Tech-Spring Report A
Identification of Software Features and Implementation into Toolkit

Introduction

This report serves the following purposes:-

1. Identify any data items/ features / parameters that could be usefully added to the Tech-Spring software toolkit. (deliverable 2.1, that had previously not been reported), and also elements of deliverables 2.2 and 2.3.
2. Make an initial proposal for how the data / feature / parameter can be incorporated into the Tech-Spring toolkit. (deliverable 2.2 partially – See also Tech-Spring software toolkit for this deliverable)
3. Summarise the actual changes made to the software toolkit in order to fulfil the requirements identified in item 1. (partially deliverable 2.4, but see also the software toolkit)
4. Summarise the benefit to spring makers of the new software features.

IST brought the existing version 7.50 spring design software to the Tech-Spring project as the starting basis onto which the software toolkit would be added during the project.

Identification of Data / Features / Parameters to Add Into the Tech-Spring Software

Features that were identified for incorporation into the Tech-Spring toolkit at the start of the project were as follows:-

1. The fatigue performance of extension spring end hooks.
2. The effect of prestressing on springs. (compression)
3. Shortening of compression springs during prestressing.
4. The effect of non axial forces on fatigue life of compression springs.
5. End coil failures.
6. The effect on fatigue life of operating a compression springs in push – pull mode.
7. Incorporation of the new high strength material into the software toolkit.
8. Shot peening of springs.
9. The speed of fatigue testing.

The exact nature of how these features could be incorporated could not be decided until after at least a proportion of the results for a given investigation were known.

In addition to the above a number of features / data / parameters were identified as the project progressed – these are summarised below:-

1. Report 20A identified that a dynamically induced stress can be generated within the first coil of a compression spring when that spring operates near resonance or at a sub harmonic of the natural frequency of a spring.

2. Lateral and torsional resonances were identified and investigated in report number 20B – this is currently being worked upon for addition into the software toolkit 3.

3. Stress Relief Temperature Effects on Carbon Steel Spring Fatigue Tests.

4. The ability for the software to automatically request the use of high cost analysis tools.

The initial draft of item 1 has been incorporated into the software toolkit, but items 2, 3, and 4 are still under development at present.

Initial Definition of Software Addition, and Final Solution Adopted

1. Extension Spring End Hooks

Before the Tech-Spring project there were no known published studies that detailed the effect of extension spring end loop design on the fatigue performance of the extension spring itself. Estimates of fatigue life for extension springs were always based upon the expected fatigue life of the body coils only, ignoring the end hooks. In the real world almost always fatigue failures in this type of spring are confined to the end hooks, indicating that it is this feature that controls the useful fatigue life of this spring type, rather than the body coils. Report no 11 examined this in greater detail, and generated much data on the influence of the end hooks.

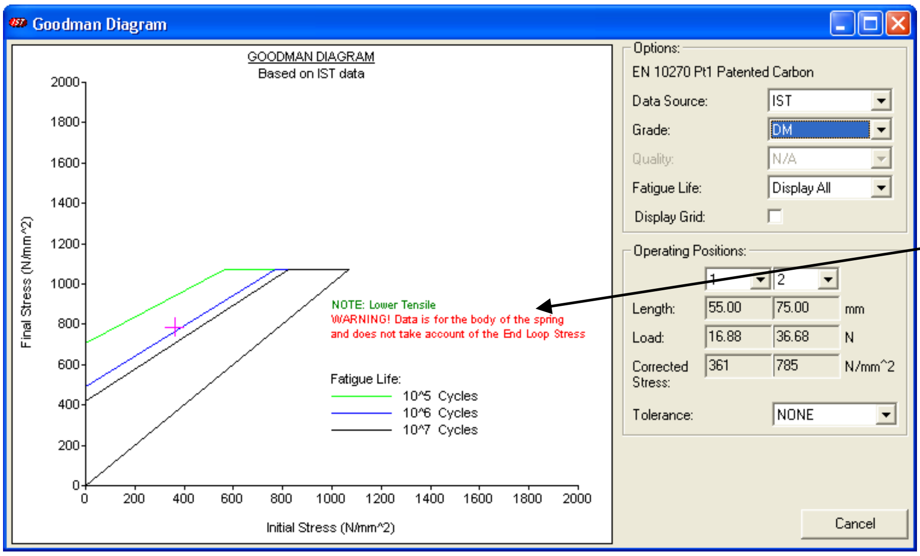
Originally no hard data was available on the effect of the end hooks on fatigue life. Report 11 developed the information that needed to be incorporated within the software. Once the nature of the results obtained was known then it became possible to specify an addition to the software toolkit to enable this information to be incorporated. The proposed solution was to allow a spring design to progress as normal until the Goodman diagram was displayed. The initial Goodman diagram would then have a note appended to it detailing that the plot was for the body coils only. A “click on” button would then be provided to enable the calculation of end loop stresses. A second warning could then be added to the Goodman diagram to indicate that this graph was for the end hooks not the body coils. Obviously a number of additional input boxes would also be required to allow dimensioning of the end hooks. End hook failures on modified hooks were quantified in terms of the dimensions of the hook in relation to the body coil – with this relationship stored within the software the actual processing of the estimated end hook fatigue data could then be an automated subroutine embedded with the software.

A worked example of an extension spring follows:-

- Material: EN 10270-1 Patented Carbon steel
- Spring End Types: Closed & Ground, 50% tip thickness, 2 dead coils
- Wire diameter: 1 mm
- Outside diameter: 8 mm
- Total coils: 30
- Initial tension: 5 N
- Free length: 43 mm
- Operating positions: 55 mm and 75 mm

Extension spring - EN design method (EN 13906-2) – Pre Tech-Spring

Fatigue diagram for DM strength material (using IST's fatigue data):



GOODMAN DIAGRAM
Based on IST data

NOTE: Lower Tensile
WARNING! Data is for the body of the spring and does not take account of the End Loop Stress

Options:
EN 10270 Pt1 Patented Carbon
Data Source: IST
Grade: DM
Quality: N/A
Fatigue Life: Display All
Display Grid: ☐

Operating Positions: 1 2
Length: 55.00 75.00 mm
Load: 16.88 36.68 N
Corrected Stress: 361 785 N/mm^2
Tolerance: NONE

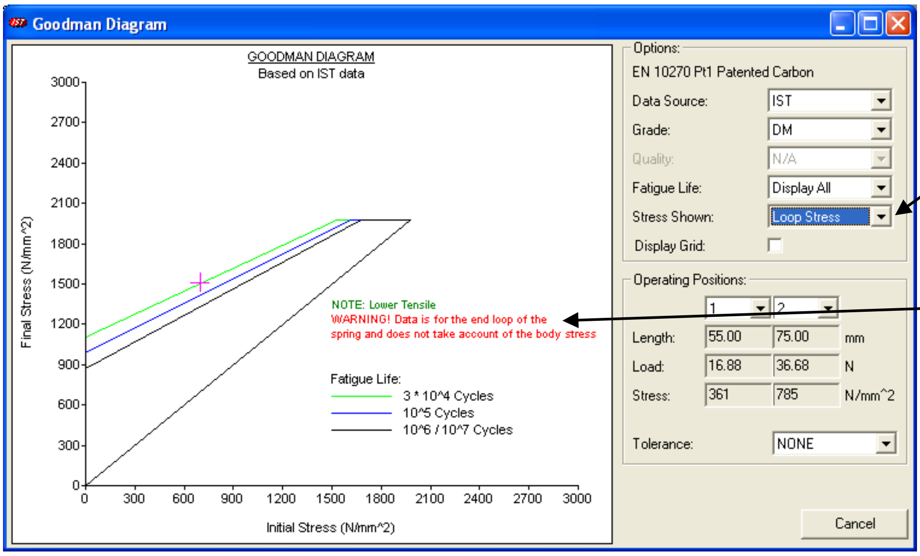
Warning added

Fig 1

This gave an expected fatigue life of just under a million cycles.

Extension spring - Tech-Spring design method

The Tech-Spring toolkit gives the same fatigue diagram for fatigue life in the body, but also has the option to show loop stress failure predictions:



GOODMAN DIAGRAM
Based on IST data

NOTE: Lower Tensile
WARNING! Data is for the end loop of the spring and does not take account of the body stress

Options:
EN 10270 Pt1 Patented Carbon
Data Source: IST
Grade: DM
Quality: N/A
Fatigue Life: Display All
Stress Shown: Loop Stress
Display Grid: ☐

Operating Positions: 1 2
Length: 55.00 75.00 mm
Load: 16.88 36.68 N
Stress: 361 785 N/mm^2
Tolerance: NONE

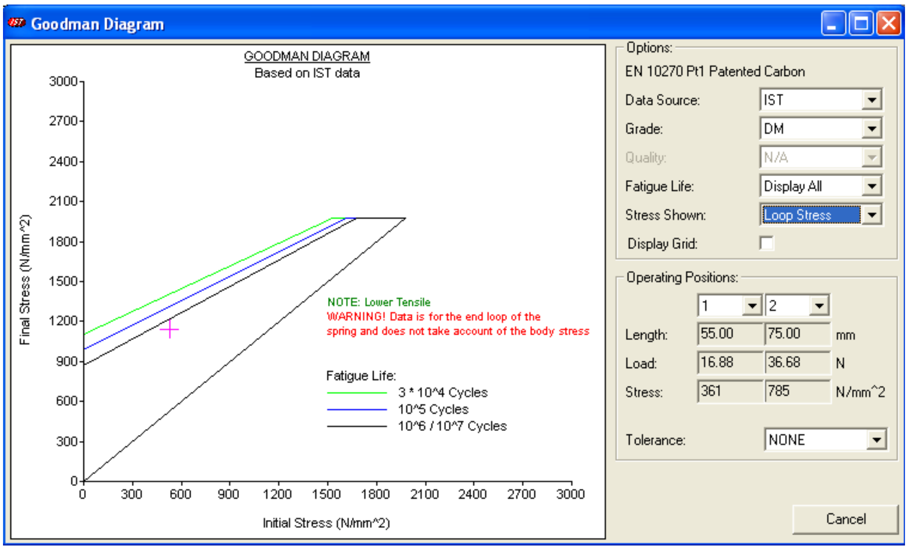
Drop down box to allow end loop calculations

Warning added

Fig 2

For the example spring a fatigue life that is almost exactly on the 30,000 cycles boundary is predicted for the end loop – in other words the end loop will actually control the working life of the spring. Redesigning the spring with smaller end loop diameter - reduced from 8mm to

6mm. This did not change the calculations (apart from introducing a slight added length of 4mm to produce the same free length), or the fatigue life prediction in the body. But the end loop Goodman diagram is altered as shown below:



NOTE: Lower Tensile

WARNING! Data is for the end loop of the spring and does not take account of the body stress

Options:

EN 10270 Pt1 Patented Carbon

Data Source: IST
Grade: DM
Quality: N/A
Fatigue Life: Display All
Stress Shown: Loop Stress
Display Grid: ☐

Operating Positions:

	1	2	
Length:	55.00	75.00	mm
Load:	16.88	36.68	N
Stress:	361	785	N/mm^2

Tolerance: NONE

Fig 3

The life is now over the 10^6/10^7 cycle boundary line, more than matching the life of the main body coils.

