Cautionary Tales Part XIX

End Coil Failure / Use of Finite Element Analysis

IST are asked to investigate the problem of end coil fatigue failure from time to time and the frequency with which this problem arises is increasing. Test springs that have been specifically designed with very high levels of solid stress to ensure that they could be broken on fatigue test are particularly prone to this problem, and it is arising in real springs more frequently as end users design lighter, more highly stressed springs.

In order to gain an understanding of why compression springs might fail by fatigue at the end coil - which is nominally unstressed - finite element analyses were undertaken of the four end coil lay-ons that had been supplied to *IST*. These end coil lay-ons 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.

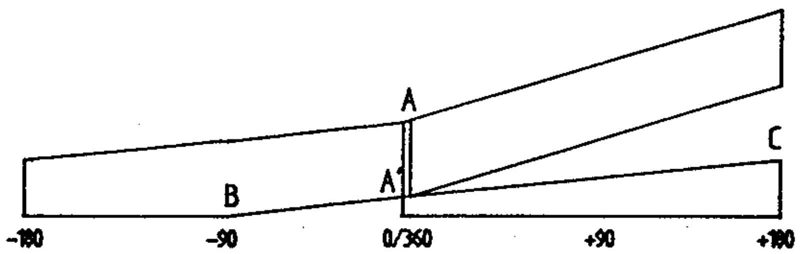

Figure 1 Spring Design One

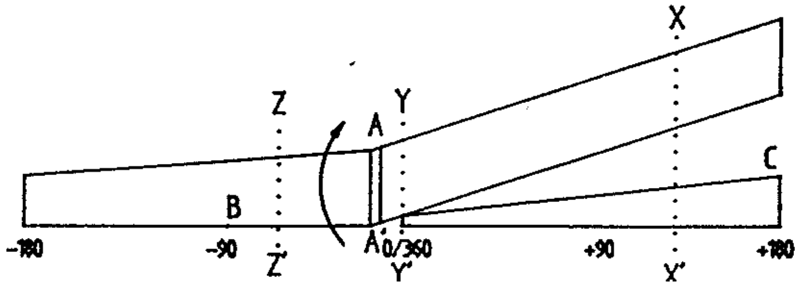

Figure 2 Spring Design Two

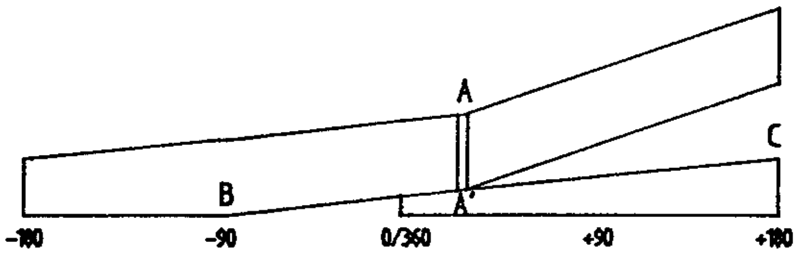

Figure 3 Spring Design Three

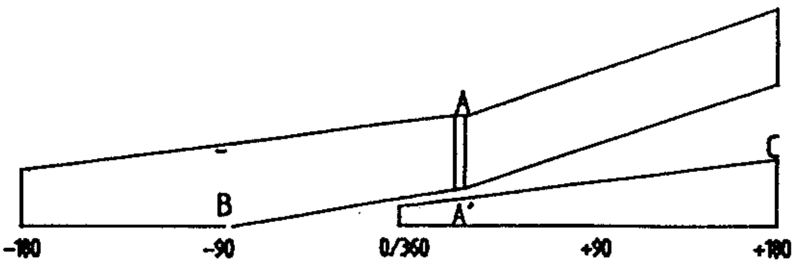

Figure 4 Spring Design Four

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, providing that the cut-off tool did not push up a burr to dig into the first active coil.

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 more gradual and not so sharply defined as in these diagrams, and will be different at the two ends of the spring. 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.

Unfortunately, many springs that do not show this end coil lift are prone to failure at this position, and a solution to the problem is not always easy to find. Spreading the contact between the end coil and first active coil helps as does rolling contact (rather than sudden contact) between these two surfaces, but the wear will eventually be great enough to cause fatigue at this vulnerable position – vulnerable because it cannot be shot peened and any corrosion protection will be worn away. The problem occurs most in wire sections larger than 0.200" and with SiCr and 17/7PH materials. Use of SiCrV and/or nitriding does not appear to reduce wear (abrasive, fretting or adhesive –terms that will be discussed in next month's cautionary tale) at this position.

The moral of this cautionary tale is that, to reduce the risk of end coil failures occurring in dynamic applications, end coil lay-ons similar to those shown in Figures 1,3 or 4 should be attained, and you should be very wary of accepting spring designs that have a solid stress greater than that recommended in design standards, especially if the wire section is greater than 5mm (0.200") and/or the anticipated design life is greater than 20 million cycles. The other moral is that this is the type of problem for which Finite Element Analysis is helpful, but whether the method can predict problems arising from wear has not yet been adequately studied.

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