INSTITUTE of SPRING TECHNOLOGY

# Tech-Spring Report 22

# Finite Element Analysis of a Spring Supplied by TSL Turton Ltd

## 1. Introduction

The technique of Finite Element Analysis (FEA) is widely used in engineering as a stress analysis and design tool. The aim of this report was to evaluate its effectiveness in analysing springs, in comparison with existing commercial spring design software as well as physical load testing of the spring.

## 2. General setup

The software used was ANSYS Structural v11, which is an industry standard non-linear FEA package. It is of course necessary for the operator to have a certain level of skill, and probably undergo a considerable amount of training. As with all FEA software, there is an obvious temptation for novice users to treat the system as a “magic black box” and trust its output implicitly.

The comparison software was IST’s Spring Design & Validation v7.5. This enables any of the wire diameter, coil diameter and pitch to be varied along the length of a spring. Its use is limited to axially symmetrical helical compression springs.

The spring was also tested using one of IST’s load testing machines. The LT5-50000 (a standard commercially available machine) has a load capacity of 50 kN, with a load resolution of 0.5 N and a length resolution of 0.01 mm.

The spring is shown below in Figure 1. It is approximately 320mm long, with a maximum OD of 128mm, and made from 11.68mm wire. One end (the left of the photograph) has a flat pigtailed end for around half a coil, the other end has the last turn butted in to give about half the coil-to-coil distance of the main body.

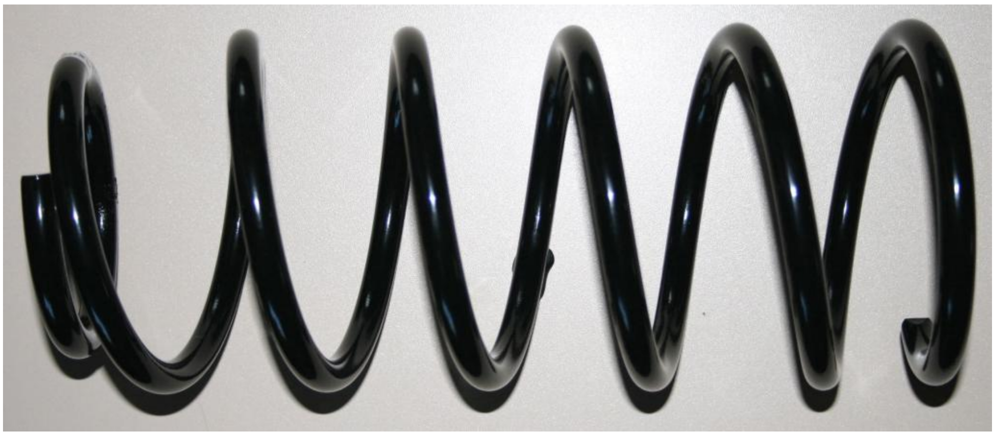


Figure 1 - The spring to be modelled

## 3. FEA Model creation

### *i. Meshing*

The basic technique used to create the mesh was to sweep a 2D mesh along a helix defining the centre-line of the spring coils. This guarantees a good mesh shape and helps to keep the number of elements (and therefore processing time) to a reasonable level. Figure 2 below shows the 2D mesh and the lines used to sweep along.

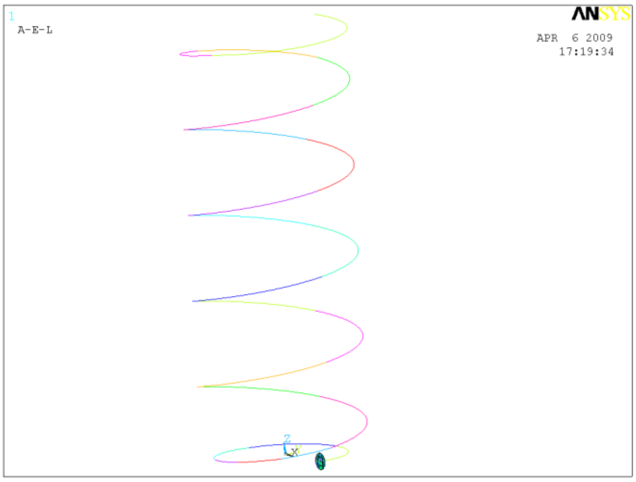


Figure 2 - Sweeping a 2D mesh around the centreline of the spring coils

One of the difficulties in modelling springs is to create a realistic transition around the end coils. The obvious way is to create one coil at an initial pitch, then change the pitch for the main body of the spring, but this creates a model where the body of the spring tries to bend around one position, and gives a huge stress. In this model the pitch was gradually increased in 0.1 coil increments to smooth out this effect.

