Optimisation of Extension Spring Designs

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The usual situation in the spring industry globally is that the responsibility for spring designs lies with the end user, and the spring manufacturer's role is that of subcontractor, interpreting the design requirements of their customers. The spring manufacturer will expect to purchase wire of high quality that enables him to produce precise springs that meet his customer's tolerances without significant wastage, and that the springs will meet the performance criteria specified. To facilitate this process IST have developed spring design software suitable for all companies in the springs supply chain – software marketed under the banner "Spring Calculator Professional". However, this approach is not always sufficient because the spring not only has to function accurately and reliably, it may also be essential that the design is optimised for that spring to be competitive in a world market.

IST, in collaboration with a major end user of springs, Schneider Electric of France, have developed additional modules within their suite of programs to enable spring designs to be optimised. That is to say optimised to be of the lowest mass possible, or the design might have to optimised with respect to the space envelope, or optimised for rate (maximum or minimum). Indeed within these modules there is scope to optimise many parameters of spring designs.

This paper is the third in a series (References 1 and 2). The first described the optimisation of compression springs and was given at the SNFR Congress one year ago and was repeated at the Interwire conference in Atlanta in May 2011. The second described the optimisation of conical and torsion springs and that was given at the ESF (European Spring Federation) Congress in Paris in September 2011. These papers are available on request from IST. This third and last in the series concerns the optimisation of extension spring designs.

A simple extension spring like the one in figure 1 works well, but the end user may find significant advantage if the spring could be made lighter or smaller, and it is almost certain that a cheaper spring that does the same job would be helpful.

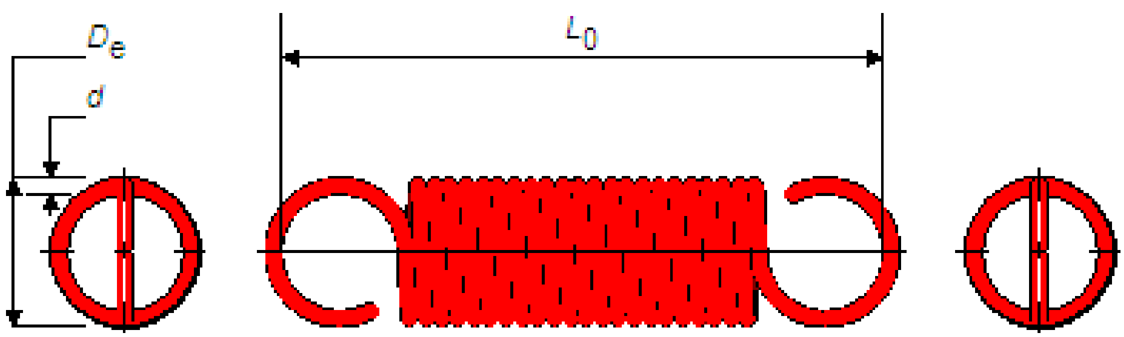


Figure 1 Extension spring

This spring is currently manufactured in 1.8 mm diameter carbon steel to EN10270-1 DM. It has 22 coils, an outside diameter of 14.8 mm and an initial tension load of 12N. It has a mass of 15.4g. The processes used in its manufacture are spring coiling and stress relieving. No other processes are utilised other than oiling to protect it against corrosion in transit to the customer. The end user operates the spring between loads of 25N and 80N and hopes that it will survive a design life of 30,000 cycles. Until the advent of "Spring Calculator Professional" in July 2011 it was only possible to check the fatigue life of the body coils of this spring. The applicable Goodman Diagram is shown as figure 2.

