Tech-Spring Report 13A
Fatigue Testing of Torsion Springs.

This report represents the completion of the testing program that was previously partially reported in report 13.

Introduction

This programme of work is designed to enable the fatigue performance to be quantified for torsion springs with various leg types, both in the wind up and in the unwind directions. Both carbon steel and 302 stainless steel springs have now been tested. Necessarily test speeds for this type of spring are low and IST's capacity is limited making the overall test programme quite protracted.

It was agreed by the Consortium partners to use uncorrected stresses for the purpose of this report.

Stainless Steel Spring Test Program

All the springs 5A-5D were manufactured from 2.75mm diameter EN 10270-3 1.4301 NS grade wire, that has been checked by IST to be free from significant surface defects. The springs had the appearance of having been stress relieved after coiling. Springs with internal radial legs were tested at 500rpm and springs with tangential or external radial legs were tested at approximately 40rpm.

The spring designs were as follows:

Design	Do/mm	Coils	Leg	Coiling
5A (d = 2.75mm)	26.95	5.27	Internal radial	Close coiled
5B (d = 2.75mm)	26.95	5.27	Internal radial	Open coiled
5C (d = 2.75mm)	26.95	5.42	External radial	Close coiled
5D (d = 2.75mm)	26.95	5.42	Tangential	Close coiled
6 (d = 3mm)	24.3	5.68	Tangential	Open coiled

Fig 1

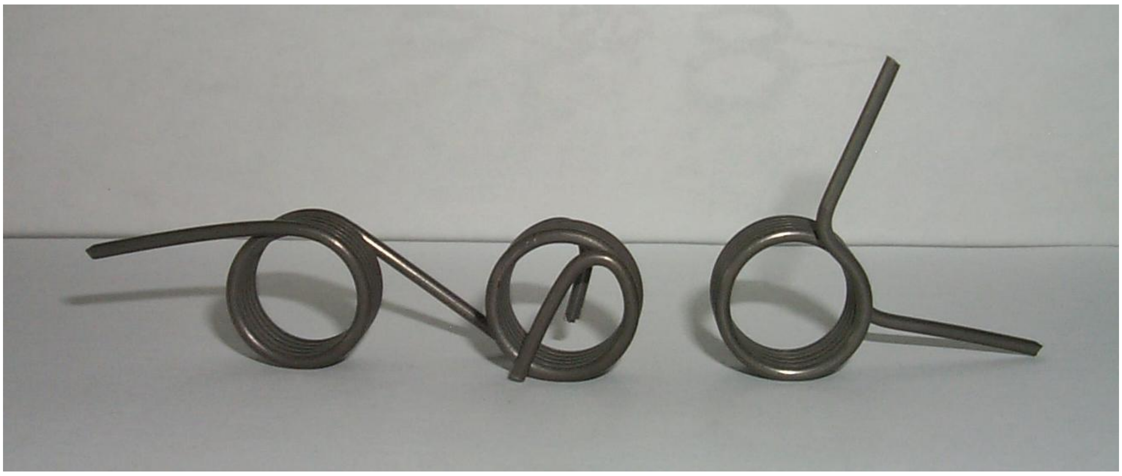
Fig 2 Spring designs – tangential legs, internal radial legs and external radial legs

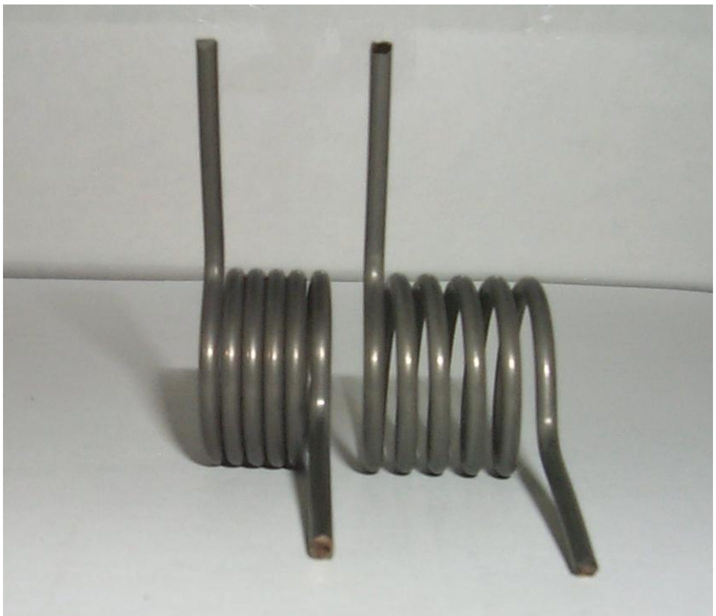
Fig 3 - Close coiled and open coiled

A typical stainless steel spring design printout from IST's CAD program is shown below utilising the EN 13906-3 design methodology.

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Identifier: 5C
Part No.: External radial legs
Details: 810j)

Spring Type Round / Rect Wire Torsion

Designed To:	EN 13906-3: 2002	
Tolerance Standard:	DIN 2194: 2002	

Material

EN 10270 Pt3 Aust. Stainless

Youngs Mod (E):	185000	N/mm^2
Rigidity Mod (G):	73000	N/mm^2
Density:	.00000790	Kg/mm^3
Unprestress:	0-70	%
Prestress:	70-100	%
Wire Section:	Round Wire	
Leg Type:	Radial Leg	
Length Leg 1:	17.00	mm
Length Leg 2:	35.00	mm

Calculated Data

Body Length:	18.03	mm
Body Length (Max):	19.54	mm
Partial Angle (Free):	208.80	Deg
Stress Factor:	1.10	
Spring Index:	8.84	
Inside Diameter:	21.47	mm
Mean Coil Dia.	24.21	mm
Wire Length:	476.68	mm
Weight / 100:	2.22	Kg
Natural Freq:	9662.9	RPM

Design Parameters

Wire Diameter:	2.74	mm
Outside Diameter:	26.95	mm
Total Coils:	5.58	
Spring Rate:	20.22	Nmm/Deg (Calculated)

