coupling.

C. **Interference fit**
It is a fit always ensuring some interference between the hole and shaft in the coupling. The upper limit size of the hole is smaller or at least equal to the lower limit size of the shaft.







- There are two ways for specifying plus/minus tolerance values for dimensions:
  - **Bilateral tolerance**: the variation in both directions from the basic size (*the basic size is the exact desired theoretical size*).

    Example: 100 ± 0.2

    Basic size Limits

    - Usually used for parts that fit besides each other

  - **Unilateral tolerance**: the basic size is taken as one of the limits and the variation is only in one direction.

    Example: $40^{+0}_{-0.1}$ *or* $40^{+0.1}_{-0}$

    Basic size Limits

    - Usually used for parts that fit inside each other (*e.g., shaft & hole, key & keyway*)

Why do we specify tolerance?

Because parts cannot be manufactured to the exact geometry and dimensions, so we specify the acceptable range of variation.

In general, the variations in dimensions of manufactured parts (*the actual size*) occur at random (*within the tolerance zone*) and, usually, they follow a normal distribution.