IST
INSTITUTE of SPRING TECHNOLOGY

Tech-Spring Report 15
End Coil Failures

Introduction

Compression springs are very reliable, but they can become at risk of failure or malfunction due to relaxation, fatigue or corrosion mechanisms. The usual position of maximum stress is at the inside surface of an active coil, and this is usually where they fail.

However, there are a number of specific circumstances that can lead to a risk of failure within the end coils, and spring manufacturers need to be fully aware of these possibilities. Nominally the end coils of a compression spring have zero applied stress in service, but, this is almost never the case. Nonetheless the applied stress within the end coil should always be very much less than that at the inside coil position of a fully active coil, and spring manufacturers need to be informed as to how to ensure that this is the case. Then, end coils will only be at risk due to corrosion.

15.1 End Coil Modelling

In order to gain an understanding of why compression springs might fail at the end coil - which is nominally unstressed - finite element analyses were undertaken of the four end coil lay-ons that are shown diagrammatically in Figures 1-4 below.

The narrow zone AA' is the position at which there is a change in the pitch angle from that required for the end coil to that required for the main body of the spring.

Figure 1 represents the case when the end coil pitch transition AA' occurs at just one coil from the end tip. Figure 2 represents the transition occurring at just less than one coil from the end tip, and Figures 3 and 4 represent AA' occurring at slightly more than one coil from the end tip. The only difference between Figures 3 and 4 being that the end coil pitch is greater in Figure 4 and so there is a small gap between the end tip and the first active coil.