Conclusion

The availability of this technical information and a rapid means of calculating the resultant fatigue life changes within the toolkit at modest effort is a major breakthrough for the spring industry. Until now there has been great reluctance to use extension springs in fatigue applications because the end hook effect has not been adequately quantified. This outcome needs to be publicised to the spring users so that the usage of this spring type will become more popular, as one of this spring type’s main drawbacks is now quantified and understood.

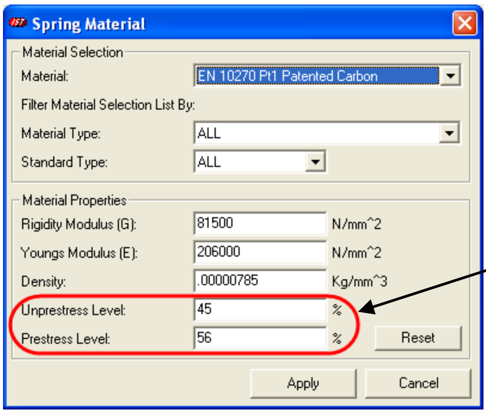
2a Prestressing Effect On Springs

In existing fatigue life predictions for carbon, oil tempered and stainless materials, the Goodman diagrams are enlarged by a fixed amount if the spring design is prestressed in comparison with an unprestressed design – regardless of the actual stress levels involved. So a design where the solid stress is only just over the prestress limit enlarges the fatigue diagram prediction as much as one where the solid stress is on the limit of being overstressed. This is incorrect, as the benefit given by prestressing should depend on the amount of permanent set taken by the spring. As a result of report 12 this prediction could be modified to give a variable level of benefit from prestressing based upon how highly stressed the original spring design is - this is based upon the spring index of the designed spring. The original design software incorporated the published data on the fixed levels at which unprestressed and prestressed springs could be operated as follows:-

Example Compression spring

- Material: EN 10270-1 Patented Carbon steel
- Spring End Types: Closed & Ground, 50% tip thickness, 2 dead coils
- Wire diameter: 1 mm
- Outside diameter: 8 mm
- Total coils: 8
- Free length: 19 mm

Compression spring - EN design method (EN 13906-1) Pre Tech-Spring



Spring Material

Material Selection

Material: EN 10270 Pt1 Patented Carbon

Filter Material Selection List By:

Material Type: ALL

Standard Type: ALL

Material Properties

Rigidity Modulus (G): 81500 N/mm^2

Youngs Modulus (E): 206000 N/mm^2

Density: .00000785 Kg/mm^3

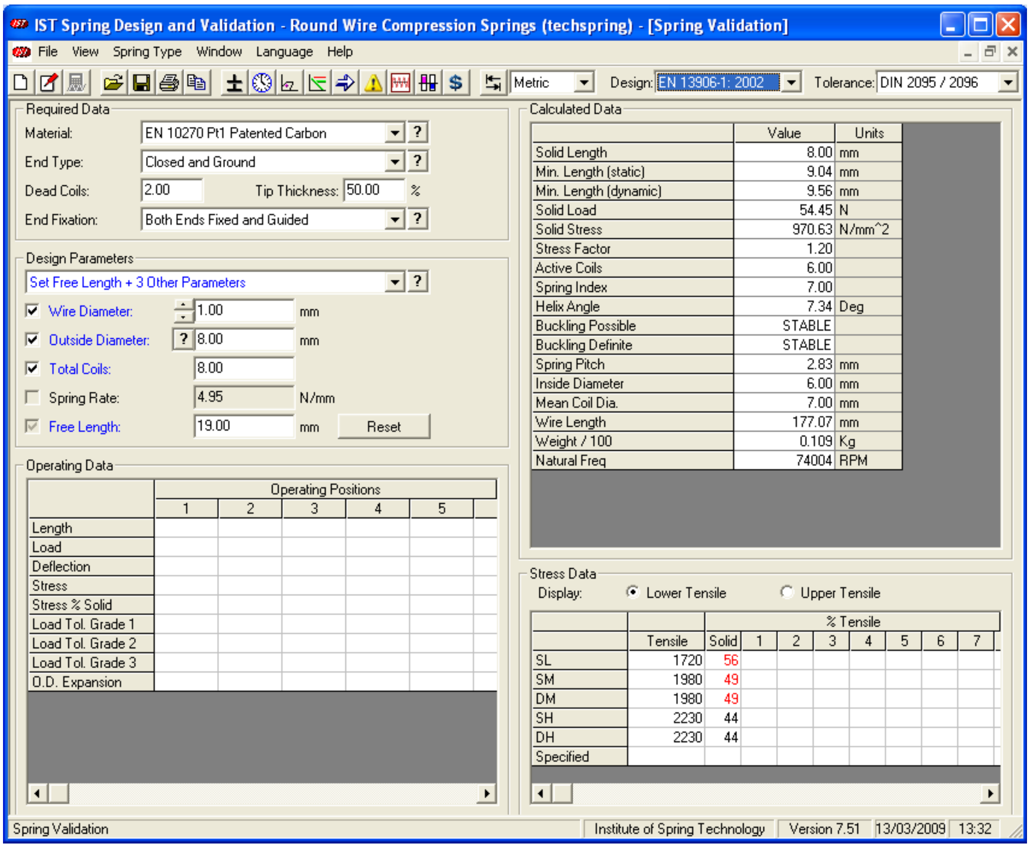
Unprestress Level: 45 %

Prestress Level: 56 %

Preset design limits
From standard

Fig 4

Note the design limits of 45% and 56% UTS for unprestressed and prestressed limits respectively. This generated the following spring design:-



Metric

Design: EN 13906-1: 2002

Tolerance: DIN 2095 / 2096

Required Data

Material: EN 10270 Pt1 Patented Carbon

End Type: Closed and Ground

Dead Coils: 2.00 Tip Thickness: 50.00 %

End Fixation: Both Ends Fixed and Guided

Design Parameters

Set Free Length + 3 Other Parameters

☑ Wire Diameter: 1.00 mm

☑ Outside Diameter: 8.00 mm

☑ Total Coils: 8.00

☐ Spring Rate: 4.95 N/mm

☑ Free Length: 19.00 mm

Operating Data

	Operating Positions				
	1	2	3	4	5
Length					
Load					
Deflection					
Stress					
Stress % Solid					
Load Tol. Grade 1					
Load Tol. Grade 2					
Load Tol. Grade 3					
O.D. Expansion					

Calculated Data

	Value	Units
Solid Length	8.00	mm
Min. Length (static)	9.04	mm
Min. Length (dynamic)	9.56	mm
Solid Load	54.45	N
Solid Stress	970.63	N/mm^2
Stress Factor	1.20	
Active Coils	6.00	
Spring Index	7.00	
Helix Angle	7.34	Deg
Buckling Possible	STABLE	
Buckling Definite	STABLE	
Spring Pitch	2.83	mm
Inside Diameter	6.00	mm
Mean Coil Dia.	7.00	mm
Wire Length	177.07	mm
Weight / 100	0.109	Kg
Natural Freq	74004	RPM

Stress Data

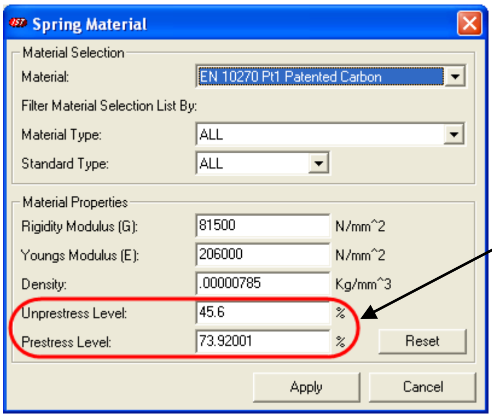
Display: ● Lower Tensile ○ Upper Tensile

			% Tensile						
	Tensile	Solid	1	2	3	4	5	6	7
SL	1720	56							
SM	1980	49							
DM	1980	49							
SH	2230	44							
DH	2230	44							
Specified									

Fig 5

The original software design concept was to add in an additional design method (which we called Tech-Spring 2008), that could be preselected before a spring design was started. The designer then types in the known design parameters, and the software recalculates the prestress limit automatically based upon the data generated in report 12. Taking the previous example design and applying the modified Tech-Spring method:-

Compression spring - Tech-Spring design method



Material Selection

Material: EN 10270 Pt1 Patented Carbon

Filter Material Selection List By:

