SSC-JE 2025

Staff Selection Commission

Junior Engineer Examination

Mechanical Engineering

Machine Design

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Machine Design

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CHAPTER 01

Design Against Fluctuating Load

1.1 Introduction to Fluctuating Stress

The stresses which vary from a minimum value to a maximum value of the same nature (i.e. tensile or compressive) are called fluctuating stresses.

1.2 Types of Stresses

1.2.1 Fluctuating Stress

- The stresses which vary from a minimum value to a maximum value of the same nature (i.e. tensile or compressive) are called fluctuating stresses.

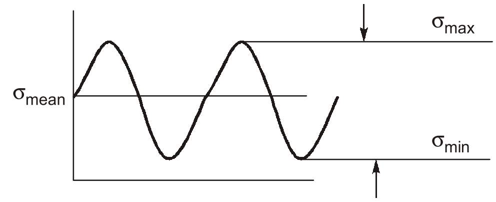
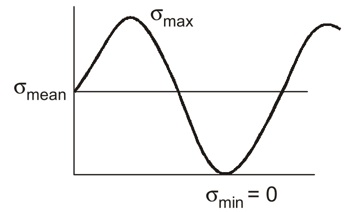


Figure 1.1: Fluctuating stress cycle

1.2.2 Repeated Stress

- Stress variation is such that the minimum stress is zero, mean and amplitude stress have the same value for repeated loading.

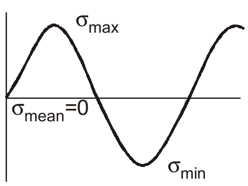


$\sigma_{mean} = \sigma_a$

Figure 1.2: Repeated stress cycle

1.2.3 Cyclic Stress

- The stresses which vary from one value of compressive to the same value of tensile or vice versa, are known as completely reversed or cyclic stresses.



$\sigma_{max} = -\sigma_{min}$

Figure 1.3: Completely reversed or cyclic stress

1.2.4 Alternating Stress

- The stresses which vary from a minimum value to a maximum value of the opposite nature (i.e. from a certain minimum compressive to a certain maximum tensile or from a minimum tensile to a maximum compressive) are called alternating stresses.

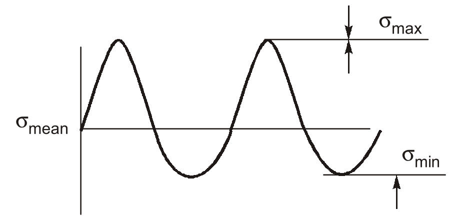


Figure 1.4: Alternating Stress

1.3 Fatigue

- Fatigue is a phenomenon associated with variable loading or cyclic stressing just like animals and humans get fatigue when specific task (applying specific stress) is repeatedly performed.

  In this manner components subjected to variable loading get fatigue which leads to their premature failure known as fatigue failure.
- Most mechanical components experience variable loading due to change in the magnitude or direction of applied load.
- Worst case of fatigue loading is fully-reversible load.

1.3.1 Fatigue Failure

- When a material is subjected to repeated stresses, it fails at stresses below the yield point stresses. Such type of failure of a material is known as **fatigue.** The failure may occur even without any prior indications. The fatigue of material is effected by the size of the component, relative magnitude of static and fluctuating loads and the number of load reversals.

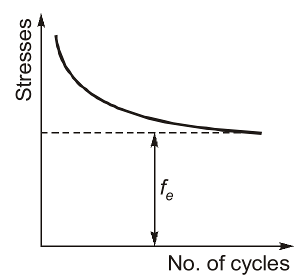


Figure 1.5

- If the stress is kept below a certain value as shown by dotted line, the material will not fail whatever may be the number of cycles. This stress, as represented by dotted line, is known as **endurance or fatigue limit (f_e).** It is defined as maximum value of the completely reversed bending stress which a polished standard specimen can withstand without failure, for infinite number of cycles (usually 10^6 cycles).
- The term endurance limit is used for reversed bending only; while for other types of loading, the term endurance strength may be used when referring the fatigue strength of the material.