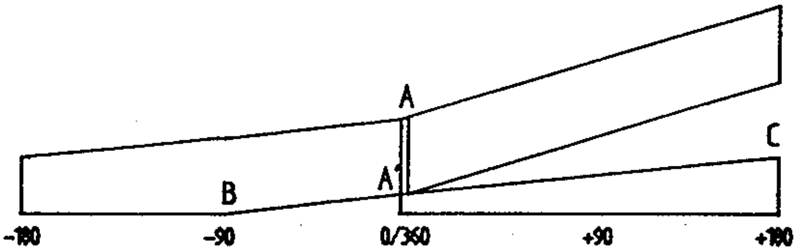


Figure 1 Spring Design One

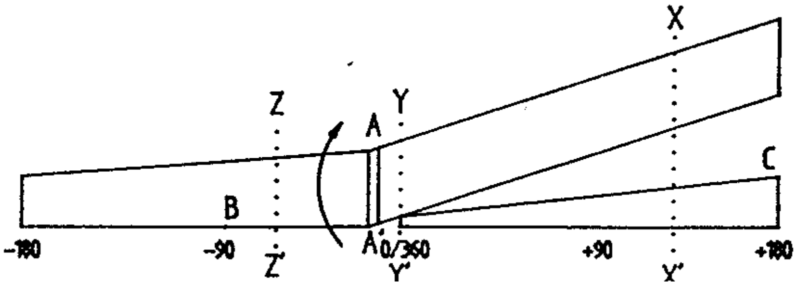


Figure 2 Spring Design Two

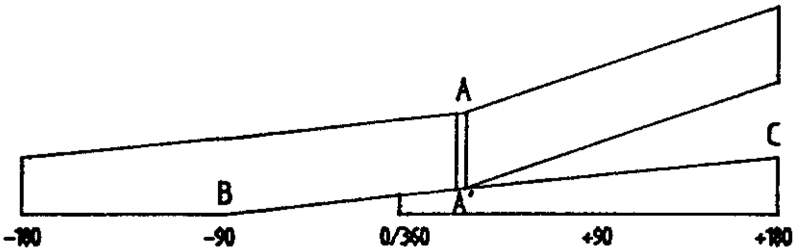


Figure 3 Spring Design Three

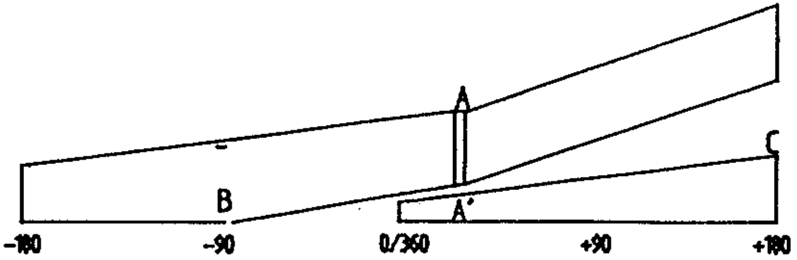


Figure 4 Spring Design Four

The finite element analysis clearly showed that abnormally high torsional and bending stresses would only occur if the end coil lay-on was as shown in Figure 2 - i.e. the pitch transition AA’ occurring just before one complete turn. No abnormally high stresses occurred anywhere in the end coil region for the lay-on shown in Figures 1,3 and 4.

It is very difficult to visually identify springs with end lay-ons that correspond to that illustrated in Figure 2, especially since, in practice this transition will be gradual and not nearly so sharply defined as in these diagrams. However, when such springs are identified, observation of the spring action during loading presents some very interesting results. As the spring is loaded to approximately 50% of the available deflection, it will be observed that part of the end coil (up to the position marked ZZ’ on Figure 2) lifts off the loading platen. This action is believed to be a consequence of the first active coil of the spring pivoting about the end tip.

It is clear from the foregoing how spring manufacturers should lay their end coils. This advice has been proven to be useful to manufacturers of die springs and diesel engine valve springs. All spring manufacturers will encounter this problem eventually as end users specify lighter compression springs that will inevitably be higher stressed and have a sharper transition from end coil pitch to active coil pitch, in order to make most efficient use of the spring wireform which the spring is made.

15.2 Other Mechanisms of End Coil Failure

15.2.1 *Gap beneath the end tip*

The modelling shows that this is not a problem unless the gap is not closed at the first working position. If the gap is not closed at L_1, then the spring will be excessively noisy and will be impact loaded during every cycle. This is disastrous.

15.2.2 *No Peening under end tip*

This is inevitable if there is no gap and very likely when the gap is small. A typical pattern of shot peening is shown below in Figure 2.

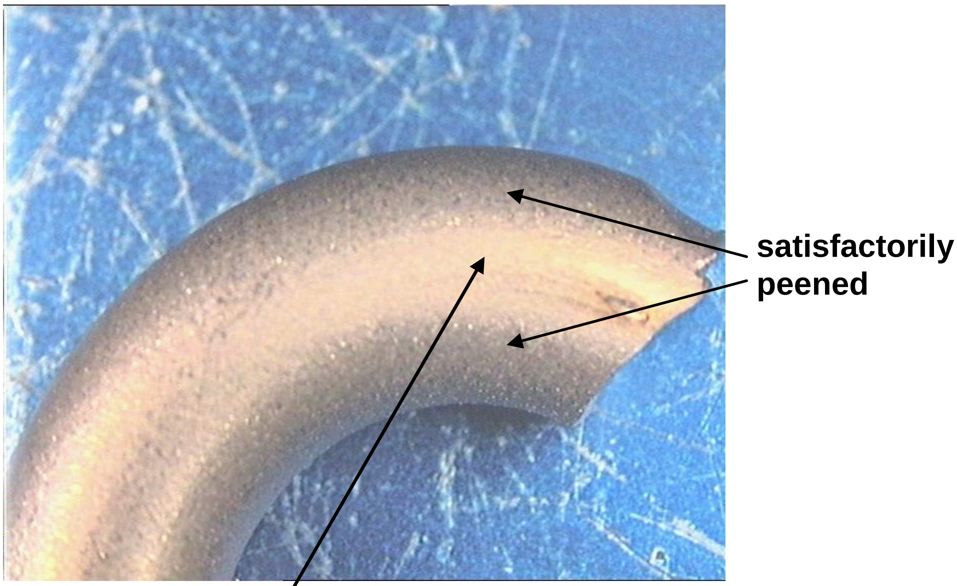


Figure 2 shadowed area under end tip is not peened.