Stress Data

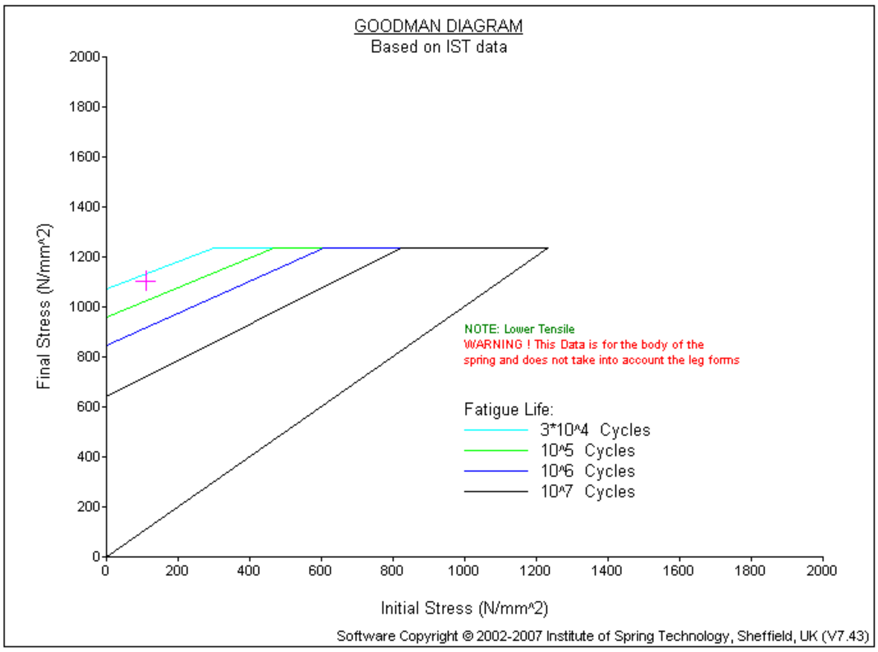
	Lower Tensile	Operating Positions % Tensile 1	2	3
NS	1600	13 U	25 U	75 P
HS	1700	12 U	24 U	71 P
Specified				

Operating Data

	Operating Positions 1	2	3
Torque (Nmm)	404.47	808.94	2426.8
Deflection (Deg)	20.00	40.00	120.00
Partial Angle (Deg)	228.80	248.80	328.80
Stress (Deg)	200	401	1202
Inside Diameter (N/mm^2)	21.23	21.00	20.11
Body Length (Max) (mm)	19.69	19.85	20.46
Load Tol. Grade 1 (mm)	337.65	337.65	337.65
Load Tol. Grade 2 (Nmm)	535.95	535.95	535.95
Load Tol. Grade 3 (Nmm)	857.52	857.52	857.52

Operating Positions

	1	3
Deflection: (Deg):	10.00	100.00
Torque: (Nmm):	202.24	2022.4
Corrected Stress (N/mm^2):	110	1103



One example of each spring type was torque tested in the wind up direction to establish the performance of each spring type. Results for the five designs were as follows:-

