Unit – I

Lecture note/Handout for Fatigue

Handouts :- 1 and 2

FATIGUE

At the end of this lesson, the students should be able to understand

What is Fatigue?

Fatigue loading is loading which causes progressive failure of the member by repeatedly imposing stresses generally below the yield point of the material. Fatigue failure occurs without perceptible yielding or necking.

They originate at a localized point and progress gradually through a portion of the member. Ultimate fatigue failures take place because the reduced cross-section can no longer withstand the load. For example in a rotating shaft, during each revolution the stress varies from a maximum compression to a maximum tension and back to a compression, that is, a complete reversal of stress will eventually cause failure by fatiguing the steel if the stress range is great enough and if it is applied a sufficient number of times. The range of stress and the number of times that this stress range is repeated during the life of a member are the factors, which indicate the tendency of a part to fatigue under a fluctuating load.

Handouts :- 3 and 4

At the end of this lesson, the students should be able to understand

Stress Concentration

- Stress concentration and the factors responsible.
- Determination of stress concentration factor; experimental and theoretical methods.
- Fatigue strength reduction factor and notch sensitivity factor.
- Methods of reducing stress concentration.

Any discontinuity in a member affects the stress distribution in the neighbourhood and the discontinuity acts as a stress raiser.

It is possible to predict the stress concentration factors for certain geometric shapes using theory of elasticity approach.

Stress concentration factors may also be obtained using any one of the following experimental techniques:

1. Strain gage method
2. Photoelasticity method
3. Brittle coating technique
4. Grid method

In design under fatigue loading, stress concentration factor is used in modifying the values of endurance limit while in design under static loading it simply acts as stress modifier.

This means Actual stress= k × calculated stress,
where k = stress concentration factor

For ductile materials under static loading effect of stress concentration is not very serious but for brittle materials even for static loading it is important.

It is found that some materials are not very sensitive to the existence of notches or discontinuity. In such cases it is not necessary to use the full value of k and instead a reduced value is needed. This is given by a factor known as fatigue strength reduction factor kf and this is defined as kf Endurance limit of notch free specimens

$$q = \frac{k_f - 1}{k_t - 1}$$

The value of ‘q’ usually lies between 0 and 1. If q=0, f k =1 and this indicates no notch sensitivity. If however q=1, then f k = t k and this indicates full notch sensitivity. Design charts for ‘q’ can be found in design hand-books and knowing k, kf may be obtained.

A number of methods are available to reduce stress concentration in machine parts. Some of them are as follows:

1. Provide a fillet radius so that the cross-section may change gradually.
2. Sometimes an elliptical fillet is also used.
3. If a notch is unavoidable it is better to provide a number of small notches rather than a long one. This reduces the stress concentration to a large extent.
4. If a projection is unavoidable from design considerations it is preferable to provide a narrow notch than a wide notch.

5. Stress relieving groove are sometimes provided.

Handouts :- 5 to 8

At the end of this lesson, the students should be able to understand

- Mean and variable stresses and endurance limit.
- S-N plots for metals and non-metals and relation between endurance limit and ultimate tensile strength.
- Low cycle and high cycle fatigue with finite and infinite lives.
- Endurance limit modifying factors and methods of finding these factors.
- Design of components subjected to low cycle fatigue; concept and necessary formulations.
- Design of components subjected to high cycle fatigue loading with finite life; concept and necessary formulations.
- Fatigue strength formulations; Gerber, Goodman and Soderberg equations.

Any fiber on the shaft is therefore subjected to fluctuating stresses. Machine elements subjected to fluctuating stresses usually fail at stress levels much below their ultimate strength and in many cases below the yield point of the material too. These failures occur due to very large number of stress cycle and are known as fatigue failure. These failures usually begin with a small crack which may develop at the points of discontinuity, an existing subsurface crack or surface faults. Once a crack is developed it propagates with the increase in stress cycle finally leading to failure of the component by fracture.

