ON THE RISK OF FATIGUE IN EXTENSION SPRING HOOKS

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The hook of an extension spring is its most vulnerable part. This paper quantifies the risk of fatigue failure in the hook and sets out strategies to eliminate that risk.

Introduction

The simplest and cheapest way to design and manufacture an extension spring is to make the end hooks and spring body out of a single piece of wire and for the hooks to be the same diameter as the spring body. An example is shown in Figure 1.

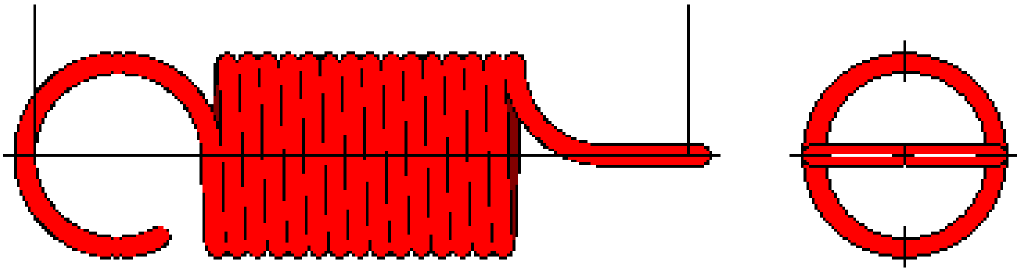

Figure 1 Typical Extension Spring

The position of maximum stress in this spring is at the inside surface of the hook where a bending stress operates (Figure 2). The applied stress is additive to the residual stress remaining after coiling and stress relieving, and it is of no import whether the spring has German, English or D-type hooks.

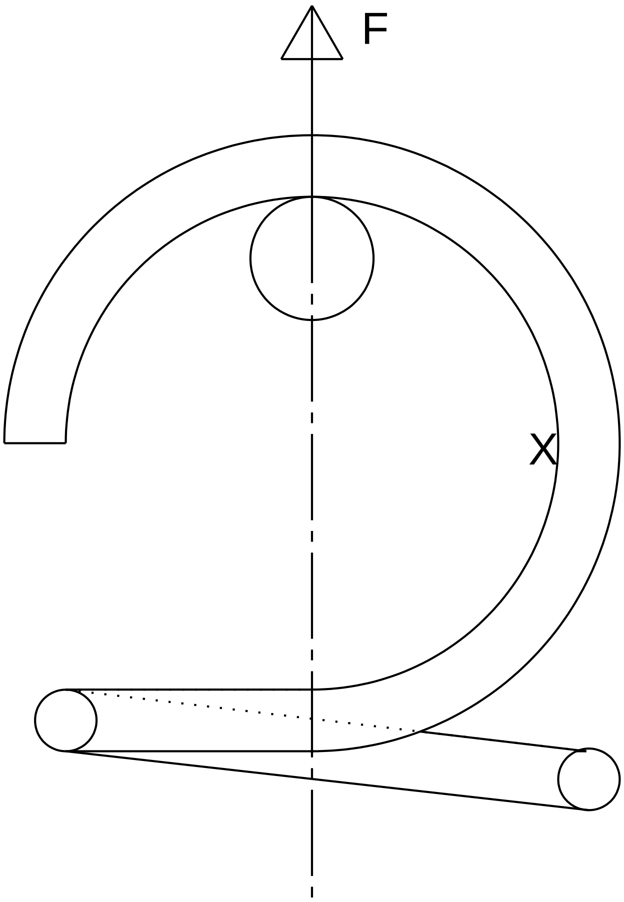

Figure 2 End Hook Stress

The bending stress q_b at the inside of the hook at position X is calculated using the following formula, and is made up of a large bending component and a smaller tensile component.

$$q_b = \frac{16FD_L K_L}{\pi d^3} + \frac{4F}{\pi d^2} \qquad \text{Equation 1}$$

Where d = wire diameter
D_L = mean diameter of the loop or hook
F = applied load
K_L = curvature correction factor (unbending)

It will be observed that the residual stress is not calculated. That will depend upon the spring index and the stress relief heat treatment. All the carbon steel springs tested here were stress relieved at 250-270°C, and the 302 stainless steel springs at 350°C.

TechSpring

A European Commission Collective project with the acronym 'Techspring' studied stress analysis methods for springs. The project will be complete in November 2009. One of many topics studied in that project was extension springs with a view to providing sufficient data that the risk of fatigue failure in the end hook could be predicted accurately. The results presented below were all generated in the Techspring project and are published here for the first time. The results have been incorporated into a computer aided program so that this data has become accessible to spring manufacturers and their customers, and typical results from that program are also published here for the first time.

Experimental Method

Extension springs were manufactured to the basic design shown in Figure 3. The amount by which the end hooks were made smaller than the body diameter was varied. Springs with end hooks slightly smaller than the body always failed on dynamic testing in the end hook. Those with a greater reduction in end hook diameter failed either in the hook or the body coils and it was an equal chance which fatigue failure mode occurred. The springs with the smallest end loops always had fatigue fracture from the inside surface of the full diameter coils of the spring body, and the stress at this position was entirely torsional. If the end hooks are smaller than the body coils, it is essential that the coils at either end of the body had to be tapered down so as to avoid a stress raiser where the hook was made directly from the body coil diameter.