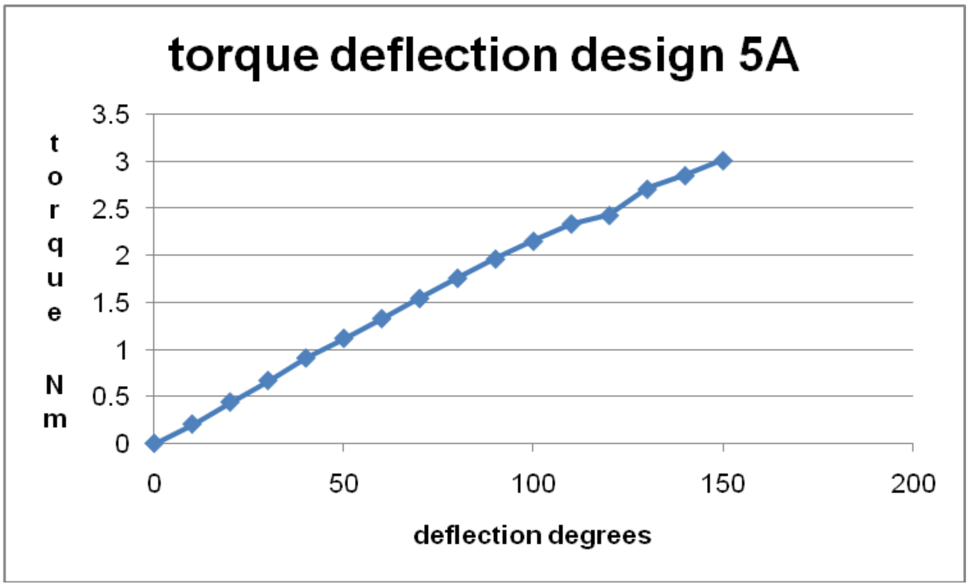


Fig 4

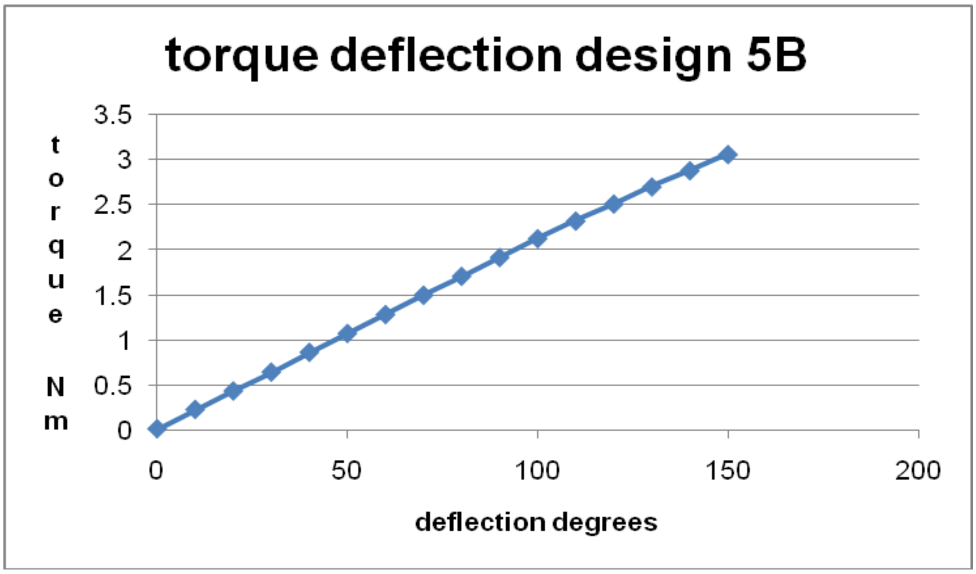


Fig 5

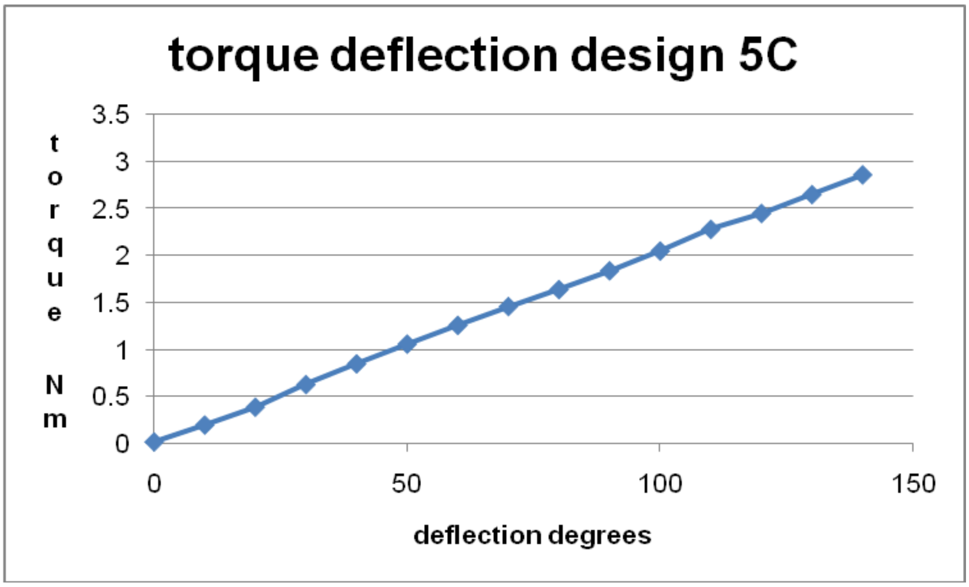


Fig 6 with L_1 = 17mm and L_2 = 35mm

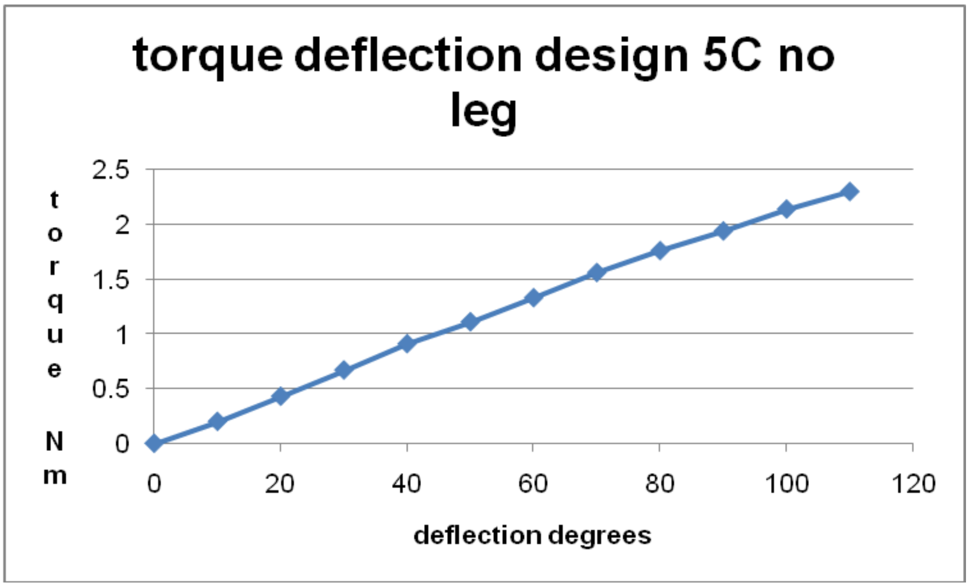


Fig 7 with $L_1 = L_2 = 0$mm

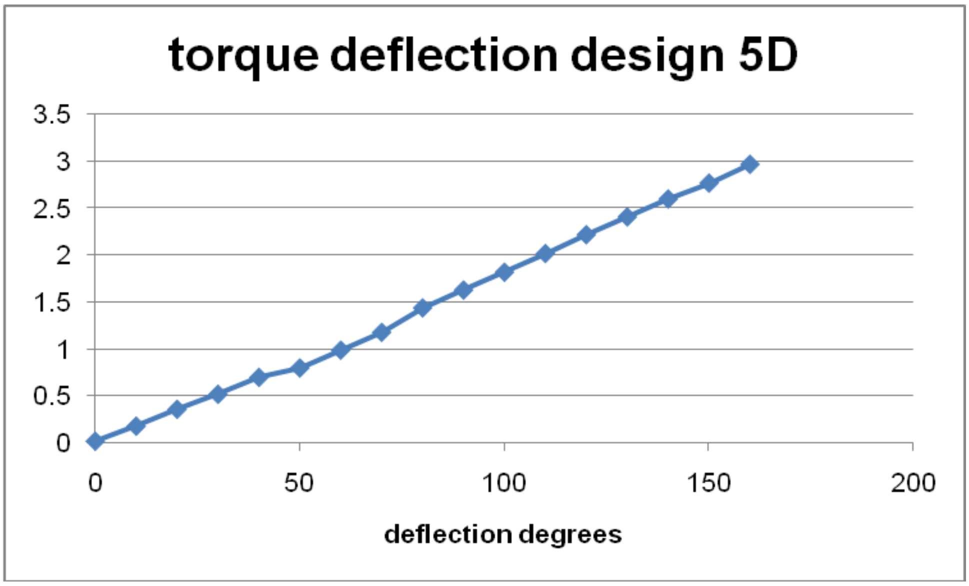


Fig 8 with $L_1 = 30$mm and $L_2 = 25$mm

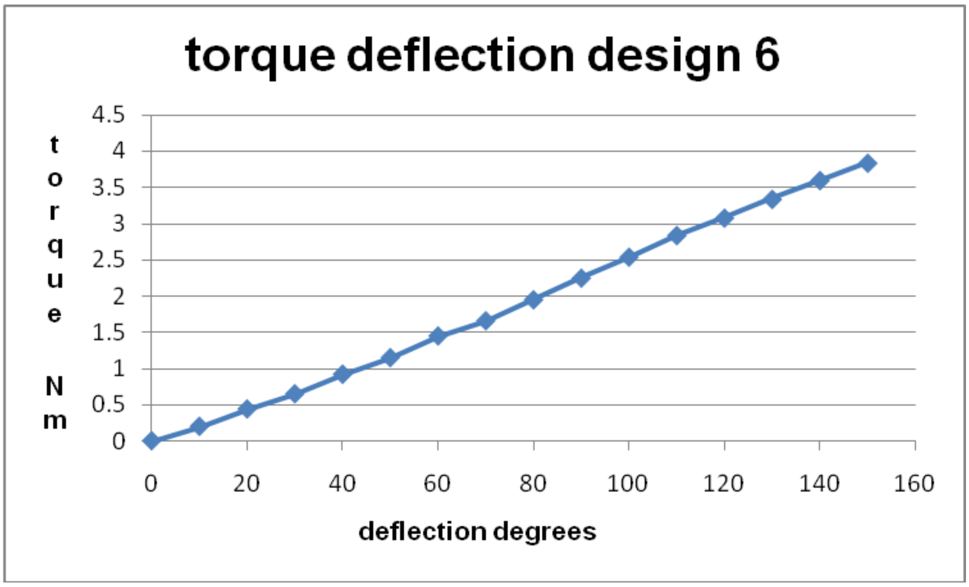


Fig 9 with L_1 = 50mm and L_2 = 28mm

Further examples of each spring type were then fatigue tested at IST. The following fatigue test results were obtained:-

Batch	Stress Range N/mm²	Lives
5A close IR	108-1291(no mandrel)	1,000,000, 1,000,000 both unbroken
5A close IR	108-1399(no mandrel)	128,530, 170,980
5A close IR	108-1506(no mandrel)	39,430 ~ 45,000
5A close IR	108-1614(no mandrel)	28,700 ~ 40,000
5B open IR	108-1184(no mandrel)	3,152,000 unbroken
5B open IR	108-1291(no mandrel)	1,000,000, 2,000,000 both unbroken
5B open IR	108-1399(no mandrel)	310,000, 325,000
5B open IR	108-1506(no mandrel)	225,740, 106,470, 107,760, 149,350
5B open IR	108-1614(no mandrel)	150,550, 38,000, 64,200, 71,570, 84460, 78,850, 39,480
5C (L_1 17, L_2 35) Close ER	102 - 614	132,590, 131,477, 133,171, 125,302
5C (L_1 17, L_2 35) Close ER	102 - 818	36,679, 48,520, 54,650, 46,526
5C (L_1 17, L_2 35) Close ER	102 - 1023	23,416, 21,871, 25,502, 21,557
5C (L_1 17, L_2 35) Close ER	102 - 1125	16,738, 19,111, 19,568, 15,569
5C (L_1 = L_2 = 0) Close ER	108 - 812	251,440 Unbroken
5C (L_1 = L_2 = 0) Close ER	108 - 1028	224,501 Unbroken