1.4 Some Values of Stress

- Means stress, $\sigma_m = \dfrac{\sigma_{max} + \sigma_{min}}{2}$
- Stress amplitude, $\sigma_a = \dfrac{\sigma_{max} - \sigma_{min}}{2}$

- Stress range, $\sigma_r = \sigma_{max} - \sigma_{min}$
- Stress ratio, $R = \dfrac{\sigma_{max}}{\sigma_{min}}$
- Amplitude ratio, $A = \dfrac{\sigma_a}{\sigma_m}$

here σ_{max} = maximum stress value during complete cycle
σ_{max} = maximum stress value during complete cycle

1.5 Stress Concentration/Stress Concentration Factor

- Stress concentration is defined as the localization of high stresses due to the irregularities present in the component and abrupt changes of the cross-section.

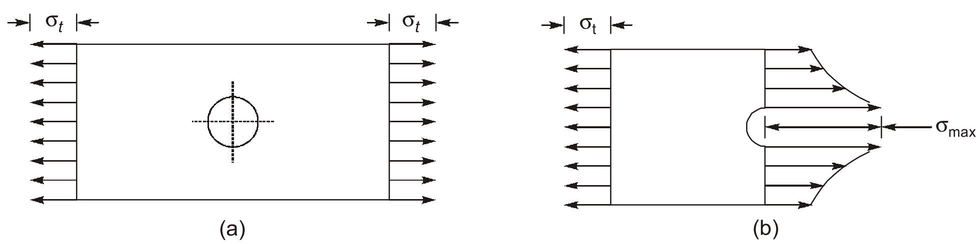


Figure 1.6

1.5.1 Stress Concentration Factor (k_t)

$$k_t = \frac{\text{Highest value of actual stress near discontinuity}}{\text{Nominal stress obtained by elementary equations for minimum cross-section}}$$

or
$$k_t = \frac{\sigma_{max.}}{\sigma_0} = \frac{\tau_{max.}}{\tau_0}$$

1.5.2 Stress Concentration Due to Hole

- The stress at the joints away from the hole is practically uniform and the maximum stress will be induced at the edge of the hole.

$$\sigma_{max} = \sigma\left(1 + \frac{2a}{b}\right)$$

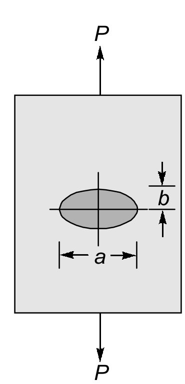
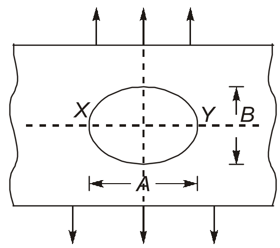


Figure 1.7

Example 1.1 A loaded semi-infinite flat plate is having an elliptical hole ($A/B = 2$) in the middle as shown in the figure. Find the stress concentration factor at either X or Y is



Solution :

As we know,

Stress concentration factor, $$k_T = 1 + \frac{2A}{B}$$

$$k_T = 1 + 2 \times 2 = 5$$

Example 1.2 A rotating shaft carrying a unidirectional transverse load is subjected to which types of stresses?

Solution :

Variable Bending Stress:

- Some fibre is subjected to tensile and compressive bending stress.

Example 1.3 A cold rolled steel shaft is design on the basis of maximum shear stress theory (MSST). The principal stresses induced at its critical section are 60 MPa and –60 MPa respectively. If the yield stress for the shaft material is 360 MPa, find the factor of safety of the design.