Material Type: ALL

Standard Type: ALL

Material Properties

Rigidity Modulus (G): 81500 N/mm^2

Youngs Modulus (E): 206000 N/mm^2

Density: .00000785 Kg/mm^3

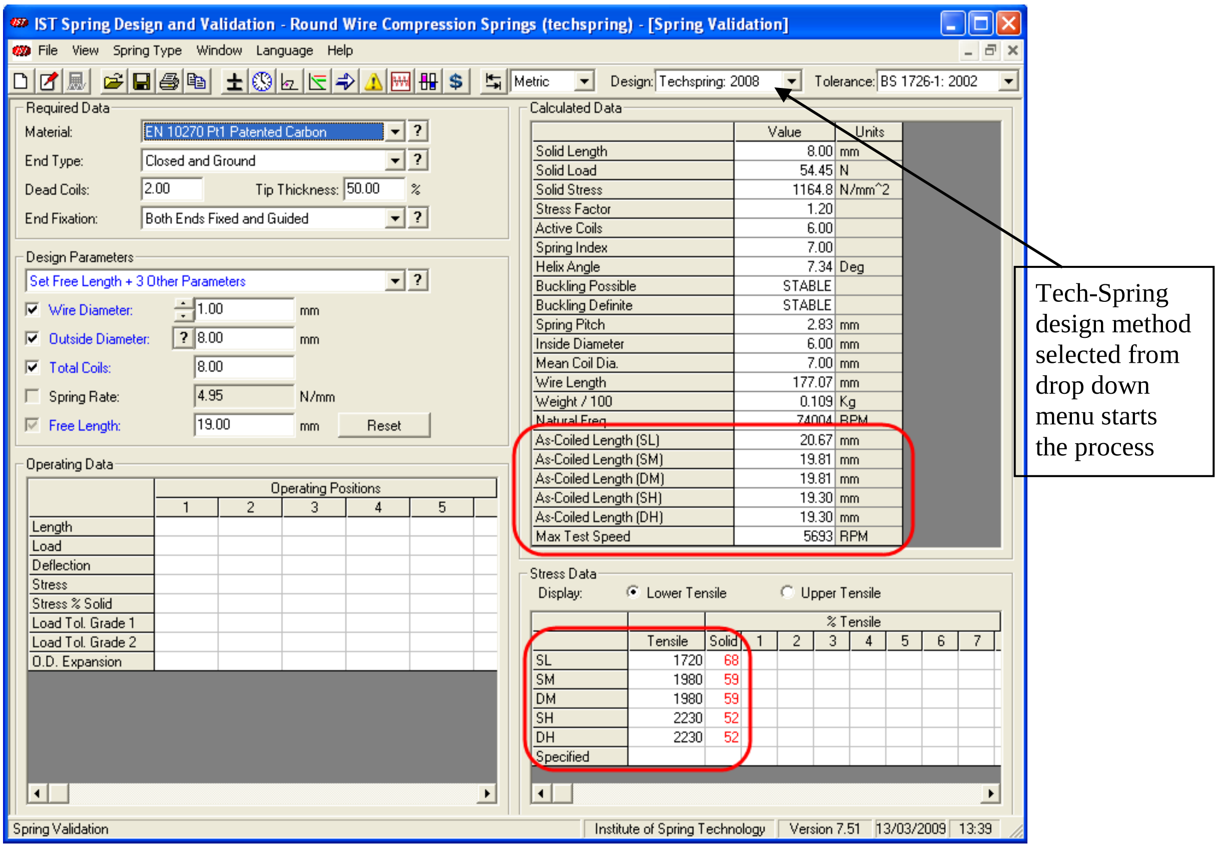
Unprestress Level: 45.6 %

Prestress Level: 73.92001 %

Stress limits recalculate themselves based upon spring index

Fig 6

Note the change in stress limits (and remembering that this design method, unlike EN 13906, uses a correction factor in all stress calculations).



Metric

Design: Techspring: 2008

Tolerance: BS 1726-1: 2002

Required Data

Material: EN 10270 Pt1 Patented Carbon

End Type: Closed and Ground

Dead Coils: 2.00

Tip Thickness: 50.00 %

End Fixation: Both Ends Fixed and Guided

Design Parameters

Set Free Length + 3 Other Parameters

☑ Wire Diameter: 1.00 mm

☑ Outside Diameter: 8.00 mm

☑ Total Coils: 8.00

☐ Spring Rate: 4.95 N/mm

☑ Free Length: 19.00 mm

Operating Data

	Operating Positions				
	1	2	3	4	5
Length					
Load					
Deflection					
Stress					
Stress % Solid					
Load Tol. Grade 1					
Load Tol. Grade 2					
O.D. Expansion					

Calculated Data

	Value	Units
Solid Length	8.00	mm
Solid Load	54.45	N
Solid Stress	1164.8	N/mm^2
Stress Factor	1.20	
Active Coils	6.00	
Spring Index	7.00	
Helix Angle	7.34	Deg
Buckling Possible	STABLE	
Buckling Definite	STABLE	
Spring Pitch	2.83	mm
Inside Diameter	6.00	mm
Mean Coil Dia.	7.00	mm
Wire Length	177.07	mm
Weight / 100	0.109	Kg
Natural Freq	74004	RPM
As-Coiled Length (SL)	20.67	mm
As-Coiled Length (SM)	19.81	mm
As-Coiled Length (DM)	19.81	mm
As-Coiled Length (SH)	19.30	mm
As-Coiled Length (DH)	19.30	mm
Max Test Speed	5693	RPM

Stress Data

Display: ● Lower Tensile ○ Upper Tensile

			% Tensile						
	Tensile	Solid	1	2	3	4	5	6	7
SL	1720	68							
SM	1980	59							
DM	1980	59							
SH	2230	52							
DH	2230	52							
Specified									

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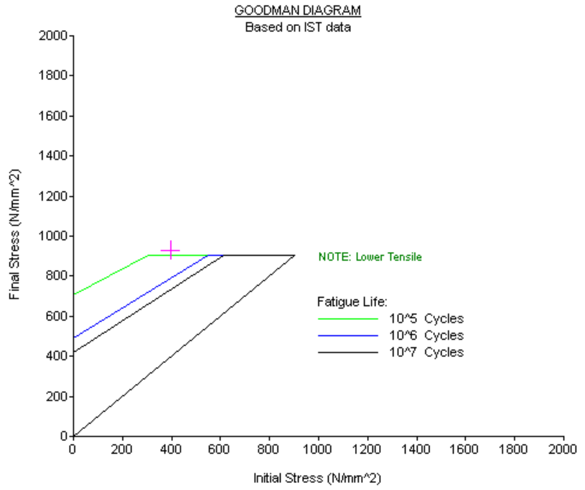
Tech-Spring design method selected from drop down menu starts the process

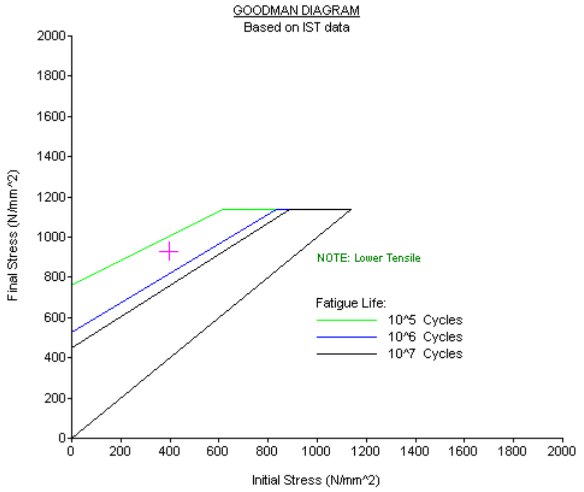
Fig 7

In this example a gain in available prestress of just under 4% of the tensile strength can be achieved (using corrected stress values).

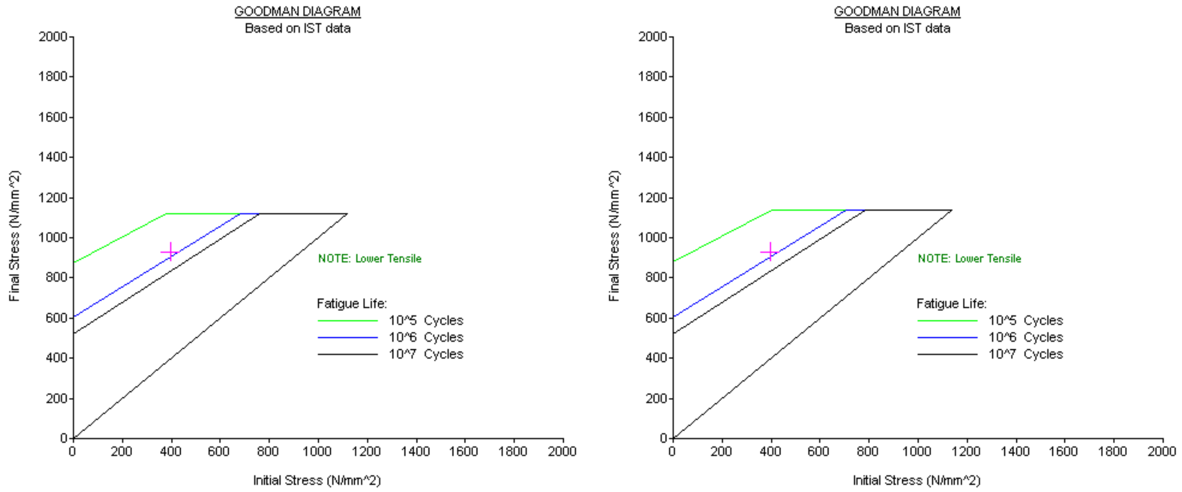
Compression springs – effect of prestressing level on Goodman diagram

An example is shown below. The first pair of Goodman diagrams are for DM strength material, where the solid stress is 57% of UTS (compared to the Tech-Spring index-dependent unprestress limit of 45.6%). The change in the diagrams without (left) and with (right) the prestress option selected is considerable.





The second pair of diagrams is for a specified grade of material with much higher strength (2450 MPa). Here the solid stress is 46% of UTS, which is only just over the unprestressed limit, so the change in the fatigue diagrams made by ticking the prestress option button is minimal.



