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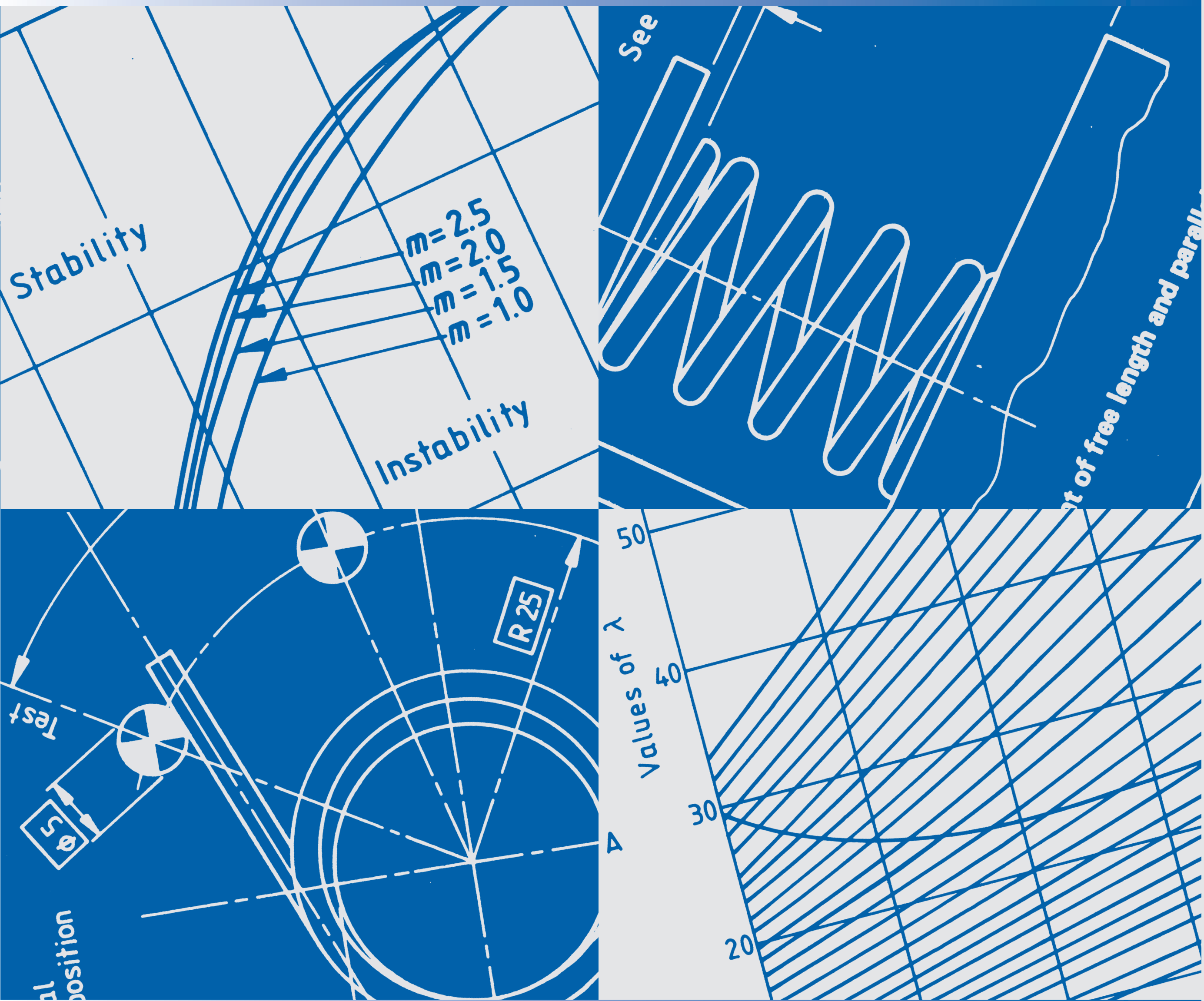

ENGINEERS GUIDE

Designing & Specifying

Compression, Extension and Torsion Springs

*** These standards have been superceded by:**

BS 1726-1:2002
Cylindrical helical springs made from round wire and bar -
Guide to Methods of specifying, tolerances and testing -
Part 1: Compression springs

BS 1726-2:2002
Cylindrical helical springs made from round wire and bar -
Guide to methods of specifying, tolerances and testing -
Part 2: Extension springs

BS 1726-3:2002
Cylindrical helical springs made from round wire and bar -
Guide to methods of specifying, tolerances and testing -
Part 3: Torsion springs

The following standards now also apply:

BS 8726-1:2002
Cylindrical helical springs made from rectangular and square section wire and bar -
Guide to calculation and design -
Part 1: Compression springs

BS 8726-2:2002
Cylindrical helical springs made from rectangular and square section wire and bar -
Guide to calculation and design -
Part 2: Torsion springs

BS EN 13906-1:2002
Cylindrical helical springs made from round wire and bar -
Guide to calculation and deisgn -
Part 1: Compression springs

BS EN 13906-2:2001
Cylindrical helical springs made from round wire and bar -
Guide to calculation and design -
Part 2: Extension springs

BS EN 13906-3:2001
Cylindrical helical springs made from round wire and bar -
Guide to calculation and design -
Part 3: Torsion springs

ENGINEERS GUIDE

To Designing & Specifying Compression, Extension and Torsion Springs

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Introduction

This guide provides detailed information on the design and specification of compression, extension and torsion springs manufactured from round wire.

For ease of reference the structure of this guide is aligned with BS 1726 which gives standards as follows:

*BS 1726 : Part 1 :	Guide for the design of helical compression springs
*BS 1726 : Part 2 :	Guide for the design of helical extension springs
*BS 1726 : Part 3 :	Guide for the design of helical torsion springs

All the essential elements of spring design and construction are covered including formulae, tolerances, material selection as well as the testing of dimensions, properties and performance.

The guide covers springs made from materials to:

BS EN 10270-1:2001	Patented cold drawn steel wire for mechanical springs
BS EN 10270-2:2001	Pre-hardened and tempered carbon and low alloy round steel wire for springs for general engineering purposes
BS EN 10270-3:2001	Stainless steel wire for mechanical springs

Materials commonly used to manufacture springs include:

Carbon steels
Low alloy steels
Stainless steels
Copper based alloys
Nickel based alloys

Key factors affecting material choice for a particular application include:

- Material meets the required stress conditions either static or dynamic
- Material must be capable of functioning satisfactorily at the required operating temperature
- Material is compatible with its surroundings i.e. corrosive environment
- Special requirements such as conductivity, constant modulus, weight restrictions, magnetic limitations, etc.