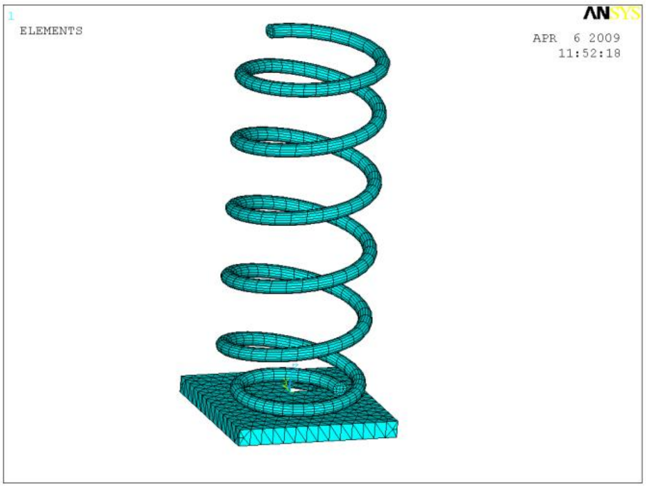


Figure 3 - The final mesh including the flat block used to constrain one end of the spring

### *ii. End conditions*

The pigtail end was modelled using a flat plate. The first model constructed simply restrained the first flat half-coil, but at high deformations this enabled the next part of the spring to deflect down past this position (see Figure 4 below). Therefore a simple flat block with contact elements was also used.

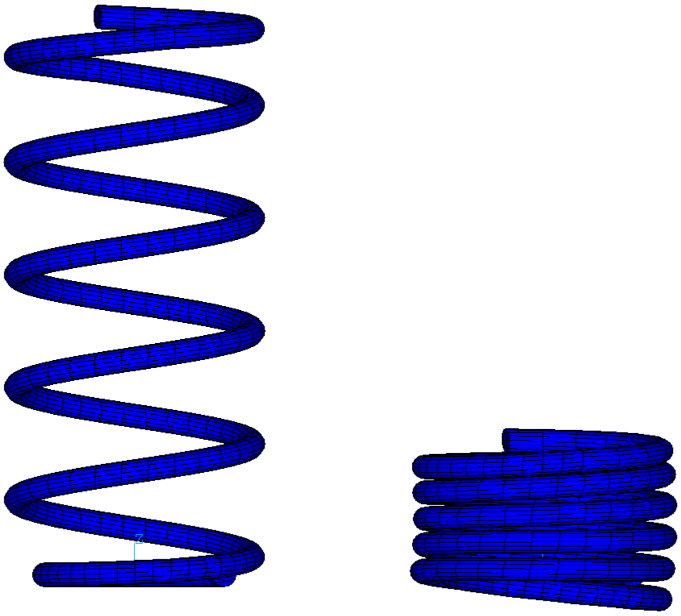


Figure 4 - Unrealistic deformed shape produced by clamping the flat part of the end coil, but not preventing the subsequent coils from passing this point.

The other end of the spring was assumed to fit in a seat. The easiest way to model this was to simply move the end tip together with a point located half a coil around by the same vertical distance. This is equivalent to immobilising this part of the spring in a seat or cup. Figure 5 below shows a common problem that occurs when the deformation is not defined properly. In this case an axial displacement was applied purely to the tip of the spring, and the deformation was achieved by buckling rather than the deflection that might be expected.

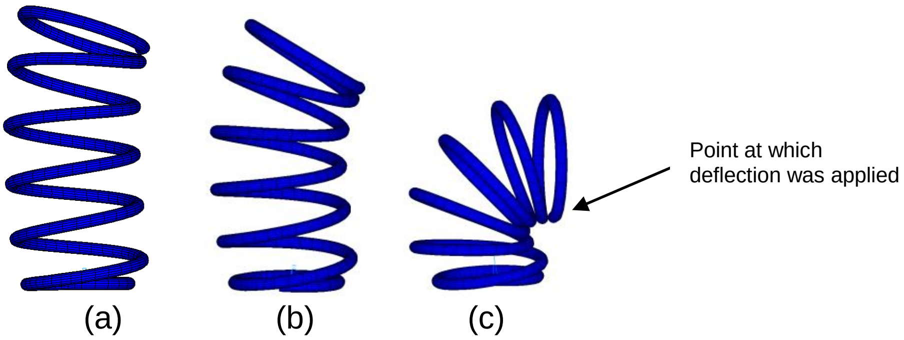


Figure 5 - Unrealistic deformed shape (shown side-on) produced by simply displacing a single point at the tip of the spring vertically downwards by (a) 80 mm, (b) 117 mm and (c) 240 mm.

The final set of contact elements is shown in Figure 6 below, with the red elements facing downwards and the blue elements upwards being the two element types whose contact would be detected. In reality, it is probably not necessary to mesh the whole of this spring as the majority of it is constant coil diameter and pitch, but many springs of this type have continually varying diameter and pitch, so the model must be able to cope with contact at any point. In addition, this model was deformed very close to solid, so there was in fact contact in the main body.

