Cautionary Tale XXVI – Greatest Hits

The cautionary tale that prompted the most correspondence was Tale XIX, which was meant to describe an example where finite element analysis has proved to be helpful in explaining a spring problem. However, all the enquiries related to failures at the end coil of compression springs, a problem encountered by manufacturers of engine valve springs, particularly diesel engines at long lives, suspension springs for cars, motorbikes and earth moving trucks, hydraulic valve springs and safety relief valve springs.

If you manufacture compression springs, then one of your customers, sooner or later, is likely to complain that the end coil has broken off. The reason for fracture at this position will probably be fatigue, corrosion or both, but tool marks, wear, fretting and spring end grinding can also play a contributory role.

Tale XIX figure 2 explained how the end coil lay-on at either the first or last end of the spring can lead to very high stresses at the position where the end tip contacts the first active coil. If the active coil pitch starts before one complete end coil has been formed, and the end coil pitch is less than one wire diameter then this is likely to be the position of maximum stress in the loaded spring. In fact, there is often initial tension holding the end coil tight to the first active coil – the additional stresses consequent upon this are thought to be small, but this opinion has yet to be proven.

IST's solid modelling capabilities have been used to provide 3-D representation of an ideal end coil lay-on - figure 1 in cautionary Tale XIX and the case described above – figure 2 from XIX. Figure 2 shows diagrammatically the transition between the end coil and active coil pitch is still shorter than it will be in practice, but it shows the fact that a wedge type pitching tool cannot be deployed instantaneously and so there will be a transition. Furthermore setters are aware that the pitching tool affects the wire either side of the location at which it is deployed, and so this diagram shows the effect of the tool and not the position where it acts. Achieving the ideal end coil lay-on is never easy, and inspection of first off parts is difficult, but it is hoped that these diagrams explain what IST believe is least likely to lead to failure at this vulnerable position.

End coil lay-on is the most important factor affecting the propensity to failure at this position, but there are a number of other factors at this position that can lead to stress raising effects including:

a) Cut-off tool nicking the first active coil when it cuts the end of the spring.

b) The cut-off tool after wear of the tool, or badly set-up, can push a burr in the direction towards the first active coil, thereby providing a pivot about which the first coil can bend to add to the torsional stresses at this position.

c) There will inevitably be wear between the top of the end coil and the bottom of the first active coil. If this wear is caused by a rolling action, then it will be reduced and will minimise the risk. However if the end tip is thin the first active coil may push the end tip radially on every cycle and then the abrasive wear will be considerable and will undermine the residual compressive stress due to peening. The wear may be severe enough to induce fretting and fretting oxide will accumulate, and provide an abrasive paste encouraging further wear, and residual tensile stresses. Fatigue failure can follow soon thereafter.

d) If the contact pressure between the end coil and first active coil is high, then the wear regime may be adhesive rather than abrasive and the stress raising effect set up will be considerable – this is a problem with very long life diesel engine valve springs made from 5 – 8 mm wire used on boats, statics, and trains, whether the spring is made of CrSi or 17/7PH. Furthermore there will be Hertzian stresses set up at the contact area and this becomes significant at larger wire sizes. Hence as wire diameter increases, contact pressure increases, wear increases and the life of springs will be reduced.

e) The area shielded from the benefits of shot peening also affects the risk of failure. Inevitably, a spring with closed ends will have an area where the shot peening cannot reach and so there will be no residual compressive stress here if the ‘masked area’ is large – indeed the residual stress may even be tensile. Hence leaving a small gap at this location can often be beneficial, but then more shot than normal gets trapped, and this causes other problems.

f) The position most at risk of corrosion on a compression spring is where a meniscus of fluid becomes trapped between the end tip and first coil, and where the inevitable wear has removed the corrosion protective finish exposing bare steel. Corrosion at this position often leads to corrosion induced hydrogen embrittlement in high strength spring steels with a martensitic microstructure.

It may appear that I have sufficient reasons here to explain all end coil failures. Unfortunately this is not the case, and it is very difficult to give clear and accurate guidance to eradicate this problem. More research work needs to be undertaken. This could be an ideal multi-client collaborative project, and any reader interested should contact the author.

In the meantime I am sure this cautionary tale will help some readers.