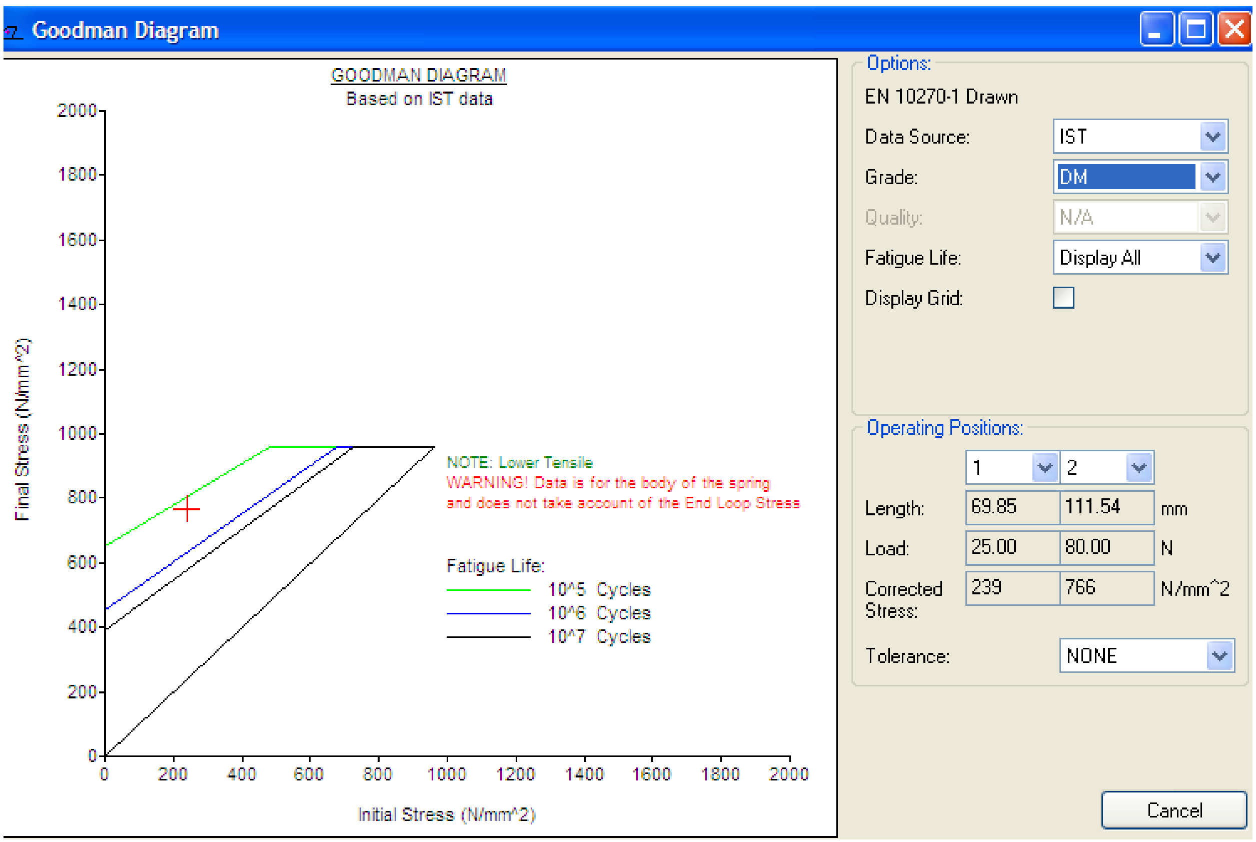


Figure 2 The spring body will not be at risk of fatigue failure before 100,000 cycles

Using the "Techspring" design rules within Spring Calculator Professional a prediction of the risk of fatigue failure within the end hook is shown as figure 3.

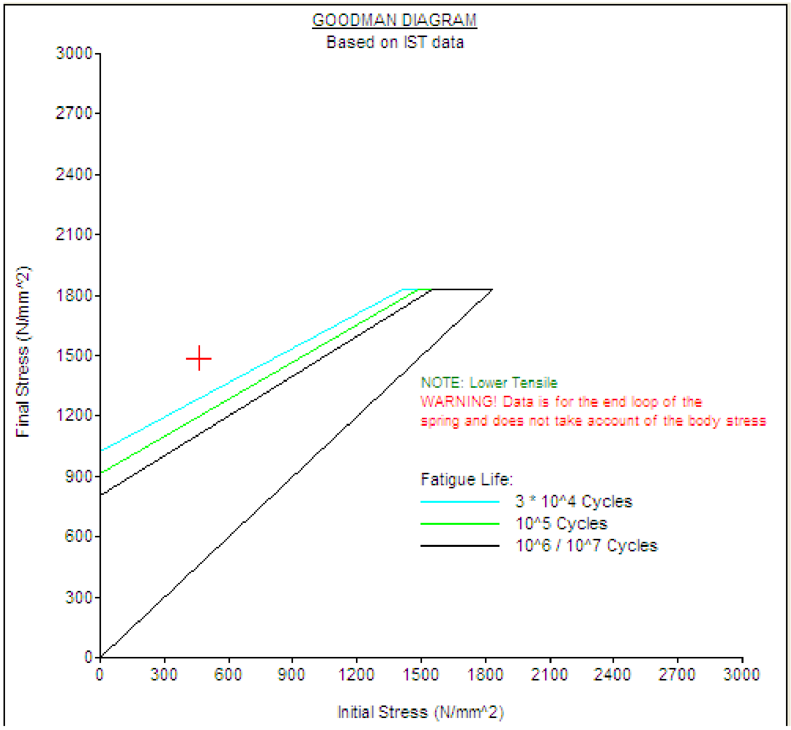


Figure 3 The end loops will be at risk of fatigue failure before 30,000 cycles

To remedy this risk without changing the design significantly, there are three options:

1. Use DH wire in preference to DM

2. Shot peen the end loops

3. The diameter of the end loops could be reduced from 14.8 mm to 12.0 mm

The prediction is that a small risk will remain when using DH wire. Techspring research results (ref. 3) indicate the shot peening of the end loops will be effective, as will the reduction in loop diameter, as shown in figure 4.

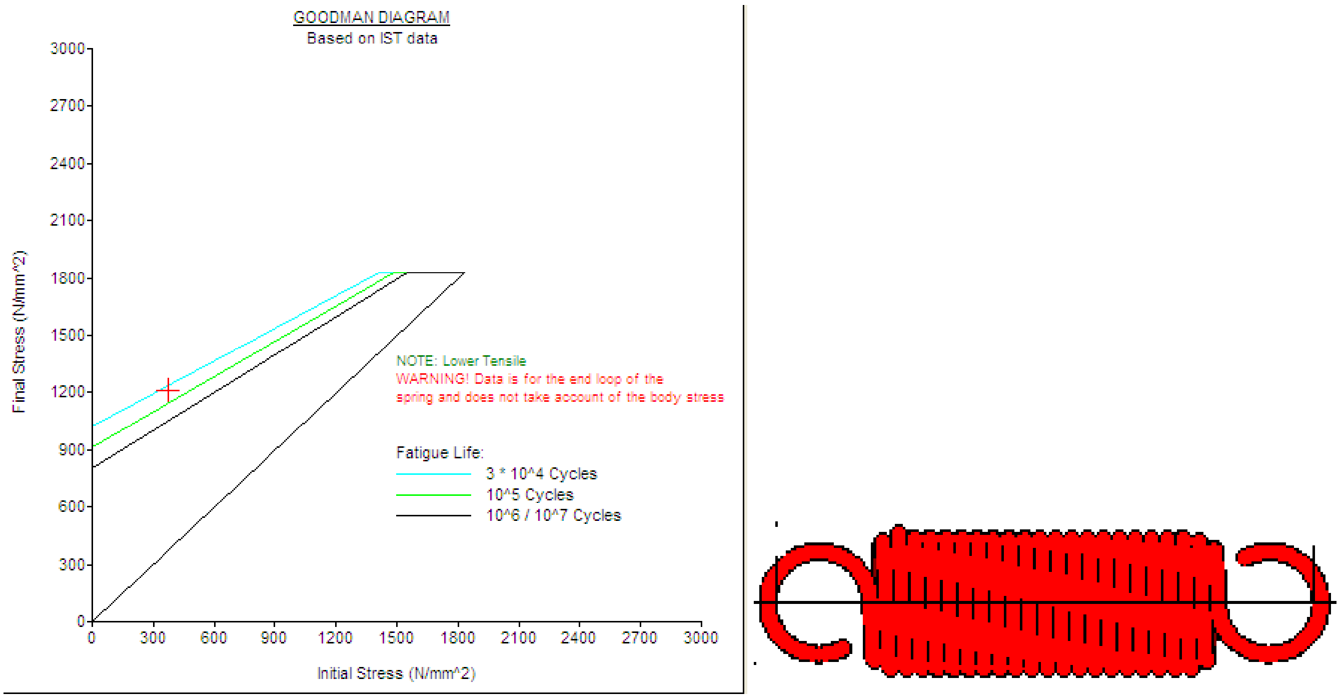
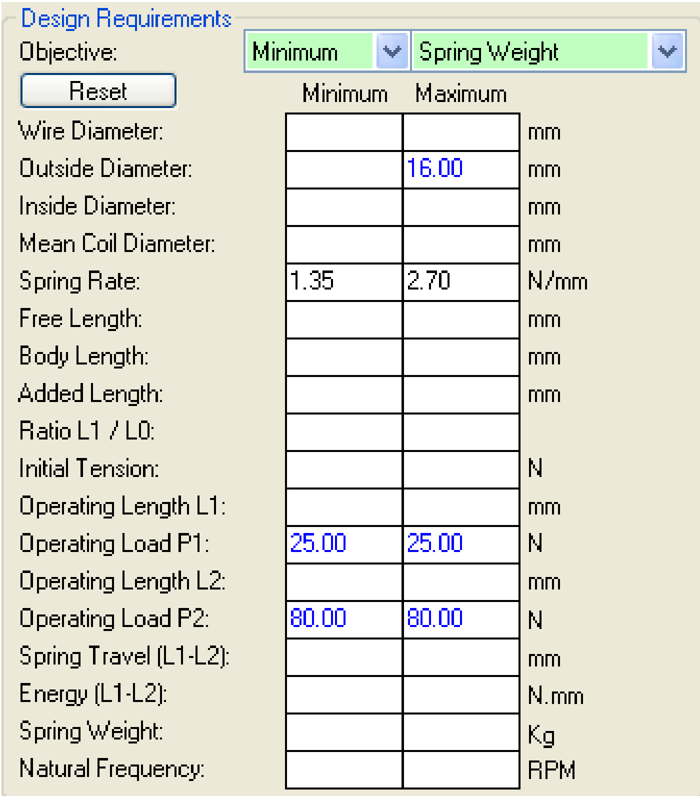