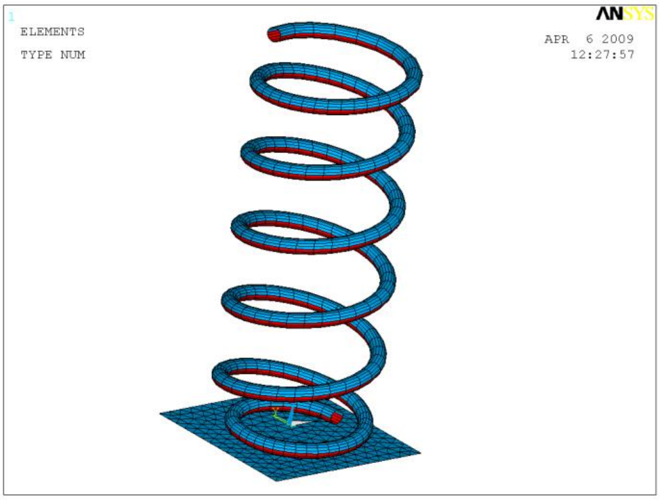


Figure 6 - Contact elements assigned to the spring

## 4. IST software model

The spring was also modelled in IST’s commercial spring design software (v7.5 Non-Standard spring type). The aim was to recreate the same spring as defined in the FEA as closely as possible, to validate both techniques against the physical testing. IST’s software allows the OD to be varied linearly from one coil position to another, and the pitch varied in steps, by specifying an axial distance between two coil positions. Although this is not ideal for defining a real spring (in manufacturing, the pitch will gradually change as the pitch tool moves), it does enable exactly the same design to be specified easily in both software packages. The only noteworthy feature of this design is the way the end coils are defined. The pigtailed end is created simply by specifying zero pitch in the first half a turn. The other end is omitted completely from the design, as IST’s software does not allow part of the spring to be defined as inactive. This will of course lead the software to calculate a free length that is too short.

These numerical specifications are shown in Table 1 below, together with the final design printout in Figure 7 and the spring drawing in Figure 8.

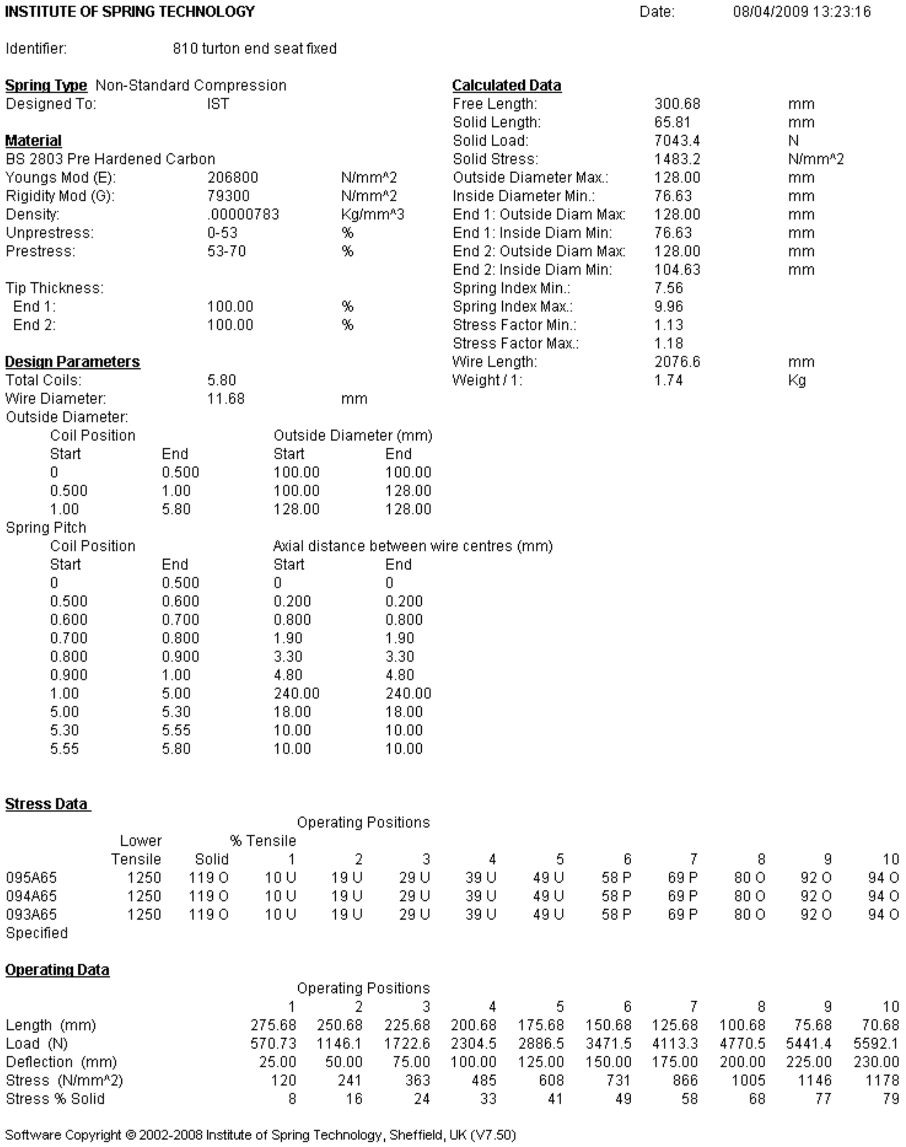
| Coil position | OD (mm) |
|---|---|
| 0 | 100 |
| 0.5 | 128 |
| 5.8 | 128 |