Solution :

$$\sigma_1 = 60 \text{ MPa}$$

$$\sigma_2 = -60 \text{ MPa}$$

So, $$\tau_{max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{60 + 60}{2} = 60 \text{ MPa}$$

According to MSST, yield stress in shear $= S_{se}$

$$S_{se} = 0.5 S_{yt} = 0.5 \times 360 = 180 \text{ MPa}$$

$\Rightarrow$ $$\tau_{allowable} = \frac{S_{se}}{FOS}$$

$\Rightarrow$ $$\text{F.O.S.} = \frac{S_{se}}{\tau_{allowable}} = \frac{180}{60} = 3$$

1.6 Causes of Stress Concentration

- Geometric discontinuities like cracks, sharp corners, holes, cross-sectional changes etc.
- Discontinuity in applied loads.
- Material discontinuities occurred during manufacturing.

Methods to Avoid Stress Concentration

- Avoid sharp edges.
- If a crack is present then drill a large hole at the end of the crack.
- Make the stress intensity uniform if already a notch is there then make more notches for uniform strength.

Notch Sensitivity

Sensitivity is defined as the susceptibility of a material to succumb to the damaging effects of stress raising in fatigue loading. The notch sensitivity factor q is defined as

$$q = \frac{\text{Increase of actual stress over nominal stress}}{\text{Increase of theoretical stress over nominal stress}}$$

Since σ_0 = nominal stress as obtained by elementary equations

$\therefore$ Actual stress $= k_f \sigma_0$

theoretical stress $= k_t \sigma_0$

Increase of actual stress over nominal stress $= (k_f \sigma_0 - \sigma_0)$

Increase of theoretical stress over nominal stress $= (k_t \sigma_0 - \sigma_0)$.

k_f - fatigue stress concentration factor

Notch sensitivity,
$$q = \frac{k_f\ \sigma_0 - \sigma_0}{k_t\ \sigma_0 - \sigma_0} = \frac{k_f - 1}{k_t - 1}$$

$$k_f = 1 + q(k_t - 1)$$

Revised Endurance Limit (σ_e')

Endurance limit is not a true property of material it can be changed and depend on lots of factors such as:

1. Size factor, (k_{size})
2. Load factor, (k_{load})
3. Surface finish factor, (k_{sf})
4. Reliability factor, ($k_{reliability}$)
5. Temperature factor, k_{temp}
6. Modification factor, k_{modi}
7. Miscellaneous, ($k_{miscellaneous}$)

If designer considers effect of all these factors, Endurance strength value can be determined by given equation

$$\sigma_e' = k_{sf}\ k_{temp}\ k_{load}\ k_{size}\ k_{relilability}\ k_{modi}\ k_{miscelleneous}\ \sigma_e$$

1.7 Gerber Line/Soderberg Line/Goodman Line

Gerber Line

- A parabolic curve joining S_e on the ordinate to S_{ut} on the abscissa is called the Gerber line.

Soderberg Line

- A straight line joining S_e on the ordinate to S_{yt} on the abscissa is called the Soderberg line.

Goodman Line

- A straight line joining S_e on the ordinate to S_{ut} on the abscissa is called the Goodman line.