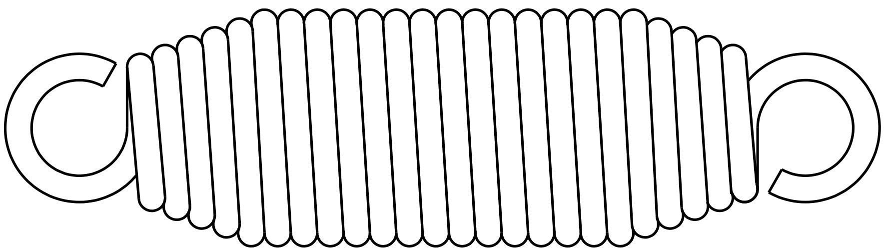

Figure 3

The springs of the above design were fatigue tested on forced motion fatigue test machines over a wide range of test conditions. When the stress range was high, fatigue failures occurred at short lives, and as the stress range was reduced the fatigue life increased. At the lowest stress range used, no fatigue failures occurred.

Results

A typical set of results for carbon steel springs made from 3.24 mm diameter EN 10270-1 DH wire are shown in Table 1.

1A

Lengths	Body stress/ MPa	Loop stress/ MPa	Fatigue lives/k cycles
175 – 330	195 – 736	305 – 1152	76^{L} 92^{L} 154^{B} 169^{B}
175 – 320	195 – 701	305 – 1097	107^{L} 131^{L} 168^{L} 190^{L}
190 – 320	247 – 701	387 – 1097	99^{L} 146^{B} 2@10^{6}
190 – 350	247 – 666	387 – 1042	256^{L} 224^{B} 2 @ 10^{6}
190 – 300	247 – 632	387 – 987	4 @ 10^{6}

1B

Lengths	Body stress/ MPa	Loop stress/ MPa	Fatigue lives/k cycles
166 – 321	199 – 772	279 – 1082	183^{L} 124^{B} 242^{B} 327^{B}
166 – 311	199 – 735	279 – 1031	129^{L} 131^{B} 161^{B} 242^{B}

1C

Lengths	Body stress/ MPa	Loop stress/ MPa	Fatigue lives/k cycles
158 – 311	182 – 772	222 – 940	113^{B} 113^{B} 121^{B} 133^{B}
158 – 301	182 – 733	222 – 893	157^{B} 166^{B} 184^{B} 204^{B}
168 – 311	221 – 772	269 – 940	138^{B} 192^{B} 214^{B} 355^{B}
178 – 311	259 – 772	316 – 940	162^{B} 661^{B} 751^{B} 1 @ 10^{6}
188 – 311	298 – 772	363 – 940	4 @ 10^{6}

Table 1 Fatigue test results, where the superscript L indicates failure in the end hook, and the superscript B indicates failure in the spring body coils.

These fatigue test results and other similar results have enabled the drawing of Goodman diagrams for both the extension springs body (which has been available previously) and extension spring end hooks (which is new). Typical examples of these diagrams are shown in figure 4.