(a)

| Coil Positions | Axial Distance |
|---|---|
| 0 - 0.5 | 0 |
| 0.5 - 0.6 | 0.2 |
| 0.6 - 0.7 | 0.8 |
| 0.7 - 0.8 | 1.9 |
| 0.8 - 0.9 | 3.3 |
| 0.9 - 1 | 4.8 |
| 1 - 5 | 240 |
| 5 - 5.3 | 18 |
| 5.3 - 5.55 | 10 |
| 5.55 - 5.8 | 10 |

(b)

Table 1 - Showing the specifications for OD and axial range



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INSTITUTE OF SPRING TECHNOLOGY                                              Date:        08/04/2009 13:23:16

Identifier:              810 turton end seat fixed

Spring Type  Non-Standard Compression                    Calculated Data
Designed To:             IST                              Free Length:                300.68        mm
                                                          Solid Length:               65.81         mm
Material                                                  Solid Load:                 7043.4        N
BS 2803 Pre Hardened Carbon                               Solid Stress:               1483.2        N/mm^2
Youngs Mod (E):          206800          N/mm^2           Outside Diameter Max.:      128.00        mm
Rigidity Mod (G):        79300           N/mm^2           Inside Diameter Min.:       76.63         mm
Density:                 .00000783       Kg/mm^3          End 1: Outside Diam Max:    128.00        mm
Unprestress:             0-53            %                End 1: Inside Diam Min:     76.63         mm
Prestress:               53-70           %                End 2: Outside Diam Max:    128.00        mm
                                                          End 2: Inside Diam Min:     104.63        mm
Tip Thickness:                                            Spring Index Min.:          7.56
  End 1:                 100.00          %                Spring Index Max.:          9.96
  End 2:                 100.00          %                Stress Factor Min.:         1.13
                                                          Stress Factor Max.:         1.18
Design Parameters                                         Wire Length:                2076.6        mm
Total Coils:             5.80                             Weight / 1:                 1.74          Kg
Wire Diameter:           11.68           mm
Outside Diameter:
      Coil Position                 Outside Diameter (mm)
      Start        End              Start        End
      0            0.500            100.00       100.00
      0.500        1.00             100.00       128.00
      1.00         5.80             128.00       128.00
Spring Pitch
      Coil Position                 Axial distance between wire centres (mm)
      Start        End              Start        End
      0            0.500            0            0
      0.500        0.600            0.200        0.200
      0.600        0.700            0.800        0.800
      0.700        0.800            1.90         1.90
      0.800        0.900            3.30         3.30
      0.900        1.00             4.80         4.80
      1.00         5.00             240.00       240.00
      5.00         5.30             18.00        18.00
      5.30         5.55             10.00        10.00
      5.55         5.80             10.00        10.00


Stress Data
                                      Operating Positions
             Lower        % Tensile
             Tensile   Solid      1       2       3       4       5       6       7       8       9      10
095A65         1250    119 O   10 U    19 U    29 U    39 U    49 U    58 P    69 P    80 O    92 O    94 O
094A65         1250    119 O   10 U    19 U    29 U    39 U    49 U    58 P    69 P    80 O    92 O    94 O
093A65         1250    119 O   10 U    19 U    29 U    39 U    49 U    58 P    69 P    80 O    92 O    94 O
Specified

Operating Data
                                      Operating Positions
                              1       2       3       4       5       6       7       8       9      10
Length  (mm)             275.68  250.68  225.68  200.68  175.68  150.68  125.68  100.68   75.68   70.68
Load  (N)                570.73  1146.1  1722.6  2304.5  2886.5  3471.5  4113.3  4770.5  5441.4  5592.1
Deflection  (mm)          25.00   50.00   75.00  100.00  125.00  150.00  175.00  200.00  225.00  230.00
Stress  (N/mm^2)            120     241     363     485     608     731     866    1005    1146    1178
Stress % Solid                8      16      24      33      41      49      58      68      77      79

Software Copyright © 2002-2008 Institute of Spring Technology, Sheffield, UK (V7.50)
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Figure 7 - Design printout from IST software

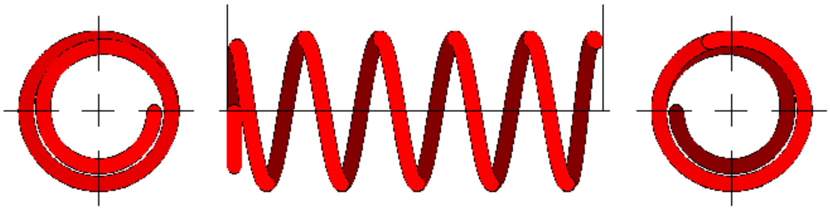


Figure 8 - Spring drawing from IST software

## 5. Load testing

The test machine compresses a spring between two flat platens. The butted end was fixed using a spigot, to immobilise the end half turn in the same way as both the software simulations. Because the other end was flat, it was allowed to simply sit against the platen.