NOTE: *This is for a free length of 18.75mm, rest of design as before with operating data 15mm & 10mm.*

Fig 8

2b Prestressing Effect On Springs

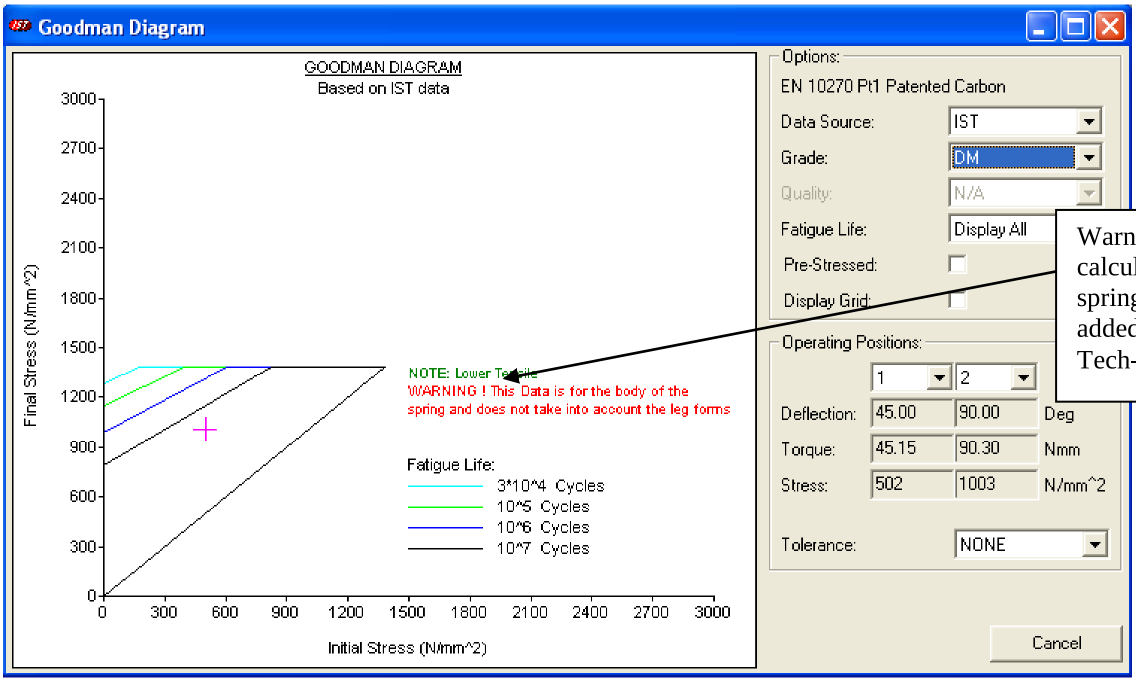
Report 13and 13A addressed the testing and fatigue performance of various torsion spring designs, and as a consequence rated the leg types in order of preference for use in fatigue applications. Torsion spring fatigue testing is significantly slower than testing compression and extension springs, meaning that the amount of torsion spring fatigue data generated within Tech-Spring was insufficient to develop a fully robust calculation method for torsion spring fatigue predictions. The planned alteration to the toolkit was to add a number of warnings / guidance notes to the Goodman diagrams for torsion springs. A number of additional warning flags were created within the Tech-Spring toolkit to help users select suitable torsion spring designs. One of the dominant features for torsion spring fatigue performance is the leg length and leg type. Examples of those flags follow:-

Conclusion 2a

Historically the unprestressed and prestress limits for compression springs within design standards have been set to be conservative – to avoid problems and premature fatigue failures in use – this was done around fifty years ago, before prestressing and its effects were fully understood. The main benefit of adopting this Tech-Spring method / format is that the use of more highly stressed spring designs, where prestressing can be used to maximum effect is encouraged (The spring designer must however be aware of the change he is making and the risk that is being taken with this design methodology). This in turn will lead to a lighter spring (weight savings usually in the range 10-30%) being used for a given application, which in turn leads to less material consumption and greater energy efficiency, which were original goals of the Tech-Spring project.

Conclusion 2b

Torsion springs fatigue performance is now significantly better understood than previously, so that guidance and warnings concerning leg types can be given. Sigificantly more additional fatigue results will be required to enable torsion springs fatigue performance to be fully predicted like the other two spring types.



NOTE: Lower Tensile
WARNING ! This Data is for the body of the spring and does not take into account the leg forms

Options:
EN 10270 Pt1 Patented Carbon
Data Source: IST
Grade: DM
Quality: N/A
Fatigue Life: Display All
Pre-Stressed: ☐
Display Grid: ☐

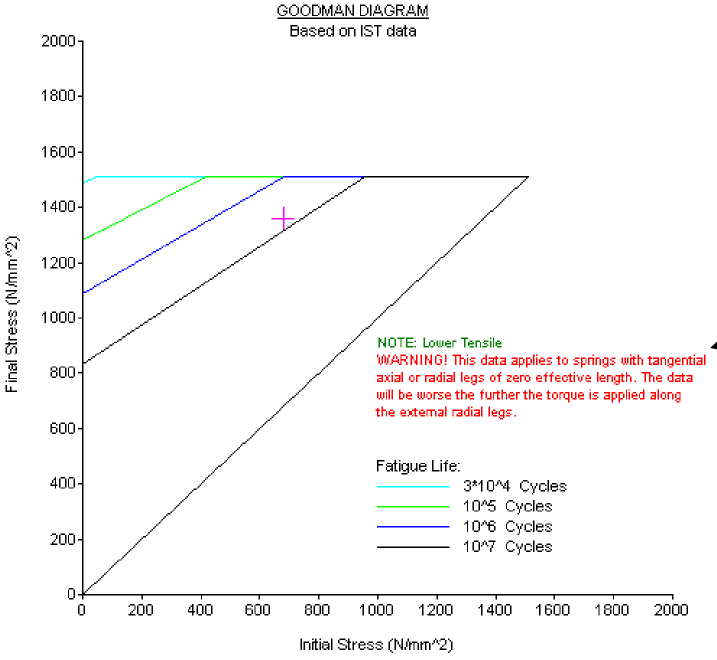
Operating Positions:

	1	2	
Deflection:	45.00	90.00	Deg
Torque:	45.15	90.30	Nmm
Stress:	502	1003	N/mm^2

Tolerance: NONE

Warning that calculation is for spring body only – added as a result of Tech-Spring

Fig 9



NOTE: Lower Tensile
WARNING! This data applies to springs with tangential axial or radial legs of zero effective length. The data will be worse the further the torque is applied along the external radial legs.

Warning about fatigue performance of various leg types- added as a result of Tech-Spring

Fig 10

3. Shortening of Compression Springs During Prestressing

This was examined in report 12. Up until the Tech-Spring work a spring maker had to guess the as coiled length of a compression spring, so that the required length of spring was produced after prestressing (all compression springs shorten during prestressing). Alternatively the spring maker had to perform production trials to assess the shortening on an individual production job basis. This usually required several prototype springs to be coiled and prestressed to determine the final length – a time consuming and expensive process. Report 12 enabled a much more precise estimate of shortening to be generated.

Customer requires   length at coiler

Fig 11

The amount of shortening for a spring was found to be related to the index of the spring and its tensile strength, as the following two diagrams indicate:-

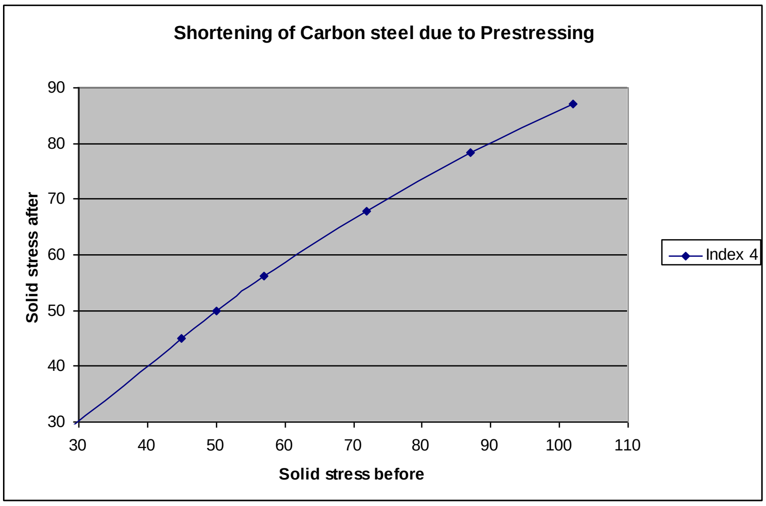


Fig 12

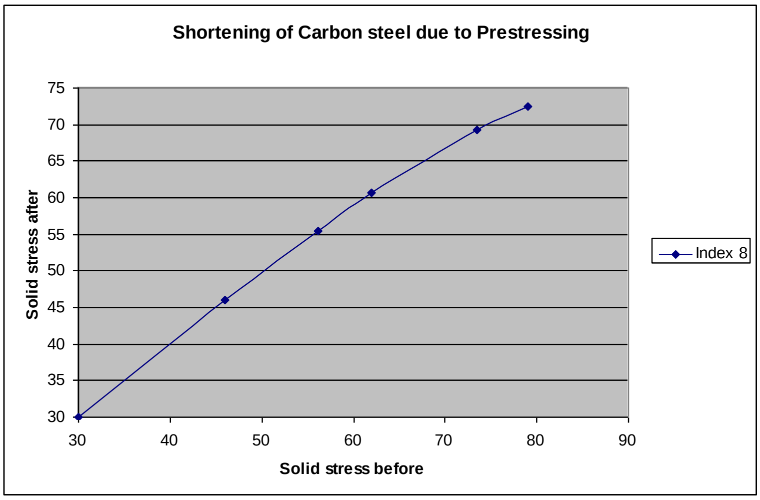
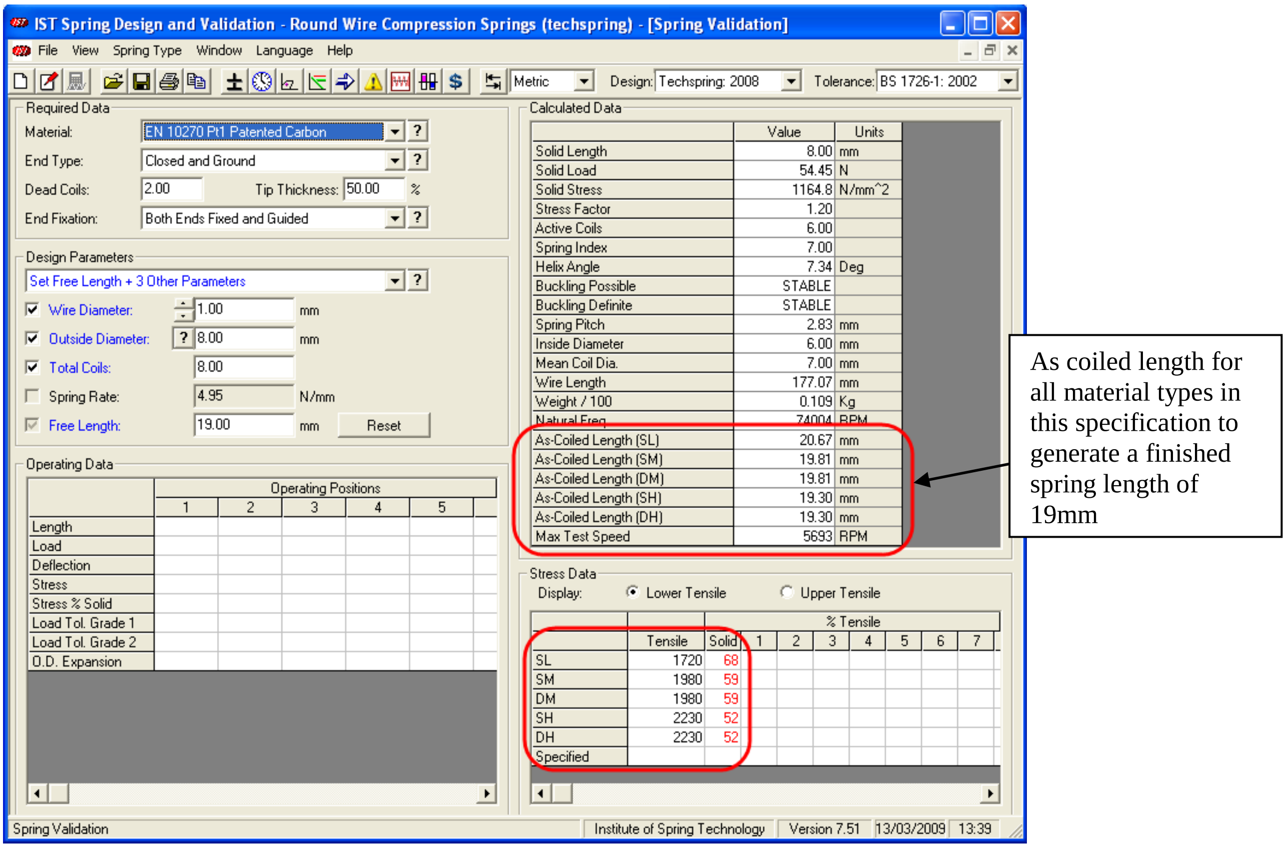