Useful reference data on material properties and conversion tables are also included.

Information included in this guide is based on Lee Spring's 90 years of experience working with engineers to develop solutions using spring technology in industries throughout the world.

** These standards have been superceded. See adjacent page.*

Compression springs

Description

A compression spring is an open-coil helical spring that offers resistance to a compressive force applied axially. Such springs are usually coiled as a constant diameter cylinder; other common forms are conical, tapered, concave, convex, and combinations of these. Most compression springs are manufactured in round wire - since this offers the best performance and is readily available and suited to standard coiler tooling - but square, rectangular, or special-section wire can be specified.

Key design factors

Compression springs should always be supplied in a stress-relieved condition in order to remove residual bending stresses induced by the coiling operation. Depending on design and space limitations, springs can be categorised according to the level of stress.

Specification will depend on pitch, solid height, number of active and total coils, free length, and the seating characteristics of the spring.

In designing compression springs, the space allotted governs the dimensional limits with regard to allowable solid height and outside and inside diameters. These dimensional limits, together with the load and deflection requirements, determine the stress level. It is extremely important that the space allotted is carefully considered so that the spring will function properly; otherwise, costly design changes may be needed.

Compression springs feature four basic types of ends. A compression spring can not be ground so that its ends are consistently square. Also the helix angles adjacent to the end coils will not be uniform either. It follows that springs can not be coiled so accurately as to permit all coils to close out simultaneously under load. As a result the spring rate tends to lag over the initial 20% of the deflection range. As the ends seat during the first stage of deflection the spring rate rises to the calculated value. In contrast, the spring rate for the final 20% of the deflection range tends to increase as coils progressively close out.

Since the spring rate over the central 60% of the deflection range is linear, critical loads and rates should be specified within this range. This can be increased to about 80% of total deflection by special production techniques but such modifications will add to the cost of the spring.

It is useful to note that two compression springs used in series will double the deflection for the same load and three springs in series will triple the deflection for the same load.

Conversely two springs in parallel will double the load for the same deflection and three springs will triple the load for the same deflection.

Adding springs will continue to increase the deflection and load as described.

The total load is equal to the sum of the load of the individual springs.

Two compression springs 'nesting' - one inside another - should be of opposite handing to prevent coils tangling. Also it is important to allow working clearances between the I.D and the O.D of the springs.

Spring Index - the ratio of mean coil diameter to spring wire diameter - is another key definition used to assist in the evaluation and presentation of tolerances.

The squareness of compression spring ends influences the manner in which the axial force produced by the spring can be transferred to adjacent parts in a mechanism. In some applications open ends may be entirely suitable; however, when space permits, closed ends afford a greater degree of squareness and reduce the possibility of interference with little increase in cost. Compression springs with closed ends often can perform well without grinding, particularly in wire sizes smaller than 0.4mm diameter.

Many applications require the ends to be ground in order to provide greater control over squareness. Among these are those in which heavy duty springs are specified; usually close tolerances on load or rate are needed; solid height has to be minimised; accurate seating and uniform bearing pressures are required; and a tendency to buckle has to be minimised.

A spring can be specified for grinding square in the unloaded condition, or square under load - but not in both conditions with any degree of accuracy.

Definitions

Active coils - Coils that at any instant are contributing to the rate of the spring

Buckling - Unstable lateral distortion of the major axis of a spring when compressed

Closed end - End of a helical spring in which the helix angle of the end coil has been reduced until it touches the adjacent coil

Compression spring - A spring whose dimension reduces in the direction of the applied force

Creep - Change in length of a spring over time under a constant force

Deflection - Relative displacement of spring ends under load

Elastic limit - Maximum stress to which a material may be subjected without permanent deformation

Free length - Length of a spring when not under load

Hand - Direction of spring coil helix i.e. left or right

Open end - End of an open coiled helical spring where the helix angle of the end coil has not been progressively reduced

Permanent set - Permanent deformation of a spring after the load has been removed

Pitch - Distance from one coil to the corresponding point in the next coil measured parallel to the spring axis

Prestressing (scragging) - Process where stresses are induced into a spring to improve performance

Shot peening - Process of applying shot to the surface of a spring to induce residual stresses in the outer surface of the material to improve fatigue resistance

Solid force - Theoretical force of a spring when compressed to its solid length

Solid length - Length of a compression spring when all the coils are in contact with each other

Spring index - Ratio of mean coil diameter to material diameter or radial width of cross section for square/trapezoidal springs

Spring rate - Change in load per unit of deflection

Stress relieving - Low temperature heat treatment used to relieve residual stresses, caused by the manufacturing process, that causes no change in the metallurgical structure of the spring material

Calculations

Proper design of compression springs requires knowledge of both the potential and the limitations of available materials together with simple formulae. Since spring theory is normally developed on the basis of spring rate the formula for spring rate is the most widely used in spring design. The primary characteristics useful in designing compression springs are:

Term		Unit
S	spring rate in	N/mm
F	spring force	N
ΔF	change in spring force	N
ΔL	deflection	mm
D	mean coil diameter	mm
d	wire diameter	mm
G	modulus of rigidity	N/mm
n	number of active coils	-
c	spring index	-
K	stress correction factor	-
N	total number of coils	-
L	spring length	mm
L_o	free length of spring	mm
L_s	theoretical solid length of spring	mm
$L_{s(max)}$	maximum allowable free length	mm
H	end fixation factor	-
τ	shear stress	N/mm^2

For compression springs with closed ends, ground or not ground, the number of active coils (n) is two less than the total number of coils (N).

To determine spring rate:

$$S = \frac{\Delta F}{\Delta L} = \frac{Gd^4}{8nD^3}$$

To determine spring index:

$$c = \frac{D}{d}$$

To determine stress correction factor:

$$K = \frac{c + 0.2}{c - 1}$$

where $c = \frac{D}{d}$

To determine shear stress:

$$\tau = \frac{8FDK}{\pi d^3}$$

Buckling of compression springs results from the ends of unsupported (i.e. not used over a shaft) springs not being ground exactly square, which is commonly the case as mentioned earlier. BS 1726 : Part 1 says that a spring will buckle if the deflection as a proportion of the free length of the spring exceeds a critical value of H (end fixation factor) - in the equation H /(free length of spring/mean coil diameter). Values of H are given for laterally and non-laterally constrained applications but it says the minimum figure should be 0.4 to 0.5.

