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Fatigue strength of steel coned disc springs (Tentative)

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THE PREPARATION OF THIS DATA ITEM

The work on this particular Data Item was monitored and guided by the Stress Analysis and Strength of Components Committee. This Committee first met in 1964 and now has the following membership:

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FATIGUE STRENGTH OF STEEL CONED DISC SPRINGS (TENTATIVE)

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FATIGUE STRENGTH OF STEEL CONED DISC SPRINGS (TENTATIVE)

1. NOTATION

a	external radius of spring (see Sketch 2.2)	m	in
b	internal radius of spring (see Sketch 2.2)	m	in
E	modulus of elasticity of spring material	N/m ²	lbf/in ²
$f_{1,2,3,4}$	stresses at perimeters 1 to 4, respectively (see Sketch 2.1)	N/m ²	lbf/in ²
f_{max}	maximum stress at indicated location of failure	N/m ²	lbf/in ²
f_{min}	minimum stress at indicated location of failure	N/m ²	lbf/in ²
f_0	notional stress used to correlate fatigue strength (see Section 3)	N/m ²	lbf/in ²
f_{range}	range of stress at a perimeter, $f_{max} - f_{min}$	N/m ²	lbf/in ²
f_y	proof stress of spring material	N/m ²	lbf/in ²
h	internal height of unloaded single spring (see Sketch 2.2)	m	in
N	endurance		
P	total load applied uniformly to perimeters 1 and 3 of single spring (see Sketch 2.2)	N	lbf
t	thickness of material of single spring (see Sketch 2.2)	m	in
α	ratio of external to internal radii of spring, a/b		
δ	deflection of single spring under load P (see Sketch 2.2)	m	in
ν	Poisson's ratio of spring material		

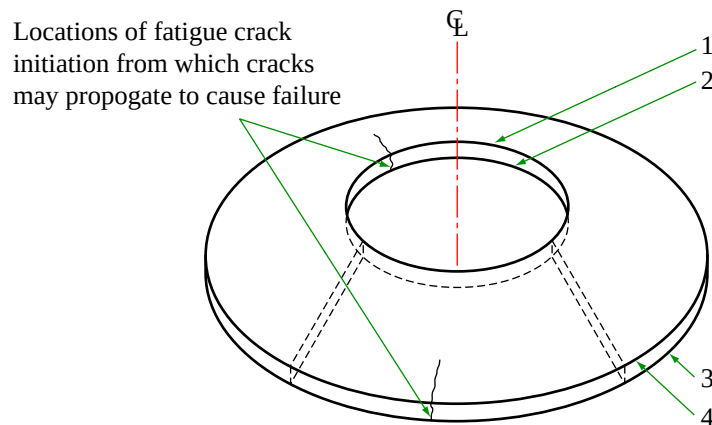
Subscripts

max, min refer to maximum and minimum deflections, loads and stresses of working cycle respectively

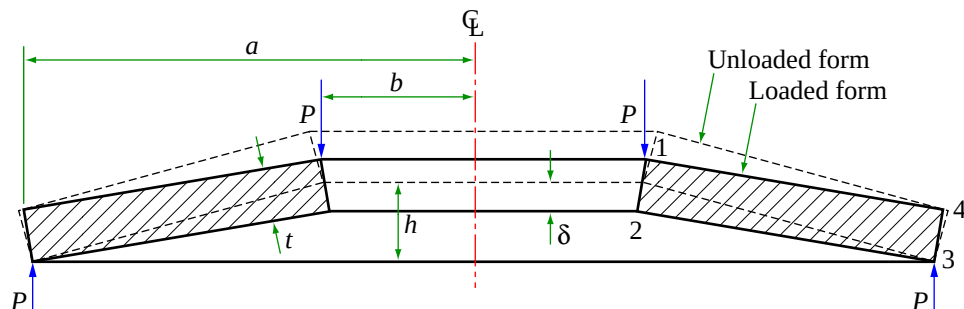
Both SI and British units are quoted but any coherent system of units may be used.

2. NOTES

This Item presents data on the fatigue strength of preset, steel coned disc springs in series combination (as defined in Sketch 2.1 of Reference 16). The great majority of the test data available come from Derivation 3. In both that derivation and Derivation 4 the results of the fatigue tests are presented in terms of a notional stress, f_0 (explained in Section 3 and in Appendix A). This gives excessive scatter in results. The lack of detailed test data on the actual material thicknesses, the geometrical ratios α , h/t and h/a of the springs and on the ranges of load and deflection employed in the tests prevents a satisfactory re-analysis of the data to reduce this scatter. Accordingly, it is only possible now to present the existing data in terms of the notional stress, f_0 , and therefore the Data Item is designated tentative*.