Fig 13

The original intention was to add a separate page into the software display to enable shortening during prestressing to be calculated. During development it was realised that this new data could be added directly into the calculated spring data page itself. This was incorporated as follows:-

A worked example of a compression spring

- Material: EN 10270-1 Patented Carbon steel
- Spring End Types: Closed & Ground, 50% tip thickness, 2 dead coils
- Wire diameter: 1 mm
- Outside diameter: 8 mm
- Total coils: 8
- Free length: 19 mm



Metric
Design: Techspring: 2008
Tolerance: BS 1726-1: 2002

Required Data
Material: EN 10270 Pt1 Patented Carbon
End Type: Closed and Ground
Dead Coils: 2.00
Tip Thickness: 50.00 %
End Fixation: Both Ends Fixed and Guided

Design Parameters
Set Free Length + 3 Other Parameters
☑ Wire Diameter: 1.00 mm
☑ Outside Diameter: 8.00 mm
☑ Total Coils: 8.00
☐ Spring Rate: 4.95 N/mm
☑ Free Length: 19.00 mm

Operating Data

	Operating Positions				
	1	2	3	4	5
Length					
Load					
Deflection					
Stress					
Stress % Solid					
Load Tol. Grade 1					
Load Tol. Grade 2					
O.D. Expansion					

Calculated Data

	Value	Units
Solid Length	8.00	mm
Solid Load	54.45	N
Solid Stress	1164.8	N/mm^2
Stress Factor	1.20	
Active Coils	6.00	
Spring Index	7.00	
Helix Angle	7.34	Deg
Buckling Possible	STABLE	
Buckling Definite	STABLE	
Spring Pitch	2.83	mm
Inside Diameter	6.00	mm
Mean Coil Dia.	7.00	mm
Wire Length	177.07	mm
Weight / 100	0.109	Kg
Natural Freq	74004	RPM
As-Coiled Length (SL)	20.67	mm
As-Coiled Length (SM)	19.81	mm
As-Coiled Length (DM)	19.81	mm
As-Coiled Length (SH)	19.30	mm
As-Coiled Length (DH)	19.30	mm
Max Test Speed	5693	RPM

Stress Data
Display: ● Lower Tensile ○ Upper Tensile

			% Tensile						
	Tensile	Solid	1	2	3	4	5	6	7
SL	1720	68							
SM	1980	59							
DM	1980	59							
SH	2230	52							
DH	2230	52							
Specified									

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As coiled length for all material types in this specification to generate a finished spring length of 19mm

Fig 14

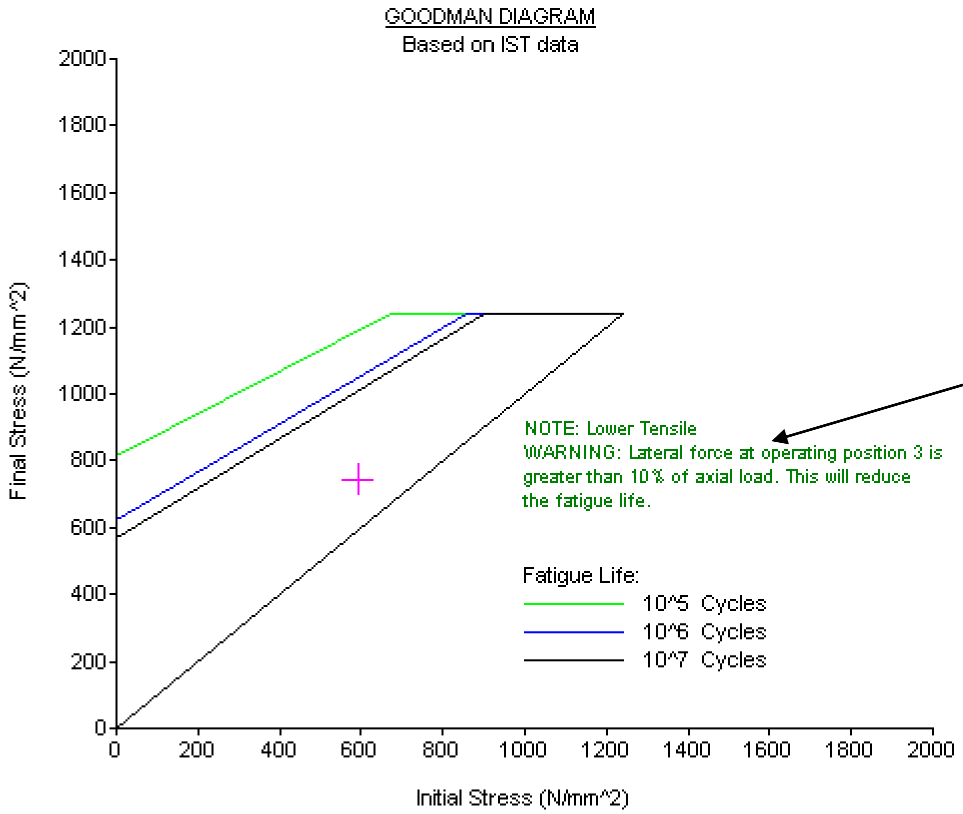
In this case to obtain a finished spring length of 19 mm after prestressing, the spring had to be coiled longer (1.67mm for the lowest strength wire and 0.3 mm longer for the highest strength wire)

Conclusion

Historically it is well known that a compression spring shortens during prestressing, but no study had been made to quantify this change, because this was known to be very difficult to predict. Spring makers were forced to make samples, prestress and measure, or guess the shortening due to prestressing and make allowances for this at the coiling stage. The Tech-Spring work has quantified approximately the length change due to prestressing saving spring makers production time, reducing wasted material, and making production leaner and more efficient – again all objectives of the original Tech-Spring project.

4. The Effect of Non Axial Forces on Fatigue Life of Compression Springs

Report no 14 identified that there was no effect on fatigue performance when the shear force was less than 10% of the axial load for compression springs. The initial plan was to incorporate a warning on the Goodman diagrams generated by the toolkit that warned when 10% additional stress was possible. Since this never arose during the Tech-Spring project the warning was only used when a transverse load was applied. This was incorporated into the software so that the following style of warning is produced:-

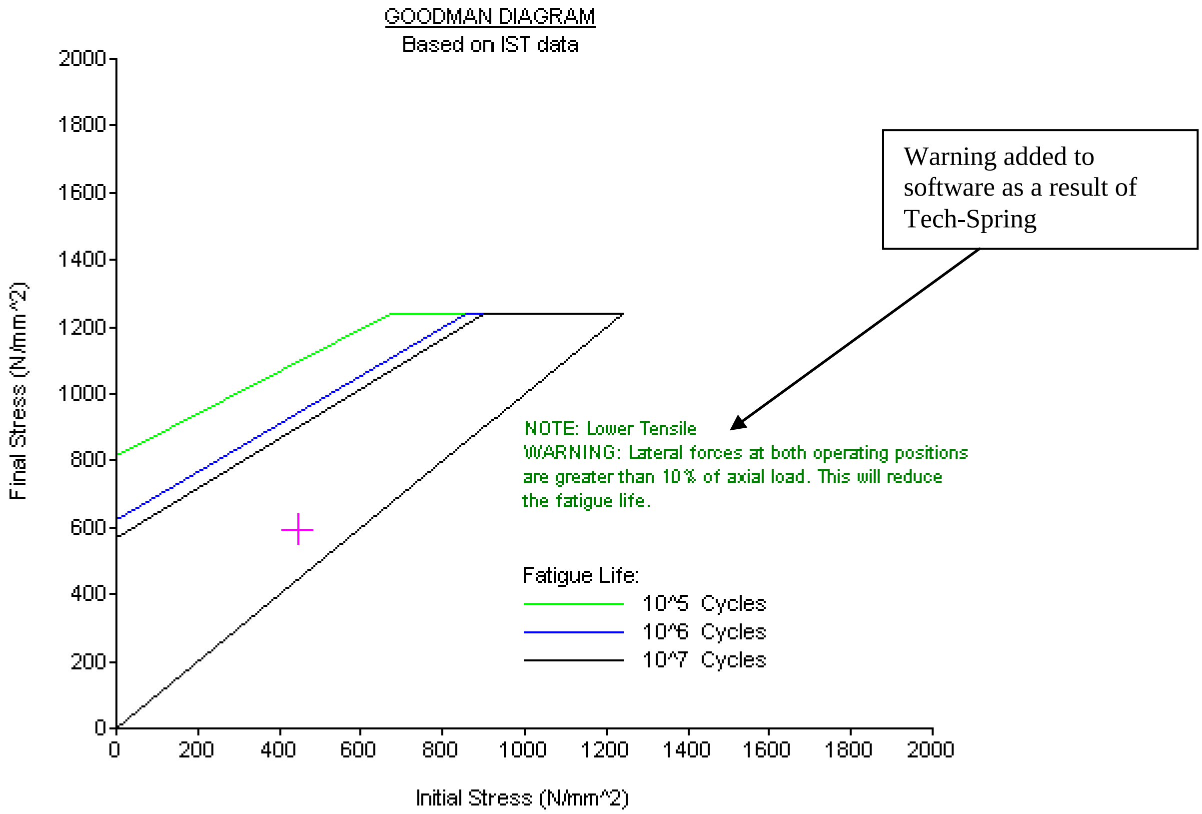


NOTE: Lower Tensile
WARNING: Lateral force at operating position 3 is greater than 10% of axial load. This will reduce the fatigue life.