In this way, the three tests were as close as possible. However, the deflection of the load tester was limited to 125 mm, the last of the operating positions that IST's software predicted was "safe" before permanent deformation occurred.

## 6. Comparison of load/deflection results

The two numerical results aimed for in this study were load/deflection characteristics, and stress calculations. A comparison of load results is shown below in Figure 9 – the two software methods were calculated right up to the solid position, and the spring would probably fail before this point.

It can be seen that the FEA and load tester results are extremely close, with the IST software having a slightly higher rate. The main difference here is probably due to the way the deflections are handled at the butted (non-pigtailed) end. The immobilised half turn was removed in the software, but of course this will affect the behaviour of the next part of the spring, and it is an over-simplification to just "cut off" the spring at this point.

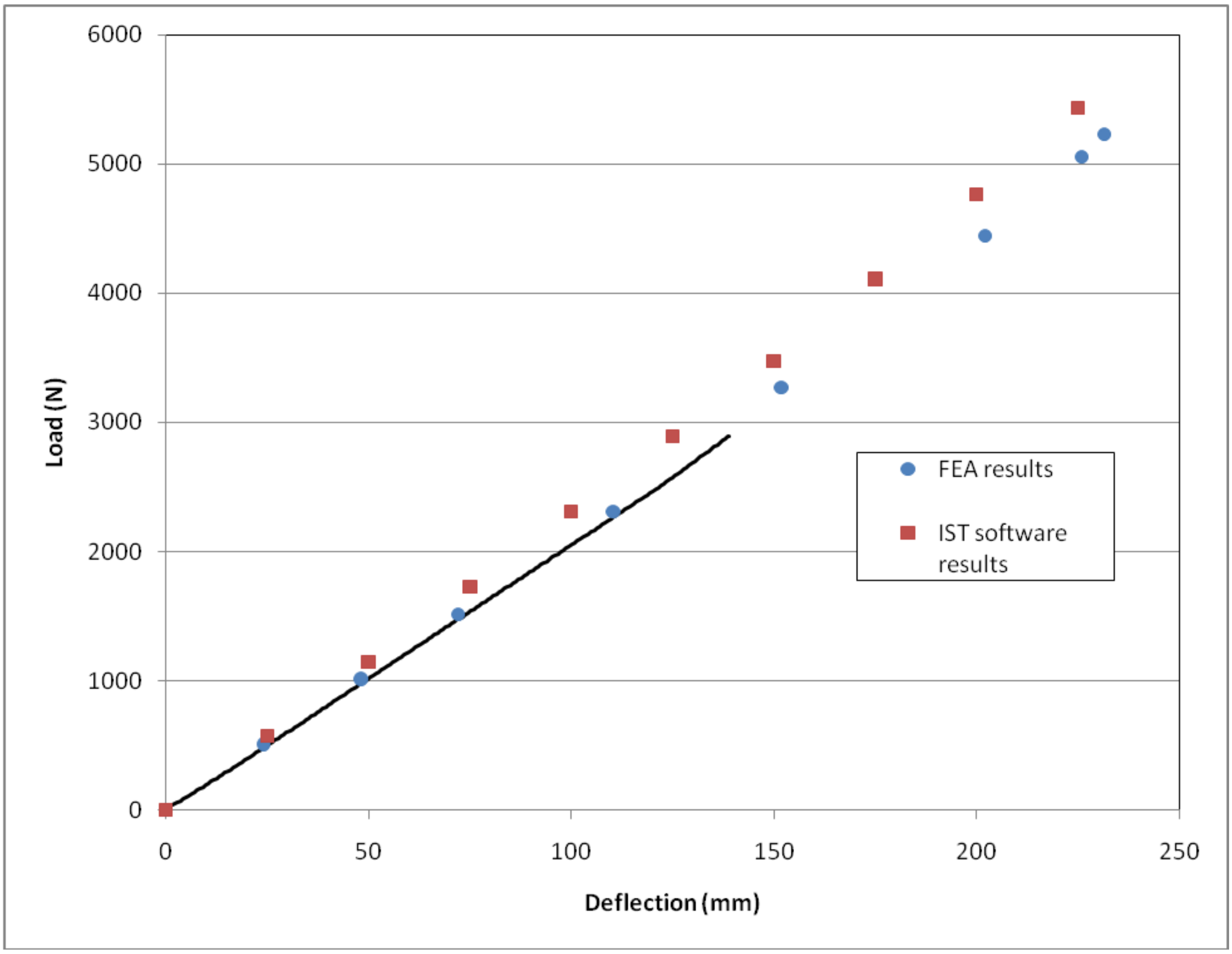
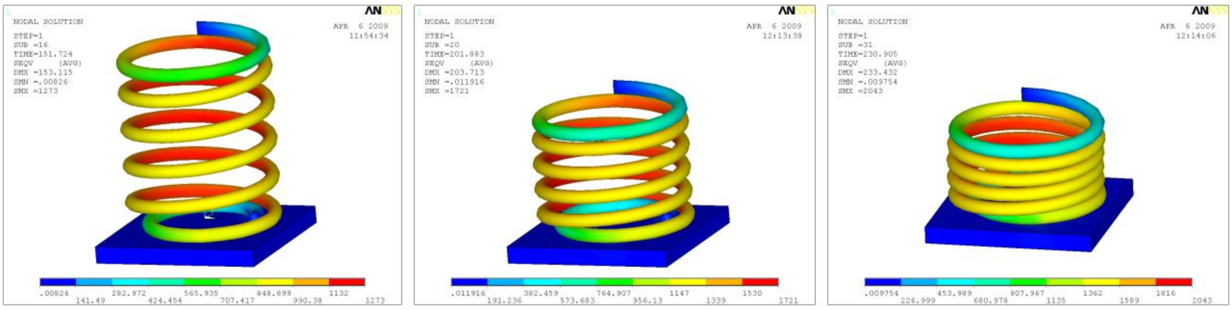