Sketch 2.1 Initially coned disc spring showing perimeter reference numbers and likely locations of fatigue cracks



Sketch 2.2 Section through an initially coned disc spring showing basic notation

Springs covered by this Item had cone angles less than 15 degrees, values of the radius ratio, α , less than 5.0 and values of h/t less than $\sqrt{2}$ (that is the springs did not exhibit negative stiffness). The springs were not deflected through the flat position, $\delta/h = 1.0$. Data presented are from tests made on spring stacks containing between 2 and 30 identical springs in series.

* Any further experimental data relating particularly to the factors discussed in this Item that you can communicate to ESDU may make it possible to revise and improve this Data Item.

In a coned disc spring under compressive loading a high compressive stress is produced at perimeter 1, tensile stresses of somewhat lesser magnitude are produced at perimeters 2 and 3 and a low compressive stress is produced at perimeter 4. (At low deflections in springs of certain geometries the stress at perimeter 2 is compressive and can become tensile with increasing deflection.) These stresses can be determined from Equations (3.2) to (3.5). It is the tensile stresses at perimeter 2 or 3 that usually leads to the initiation of fatigue cracks at these points, see Section 6.1. The cracks propagate through the thickness of the spring and radially across the spring section as illustrated in Sketch 2.1.

Figure 1 indicates the effects of geometry and maximum deflection on the location of maximum tensile stress, see Section 6.1. Figure 2 gives the available data presented in terms of f_0 showing the spring thicknesses tested and giving bounds on the data. However, there is some doubt as to the effect of spring thickness on fatigue strength derived from these data. Notes are provided on the effects of the method of production and the resulting surface finish on fatigue strength and the need for, and effect of, presetting and/or the application of a minimum load. The location of failure in a spring, and the position within a stack at which this failure occurs, is described.

3. PRESENTATION OF DATA

The data given in Figure 2 are presented in terms of the notional stress, f_0 , which is calculated using Equation (3.1)*, see Appendix A:

$$f_0 = f_{max} - 0.5 f_{min} . \quad (3.1)$$

Values of f_{max} and f_{min} are found[†] by substituting the maximum and minimum deflections of the loading cycle respectively into either Equation (3.3) for perimeter 2 or Equation (3.4) for perimeter 3, see Appendix A. (If the maximum and minimum loads rather than deflections are known, Reference 15 should be consulted for the relevant load/deflection relationship.)

$$f_1 = \frac{E}{(1 - \nu^2)} \left(\frac{h}{a} \right)^2 \left(\frac{\alpha}{\alpha - 1} \right)^2 \left[\left(1 - 0.5 \frac{\delta}{h} \right) \left(1 - \frac{\alpha - 1}{\log_e \alpha} \right) - \frac{\alpha - 1}{2} \frac{t}{h} \right] \frac{\delta}{h} , \quad (3.2)$$

$$f_2 = \frac{E}{(1 - \nu^2)} \left(\frac{h}{a} \right)^2 \left(\frac{\alpha}{\alpha - 1} \right)^2 \left[\left(1 - 0.5 \frac{\delta}{h} \right) \left(1 - \frac{\alpha - 1}{\log_e \alpha} \right) + \frac{\alpha - 1}{2} \frac{t}{h} \right] \frac{\delta}{h} , \quad (3.3)$$

$$f_3 = \frac{E}{(1 - \nu^2)} \left(\frac{h}{a} \right)^2 \left(\frac{\alpha}{\alpha - 1} \right)^2 \left[\left(1 - 0.5 \frac{\delta}{h} \right) \left(1 - \frac{\alpha - 1}{\alpha \log_e \alpha} \right) + \frac{\alpha - 1}{2\alpha} \frac{t}{h} \right] \frac{\delta}{h} \quad (3.4)$$

and

$$f_4 = \frac{E}{(1 - \nu^2)} \left(\frac{h}{a} \right)^2 \left(\frac{\alpha}{\alpha - 1} \right)^2 \left[\left(1 - 0.5 \frac{\delta}{h} \right) \left(1 - \frac{\alpha - 1}{\alpha \log_e \alpha} \right) - \frac{\alpha - 1}{2\alpha} \frac{t}{h} \right] \frac{\delta}{h} . \quad (3.5)$$

* The factor of 0.5 in Equation (3.1) is based upon fatigue limit stresses. The fatigue limit chosen by the author of Derivation 3 was that at 2×10^6 cycles.

† The data in the Item are given in terms of stresses calculated using the theory of Almen and Laszlo, see Derivation 1 and Equations (3.2) to (3.5). Deviations of actual stresses from those calculated on this basis may be significant at high values of the ratios h/t and α .