5C (L_1 = L_2 = 0) Close ER	108 - 1244	205,405 Unbroken

Batch	Stress Range N/mm²	Lives
5C ($L_1 = L_2 = 0$) Close ER	108 - 1461	93,239
5C ($L_1 = L_2 = 0$) Close ER	108 - 1677	5,835
5D Close Tangential	95 - 945	802, 165, 4 spring unbroken
5D Close Tangential	95 - 1134	71,737, 87,534, 114,854, 152,545
5D Close Tangential	95 - 1323	37,582, 47,138, 58,117, 77,044
5D Close Tangential	95 - 1512	23,756, 25,424, 27,238, 33,249
6	128 - 1150	600, 148 4 springs unbroken
open T	128 - 1278	73,787, 102,123, 114,759, 172,014
	128 - 1406	35,462, 61,337, 69,287, 70,675, 98,281
	128 - 1534	30,535
	128 -1661	29,488, <29,488

Fig 10

Carbon Steel Spring Test Program

All the springs 4A-4C were manufactured from 2.00mm diameter EN 10270-1 DH (DIN 17223-1 type D) grade wire, that has been checked by IST to be free from significant surface defects. The springs had the appearance of having been stress relieved after coiling. Springs with internal radial legs were tested at 500rpm and springs with tangential or external radial legs were tested at approximately 40rpm.

The spring designs were as follows:

Design	Do/mm	Coils	Leg	Coiling
4A1 (d = 2.00mm)	19.5	5.16	External radial	Open coiled
4A2 (d = 2.00mm)	19.5	5.16	External radial	Close coiled
4B1	19.5	5.0	Internal radial	Open coiled
4B4	19.5	5.0	Internal radial	Close Coiled
4C1 (d = 2.00mm)	19.5	5.16	Tangential	Open coiled
4C2 (d = 2.00mm)	19.5	5.16	Tangential	Close coiled

Fig 11

A typical carbon steel spring design printout from IST's CAD program is shown below utilising the EN 13906-3 design methodology.