Figure 9 - Load/deflection graph comparing the results from FEA and IST software

## 7. Comparison of FEA and IST software stress predictions

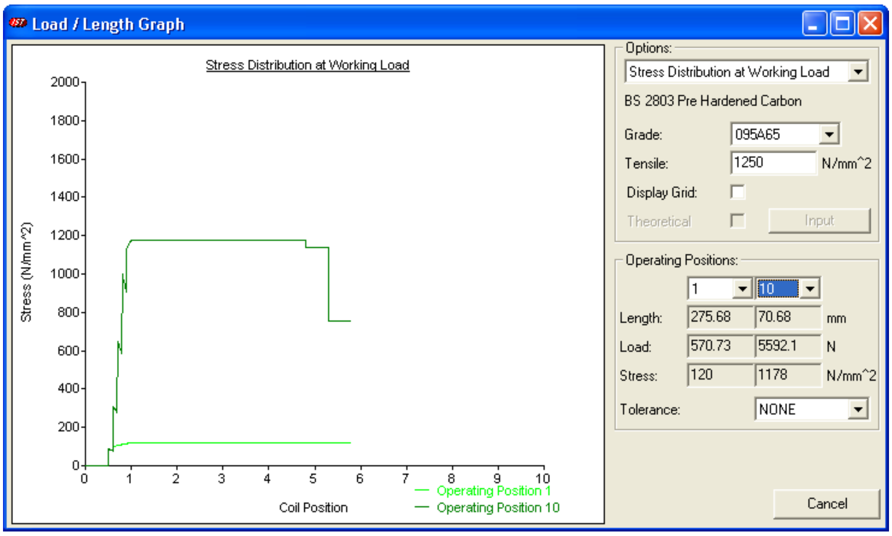
FEA stress results at different deflections can be seen from the three images below. The contour plots show the Von Mises ("equivalent stress" in ANSYS terms) stress at 152, 202 and 231 mm deflection. Note that the colours are not equivalent, as each one plots the maximum stress at that particular position in red.



(a) (b) (c)

Figure 10 - Von Mises stress at (a) 152 mm, (b) 202 mm and (c) 231 mm deflection.

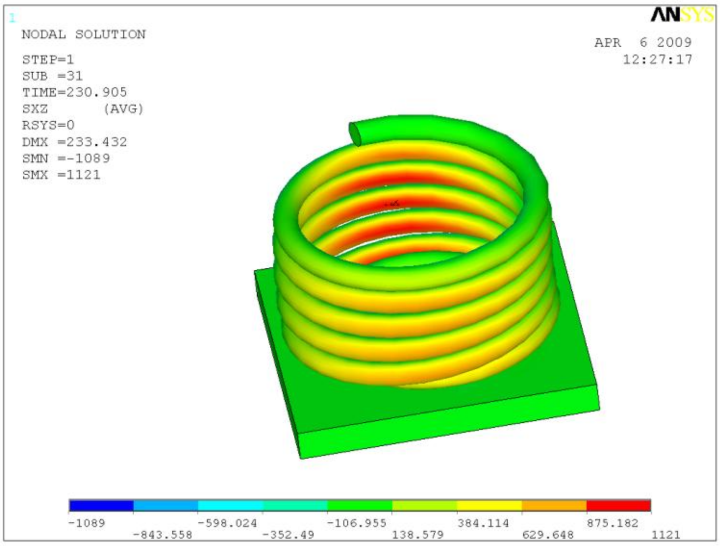
The stress output from IST's software is commonly used as a single number, which represents the maximum stress found along the spring. The stress distribution can be plotted at a working length, and an example of this is shown in Figure 11 below, for two operating positions (deflections of 25 and 230 mm). A full discussion of this graph is beyond the scope of this report, but by considering the dark green plot for Operating Position 10 it can be seen that the stress rises rapidly from coil position 0.5 to 1 as the available deflection rises, and then drops in the last half a turn as the pitch reduces. It is also clear that at the pigtail end, where the pitch information was provided in 0.1 turn increments, the predicted stress distribution is much smoother than at the other end where the pitch input was coarser.