Figure 4 Reducing end loop diameter means the customer design life will be met reliably.

This spring will now give the required design life, but it still weighs 15.4g. The question now is “Can the design be optimized?” To explore the possibilities for optimisation, this paper will consider whether the mass of the spring can be reduced without compromising its function and reliability. This will be accomplished by using the new “Optimisation Module” in IST’s programs, a module developed in collaboration with Schneider Electric.

The premise for optimization is that the two loads cannot be altered. The spring must fit with a 16 mm hole, and the spring rate must be within the range 1.35 to 2.70 N/mm. The current spring has a rate at the bottom of this range. The optimization program will calculate the lowest weight spring that will provide this function by varying wire diameter, outside diameter and number of coils, but maintaining the use of DM wire initially. The input values are DM wire, 30,000 cycle design life, and the values shown in figure 5.



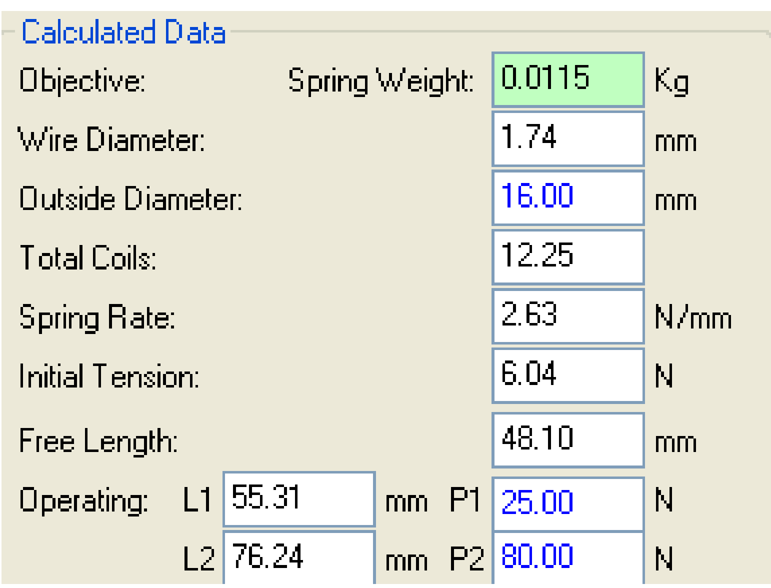
Design Requirements

Objective: Minimum — Spring Weight

	Minimum	Maximum	
Wire Diameter:			mm
Outside Diameter:		16.00	mm
Inside Diameter:			mm
Mean Coil Diameter:			mm
Spring Rate:	1.35	2.70	N/mm
Free Length:			mm
Body Length:			mm
Added Length:			mm
Ratio L1 / L0:			
Initial Tension:			N
Operating Length L1:			mm
Operating Load P1:	25.00	25.00	N
Operating Length L2:			mm
Operating Load P2:	80.00	80.00	N
Spring Travel (L1-L2):			mm
Energy (L1-L2):			N.mm
Spring Weight:			Kg
Natural Frequency:			RPM

Figure 5 Input values to optimisation module showing the design criteria.