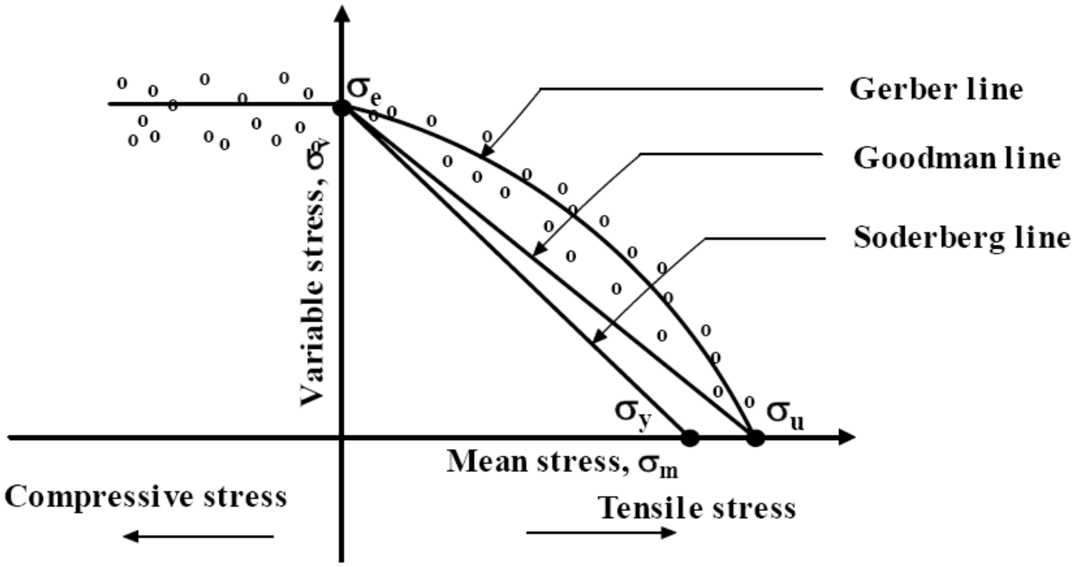
There are mainly two characteristics of this kind of failures:
(a) Progressive development of crack.
(b) Sudden fracture without any warning since yielding is practically absent.

Fatigue failures are influenced by
(i) Nature and magnitude of the stress cycle.
(ii) Endurance limit.
(iii) Stress concentration.
(iv) Surface characteristics.

These factors are therefore interdependent. For example, by grinding and polishing, case hardening or coating a surface, the endurance limit may be improved. For machined steel endurance limit is approximately half the ultimate tensile stress. The influence of such parameters on fatigue failures will now be discussed in sequence.

Fatigue cracks can start at all forms of surface discontinuity and this may include surface imperfections due to machining marks also. Surface roughness is therefore an important factor and it is found that fatigue strength for a regular surface is relatively low since the surface undulations would act as stress raisers.

Another important surface effect is due to the surface layers which may be extremely thin and stressed either in tension or in compression. For example, grinding process often leaves surface layers highly stressed in tension. Since fatigue cracks are due to tensile stress and they propagate under these conditions and the formation of layers stressed in tension must be avoided. There are several methods of introducing pre-stressed surface layer in compression and they include shot blasting, peening, tumbling or cold working by rolling. Carburized and nitrided parts also have a compressive layer which imparts fatigue strength to such components. Many coating techniques have evolved to remedy the surface effects in fatigue strength reductions.



$$\left(\frac{\sigma_m}{\sigma_y}\right) + \left(\frac{\sigma_v}{\sigma_e}\right) = 1 \quad \text{Soderberg line}$$

$$\left(\frac{\sigma_m}{\sigma_u}\right)^2 + \left(\frac{\sigma_v}{\sigma_e}\right) = 1 \quad \text{Gerber line}$$

$$\left(\frac{\sigma_m}{\sigma_u}\right) + \left(\frac{\sigma_v}{\sigma_e}\right) = 1 \quad \text{Goodman line}$$

Text books

i. Robert L. Norton , "Machine Design", Pearson Education India, 2000
ii. John, V. Harvey, "Pressure Vessel Design: Nuclear and Chemical Applications", Affiliated East West Press Pvt. Ltd., 1969
iii. Prashant Kumar, "Elements of Fracture Mechanics", Wheeler Publishing, New Delhi1999
iv. V. Rammurti, "Computer Aided Mechanical Design and Analysis", Tata Mc Graw Hill1992
v. L. S. Srinath, "Advanced Solid Mechanics", Tata McGraw-Hill, 2002
vi. Burr and Cheatham, "Mechanical analysis & Design", Prentice Hall, 1995