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Spring Type Round / Rect Wire Torsion

Designed To:	EN 13906-3: 2002	
Tolerance Standard:	DIN 2194: 2002	

Material

EN 10270 Pt1 Patented Carbon

Youngs Mod (E):	206000	N/mm^2
Rigidity Mod (G):	81500	N/mm^2
Density:	.00000785	Kg/mm^3
Unprestress:	0-70	%
Prestress:	70-100	%
Wire Section:	Round Wire	
Leg Type:	Radial Leg	
Length Leg 1:	13.50	mm
Length Leg 2:	15.00	mm

Calculated Data

Body Length:	12.32	mm
Body Length (Max):	13.49	mm
Partial Angle (Free):	57.60	Deg
Stress Factor:	1.10	
Spring Index:	8.75	
Inside Diameter:	15.50	mm
Mean Coil Dia.	17.50	mm
Wire Length:	312.37	mm
Weight / 100:	0.770	Kg
Natural Freq:	15453	RPM

Design Parameters

Wire Diameter:	2.00	mm
Outside Diameter:	19.50	mm
Total Coils:	5.16	
Spring Rate:	9.63	Nmm/Deg (Calculated)

Stress Data

	Lower Tensile	Operating Positions % Tensile 1	2
SL	1520	1 U	8 U
SM	1760	1 U	7 U
DM	1760	1 U	7 U
SH	1980	1 U	6 U
DH	1980	1 U	6 U
Specified			

Operating Data

	Operating Positions 1	2
Torque (Nmm)	10.00	100.00
Deflection (Deg)	1.04	10.38
Partial Angle (Deg)	58.64	67.98
Stress (Deg)	13	127
Inside Diameter (N/mm^2)	15.49	15.40
Body Length (Max) (mm)	13.49	13.54
Load Tol. Grade 1 (mm)	155.37	155.37
Load Tol. Grade 2 (Nmm)	246.62	246.62
Load Tol. Grade 3 (Nmm)	394.59	394.59

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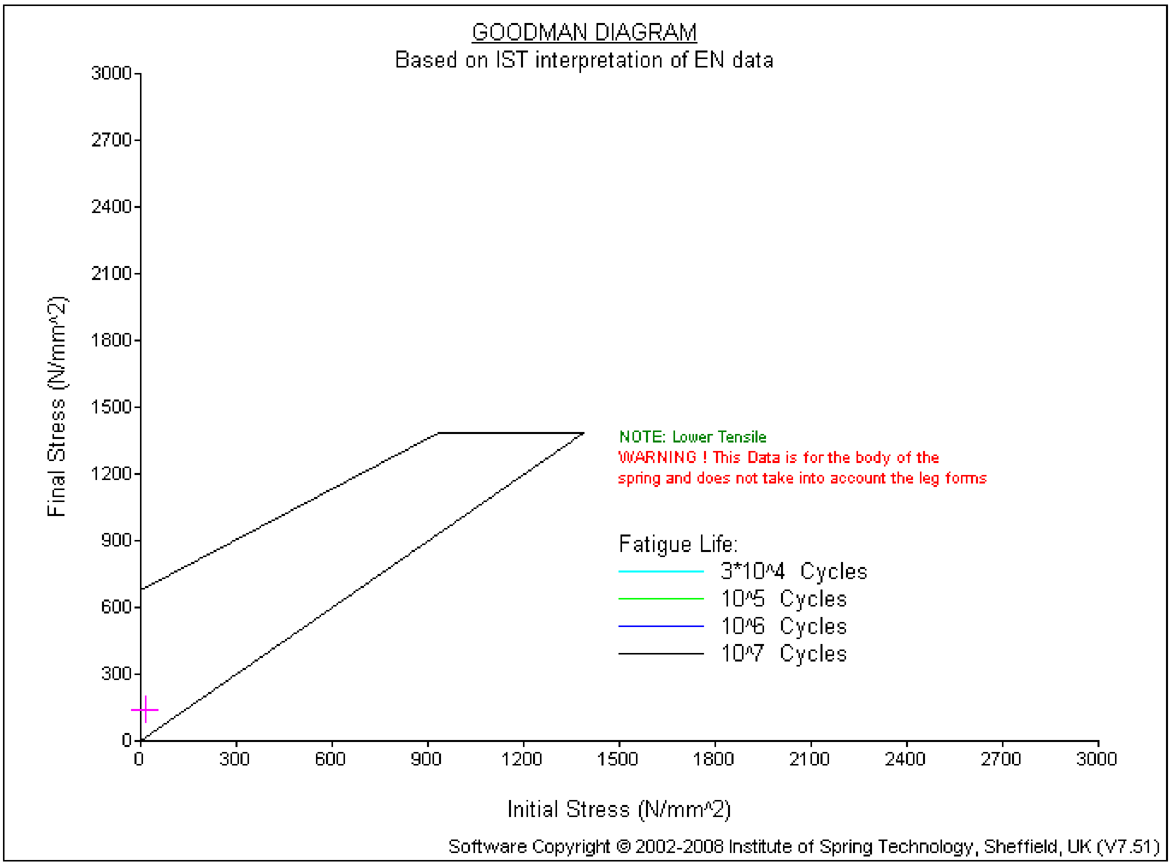
Goodman Diagram

Material:	EN 10270 Pt1 Patented Carbon
Grade:	DH
Pre-Stressed:	No

Operating Positions

	1	2
Deflection: (Deg):	1.04	10.38
Torque: (Nmm):	10.00	100.00
Corrected Stress (N/mm^2):	14	140



One example of each spring type was torque tested to establish the performance of each spring type. Results for the four designs were as follows:-