The design that resulted has a mass of 11.5g and the parameters shown in figure 6.



Calculated Data

Objective: Spring Weight:	0.0115	Kg
Wire Diameter:	1.74	mm
Outside Diameter:	16.00	mm
Total Coils:	12.25	
Spring Rate:	2.63	N/mm
Initial Tension:	6.04	N
Free Length:	48.10	mm
Operating: L1 55.31 mm, P1	25.00	N
L2 76.24 mm, P2	80.00	N

Figure 6 Spring has wire diameter increased from 1.6 to 1.74 mm, outside diameter increased to the maximum of 16.0 mm, but total coils reduced from 22 to 12.25.

This spring has the same function as the original design and the cross on the Goodman diagram is exactly on the 30,000 cycles line – i.e. optimised, but without safety margin for fatigue, as shown on figure 7.

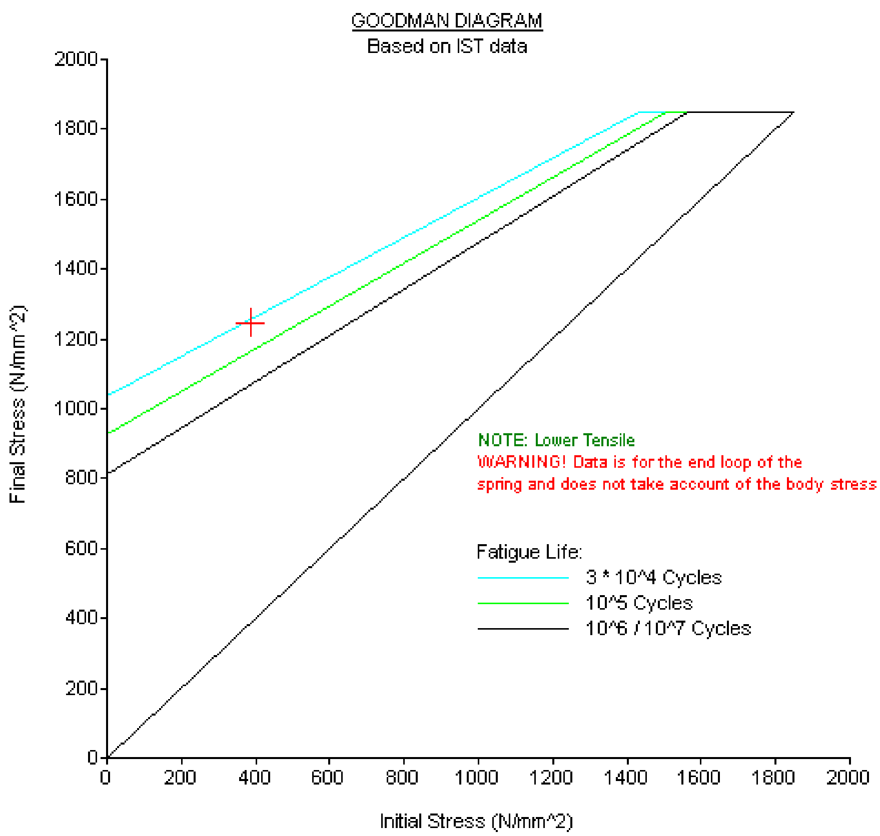


Figure 7 Prediction of fatigue risk in the end loop of the optimised spring.

The optimised spring has end loops the same size as the body, as shown in figure 8.