New warning flag added to software as a result of Tech-Spring

Fig 15

The original idea was further developed so that if there are more than one loading condition where a lateral force is applied then the software can also reflect this condition, as follows:-



Warning added to software as a result of Tech-Spring

Fig 16

5. End Coil Failures

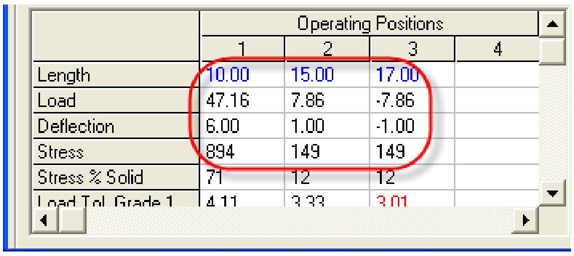
Report number 15 detailed the known parameters that influence the risk of compression spring end coil failure. No reason was identified for including these data into the toolkit.

Conclusion

End coil failure risk is low, and no reason to include warnings in the toolkit was identified.

6. The Effect on Fatigue Life of Operating a Compression Spring in Push – Pull Mode

Report number 16 identified that the stress range in fatigue is more important than the magnitude of maximum stress – negative stresses effectively increase the overall stress range applied to a spring. Previous versions of the software did not allow a working length longer than the free length to be entered, meaning that only compression of the spring could be considered. The first modification of the software toolkit was therefore to allow this without warnings or errors, as shown below. Note that the stress value is always shown as positive, regardless of direction of deflection.



	Operating Positions			
	1	2	3	4
Length	10.00	15.00	17.00	
Load	47.16	7.86	-7.86	
Deflection	6.00	1.00	-1.00	
Stress	894	149	149	
Stress % Solid	71	12	12	
Load Tol. Grade 1	4.11	3.33	3.01	

Fig 17 (for a spring free length = 16 mm)

The conventional Goodman diagrams within IST’s software plot a cross based on initial and final stress values, as shown in the example below where the initial stress was 149 MPa and the final stress was 894 MPa (the initial stress is always considered to be the lower), giving (x,y) co-ordinates of (149,894). This automatically makes the stress *range* the distance above the bottom diagonal line (where initial stress is equal to final stress, representing no deflection), as shown by the dashed line.

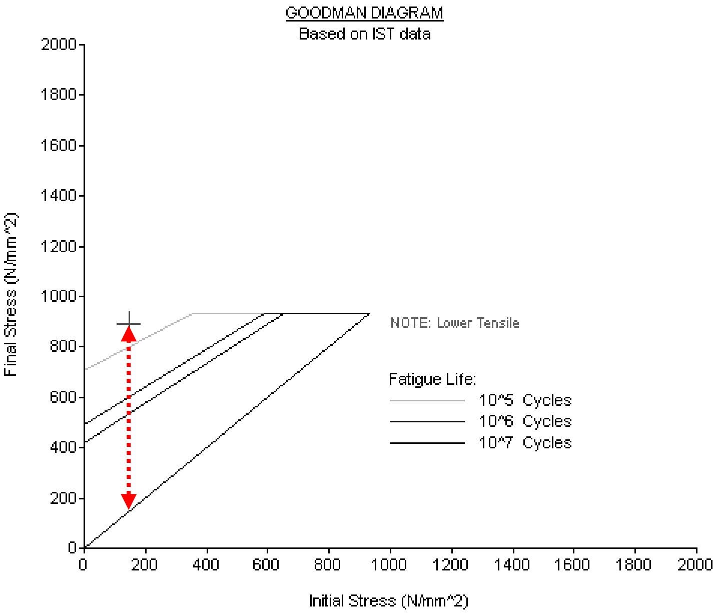


Fig 18

When one of the positions is at negative deflection, the Final Stress value becomes what is termed the Equivalent Final Stress, effectively the value needed to give the correct stress range. This is shown in the diagram below, which plots a compressive deflection resulting in a stress of 894 MPa and a negative deflection resulting in a stress of 149 MPa. The initial stress is the lower of the two (149 MPa) and the Equivalent Final Stress is 149 plus the stress range of 149+894, i.e. 1192 MPa.

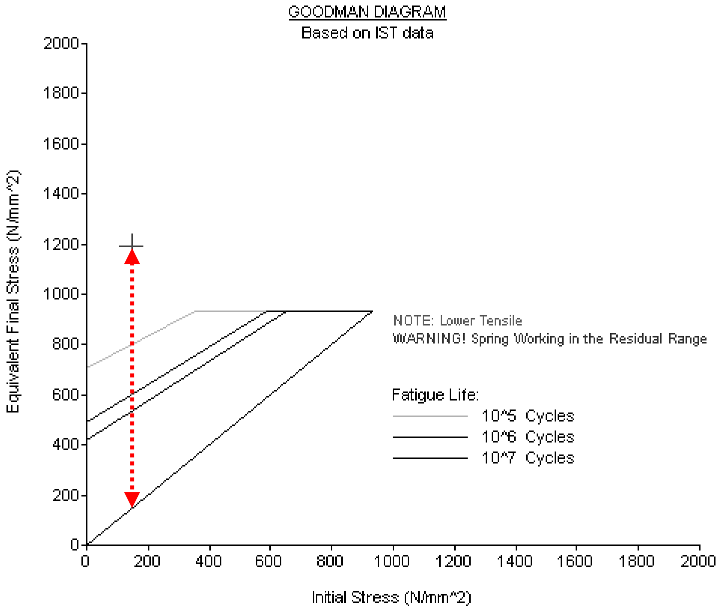


Fig 19

Conclusion

It is relatively unusual for compression springs to be operated in this push – pull mode, but certain applications require exactly this method of use. Unexpected (usually premature) fatigue failures have been common in this these uses – this is the first time that a method / technique has been developed to identify and explain this. As this report was in production Turton Springs informed the coordinator that a large vibratory screen spring has failed in a manner that appears to be identical to the above situation – further work is planned to examine this spring with the above method.

7. Incorporation of the New High Strength Material into the Software Toolkit

One way to reduce the weight of a spring is to use a higher strength material so that a higher stress can be accommodated. The Si Cr V material developed by Pengg is an example of a very high strength spring material, which is stronger than currently available high strength materials controlled by EN (European), ASTM (American) or JIS (Japanese) material specifications. The process for getting a new spring material into these world leading standards is fairly long and laborious, and could not be accommodated within the time frame of this project. But adding this material into the spring design toolkit is readily achievable within the project time frame. Pengg will probably eventually identify this new material as a proprietary product once sufficient experience has been gained with it.

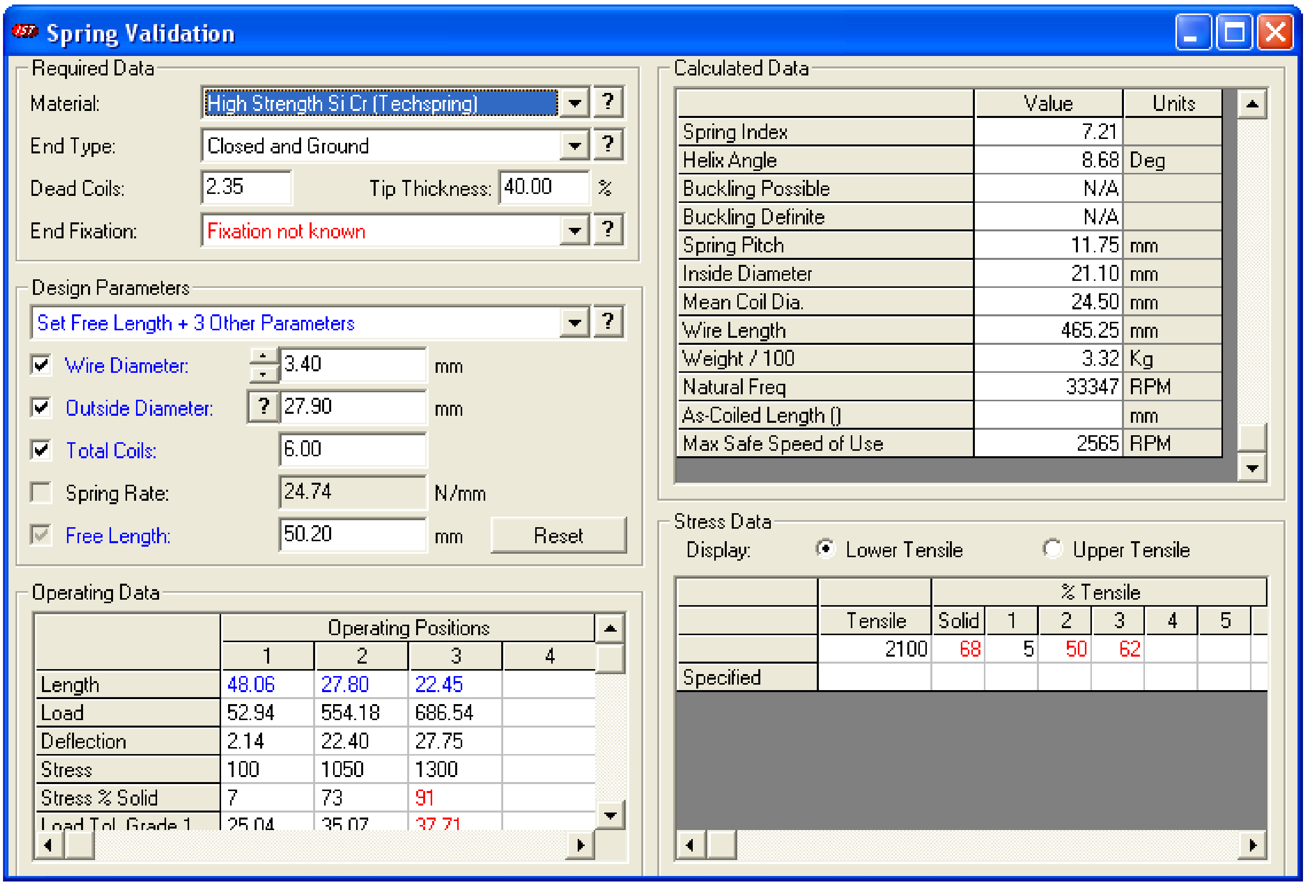
Nearly 150 materials have been previously incorporated into the spring design software, meaning that the incorporation of a new material is a routine process at IST – in this case the new material has been given the designation SiCrV (Tech-Spring) within the software.