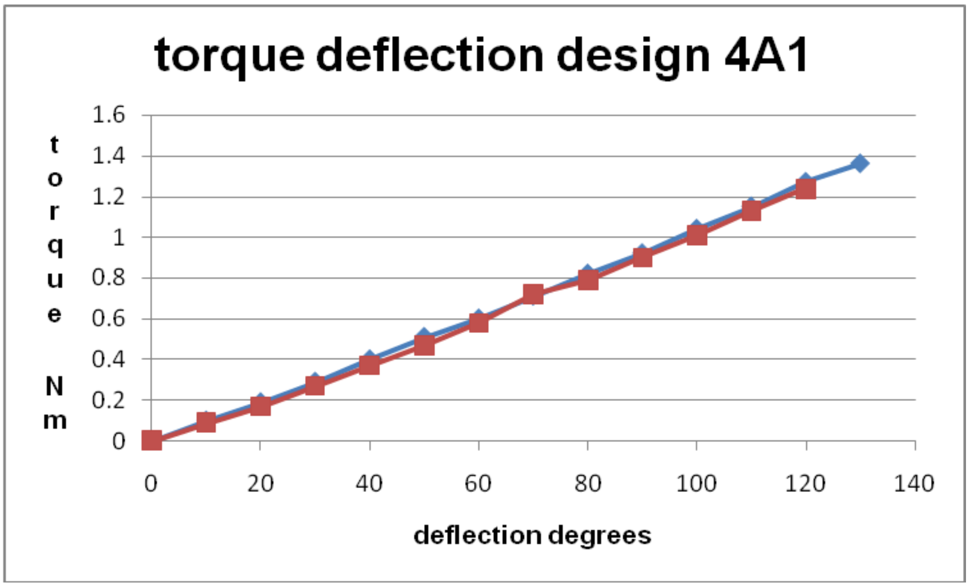


Fig 12 blue wind up, red release L1=13.5mm, L2=15 mm

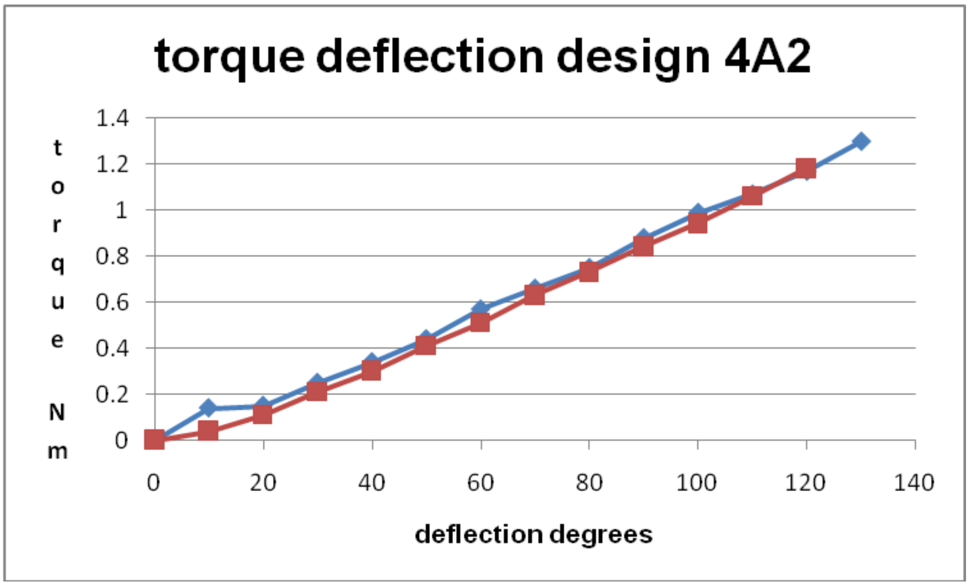


Fig 13 blue wind up, red release L1=13.5mm, L2=15 mm

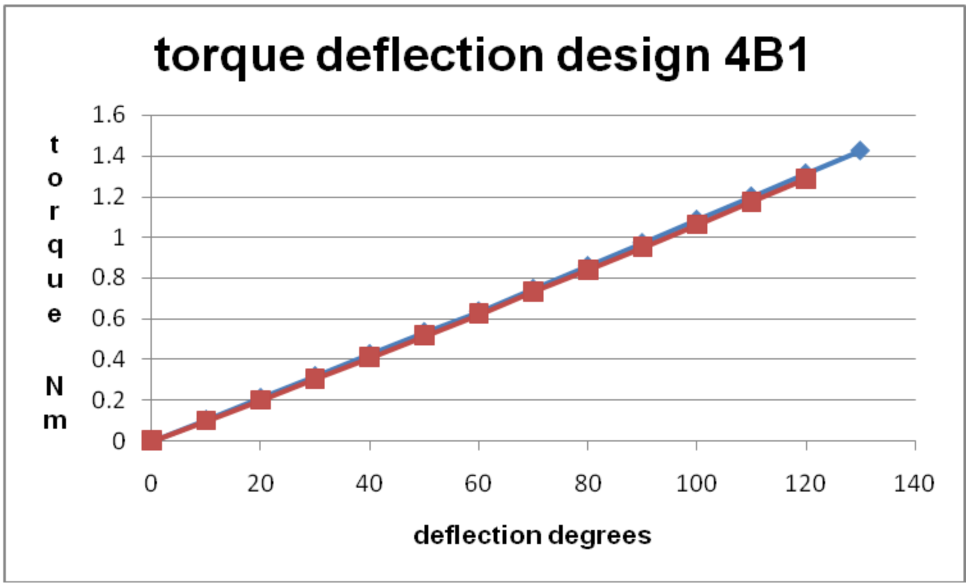


Fig 14 blue wind up, red release

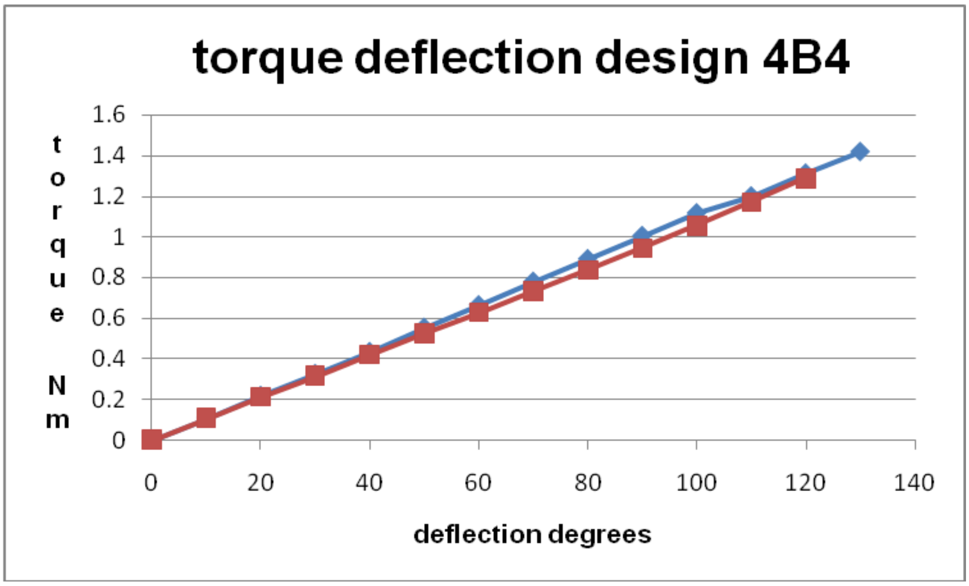


Fig 15 blue wind up, red release

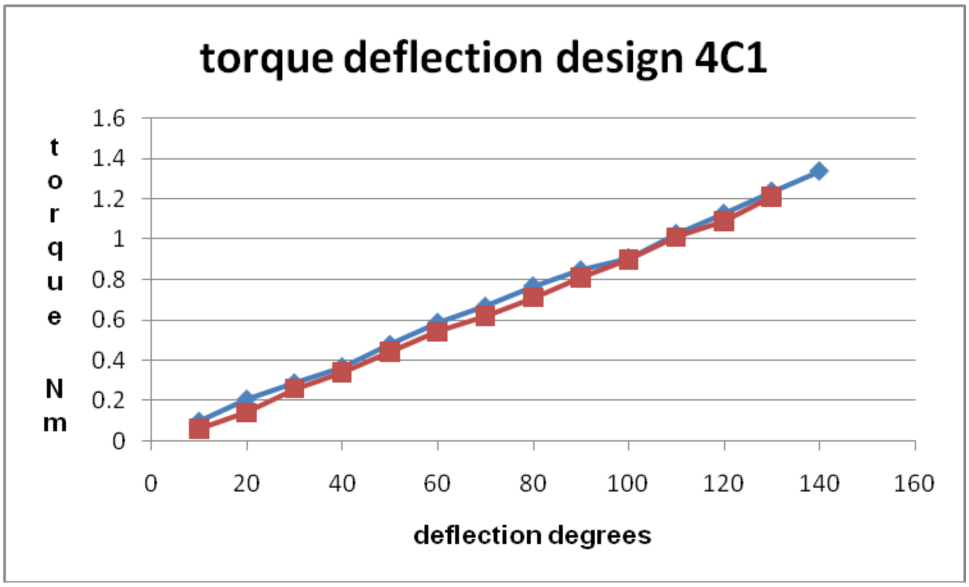


Fig 16 blue wind up, red release L1 = 23.7 mm, L2 = 22.4 mm

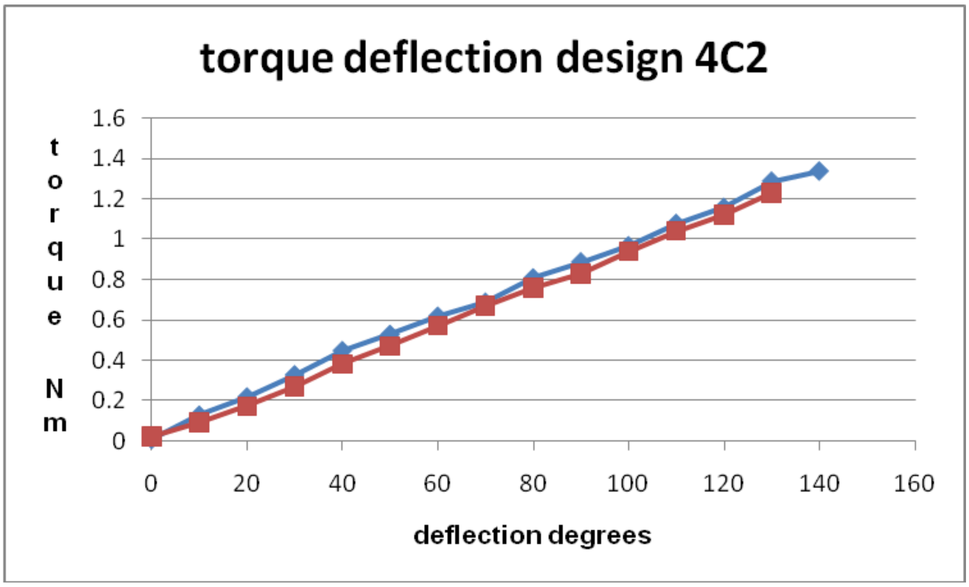


Fig 17 blue wind up, red release L1 = 23.7 mm, L2 = 22.4 mm

Further examples of each spring type were then fatigue tested at IST. The following fatigue test results were obtained:-

Batch	Stress Range N/mm²	Lives
4A1 open ER	136 - 1225	97,311, 118,754, 136,498 all broken, 570,000 unbroken
4A1 open ER	136 - 1361	43,910, 73,884, 79,297, 107,220
4A1 open ER	136 - 1497	44,053, 56,820, 59,699, 74,640
4A2 close ER	132 - 1192	125,681 broken 366,000 three springs unbroken
4A2 close ER	132 - 1325	41,240, 71,419, 89,484, 109,415
4A2 close ER	132 - 1457	28,246, 32,406, 40,173, 55,454