Solid height or length

The solid height of a compression spring is defined as the length of the spring when under sufficient load to bring all coils into contact with the adjacent coils and additional load causes no further deflection. Solid height should be specified by the user as a maximum, with the actual number of coils in the spring to be determined by the spring manufacturer.

Coatings on springs

Finishing springs by zinc plating and passivation may increase spring rate figures by effectively increasing the diameter of the wire.

Tolerances

Spring manufacturing, as in many other production processes, is not exact. It can be expected to produce variations in such spring characteristics as load, mean coil diameter, free length, and relationship of ends or hooks. The very nature of spring forms, materials, and standard manufacturing processes cause inherent variations. The overall quality level for a given spring design, however, can be expected to be superior with spring manufacturers who specialise in precision, high-quality components.

Normal or average tolerances on performance and dimensional characteristics may be expected to be different for each spring design. Manufacturing variations in a particular spring depend in large part on variations in spring characteristics, such as index, wire diameter, number of coils, free length, deflection and ratio of deflection to free length.

Tables 1 - 4 give tolerances on major spring dimensions based on normal manufacturing variations in compression and extension springs.

COMPRESSION AND EXTENSION SPRINGS
Coil Diameter Tolerances, ± mm

Wire Dia. mm	Spring Index, D/d						
	4	6	8	10	12	14	16
0.38	0.05	0.05	0.08	0.10	0.13	0.15	0.18
0.58	0.05	0.08	0.10	0.15	0.18	0.20	0.25
0.89	0.05	0.10	0.15	0.18	0.23	0.28	0.33
1.30	0.08	0.13	0.18	0.25	0.30	0.38	0.43
1.93	0.10	0.18	0.25	0.33	0.41	0.48	0.56
2.90	0.15	0.23	0.33	0.46	0.53	0.64	0.74
4.34	0.20	0.30	0.43	0.58	0.71	0.84	0.97
6.35	0.28	0.38	0.53	0.71	0.89	1.07	1.24
9.53	0.41	0.51	0.66	0.94	1.17	1.37	1.63
12.70	0.53	0.76	1.02	1.57	2.03	2.54	3.18

Table 1

COMPRESSION SPRINGS *Normal Load Tolerances, ± percent of load*

Length tolerance +/- mm	Deflection from free length to load, mm														
	1.3	2.5	3.8	5.1	6.4	7.6	10.2	12.7	19.1	25.4	38.1	50.8	76.2	101.6	152.4
0.13	12	7	6	5											
0.23		12	8.5	7	6.5	5.5	5								
0.51		22	15.5	12	10	8.5	7	6	5						
0.76			22	17	14	12	9.5	8	6	5					
1.02				22	18	15.5	12	10	7.5	6	5				
1.27					22	19	14.5	12	9	7	5.5				
1.52					25	22	17	14	10	8	6	5			
1.78						25	19.5	16	11	9	6.5	5.5			
2.03							22	18	12.5	10	7.5	6	5		
2.29							25	20	14	11	8	6	5		
2.54								22	15.5	12	8.5	7	5.5		
5.08										22	15.5	12	8.5	7	5.5
7.62											22	17	12	9.5	7
10.16												21	15	12	8.5
12.70												25	18.5	14.5	10.5

Table 2

COMPRESSION SPRINGS
Squareness in Free-Position Tolerances (closed and ground ends), ± degrees

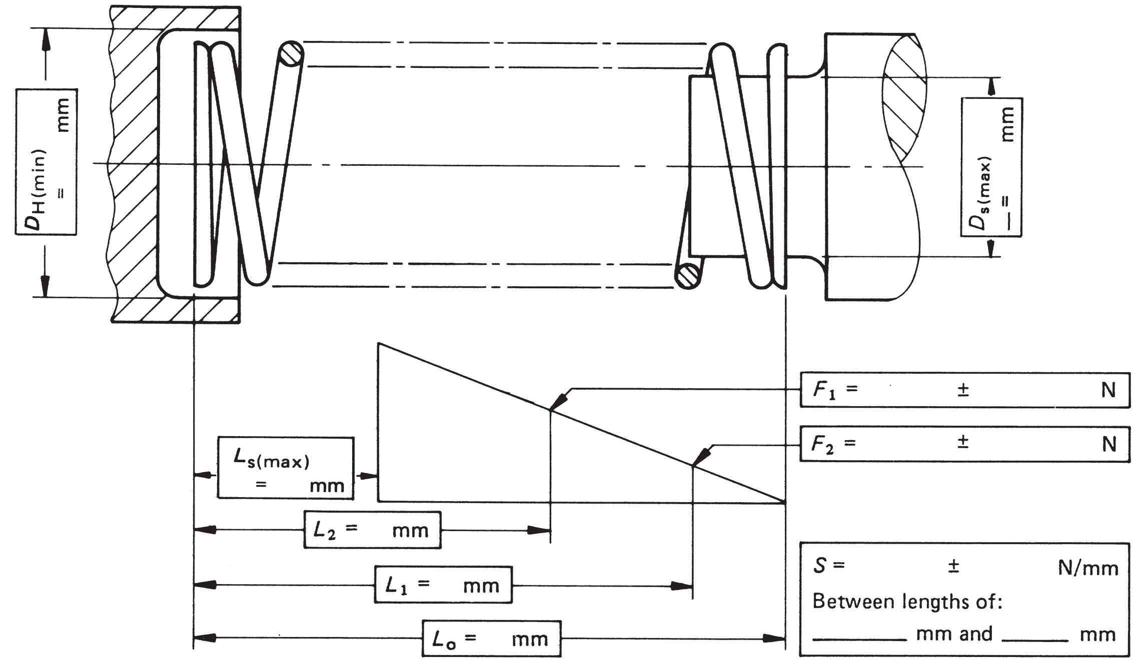
Slenderness Ratio (L/D)	Spring Index, D/d						
	4	6	8	10	12	14	16
0.5	3.0	3.0	3.5	3.5	3.5	3.5	4.0
1.0	2.5	3.0	3.0	3.0	3.0	3.5	3.5
1.5	2.5	2.5	2.5	3.0	3.0	3.0	3.0
2.0	2.5	2.5	2.5	2.5	3.0	3.0	3.0
3.0	2.0	2.5	2.5	2.5	2.5	2.5	3.0
4.0	2.0	2.0	2.5	2.5	2.5	2.5	2.5
6.0	2.0	2.0	2.0	2.5	2.5	2.5	2.5
8.0	2.0	2.0	2.0	2.0	2.5	2.5	2.5
10.0	2.0	2.0	2.0	2.0	2.0	2.5	2.5
12.0	2.0	2.0	2.0	2.0	2.0	2.0	2.5