The data incorporated into the toolkit for this material is as follows:-
Material name: **High strength Si Cr (Tech-Spring)**

Size Range 2.5 – 5 mm diameter

Tensile Range: 2100 – 2300 N/mm²

Generating the spring validation page shown below:-



Spring Validation

Required Data

Material: High Strength Si Cr (Techspring)
End Type: Closed and Ground
Dead Coils: 2.35
Tip Thickness: 40.00 %
End Fixation: Fixation not known

Design Parameters

Set Free Length + 3 Other Parameters

☑ Wire Diameter: 3.40 mm
☑ Outside Diameter: 27.90 mm
☑ Total Coils: 6.00
☐ Spring Rate: 24.74 N/mm
☑ Free Length: 50.20 mm

Operating Data

	Operating Positions			
	1	2	3	4
Length	48.06	27.80	22.45	
Load	52.94	554.18	686.54	
Deflection	2.14	22.40	27.75	
Stress	100	1050	1300	
Stress % Solid	7	73	91	
Load Tol. Grade 1	25.04	35.07	37.71	

Calculated Data

	Value	Units
Spring Index	7.21	
Helix Angle	8.68	Deg
Buckling Possible	N/A	
Buckling Definite	N/A	
Spring Pitch	11.75	mm
Inside Diameter	21.10	mm
Mean Coil Dia.	24.50	mm
Wire Length	465.25	mm
Weight / 100	3.32	Kg
Natural Freq	33347	RPM
As-Coiled Length ()		mm
Max Safe Speed of Use	2565	RPM

Stress Data

Display: ● Lower Tensile ○ Upper Tensile

		% Tensile					
	Tensile	Solid	1	2	3	4	5
	2100	68	5	50	62		
Specified							

Fig 20

Goodman Diagram:

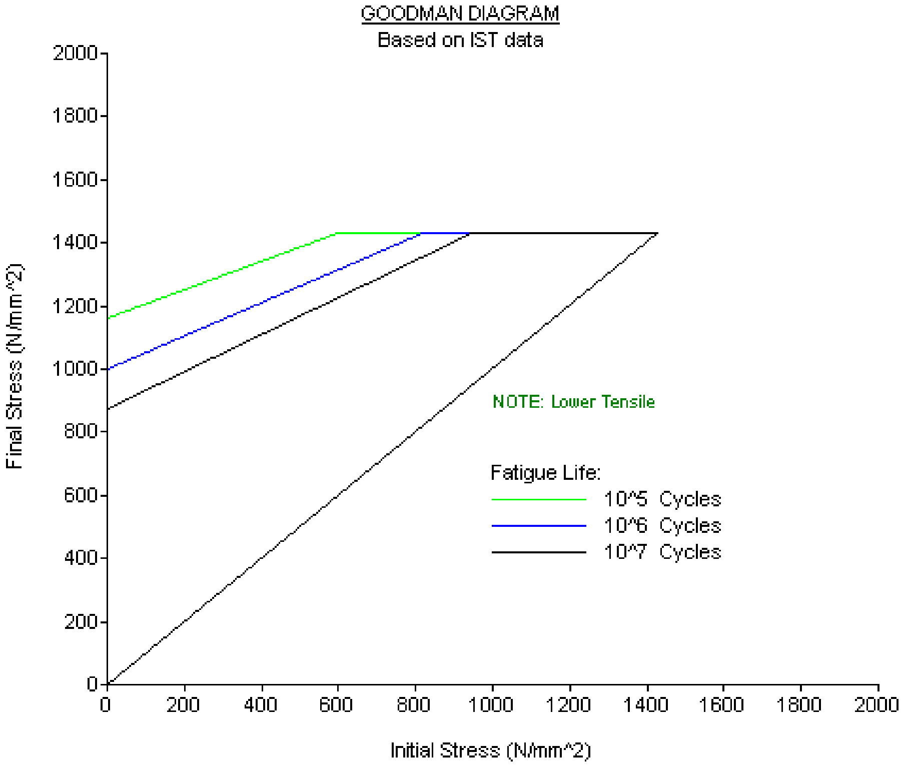
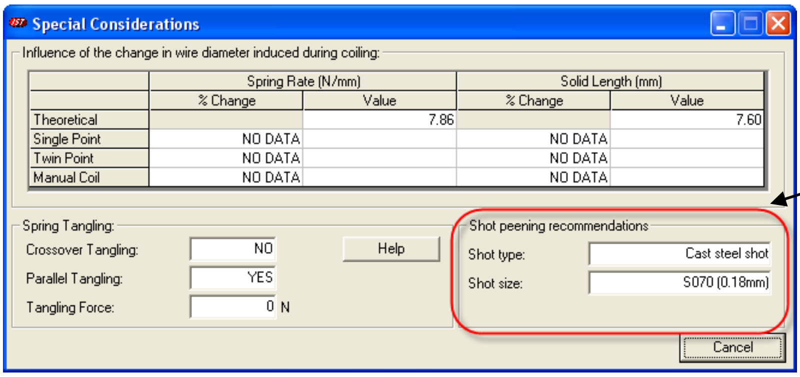


Fig 21

8. Shot Peening of Springs

Report numbers 18 and 18A define types and sizes of shot and glass beads that can be used to shot peen springs of certain sizes and material types in order to generate suitable residual stresses in the surfaces of springs for improved fatigue performance. This information is consistent and repeatable so that it can be incorporated into the software effectively as a look up table. The original concept was to allow a spring design to be done in the normal manner, and then produce an additional page within the software that could be used to display the appropriate shot peening recommendations. During development it became clear that the shot peening information could readily be presented on the “special considerations” page as the following example shows:-



Influence of the change in wire diameter induced during coiling:

	Spring Rate (N/mm)		Solid Length (mm)	
	% Change	Value	% Change	Value
Theoretical		7.86		7.60
Single Point	NO DATA		NO DATA	
Twin Point	NO DATA		NO DATA	
Manual Coil	NO DATA		NO DATA	

Spring Tangling:

Crossover Tangling: NO
Parallel Tangling: YES
Tangling Force: 0 N

Shot peening recommendations

Shot type: Cast steel shot
Shot size: S070 (0.18mm)

Recommended shot size and type identified for each design

Fig 22

An extension to this feature to include the recommended Almen Arc Rise is under consideration at present. It will always be impossible to give all recommended shot peening operating parameters such as gun air pressure, peening time, impeller speed etc as these will be potentially different for every shot peening cabinet around the world. Addition of a user defineable “peening parameters page” could potentially automate a companies peening media and process control process in the future.

Conclusion

Incorporation of some shot peening control parameters into the toolkit serves as good guidance to spring makers as to what types of peening treatements are possible and effective for a particular spring design. The report itself, which is available electronically will provide an on line reference to spring makers concerning the appearance of correctly and badly peened spring surfaces.