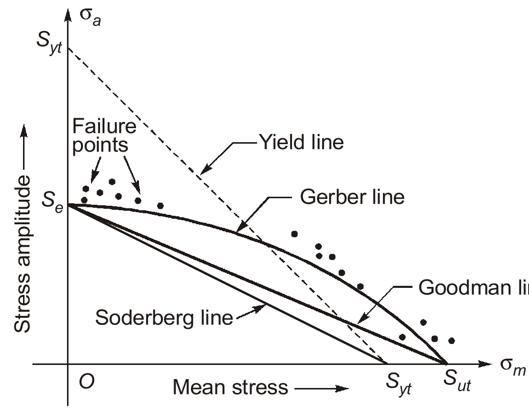


Figure 1.8: Gerber, Goodman and Soderberg lines

1.7.1 Gerber Method

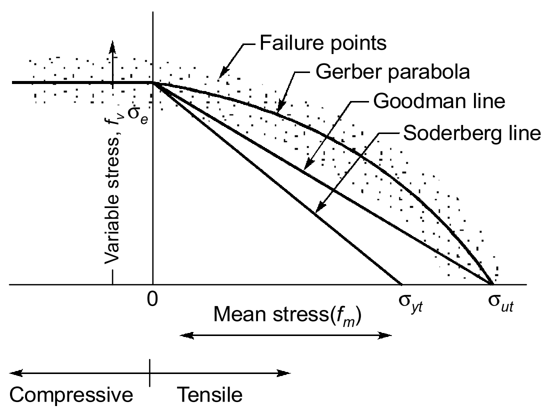


Figure 1.9: Gerber lines

σ_e = fatigue strength corresponding to the case of complete reversal ($\sigma_m = 0$)

σ_u = static ultimate strength corresponding to $\sigma_v = 0$

- Generally, the test data for ductile material fall closer to Gerber Parabola, but because of scatter in the test points, a straight line relationship (i.e. Goodman line and soderberg line) is usually preferred. According to **Gerber,**

$$\frac{1}{F.S.} = \left(\frac{\sigma_m}{\sigma_u}\right)^2 F.S. + \frac{\sigma_v}{\sigma_e}$$

where, $F.S.$ = Factor of safety

- Considering fatigue stress concentration factor (k_f)

$$\frac{1}{F.S.} = \left(\frac{\sigma_m}{\sigma_u}\right)^2 F.S. + \frac{\sigma_v . k_f}{\sigma_e}$$

1.7.2 Goodman Method for Combination of Stress

- A Goodman line is used when the design is based on ultimate strength and may be used for ductile or brittle materials. Line *AB* connecting σ_e and σ_u is called Goodman's failure stress line. If a suitable factor of safety (F.S.) is applied to endurance limit and ultimate strength, a safe stress line *CD* may be drawn parallel to the line *AB*.

$$\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_u} + \frac{\sigma_v}{\sigma_e}$$

Considering the load, surface finish and size factor.

$$\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_u} + \frac{\sigma_v k_f}{\sigma_e \cdot K_{sur} \cdot K_{sz}}$$

- Here we have assumed the same factor of safety (F.S.) for the ultimate tensile strength (σ_u) and endurance limit (σ_e). In case the factor of safety relating to both these stresses is different then

$$\frac{\sigma_v}{\sigma_e/(F.S.)_e} = 1 - \frac{\sigma_m}{\sigma_u/(F.S.)_u}$$

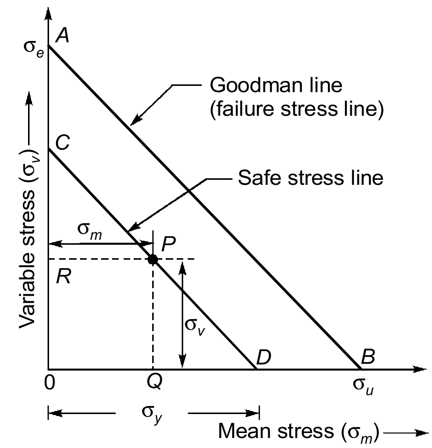


Figure 1.10: Goodman lines

1.7.3 Soderberg Method

- A straight line connecting the endurance limit (σ_e) and the yield strength (σ_y) is a soderberg line. This line is used when the design is based on yield strength.