Options: Stress Distribution at Working Load
BS 2803 Pre Hardened Carbon
Grade: 095A65
Tensile: 1250 N/mm^2
Display Grid: ☐
Theoretical ☐
Operating Positions: 1 10
Length: 275.68 70.68 mm
Load: 570.73 5592.1 N
Stress: 120 1178 N/mm^2
Tolerance: NONE

Figure 11 - IST software predictions of stress distribution at deflections of 25 mm ("Operating position 1") and 230 mm ("Operating Position 10").

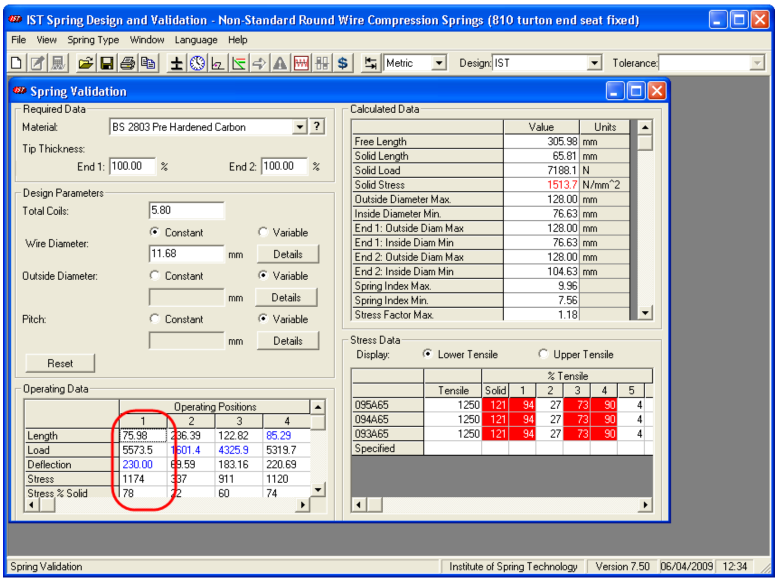
To compare the most useful output from the two software packages, a stress contour plot from the FEA is shown in Figure 12. Note that the stress plotted is shear stress – conventionally some measure of absolute stress such as Von Mises stress would be used for an engineering component, but the stress is springs is always calculated as a shear stress as this is the most important result of the torsional loading. The maximum stress shown is 1121 MPa (at 231 mm deflection), which compares well with the value of 1174 MPa calculated by IST's software (see Figure 13).



```
NODAL SOLUTION

STEP=1
SUB =31
TIME=230.905
SXZ       (AVG)
RSYS=0
DMX =233.432
SMN =-1089
SMX =1121
```

Figure 12 - Shear stresses at large deflection



Metric

Design: IST

Tolerance:

Required Data

Material: BS 2803 Pre Hardened Carbon

Tip Thickness:

End 1: 100.00 %   End 2: 100.00 %

Design Parameters

Total Coils: 5.80

Wire Diameter: ● Constant ○ Variable 11.68 mm

Outside Diameter: ○ Constant ● Variable mm

Pitch: ○ Constant ● Variable mm

Operating Data

| | Operating Positions | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Length | 75.98 | 236.39 | 122.82 | 85.29 |
| Load | 5573.5 | 1601.4 | 4325.9 | 5319.7 |
| Deflection | 230.00 | 69.59 | 183.16 | 220.69 |
| Stress | 1174 | 337 | 911 | 1120 |
| Stress % Solid | 78 | 22 | 60 | 74 |

Calculated Data

| | Value | Units |
|---|---|---|
| Free Length | 305.98 | mm |
| Solid Length | 65.81 | mm |
| Solid Load | 7188.1 | N |
| Solid Stress | 1513.7 | N/mm^2 |
| Outside Diameter Max. | 128.00 | mm |
| Inside Diameter Min. | 76.63 | mm |
| End 1: Outside Diam Max | 128.00 | mm |
| End 1: Inside Diam Min | 76.63 | mm |
| End 2: Outside Diam Max | 128.00 | mm |
| End 2: Inside Diam Min | 104.63 | mm |
| Spring Index Max. | 9.96 | |
| Spring Index Min. | 7.56 | |
| Stress Factor Max. | 1.18 | |

Stress Data

Display: ● Lower Tensile ○ Upper Tensile

| | | % Tensile | | | | | |
|---|---|---|---|---|---|---|---|
| | Tensile | Solid | 1 | 2 | 3 | 4 | 5 |
| 095A65 | 1250 | 121 | 94 | 27 | 73 | 90 | 4 |
| 094A65 | 1250 | 121 | 94 | 27 | 73 | 90 | 4 |
| 093A65 | 1250 | 121 | 94 | 27 | 73 | 90 | 4 |
| Specified | | | | | | | |

Spring Validation | Institute of Spring Technology | Version 7.50 | 06/04/2009 | 12:34

Figure 13 - Calculated results in IST's software, at a deflection of 230 mm.