Table 3

NOTE:
Squareness closer than shown requires special process techniques, which increase cost.
Springs with fine wire sizes, high spring indexes, irregular shapes, or long free lengths require special consideration in determining squareness tolerance and feasibility of grinding.

It is recommended that tables 1, 2 & 3 be used as guides in establishing tolerances, particularly in estimating whether or not application requirements may increase spring cost. In any case, as noted on the suggested specification forms that follow for the various spring types, mandatory specifications should be given only as required. Advisory data, which the spring manufacturer is permitted to change, in order to achieve the mandatory specifications, should be given separately.

APPLICATION FOR DESIGN OF HELICAL COMPRESSION SPRINGS



1 End Coil Formation

Closed ☐
Open ☐
Closed and Ground ☐

2 Operation (if dynamic)

Minimum required life ____________ cycles
Speed of operation ____________ Hz
Maximum force-length ____________ N-mm
Minimum force-length ____________ N-mm

3 Temperatures

Minimum operating temperature ____________ °C
Maximum operating temperature ____________ °C

4 Material

Specification number
Circular ☐ Diameter= ____________ mm
Rectangular ☐ Section _____ mm x _____ mm
Heat treatment

5 Assembly, or further processing details

6 Atmosphere, special protection details

7 Surface coating

8 Other requirements

Design alternatives

This chart can be used to provide guidance on how to solve certain basic compression spring design problems.

Solution ▸ / Condition to satisfy ▾	Increase deflection mm/N	Decrease number of coils ‘N’	Decrease mean dia ‘D’	Increase wire dia ‘d’	Decrease deflection rate mm/N	Decrease amount of travel	Increase amount of travel	Increase number of coils ‘N’	Increase mean dia ‘D’	Decrease wire dia ‘d’	Decrease max load ‘F’
To increase load	X	X	X	X			X				
To decrease load					X	X		X	X	X	
To decrease free length	X	X							X	X	
To increase free length			X	X	X			X			
To decrease O.D.	X		X					X		X	
To increase I.D.		X			X				X	X	
Load correct at max travel but too low at less travel	X	X	X	X			X				
Load correct at max travel but too high at less travel					X	X		X	X	X	
To decrease actual stress			X	X							X

Extension springs

Description

Springs that absorb and store energy by offering resistance to a pulling force are known as extension springs. Various types of ends are used to attach this type of spring to the source of the force.

Key design factors

The variety of extension spring ends is limited only by the imagination of the designer. These can include threaded inserts (for precise control of tension), reduced and expanded eyes on the side or in the centre of the spring, extended loops, hooks or eyes at different positions or distances from the body of the spring, and even rectangular or teardrop-shaped ends. By far the most common, however, are the machine loop and cross-over loop types shown in Fig 1. These ends are made using standard tools in one operation and should be specified whenever possible in order to minimise costs.

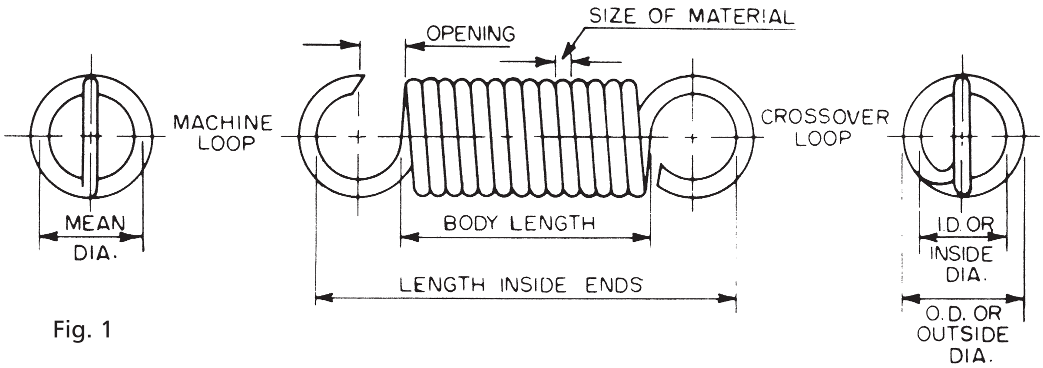


Fig. 1

It should be remembered that as the space occupied by the machine loop is shortened, the transition radius is reduced and an appreciable stress concentration occurs. This will contribute to a shortening of spring life and to premature failure. Most failures of extension springs occur in the area of the end, so in order to maximise the life of a spring, the path of the wire should be smooth and gradual as it flows in to the end. A minimum bend radius of 1.5 times the wire diameter is recommended.

Until recently, the majority of ends were manufactured in a separate operation; nowadays, however, many ends can be made by mechanical and computer-controlled machines as part of the coiling operation. As there are many machines available for coiling and looping in one operation, it is recommended that the spring manufacturer be consulted before the completion of a design.

Load deflection characteristics

Most extension springs are wound with initial tension - this is an internal force that holds the coils together tightly. The measure of the initial tension is the load necessary to overcome the internal force and start coil separation. Unlike a compression spring, which has zero load at zero deflection, an extension spring can have a pre-load at zero deflection.

In practice, this means that, before the spring will extend, a force greater than the initial tension must be applied. Once the initial tension is overcome as the spring is pulled apart, the spring will exhibit consistent load deflection characteristics.

It is useful to note that two extension springs used in series will double the deflection for the same load and three springs in series will triple the deflection for the same load.

Conversely two springs in parallel will double the load for the same deflection and three springs will triple the load for the same deflection.

Adding springs will continue to increase the deflection and load as described.

