

ESTIMATION OF ENDURANCE OF PIN JOINTS

1. NOTATION

1.1 General Notation

D	width of plate	m	in
d	hole diameter	m	in
E	Young's modulus of plate material	N/m ²	lbf/in ²
E_I	Young's modulus of pin material	N/m ²	lbf/in ²
f_{nom}	$f_{pin} + \alpha f_{pl}$	N/m ²	lbf/in ²
f_p	0.2 per cent proof strength of plate material	N/m ²	lbf/in ²
f_{pin}	average stress on net cross-sectional area of plate induced by load on pin	N/m ²	lbf/in ²
f_{pl}	average stress on net cross-sectional area of plate in addition to that induced by load on pin	N/m ²	lbf/in ²
f_t	tensile strength of plate material	N/m ²	lbf/in ²
K'_t	geometric stress concentration factor based on net cross-sectional area		
q'	maximum shear stress on transverse diameter of hole in joint with interference	N/m ²	lbf/in ²
q'_0	maximum shear stress on transverse diameter of hole due to interference alone (q'_0 obtained from Item No. 71011* and is equivalent to q of that Item)	N/m ²	lbf/in ²
S_a	alternating stress on net cross-sectional area of plate	N/m ²	lbf/in ²
S_m	mean stress on net cross-sectional area of plate	N/m ²	lbf/in ²
S_{max}	maximum stress on net cross-sectional area of plate	N/m ²	lbf/in ²
S_{min}	minimum stress on net cross-sectional area of plate	N/m ²	lbf/in ²
α	proportion of plate load treated as equivalent pin load		
ϵ	excess of pin diameter over hole diameter	m	in
ν_I	Poisson's ratio of pin material		

* Data Item No. 71011 "Stresses due to interference-fit pins and bushes in plates, strips or lugs".

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1.2 Notation for Simple Notched or Plain Specimens or Joints Without Interference

q	maximum shear stress on transverse diameter of hole in joint with push-fit pin, or at root of notch in simple specimen	N/m ²	lbf/in ²
S'_a	equivalent alternating stress	N/m ²	lbf/in ²
S'_m	equivalent mean stress	N/m ²	lbf/in ²
S'_{max}	equivalent maximum stress	N/m ²	lbf/in ²
S'_{min}	equivalent minimum stress	N/m ²	lbf/in ²

Both SI and British units are quoted but any coherent system of units may be used.

2. NOTES

2.1 General

This Data Item gives a method of estimating the endurance of pin joints from fatigue data on other types of specimen. The method depends on the equivalence of the maximum shear stresses at the origin of failure in the pin joint and the other types of specimen.

The use of maximum shear stresses is dictated by the combined stress system induced by the interference-fit pin. Under combined stresses fatigue endurance is more closely related to the maximum shear stress than to the maximum tensile stress.

The pin joints to which this Data Item can be applied may have one or more pins with or without interference fits. It applies only to joints in which failure occurs at or near the transverse diameter of the hole, which is usually the case for unclamped joints of conventional geometry.

The figures in this Data Item give the maximum shear stresses in joints of varying geometry due to the applied loads. In Figure 1, q'/q'_0 is plotted against f_{nom}/q'_0 for a range of d/D , for joints with interference. The straight (broken) lines in that figure are asymptotes to the curves; the slopes of those lines give the value of q/f_{nom} for a particular value of d/D when $q'_0 = 0$. However, Figure 2 gives q/f_{nom} directly for joints without interference. Figure 3 gives α against d/D for plates loaded independently of the pin.

All the curves in this Item are based on the results of photoelastic investigations. They are strictly valid only for elastic stresses, so use of the curves for values of q' much in excess of $0.7 f_p$ is not recommended.

2.2 Equivalent Stresses

The maximum shear stresses in a pin joint with interference, corresponding to the maximum and minimum stresses of the fatigue cycle, may be evaluated using the curves of this Data Item and Item No. 71011. These maximum shear stresses may then be expressed as an equivalent loading cycle on another type of specimen.

The maximum shear stresses in a simple notched specimen are

$$(q)_{max} = \frac{K'_t S'_{max}}{2}; \quad (q)_{min} = \frac{K'_t S'_{min}}{2}. \quad (2.1)$$

For an unnotched specimen, $K'_t = 1.0$.

The equivalent loading cycle on a simple notched specimen producing the same values of maximum shear stress q' as in the pin joint with interference is therefore

$$\left. \begin{aligned} S'_{max} &= \frac{2(q')_{max}}{K'_t}; & S'_{min} &= \frac{2(q')_{min}}{K'_t} \\ \text{or} & & & \\ S'_a &= \frac{(q')_{max} - (q')_{min}}{K'_t}; & S'_m &= \frac{(q')_{max} + (q')_{min}}{K'_t}. \end{aligned} \right\} \quad (2.2)$$

Here S'_m is elastic. If S'_m (elastic) + S'_a exceeds f_p then plastic flow will occur and the true $S'_m = f_p - S'_a$.