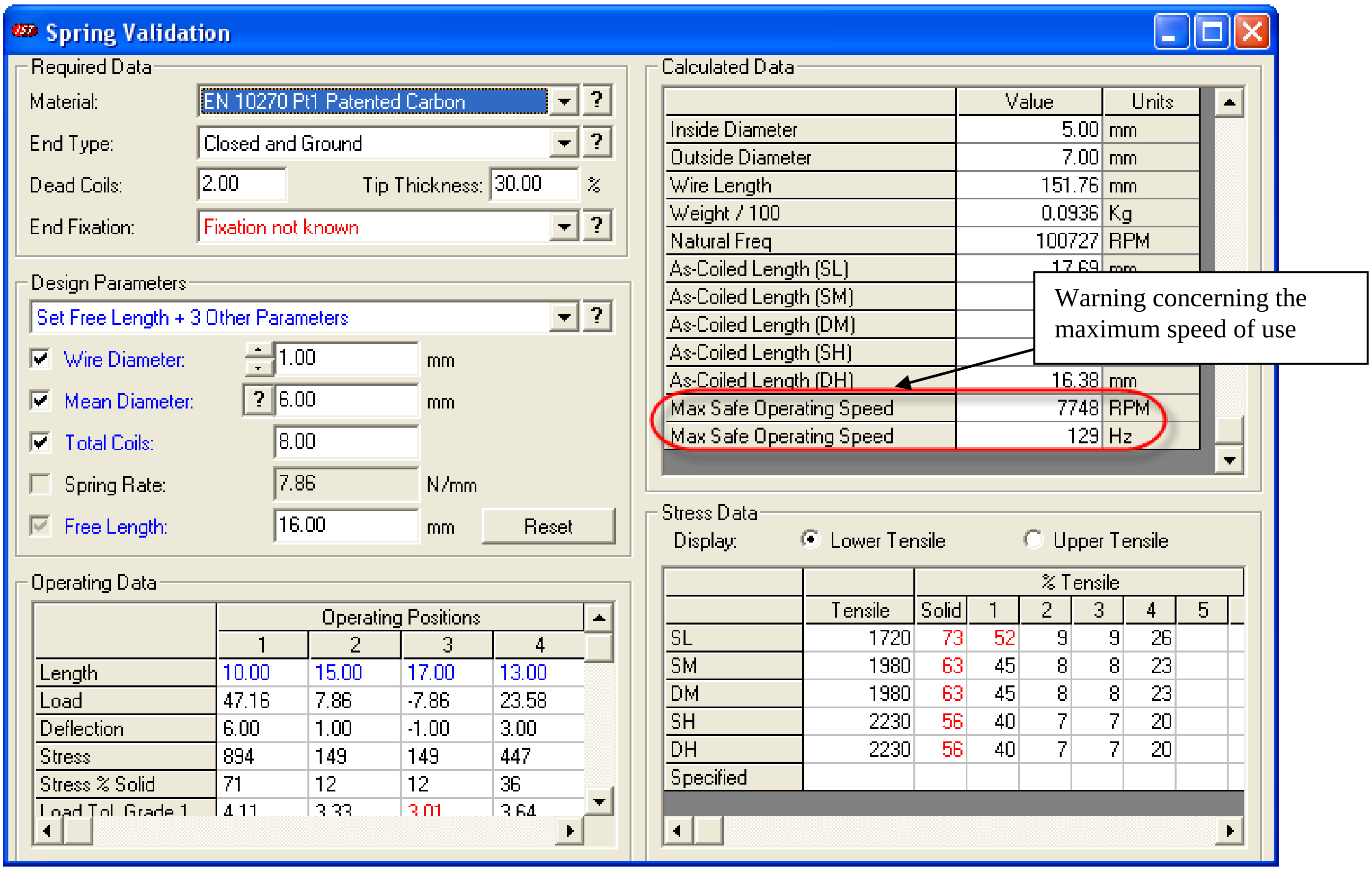
9. The Speed of Fatigue Testing

Report number 19 specifically examined the speed of testing in terms of how fast a fatigue test can be run (to minimise test duration), without adversely affecting the fatigue result obtained.

Report number 20A and 20B specifically examined spring resonance and harmonics related to resonance. Harmonics down to 1/13th of the spring’s natural frequency can produce unexpected and uncontrolled vibration within a spring that is extremely harmful to the survival of the spring.

Both of these findings point towards some form of warning being required in the toolkit to avoid springs being operated at too high a frequency.

The existing spring design software already calculates the natural frequency of a spring. The addition in the Tech-Spring toolkit is to add a maximum speed of use indication box into the calculated data page of the software. The calculation of this is built into the software in such a way that the operator has no additional work input to make. An example follows:-



Required Data

Material: EN 10270 Pt1 Patented Carbon

End Type: Closed and Ground

Dead Coils: 2.00 Tip Thickness: 30.00 %

End Fixation: Fixation not known

Design Parameters

Set Free Length + 3 Other Parameters

☑ Wire Diameter: 1.00 mm

☑ Mean Diameter: 6.00 mm

☑ Total Coils: 8.00

☐ Spring Rate: 7.86 N/mm

☑ Free Length: 16.00 mm

Operating Data

	Operating Positions			
	1	2	3	4
Length	10.00	15.00	17.00	13.00
Load	47.16	7.86	-7.86	23.58
Deflection	6.00	1.00	-1.00	3.00
Stress	894	149	149	447
Stress % Solid	71	12	12	36
Load Tol. Grade 1	4.11	3.33	3.01	3.64

Calculated Data

	Value	Units
Inside Diameter	5.00	mm
Outside Diameter	7.00	mm
Wire Length	151.76	mm
Weight / 100	0.0936	Kg
Natural Freq	100727	RPM
As-Coiled Length (SL)	17.69	mm
As-Coiled Length (SM)		
As-Coiled Length (DM)		
As-Coiled Length (SH)		
As-Coiled Length (DH)	16.38	mm
Max Safe Operating Speed	7748	RPM
Max Safe Operating Speed	129	Hz

Warning concerning the maximum speed of use

Stress Data

Display: ● Lower Tensile ○ Upper Tensile

		% Tensile					
	Tensile	Solid	1	2	3	4	5
SL	1720	73	52	9	9	26	
SM	1980	63	45	8	8	23	
DM	1980	63	45	8	8	23	
SH	2230	56	40	7	7	20	
DH	2230	56	40	7	7	20	
Specified							

Fig 23

As this report was in production it was decided to amend the “max test speed” label to be “max operating speed” reflecting the fact that whether under test or in use a spring operated at too high a frequency will experience resonance.

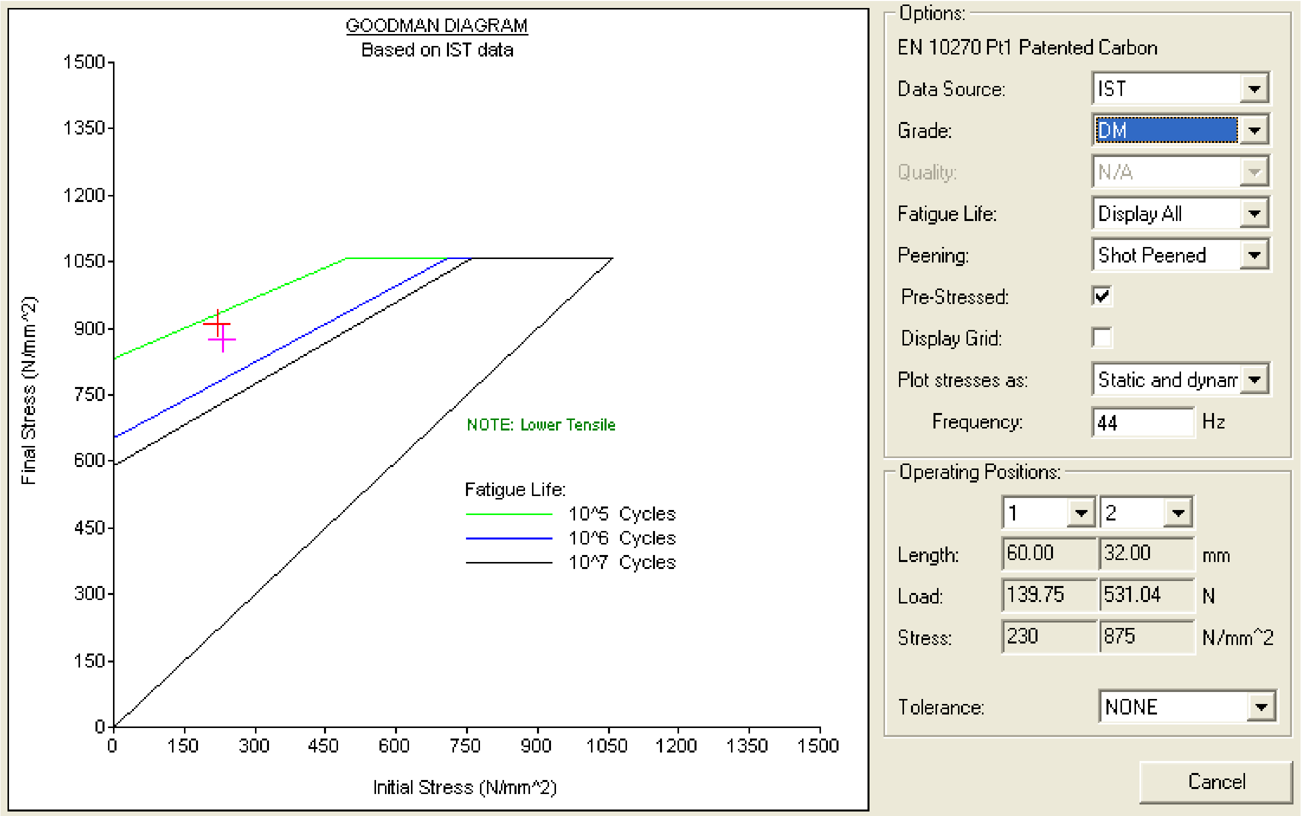
Reports 20A and 20B further identified dynamic, torsional and lateral resonances and harmonics that have an adverse effect on spring fatigue lives. The exact method of reporting these resonances is under consideration at present for incorporation into Tech-Spring toolkit 3. The toolkit has utilised the Goodman Diagram page to show the effect of dynamic stresses when the operating speed exceeds the maximum safe operating speed shown above.

Conclusion

Identification and examination of all the possible resonances and harmonics effects is vital information for springs operated at relatively high speeds, such as engine valve springs. The information is certain to enable the solution of a number of spring failures that have been hitherto unexplained.

10. Dynamically Induced Stresses

Operation of springs at resonance or at a harmonic of resonance can cause a spring to temporarily not behave in a predictable manner- this is particularly important for springs operated in a cam or in mechanisms that cause high acceleration rates in springs. Axial, torsional and lateral resonances can be predicted using the methodology given in reports 20A and 20B. The effects have been confirmed and recorded using high speed cameras. The initial idea to display this information within the software toolkit consisted of adding some additional information onto the Goodman diagram page as follows:-



Options:

EN 10270 Pt1 Patented Carbon

Data Source: IST

Grade: DM

Quality: N/A

Fatigue Life: Display All

Peening: Shot Peened

Pre-Stressed: ☑

Display Grid: ☐

Plot stresses as: Static and dynam

Frequency: 44 Hz

Operating Positions:

	1	2	
Length:	60.00	32.00	mm
Load:	139.75	531.04	N
Stress:	230	875	N/mm^2

Tolerance: NONE

Fig 24

A drop down menu was added to enable the standard Goodman diagram to be modified to display slow and high speed dynamic stress at a user definable frequency. The pink cross is a slow fatigue speed stress and the red cross is the dynamic stress, indicating that at high speeds the stress on the spring actually increases.

Conclusion

Identification of resonant frequencies in various modes will be of most use to spring users where the speed of actuation or operation of a spring is high – this is likely to include engine valve springs, vibratory screen springs and possibly electronics and solenoid valve users.

Summary

This report identifies the findings that have been incorporated into the Tech-Spring toolkit so far, that will shortly be issued to the Consortium as software toolkit 3 for further evaluation during May 2009. It is possible that some of the features will be modified as a result of evaluation. This will lead to the final version of the software – toolkit 4 later in the year.