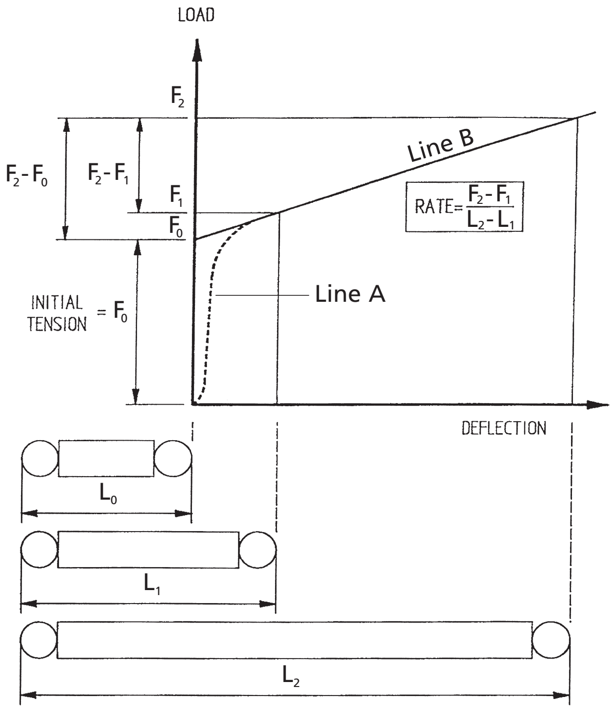
Figure 2 shows load deflection characteristics. The broken line A shows the load required to overcome initial tension and the deflection or spring rate of the end loops. Line B illustrates deflection when all coils are active.

A spring with high initial tension will exert a high load when subject to a small deflection. If this is combined with a low rate, the spring will exhibit an approximate constant force characteristic.

A typical use for this is the accelerator pedal of a car, where a minimum force must be produced by the spring to overcome friction and to return the pedal. However, on depressing the pedal, the required force does not increase.

Counterbalances, electrical switchgear and tensioning devices all make use of high initial tension - low rate springs, whereas the one major product which calls for zero initial tension is the spring balance. To ensure zero initial tension the springs for balances are invariably coiled slightly open and use screwed-in inserts for precise rate adjustment.

Load deflection characteristics



Calculations

Term		Unit
c	spring index	-
D_o	outside diameter	mm
D	mean coil diameter	mm
d	wire diameter	mm
F_o	initial tension	N
ΔF	change in spring force	N
n	number of active coils	-
L_B	body Length	mm
L_o	overall free length inside hooks	mm
L	spring length	mm
ΔL	change in spring length	mm
Δ	deflection	mm
S	spring rate	N/mm
R_m	minimum tensile strength	N/mm²
K	Stress correction factor = $K = \frac{c + 0.2}{c - 1}$	
G	Modulus of rigidity	N/mm²
τ	Shear stress	N/mm²

Formlae:

Shear stress due to load F :

$$\tau = \frac{8FDK}{\pi d^3}$$

Spring rate:

$$S = \frac{\Delta F}{\Delta L} = \frac{Gd^4}{8nD^3}$$

Free length inside hooks:

$$L_o = (n + 1)\, d + 2\,(D - d)$$

Initial tension

$$F_o = F_2 - \left[\frac{F_2 - F_1}{L_2 - L_1}\right](L_2 - L_o)$$

$$F_o = F_2 - S\,(L_2 - L_o)$$

Summary of design factors

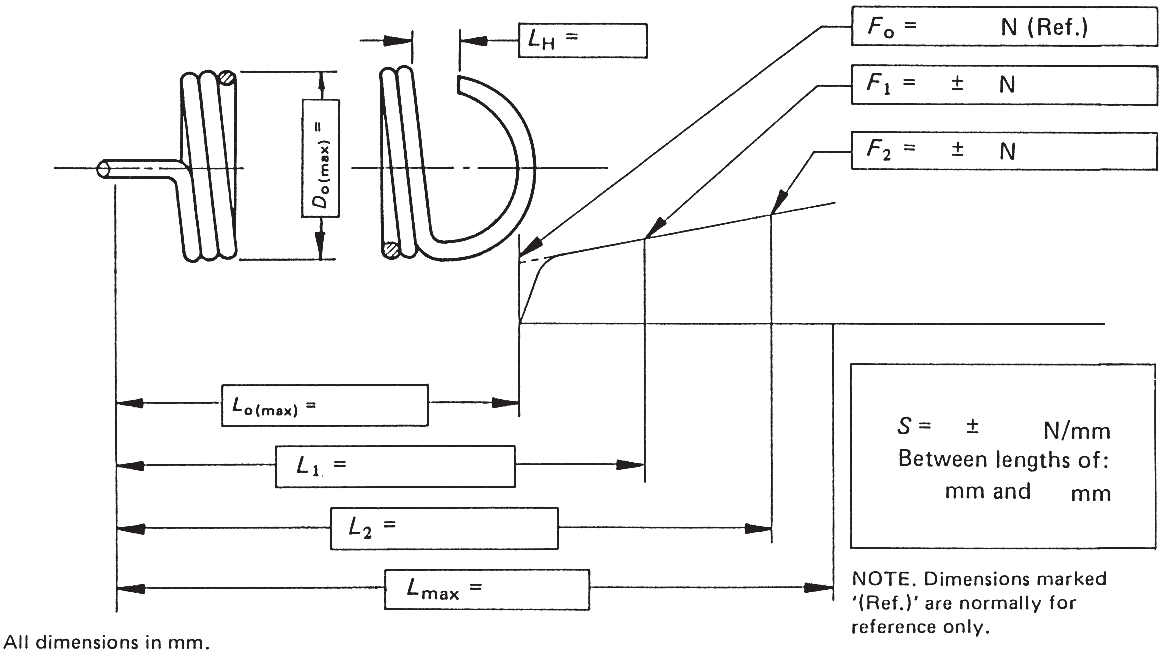
1. Stresses must always be kept lower than in compression springs because:-
   (a) most loops are weak
   (b) extension springs cannot be easily prestressed
   (c) extension springs cannot be easily shot peened
2. The loops are active and their deflection may need to be compensated for by a small reduction in active coils in the order of 0.1 to 0.25 turns
3. The initial tension should be within the preferred range for optimum tolerances
4. Do not use large loops or screwed-in inserts unless the application demands it
5. Use modified compression spring Goodman diagrams to design for dynamic applications
6. Heat treatment raises the elastic limit but reduces initial tension
7. The higher the wire strength, the higher the initial tension