4B1 open IR	140 – 1264	500,000 3 springs unbroken
4B1 open IR	140 – 1405	77,500, 95,000, 95,000
4B1 open IR	140 – 1545	50,100, 51,950, 75,000
4B4 close IR	140 – 1264	109,980 broken 500,000 unbroken two springs
4B4 close IR	140 – 1405	30,000, 44,000, 46,000
4B4 close IR	140 – 1545	60,000, 64,000, 66,000
4C1 open tangential	121 – 1209	149,737 broken 600,625 3 springs unbroken
4C1 open tangential	121 - 1330	185,897, 185,897 broken 554,167 two springs unbroken
4C1 open tangential	121 - 1451	44,863, 47,800, 54,349 broken 100,000 unbroken
4C1 open tangential	121 - 1572	34,928, 36,364, <44,000
4C2 close tangential	128 – 1283	99,451 broken 720,235 3 springs unbroken
4C2 close tangential	128 - 1411	47,640, <62,764, 62,764, 68,907
4C2 close tangential	128 - 1540	<41,276 4 springs broken
4C2 close tangential	128 - 1668	<35,850 3 springs broken, 37,045 broken

Fig 18

Wind Up / Unwind Test Program

A brief comparative study of wind / unwind testing was performed on one stainless steel torsion spring design and one carbon steel torsion spring design to determine if there was any difference between fatigue lives.