Where there is shot peening there will be a residual compressive stress and protection against the risk of fatigue. Where there is no shot peening there will be a residual tensile stress, which will have to be added to any applied stress and the risk of fatigue will be present. It is very important that the applied stress in this shadowed region is very low.

15.2.3 *Wear caused by contact between the end coil and first active coil*.

This is also inevitable, and will occur at the same shadowed region as in Figure 2. A considerable degree of abrasive wear would have had to occur at this position before end coil fatigue was a possibility. The wear zone is very flat and smooth in cases of abrasive wear, as shown in Figure 3.

Figure 3 **x 6**

The wear in Figure 3 is abrasive, but there is also fretting wear, as evidenced by the red deposit of Fe_20_3 – the fretting oxide accelerates this wear process, but several million cycles are usually required before a risk of fatigue failure arises. Lubrication greatly reduces the fretting.

However, if the contact pressure of this position is great enough the abrasive wear can become adhesive wear and then the risk of failure is greatly increased. Adhesive wear has only been observed in springs with a wire diameter greater than 4mm, but the risk becomes significant at sizes >7mm. This type of spring, subject to tens of millions of cycles, will eventually wear out..

Attempts to reduce wear at this position by use of nitriding have not been successful.

15.2.4 *Lateral movement of the end tip*.

If the end coil does not have the same concentricity as the first active coil, there will be a tendency for lateral deflection of the end tip, either inwards or outwards, particularly if it is any thinner than the end tip shown in Figure 4.

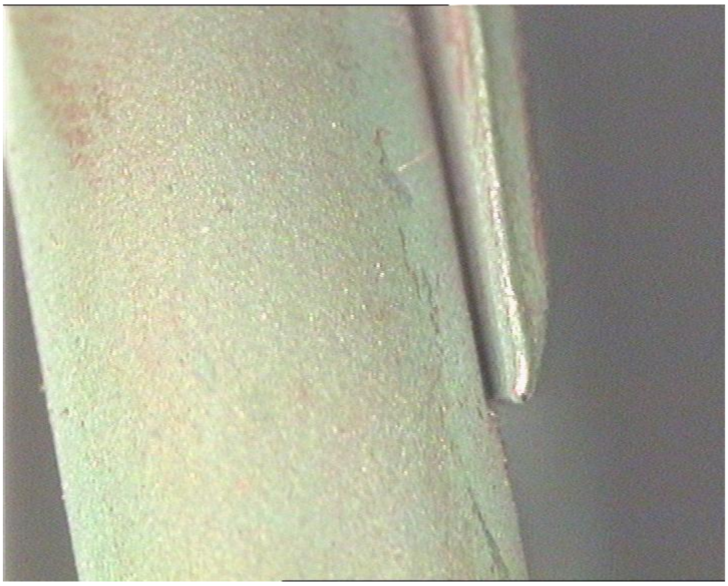


Figure 4 **x 6**

Any lateral deflection of the end tip will eventually lead to bending fatigue within the end coil and part of the end coil breaks off.

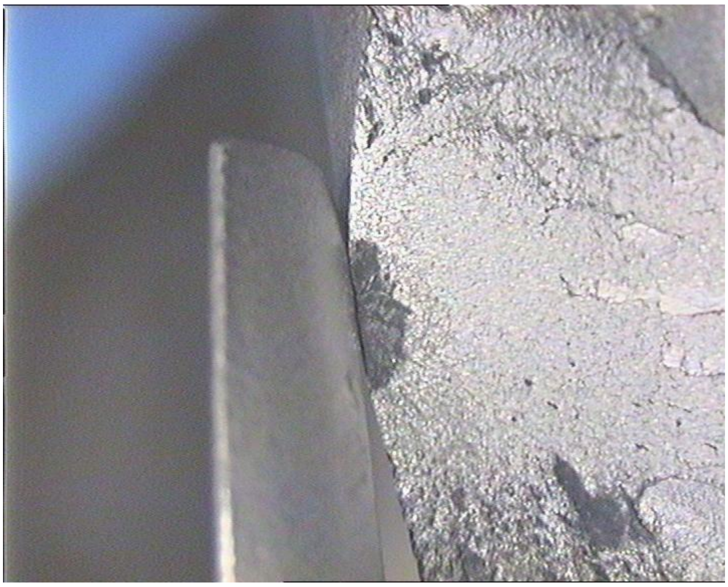
If, on the other hand, the end tip is constrained, so that it cannot deflect the first active coil may ‘ride over’ the end tip slightly and then there will be evidence of lateral movement in the abrasive wear zone, and the risk of fatigue failure at this position will be present.