## 8. Conclusions

As always, boundary conditions are vital for any FE model. The nature of this particular spring helped by making these obvious. The pigtail end gives a clear boundary at one end (although it is still possible some sort of seat could be needed on the real spring). The other end of the spring was initially defined by just moving the very end tip, but this simply caused buckling of the spring. A more realistic deflection of the real spring would be using a seat to hold a part of the end coil, and in fact this is also the easiest way to get a realistic deformation in the FE.

The process of creating the FE model is hugely more involved and requires considerably more skill than using dedicated spring design software. In IST's software, a design can be specified and analysed in less than half an hour. The FE approach took around two working days, even with the experience and knowledge gained from previous studies of springs. Results from these two methods are similar, although the FE data is closer to the real-world tests.

## 9. Appendix – input code used for the final model

```
! TECH-SPRING project - spring from Turton
/quit
/CLEAR,NOSTART  ! Clear model since no SAVE found
/prep7

d = 11.68
OD = 100 ! just of the pigtailed end

ID = OD - 2 * d
MCD = OD - d

! first, draw the wire section
csys,0
k,101, MCD/2,0,0
k,102, OD/2,0,0
k,103, MCD/2,1,0

circle, 101,d/2,103,102
l,101,102
l,101,2
l,101,3
l,101,4

!! mesh the end circle
nummrg,all
al,4,5,8
al,1,5,6
al,2,6,7
al,3,7,8
et,1,200
!keyopt,1,1,6   ! 3-D quadrilateral with 4 nodes
keyopt,1,1,7   ! 3-D quadrilateral with 8 nodes
type,1
esize,3
amesh,all

!next, define the end coil to drag along
csys,1
k,201, MCD/2,0,0
k,202, MCD/2,90,0
k,203, MCD/2,180,0

k,204, 46.955,216,0.2
k,205, 49.755,252,1
k,206, 52.555,288,2.9
k,207, 55.355,324,6.2
k,208, 58.155,360,11

l,201,202
l,202,203
l,203,204
```

```
l,204,205
l,205,206
l,206,207
l,207,208

et,2,95
mshape,1,3D
EXTOPT,ESIZE,6,0
type,2
vdrag,1,2,3,4,,, 9,10

EXTOPT,ESIZE,4,0
vdrag,20,23,26,28,,, 11,12,13,14,15

R = 58.155

k,209,R,480,31
k,210,R,600,51
k,211,R,720,71
k,212,R,840,91
k,213,R,960,111
k,214,R,1080,131
k,215,R,1200,151
k,216,R,1320,171
k,217,R,1440,191
k,218,R,1560,211
k,219,R,1680,231
k,220,R,1800,251

k,221,R,1908,269
k,222,R,1998,279
k,223,R,2088,289
k,224,R,2268,299


l,208,209
l,209,210
l,210,211
l,211,212
l,212,213
l,213,214
l,214,215
l,215,216
l,216,217
l,217,218
l,218,219
l,219,220
l,220,221
l,221,222
l,222,223
l,223,224

EXTOPT,ESIZE,10,0
vdrag,80,83,86,88,,, 107,108,109,110,111,112

vdrag,152,155,158,160,,, 113,114,115,116,117,118

vdrag,224,227,230,232,,, 119,120,121,122


nummrg,kp

dk,101,ux,0,,,uy,uz
dk,7,ux,0,,,uy,uz
dk,12,ux,0,,,uy,uz

disp = -240

dk,119,uz,disp
dk,119,ux,0
dk,119,uy,0

dk,114,uz,disp
```

```
dk,114,ux,0
dk,114,uy,0

!krefine,100,,,1,1
!krefine,120,,,1,1

! contact surfaces
! downward facing surface
et ,3,170
type ,3
asel,s,,,9,273,12
asel,a,,,12,276,12
NSLA,S,1
ESLN,S,0
ESURF

! upwards facing surface
et,4,174
type,4
KEYOPT,4,12,3  ! 3 = bonded once touch
asel,s,,,5,269,12
asel,a,,,15,279,12
NSLA,S,1
ESLN,S,0
ESURF

allsel

block,-70,70,-70,70,-20,-d/2
esize,10
vmesh,93
asel,s,,,282
NSLA,S,1
ESLN,S,0
ESURF
allsel


mp ,ex,,210000
mp ,nuxy,,0.3
/solu
nlgeom,on
NSUBST,10,0,10
OUTRES,ERASE
OUTRES,ALL,ALL
RESCONTRL,DEFINE,ALL,ALL,1
disp = -1*disp
TIME,disp

solve

/post1
pldisp,1
```

Author: Richard Dignall, IST