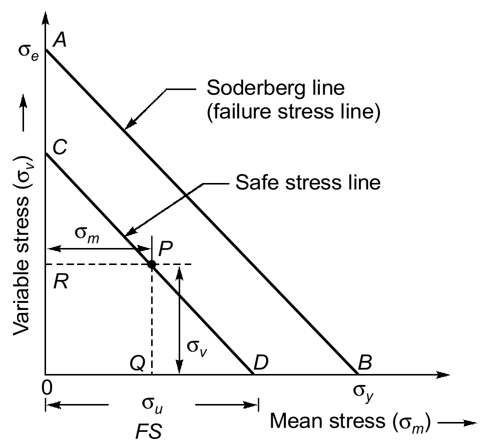


Figure 1.11

- If a suitable factor of safety (F.S.) is applied to the endurance limit and yield strength, a safe stress line CD may be drawn parallel to the line AB.

$$\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v . k_f}{\sigma_e}$$

Considering the load factor, surface finish factor and size factor the relation is

$$\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v . k_f}{\sigma_{eb} . K_{sur} . K_{sz}}$$

- The soderberg method is particularly used for ductile materials. For a reversed shear loading:

$$\frac{1}{F.S.} = \frac{\sigma_{ms}}{\sigma_{ys}} + \frac{\sigma_{vs} . k_{fs}}{\sigma_{es} . K_{sur} . K_{sz}}$$

1.8 How to Improve Fatigue Strength

- By residual compressive stresses. Because fatigue failure is always a tensile failure. Therefore residual compressive stresses will counter it.

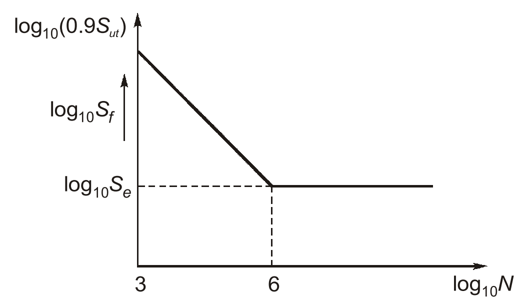
This is done by the process called shot peening.

- By providing fillets, we can change its macrostructure thus we can basically increase its mechanical property that is fatigue strength.
- Shot peening process is also known as understressing.
- Hammering
- Cold rolling
- Burnishing

Example 1.4 In designing a shaft for variable load, how the S.N. diagram is drawn?

Solution :

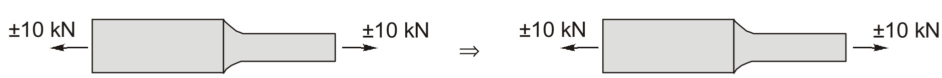
By joining the $0.9S_{at}$ at 1000 cycles and S_e at 10^6 cycles by a straight line on a log*s* - log*N* graph.



Example 1.5 Why stress concentration in a machine component of ductile materials is not so harmful as it is in brittle material?

Solution :

Stress concentration in a machine component of ductile materials, local yielding may distribute stress concentration.



Ductile material after yielding

STUDENT'S ASSIGNMENTS

Q.1 Notch sensitivity (q)

(a) $\dfrac{k_f - 1}{k_t - 1}$ (b) $\dfrac{1 - k_f}{k_t - 1}$

(c) $\dfrac{1 - k_f}{1 - k_t}$ (d) Both (a) and (c)

Q.2 Equation of Goodman line is given by

(a) $\dfrac{\sigma_m}{S_{yt}} + \dfrac{\sigma_a}{S_e} = 1$ (b) $\dfrac{S_{yt}}{\sigma_m} + \dfrac{\sigma_a}{S_e} = 1$

(c) $\dfrac{\sigma_m}{S_{ut}} + \dfrac{\sigma_a}{S_e} = 1$ (d) $\dfrac{\sigma_m}{S_{ut}} + \dfrac{S_e}{\sigma_a} = 1$

Q.3 Ratio of increase of actual stress over nominal stress to increase of theoretical stress over nominal stress is called

(a) Endurance limit

(b) Fatigue strength

(c) Mean fluctuating stress

(d) Notch sensitivity

Q.4 Stress concentration factors are used for component made of brittle material subjected to

(a) Static load (b) Fluctuating load

(c) Both (a) & (b) (d) None of these

Q.5 Theoretical stress concentration factor at the edge of hole is given by