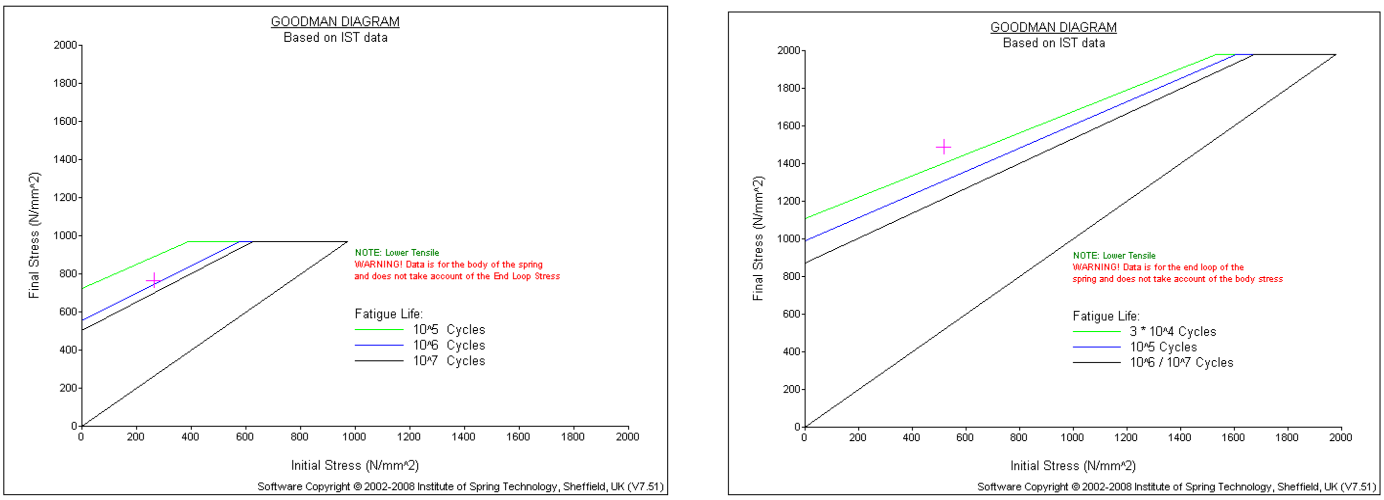

Figure 4 Goodman diagram shows spring body is at risk close to one million cycles, but the end hook is at risk of fatigue failure before thirty thousand. This data is for the spring shown in figure 1.

If the end hook diameter is reduced from 20 mm to 16 mm the risk of fatigue failure in the hook only occurs well after one hundred thousand cycles, as shown in figure 5.

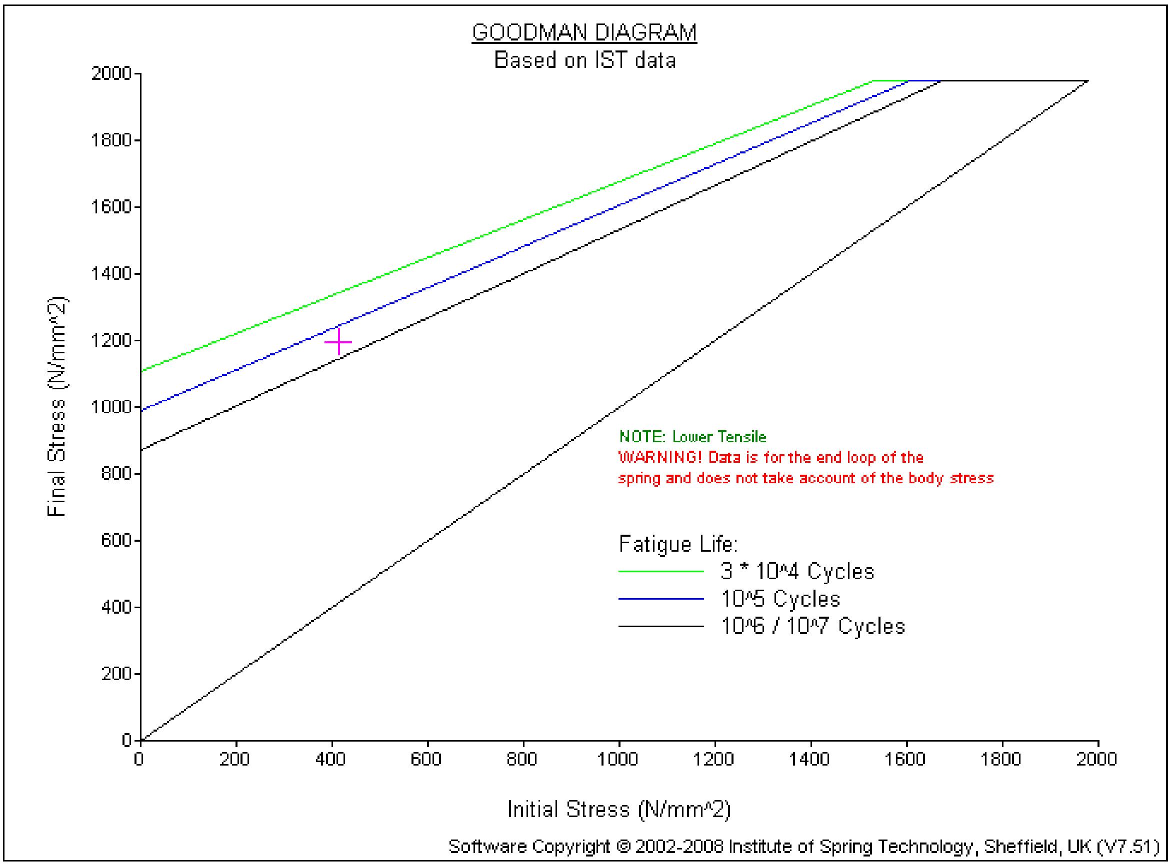

Figure 5 Goodman diagram applicable to spring with reduced diameter end hooks.

Conclusion

A spring manufacturer now has a number of strategies available to advise his customers of the predicted fatigue life of extension springs.

1. The expected fatigue life of end hooks in springs as they are supplied today can now be predicted with reasonable precision. The deflection in service can be limited to achieve the required life.
2. If the life of the hook is insufficient the spring manufacturer can see by how much the end hook needs to be reduced so that the required life is achieved.
3. Alternatively, the spring can be made with swivel loops and the size of wire for the end loops (which are often the same diameter as the body) can be calculated using the new software.

Reference

1. Techspring Project 027943 “Improving Technical Performance of Springs through Scientific Understanding of Dynamic Stress Profiles using Advances in Software Design and Measurement Technologies”