Design of Joints with Variable Loading

Instructional Objectives :

After reading this lesson the students should learn:

- Design of a bolted joint with fluctuating loading
- Design of welded joints with variable loading

1. Variable loading in mechanical joints:

Machine parts are often subjected to variable loading. In many cases pulsating or intermittent loads are applied from outside, for example, in punching press forces of very large magnitude is applied for a short while (impulsive force), in crank shafts variable loads act due to nature of force arising from combustion cycle in cylinders. Often dynamic forces appear in the moving parts, e.g., inertia forces in machines and mechanisms, forces due to unbalance of the rotating components etc. Since these forces are to be withstood by the joints, care should be taken while designing a joint capable of resisting adequate load of variable magnitude. Design of two important mechanical joints is discussed below, namely, bolted and welded joints.

2. Bolted joints with variable loading:

Consider design of bolts to fasten a flat cover to a cylinder as shown in figure 11.3.1. In order to ensure leak proofness necessary pretension (usually 2840 d, in Newton while the nominal bolt diameter d is measured in millimeter) is applied. Depending upon operating condition the pressure inside the closed cylinder is likely to vary in somewhat periodic manner. Let the minimum and maximum value of the pressure be p_{min} and p_{max}, respectively.

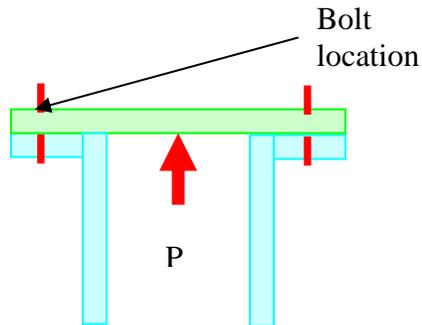Figure 11.3.1: Bolted cover plate

The pressure causes external force of magnitude $F = \dfrac{pA_c}{n}$, where

> n= number of equally spaced bolts on the bolt circle
>
> A_c = area of cross section of the cylinder
>
> p = fluid pressure inside the cylinder.

It is known that only a fraction of external load is responsible for tensile stress within bolts, that is

$$F_b = F_i + CF$$

where F_i = initial tension in the bolt

         C = factor that depends on the nature of joints. Some representative values of C's are tabulated in Table 1 below.

Table 1. Values of C for various types of joints

Type of joint	Value of C
Metal to metal joint with through bolt	0.00 – 0.10
Soft copper gasket with long bolts	0.5 – 0.7
Hard copper gasket with long bolt	0.25 – 0.5
Soft packing with through bolt	0.75 – 1.00
Soft packing with stud	1.0

Due to fluctuating external force the tensile load within each bolt takes minimum and maximum value of

$$F_{b,\min} = F_i + CF_{\min} \quad \text{and} \quad F_{b,\max} = F_i + CF_{\max}$$

respectively. The average and the fluctuating component of the normal stress are given by

$$\sigma_m = \frac{\sigma_{\max} + \sigma_{\min}}{2} = \frac{F_i}{A_b} + C\frac{F_{\max} + F_{\min}}{2A_b}$$

$$\sigma_{amp} = \frac{\sigma_{\max} - \sigma_{\min}}{2} = C\frac{F_{\max} - F_{\min}}{2A_b}$$

respectively, where A_b is the root area of each bolt. The advantage of initial pretension is at once visible from the above expressions. The ratio $\dfrac{\sigma_{amp}}{\sigma_m}$ gets drastically reduced, The safe size of the bolt can be calculated now from well-known Soderberg equation given below

$$\frac{\sigma_{av}}{\sigma_Y} + \frac{k_f \sigma_{amp}}{S_E} = \frac{1}{N}$$

where σ_Y = Yield stress of the bolt material,

S_E = Corrected endurance limit taking load-, size-, surface finish-factors

N = Factor of safety

k_f = fatigue stress concentration factor.

Alternatively, Goodman's equation or Gerber's line may be used to calculate the root area and hence the size of the bolts. The fatigue stress concentration factor plays an important role in the design. These are found by doing extensive experimentation. A few figures are shown in Table 2.

Table 2: Fatigue Stress Concentration Factor

Metric Grade	Fatigue stress Conc. factor
3.6 - 5.8	2.1 – 2.8
6.6 -10.9	2.3 – 3.8

3. Welded joints with variable loading:

Because of many intricacies involved in design of a welded joint, codes are extensively used to design such joint when it experiences variable loading. The value of the maximum fluctuating load is not allowed to exceed a limit specified in the code. This value depends on

    a. type of the joint

    b. type of stress experienced by the joint

    c. a load factor K defined as the ratio of the minimum stress to the maximum stress. When the load is a steady one the factor takes unit value. For a complete reversal of stress the value of K = -1.

The design stress for completely reversing load is calculated using the formula

$$\sigma_{-1,d} = \frac{\sigma_{-1,a}}{k_{-1}}$$

where $\sigma_{-1,d}$ = design stress for complete reversal of stress

        $\sigma_{-1,a}$ = allowable fatigue stress

        k_{-1} = fatigue stress concentration factor tabulated below

Table 3: Fatigue stress concentration factor (k_{-1})

| Type of weld	k_{-1}
Reinforced butt weld	**1.2**
T- butt joint with sharp corner	**2.0**
Toe of transverse fillet or normal fillet	**1.5**
Parallel fillet weld or longitudinal weld	**2.7**

The values of the allowable fatigue stress ($\sigma_{-1,a}$) are also tabulated in the design code for various weld geometries. For example, the allowable fatigue stress for fillet weld is given (assuming the weld to be a line) as

$$\sigma_{-1,a} = \frac{358w}{1 - K/2}, \text{ (in kgf/cm)}$$

where *w* denotes the leg size of the fillet weld measured in centimeter. The design is found to be safe if the maximum value of the fluctuating stress is found to be lesser than the design stress.

Review questions and answers:

Q.1. A strap of mild steel is welded to a plate as shown in the following figure. Check whether the weld size is safe or not when the joint is subjected to completely reversed load of 5 kN.
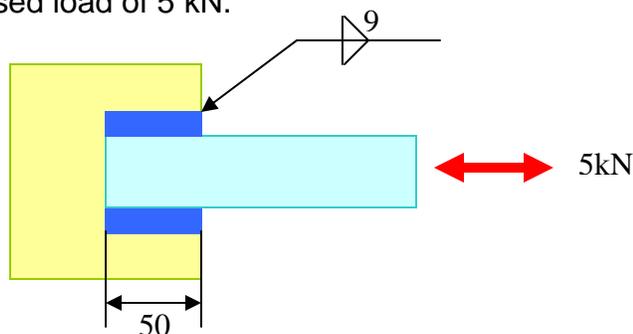
Ans. As shown in the figure the joint is a parallel fillet joint with leg size as 9 mm and the welding is done on both sides of the strap. Hence the total weld length is 2(50) = 100 mm.

In order to calculate the design stress the following data are used

$$k_{-1} = 2.7 \text{ (parallel fillet joint, refer table 3)}$$

$$w = 0.9 \text{ cm}$$

$$K = -1 \text{ for completely reversed loading}$$

The value of the allowable fatigue stress (assuming the weld to be a line) is then $\sigma_{-1} = \dfrac{358 \times 0.9}{1.5}$ = 214.8 kgf/cm = 214800 N/m (approx). The design stress is therefore $\sigma_{-1,d} = \dfrac{214800}{2.7}$ = 79556 N/m. Since the total length of the weld is 0.1 m, the maximum fluctuating load allowable for the joint is 7955.6 N. The joint is therefore safe.