Tolerances

For guidance on tolerances refer to the compression spring tables 1 to 3 on pages 3-4

Specifying springs

APPLICATION FOR DESIGN OF HELICAL EXTENSION SPRINGS



1 End Loop Form Type (see clause 6) Relative position Where important, loop details, dimensions and the method of fixing are to be given on a separate sheet of paper and attached to this data sheet.	**5 Assembly, or further processing details**
2 Operation (if dynamic) Minimum required life ____________ cycles Speed of operation ____________ Hz Maximum force-length ____________ N-mm Minimum force-length ____________ N-mm	**6 Atmosphere, special protection details**
3 Temperatures Minimum operating temperature ____________ °C Maximum operating temperature ____________ °C	**7 Surface coating**
4 Material Specification number Circular ☐ Diameter=____________ mm Rectangular ☐ Section______mm x______mm Heat treatment	**8 Other requirements**

Design alternatives

This chart can be used to provide guidance on how to solve certain basic extension spring design problems.

Solution ▸ / Condition to satisfy ▾	Increase deflection mm/N	Decrease number of coils 'N'	Decrease mean dia 'D'	Increase wire dia 'd'	Use intial tension	Decrease deflection rate mm/N	Decrease amount of travel	Increase amount of travel	Increase number of coils 'N'	Increase mean dia 'D'	Decrease wire dia 'd'	Cut down length of end loops	Increase length of end loops	Decrease max load 'F'
To increase load	X	X	X	X	X			X						
To decrease load						X	X		X	X	X			
To decrease free length	X	X						X		X	X	X		
To increase free length			X	X		X	X		X				X	
To decrease O.D.	X		X						X		X			
Load correct at max travel but too low at less travel	X	X	X	X	X			X						
Load correct at max travel but too high at less travel						X	X		X	X	X			
To decrease actual stress			X	X										X

Torsion springs

Description

Torsion springs, have ends which are rotated in angular deflection to offer resistance to externally applied torque. The wire itself is subjected to bending stresses rather than torsional stresses. Springs of this type usually are close-wound; they reduce in coil diameter and increase in body length as they are deflected. The designer must also consider the effects of friction and of arm deflection on torque.

Key design factors

Special types of torsion springs include double-torsion springs and springs having a space between the coils in order to minimise friction. Double-torsion springs consist of one right-hand and one left-hand coil section, connected, and working in parallel. The sections are designed separately with the total torque exerted being the sum of the two.

The types of ends for a torsion spring must be considered carefully. Although there is a good deal of flexibility in specifying special ends and end-forming, costs might be increased and a tooling charge incurred. Designers should check nominal free-angle tolerances relating to application requirements in the details given in tabular information prepared by manufacturers. It should be noted that in addition to the supply of specification information, the designer should provide a drawing which indicates end configurations which are acceptable to the application.

It is 'good practice' to use both left and right hand windings when ever possible.

Calculations

Term		Unit
c	spring index	
D	mean coil diameter	mm
d	material diameter	mm
E	modulus of elasticity	M/mm^2
F	Spring force	N
K_o	stress correction factor for circular section wire	-
L_o	Free body length	mm
L_t	Loaded body length	mm
L_1	Length of leg one	mm
L_2	Length of leg two	mm
n	number of active coils in spring	-
σ	bending stress in spring	N/mm
S_θ	nominal torsional rate	N.mm/degree
T	torque at any angle	N.mm
ΔT	change in torque	N.mm
θ	angular rotation of spring	degrees

Stress correction factors

Stress correction factor K_o for round section materials is given by the equation:

$$K_o = \frac{c}{c - 0.75}$$

where $c = D/d$

Stress

The bending stress for round section materials is given by the equation:

$$\sigma = \frac{32T\,K_o}{\pi d^3}$$

Torsional rate

The torsional rate for round section material is given by the equation:

$$S_\theta = \frac{\Delta T}{\theta} = \frac{Ed^4}{3667nD}$$

Torsion Springs
Coil Diameter Tolerances, ± mm

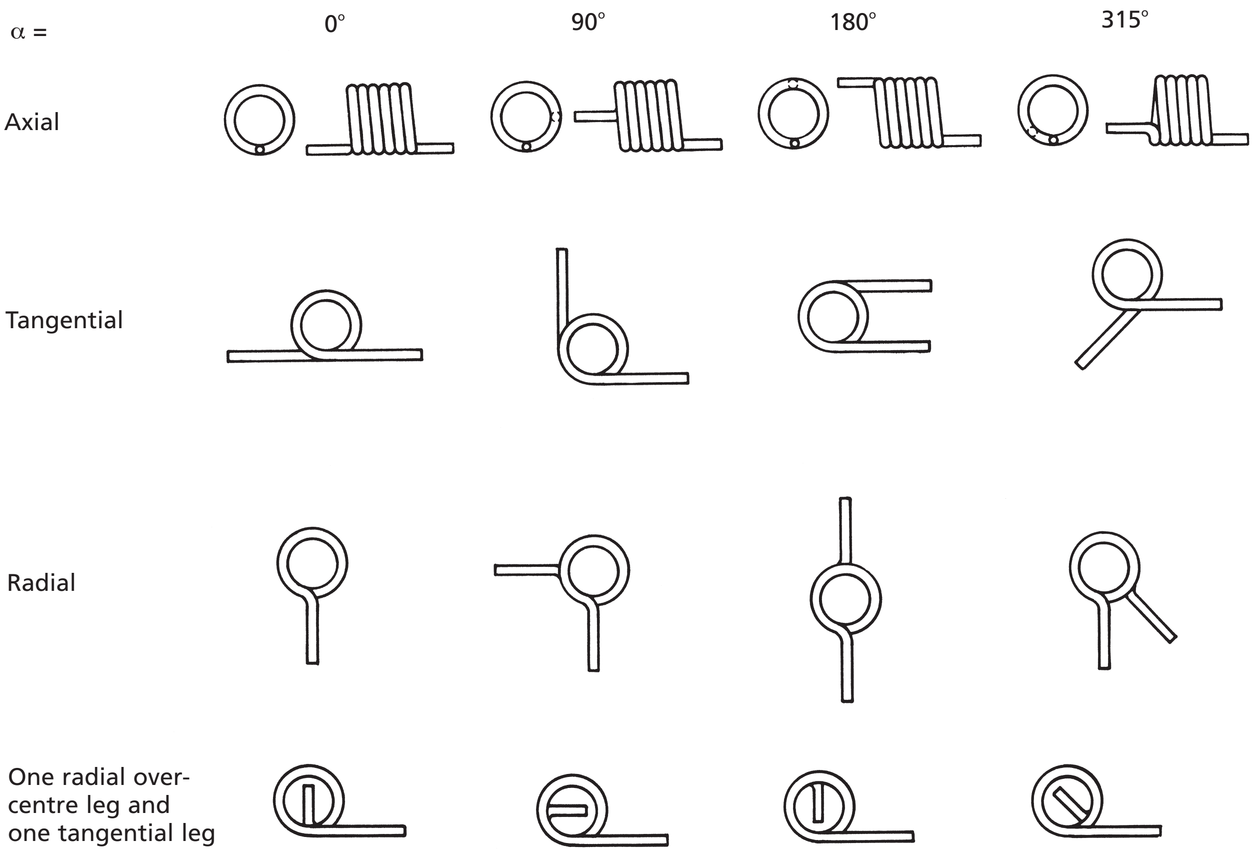
Wire Dia. mm.	Spring Index, D/d						
	4	6	8	10	12	14	16
0.38	0.05	0.05	0.05	0.05	0.08	0.08	0.10
0.58	0.05	0.05	0.05	0.08	0.10	0.13	0.15
0.89	0.05	0.05	0.08	0.10	0.15	0.18	0.23
1.30	0.05	0.08	0.13	0.18	0.20	0.25	0.30
1.93	0.08	0.13	0.18	0.23	0.30	0.38	0.46
2.90	0.10	0.18	0.25	0.33	0.46	0.56	0.71
4.34	0.15	0.25	0.33	0.51	0.69	0.86	1.07
6.35	0.20	0.36	0.56	0.76	1.02	1.27	1.52