The equivalent loading cycle on a geometrically similar joint *without* interference is

$$S'_a = \frac{f_{nom}}{2q} [(q')_{max} - (q')_{min}]; \quad S'_m = \frac{f_{nom}}{2q} [(q')_{max} + (q')_{min}]. \quad (2.3)$$

It is also possible to estimate the endurance of the joint with push-fit pins from data on simple specimens noting that for such a joint

$$K'_t = \frac{2q}{f_{nom}}. \quad (2.4)$$

The resulting curves may be compared with the experimental scatter bands in Data Item No. 80007 for lugs without interference.

3. INTERPRETATION OF RESULTS

If the endurance of a pin joint with interference is estimated from fatigue data on unnotched specimens, the estimate will generally be in good agreement with experimental results for endurances up to about 10^6 cycles. For endurances higher than this the agreement is not so good because the estimation of endurance from unnotched specimens, under equivalent stresses, ignores the effect of fretting in the joint. Nevertheless, the values of q/f_{nom} derived from photoelastic data are inherently slightly low, when used as fatigue strength reduction factors, and therefore the equivalent stresses calculated will be overestimated, compensating to some extent for fretting. At low stress levels the analysis will indicate a long life for the joint, but the occurrence of fretting may prevent its achievement.

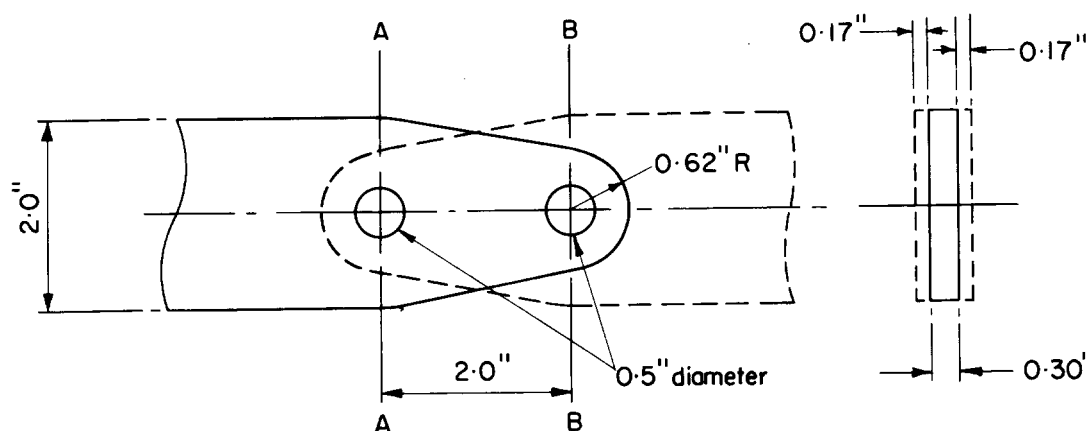
If the endurance of a pin joint with interference is estimated from fatigue data on notched specimens that are comparable with the joint to be designed the estimate will usually be high compared with experimental data, because the reduction in endurance resulting from fretting is not taken into account.

If the endurance of a pin joint with interference is estimated from fatigue data on joints without interference the result obtained will depend on the degree of clearance, size of the joint, and material on which the experimental data have been based. For instance References 9 and 10 have shown that an increase in endurance can be obtained by using clearance-fit pins. In this case failure usually occurs away from the section of highest nominal stress. This is because clearance in the hole due to a loose-fit pin precludes contact with consequent fretting damage at this highly stressed region of the joint. In other cases, see, for example, Derivation 8, endurance of joints with clearance-fit pins may be no different from those with push-fit pins. The size of the lug is also important. It has been shown in Item No. 80007 that the small joints have longer endurance than the large ones.

It should be remembered that the suggested interpretations of the estimates of endurance given by this Item depend entirely on laboratory fatigue tests for their justification. In normal practice the influence of corrosion is more significant than in short-term tests, so the advantages to be gained from the use of interference must be set against the risk of cracking due to the combined effects of corrosion and the stress due to interference. The fatigue performance of an individual joint depends on factors additional to those included in the analysis in this Item, for example, manufacturing and assembly processes. The Item can therefore only give a general indication of the effects of various design changes on the fatigue endurance of a joint.

4. EXAMPLE

It is required to estimate the endurance of the joint shown below.



The joint is to be made of L65 aluminium alloy bar with mechanical properties:

$$\begin{aligned}
 E &= 10.5 \times 10^6 \text{ lbf/in}^2, \\
 f_t &= 72\,000 \text{ lbf/in}^2 \\
 \text{and } f_p &= 63\,000 \text{ lbf/in}^2 \\
 \text{giving } f_p/f_t &= 0.875.
 \end{aligned}$$

The joint is assembled with steel bolts with $\epsilon/d = 0.003$, having $E_I = 28 \times 10^6 \text{ lbf/in}^2$ and $\nu_I = 0.25$.

The mean axial load on the joint is 5400 lbf; a convenient range of alternating load will be considered.