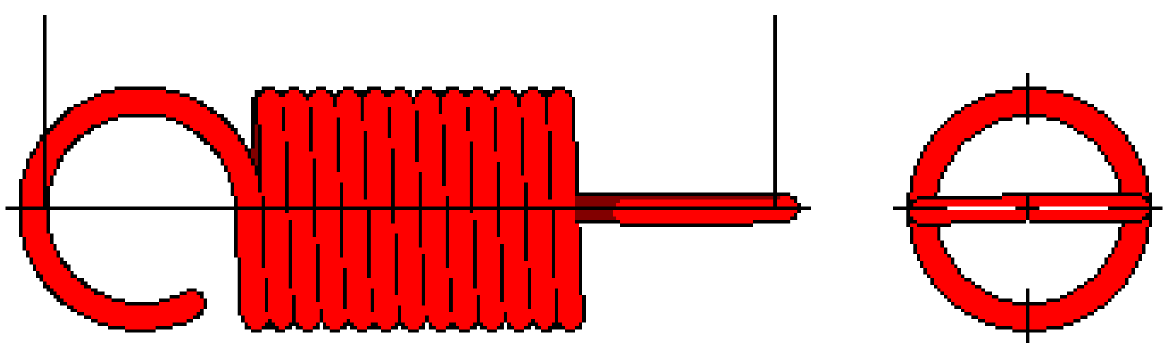


Figure 8 New design optimised for spring weight

However, there may be a possibility of reducing the mass of this spring further, by utilising DH wire in place of DM. The results with DH wire are shown in figure 9.

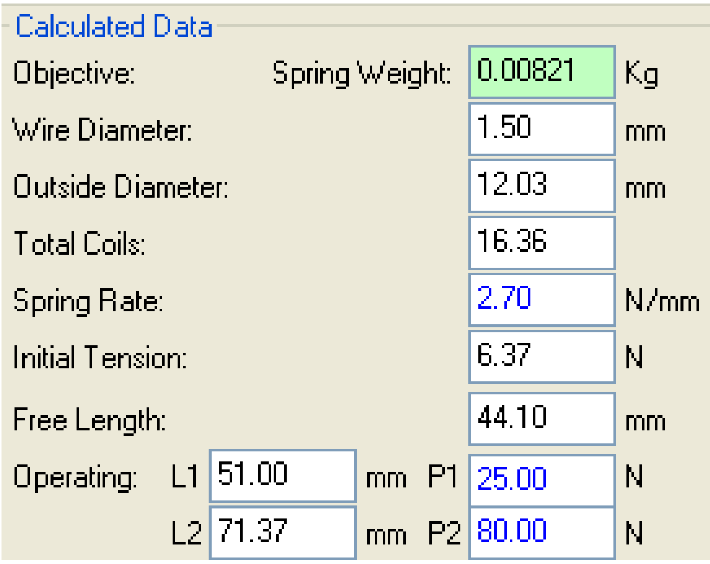


Figure 9 Optimised design in DH wire

Note that this optimisation has arrived at very different results with a reduced wire diameter and reduced outside diameter compared with the two previous designs of the spring, but the mass is down to 8.2g. The question to be answered now is whether the further saving of 28% in weight is justifies the purchase of the more expensive DH wire.

Conclusion

This new software module has enabled the original spring mass to be reduced from 15.4g to 8.2g, which is clearly significant. There are many other optimisation possibilities in which any of the following parameters may be minimised or maximised: spring rate, load at length, outside diameter, natural frequency etc utilising the default settings of the program, as shown in figure 10. There are similar optimisation modules for compression, conical and torsion springs.

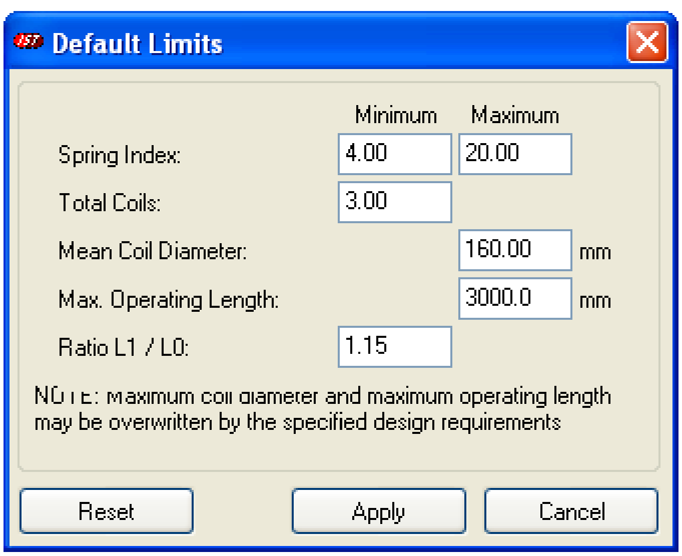


Figure 10 Default settings of the optimisation program.

References

1. "Optimisation of springs designs" M. Hayes and C. Chauvin. Paper given at Interwire, Atlanta, May 2011

2. "Optimisation of conical and torsion spring designs" M. Hayes. Paper given at ESF Conference, Paris, September 2011.

3. Report 3 of www.spring-tech.eu