Table 4

Torsion Springs
Calculated free relative leg orientation tolerance ± degrees

Number of coils	Spring Index (c)						
	4	6	8	10	12	14	16
2	8	8	8	8	8	9	10
3	8	8	9	10	11	12	13
4	8	10	11	13	14	15	16
5	9	11	13	15	16	17	19
6	11	13	15	17	18	20	21
8	13	16	18	20	22	24	26
10	15	18	21	24	26	28	30
15	20	24	28	32	35	37	40
20	24	30	35	39	42	46	49
25	29	35	40	45	49	53	57
30	32	40	46	51	56	61	65
50	46	57	66	73	80	87	93

Table 5



Conventions for describing relative leg orientation

Dimensional changes

In use the dimensions of torsion springs change. This is caused by the action of winding the spring up under torque and unwinding. During winding the following changes occur:

The number of coils in the spring increases - one complete turn of 360º of one leg will increase the number of coils in the spring by one.

Subsequently spring length increases one coil.

The mean coil diameter of the spring decreases - as the wire length remains the same during coiling, the additional material for the extra coils is drawn from a reduction in spring diameter. This reduction in mean coil diameter is proportional to the increase in the number of coils. Depending upon the spring design (few coils) the reduction in diameter can be significant.

This reduction can be calculated using the following formula:

$$\text{Mean coil diameter at working position} = \frac{\text{Number of coils in free position} \times \text{mean coil in free position}}{\text{Number of coils in working position}}$$

Bearing mind these factors it is necessary to take account of the reduction in spring diameter if a spring is to operate on a mandrel or in a tube. Failure to leave adequate clearances between the inside diameter of the spring and the mandrel will cause the body of the spring to lock up on the mandrel, leaving the legs to take additional deflection and stress. In this situation the legs will take an immediate permanent set, altering the spring characteristics and failing to provide the designed function. Secondly, the increase in body length must also be considered to ensure there is adequate clearance for the spring body to grow. Otherwise a similar situation will occur resulting in a permanent loss of spring performance and spring failure.

It is advised that a clearance equal to 10% of the spring dimensions is left between the inside diameter and the mandrel and between body length and housing length.

Spring legs

Prior to the designing of a spring it is necessary to know the deflection and leg position requirements. The leg relationship for the spring can be specified in one of two ways.

1. Required torque developed after a deflection of 0 degrees. This method does not specify the relative angle of the two legs either in the free position or the working position of the spring.
   Consequently the spring can be designed with any number of whole or partial coils to achieve the required torque deflection relationship. The leg relationship in the free position is then a result of the number of coils determined.
2. Required torque developed at a specified angle of the two legs relative to each other. When the spring rate is specified or calculated from additional torque deflection characteristics, the relative angle of the two legs in the free position may be calculated.

Torque calculations

Sometimes the requirements for a spring will be specified as a torque and other times as a load. Consequently it is necessary in the latter instance to convert the load to a torque.

Torque = Applied load x distance to spring axis

It is important to note that the distance from the line of action of the force to the centre axis of the spring is at right angles to the line of force. For the example above the distance is the same as the leg length for a tangential leg spring when the force is acting at right angles to the leg. For a spring with radial legs the torque would be calculated as follows:

$$T = F \times L$$

Deflection calculation

Based upon the spring dimensions the predicted deflection may be calculated for a specified torque using the following formula:

$$\text{Deflection } \theta = \frac{64T}{E\pi d^4}\left[\frac{L_1 + L_2}{3} + N\pi D\right] \times \frac{180}{\pi}$$

The units for the above are degrees. However, sometimes drawings are specified in radians or turns, to convert use the following factors:

Degrees to radians multiple by n and divide by 180
Degrees to turns divide by 360

Sometimes the above formula is simplified as follows:

$$\theta = \frac{64T\,ND}{Ed^4} \times \frac{180}{\pi}$$

This is only true for the case where the spring does not have any legs and so no account is made for leg deflection.

It is recommended that only the full formula above is always used to automatically account for leg deflection. As this portion of the total deflection can be very significant dependent upon the spring design (total coils and leg length).

Rate calculation

The rate (S) of a torsion spring is a constant for any spring design and is the amount of increase in torque for a given deflection.