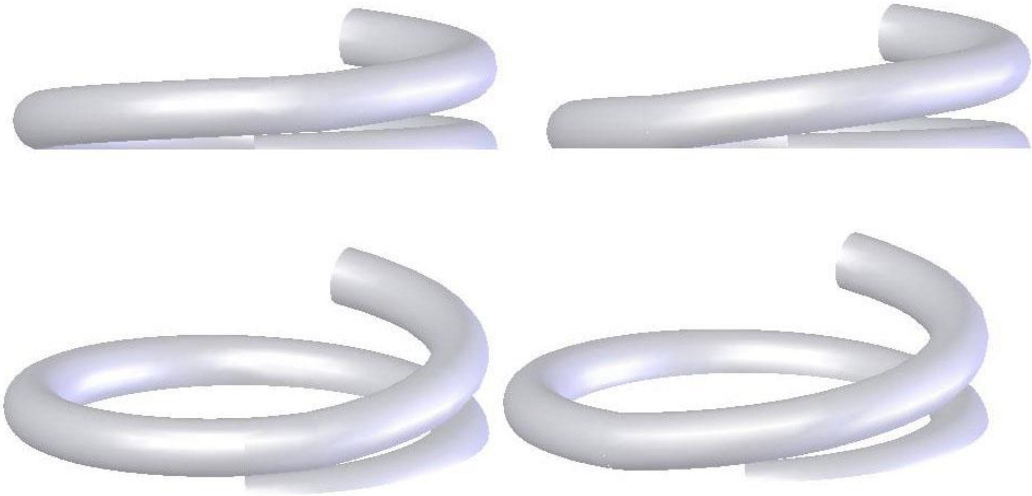

Figure 1 Solid modelling view of end coil lay-on – the one on the left is satisfactory and the one on the right is not.

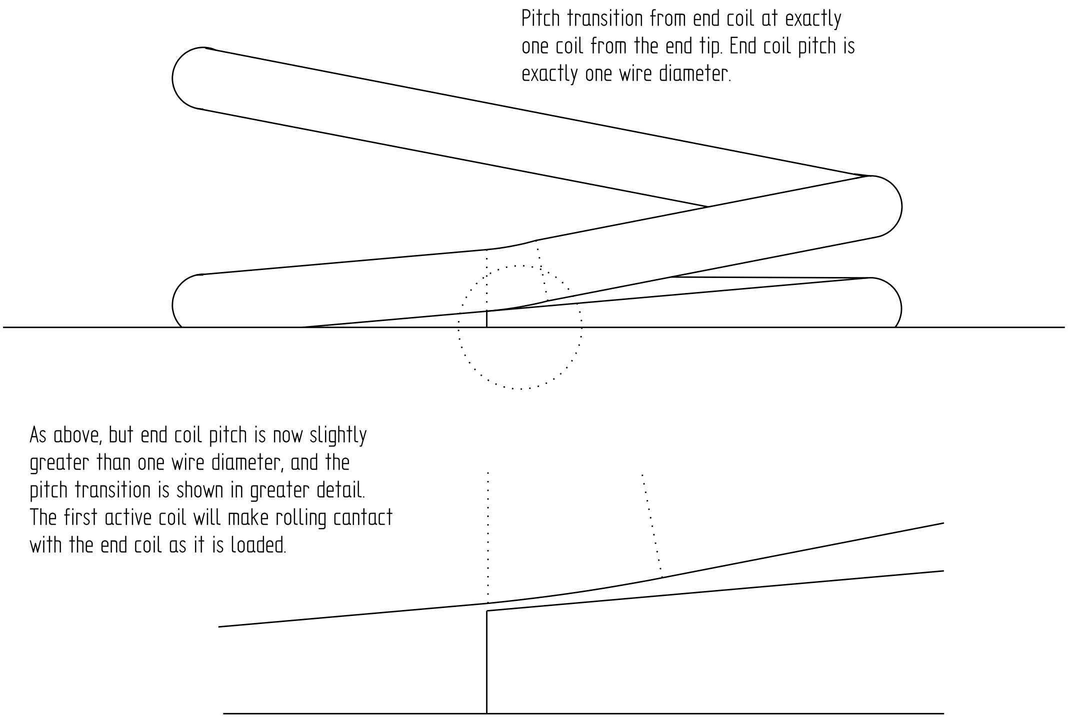

Figure 2

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Readers are encouraged to contact him with comments about this cautionary tale, and with subjects that they would like to be addressed in future tales, by telephone at (011) 44 114 252 7984, fax (011) 44 114 2527997 or e-mail m.hayes@ist.org.uk.