The spring designs were as follows:

Design	Do/mm	Coils	Leg	Coiling
6 (d = 3.00mm)	24.3	5.68	Tangential	Open Coiled
3 (d = 2.00mm)	15.00	4	External Radial	Open Coiled

Fig 19

One example of each spring type was torque tested to establish the performance of each spring type. Results for the two designs were as follows:-

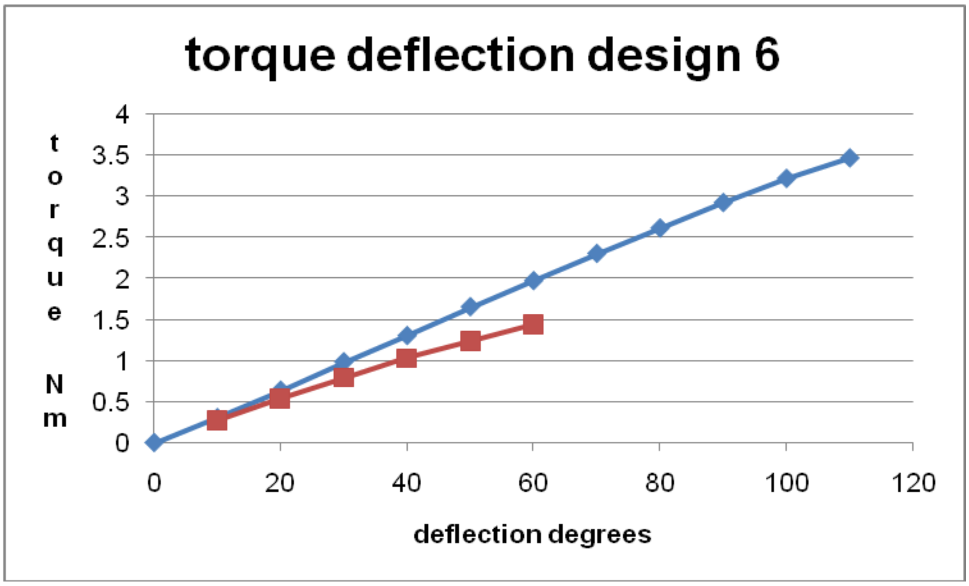


Fig 20 with L_1 = 70mm and L_2 = 26mm
Blue line wind up, red line unwind

Due to the set that this spring took in the unwind direction the spring needed to be prestressed in the unwind direction to enable fatigue tests to be performed without set.

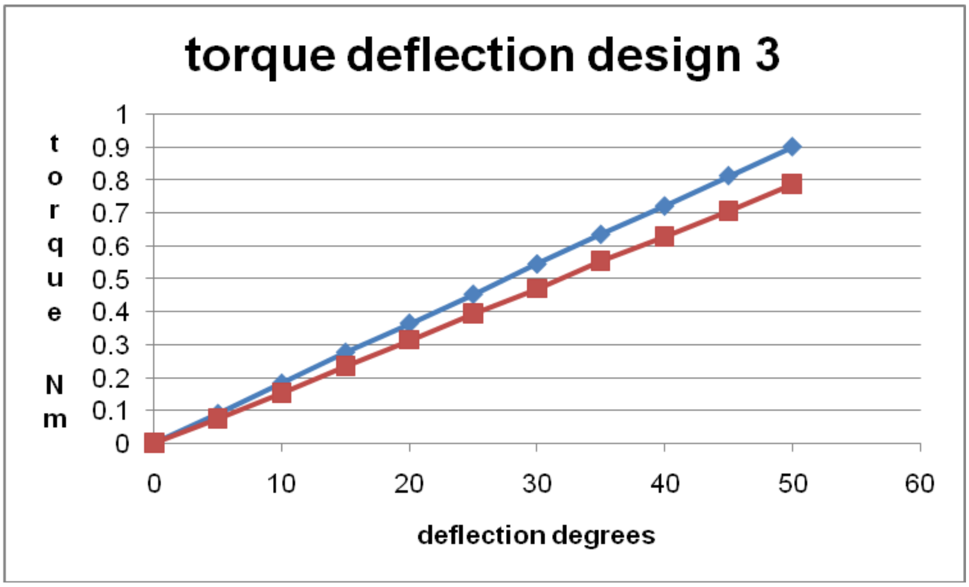


Fig 21 L1 = 25.00 mm, L2 = 15.00 mm

Further examples of each spring type were then fatigue tested at IST. The following fatigue test results were obtained:-

Batch	**Stress Range N/mm²**	**Lives**
6 stainless	116 - 1046 wind up	198,810, 136,156
6 stainless	116 – 1046 unwind	17,794, 19,875
3 carbon steel	251 - 1257 wind up	39,628, 39,791
3 carbon steel	251- 1257 unwind	20,972, <31,714

Fig 22

Conclusion

For stainless steel springs - Internal radial legs are best for fatigue applications, with open coiled being better than close coiled. Both external radial and tangential springs are inferior in fatigue performance to internal radial legs. The fatigue performance of external radial legs improves as the leg length is reduced. Tangential springs are better in fatigue if the spring is open coiled rather than close coiled.

For carbon steel springs - Internal radial legs are best for fatigue applications, with open coiled being better than close coiled. Both external radial and tangential springs are inferior in fatigue performance to internal radial legs. The fatigue performance of external radial legs and tangential legs improves if the spring is open coiled rather than close coiled.

Limited fatigue testing confirmed the expectation that operating a torsion spring in wind up mode gives superior fatigue life to operating in the unwind mode.

As a general conclusion if a torsion spring is to be used in a fatigue application the best performance will be achieved using an open coiled internal radial leg design.

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