15.2.5 *Corrosion*

Any spring subject to dynamic loading will have its fatigue life significantly reduced if there is active corrosion simultaneously. Slight corrosion is more likely under the end tip of a dynamically operated compression spring because a meniscus of fluid will tend to collect at this potion and will not evaporate completely. Hence the end tip is very vulnerable to corrosion attack, particularly if there is no corrosion protection system in place. Note that the green paint in Figures 3 and 4 is Deltatone, which should eliminate the risk of rust. Suspension springs for cars seldom have closed ends today to avoid this risk.

15.3 Failure Analysis

Failure Analysis



x 6

Figure A End coil failure in titanium alloy spring. Fatigue fracture initiated at wear. Dark area at origin is an oil stain. This grade of spring material is more susceptible to wear initiated fatigue failures than any other.

Stainless steel test springs failed due to lateral deflection of the end coil initiated by imprecise spring manufacture. In figure B the lack of concentricity of the end coil itself lead to failure adjacent to the end tip in some springs, but in figure C failure by bending fatigue initiated at half way round the end coil can be observed. This fatigue fracture initiated at the inside corner of the ground end surface. This spring was ground with very fine grit, but this type of failure has enhanced risk if the ground finish on the end coil is abnormally coarse – for instance due to using a grinding wheel with too coarse a grit size.

x 6

Figure B End coil not perfectly round. End tip or first coil will be deflected laterally in each loading cycle leading to fatigue failure adjacent to the contact position. Note that the predominant stress is still torsional in this failure

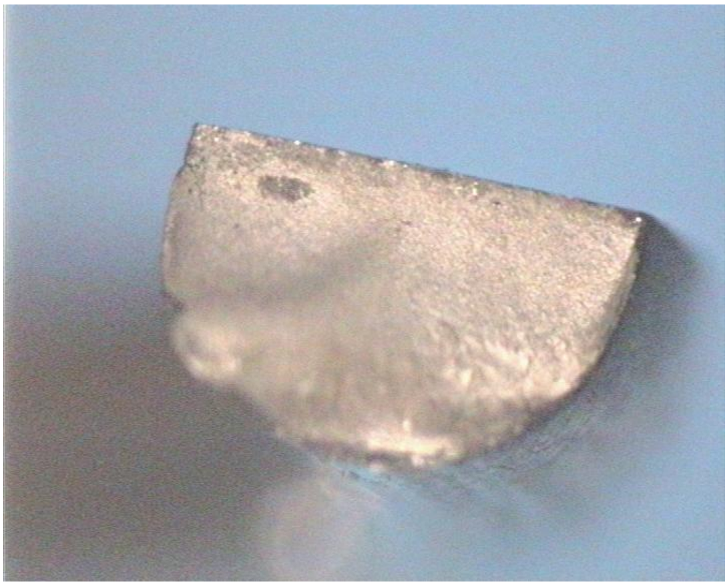


Figure C Same batch of springs as in figure B, but this spring failed by bending fatigue initiated at the inside corner of the ground end

15.4 <u>Conclusion</u>

All the known causes of compression spring end coil fatigue failure have been described above. The purpose of this document is to raise awareness of the risk of higher than expected stresses at this position, so that spring manufacturers may adopt informed strategies to reduce the chance of this type of failure, the frequency of which is increasing with demand for leaner, higher stressed springs.

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