For a spring with a deflection of 0 from free, under an applied Torque (T), the rate is the change in torque divided by the deflection.

$$S = \frac{T}{\theta}$$

Alternatively, if the torque at two angular leg positions is known then the rate is the change in torque divided by the change in leg angle.

Stress calculations

Unlike compression and extension springs where the induced stress is torsional, torsion springs operate in bending inducing a bending stress, which is directly proportional to the torque carried by the spring and is calculated as follows:

$$\sigma = \frac{32T}{\pi d^3}$$

Once again this formula can be transposed when the allowable stress is known to determine wire diameter or torque.

Body length calculation

The body length of a close coiled spring in the free position:

$$L_0 = (n + 1)d$$

In the working position the body length is:

$$L_t = \left[n + 1 + \frac{\theta}{360}\right]d$$

Stresses

Springs are stressed in bending and not torsion, as in the case for compression and extension springs. As a consequence torsion springs can be stressed higher than for compression springs.

For example, with a patented carbon steel to BS 5216, an un-prestressed compression spring can be stressed up to 49% of tensile whilst an un-prestressed torsion spring can be stressed up to 70% of tensile strength.

Unlike compression springs, which fail safe by going solid when overloaded, a torsion spring can easily be overstressed. It is therefore important that sufficient residual range is always designed into the spring. This is performed by always designing the spring to a torque I5% greater than the required torque.

A suitable low temperature heat treatment of the springs after coiling can raise the maximum permissible working stress considerably. For example, with BS 5216 material the maximum stress level can be increased to about 85%.

An important fact relating to the heat treatment of torsion springs is that they will either wind up or unwind according to material. (For example carbon steel will wind up whilst stainless steel will unwind).

APPLICATION FOR DESIGN OF HELICAL TORSION SPRINGS

Where important, full details of the spring leg forms and/or space enveloped should be included here.

1 Leg form

		One		Both
Axial	______	☐	______	☐
Tangential	______	☐	______	☐
Radial (external)	______	☐	______	☐
Radial (over-centre)	______	☐	______	☐
Other	______	☐	______	☐

2 Limiting dimensions

Maximum allowable outside diameter ______ mm
Mandrel diameter ______ mm
Maximum allowable body length ______ mm

3 Torque and rate requirements

	Pre-load position	Max. working position
α	degree	degree
T	N-mm	N-mm
T_{tol}	± N-mm	± N-mm
Loading direction	Increasing torque/ decreasing torque	Increasing torque/ decreasing torque

Torsional rate S_θ = ______ N-mm/degree
Assembly adjustment Yes/No ______ degree

4 Mode of operation

Required life (cycles) ______
Operating speed ______ (cycles/min)

5 Service temperatures

Max. operating temp ______ (°C)

Min. operating temp ______ (°C)

Working life ______ (h)

6 Service environment

7 Finish

8 Other requirements

Serial/design/Part No.

Design alternatives

This chart can be used to provide guidance on how to solve certain basic torsion spring design problems.

Solution ▸ / Condition to satisfy ▾	Increase deflection rate M/360deg	Decrease number of coils 'N'	Decrease mean dia 'D'	Increase wire dia 'd'	Decrease deflection rate M/360deg	Decrease amount of angular deflection 'θ'	Increase amount of angular deflection 'θ'	Increase number of coils 'N'	Increase mean dia 'D'	Decrease wire dia 'd'	Decrease max moment 'M'
To increase load	X	X	X	X			X				
To decrease load					X	X		X	X	X	
To decrease body length	X	X							X	X	
To increase body length			X	X	X			X			
To decrease O.D.	X		X					X		X	
To increase I.D.		X			X				X	X	
Load correct at max travel but too low at less travel	X	X	X	X			X				
Load correct at max travel but too high at less travel					X	X		X	X	X	
To decrease actual stress			X	X							X

Appendices

Definitions (as given in BS 1726)

Active coils (effective coils, working coils). The coils of a spring that at any instant are contributing to the rate of the spring.

Buckling. The unstable lateral distortion of the major axis of a spring when compressed.

Closed end. The end of a helical spring in which the helix angle of the end coil has been progressively reduced until the end coil touches the adjacent coil.

Compression spring. A spring whose dimension, in the direction of the applied force, reduces under the action of that force.

Compression test. A test carried out by pressing a spring to a specified length a specified number of times.

Creep. The change in length of a spring over time when subjected to a constant force.

Deflection. The relative displacement of the ends of a spring under the application of a force.

Elastic deformation. The deformation that takes place when a material is subjected to any stress up to its elastic limit. On removal of the force causing this deformation the material returns to its original size and shape.

Elastic limit (limit of proportionality). The highest stress that can be applied to a material without producing permanent deformation.

End fixation factor. A factor used in the calculation of buckling to take account of the method of locating the end of the spring.

Extension spring. A spring whose length, in the direction of the applied force, increases under the application of that force.

Fatigue. The phenomenon that gives rise to a type of failure which takes place under conditions involving repeated or fluctuating stresses below the elastic limit of the material.

Fatigue limit. The value, which may be statistically determined, of the stress condition below which material may endure an infinite number of stress cycles.

Fatigue strength (endurance limit). A stress condition under which a material will have a life of a given number of cycles.

Fatigue test. A test to determine the number of cycles of stress that will produce failure of a component or test piece.

Finish. A coating applied to protect or decorate springs.

Free length. The length of a spring when it is not loaded.

NOTE. In the case of extension springs this may include the anchor ends.

Grinding. The removal of metal from the end faces of a spring by the use of abrasive wheels to obtain a flat surface which is square with the spring axis.

Helical spring. A spring made by forming material into a helix.

Helix angle. The angle of the helix of a helical coil spring.

Hysteresis. The lagging of the effect behind the cause of the effect. A measure of hysteresis in a spring is represented by the area between the loading and unloading curves produced when the spring is stressed within the elastic range.

Index. The ratio of the mean coil diameter of a spring to the material diameter for circular sections or radial width of cross section for rectangular or trapezoidal sections.

Initial tension. The part of the force exerted, when a close coiled spring is axially extended, that is not attributable to the product of the theoretical rate and the measured deflection.

Inside coil diameter of a spring. The diameter of the cylindrical envelope formed by the inside surface of the coils of a spring.

Loop (eye, hook). The formed anchoring point of a helical spring or wire form. When applied to an extension spring, it is usually called a loop. If closed, it may be termed an eye and if partially open may be termed a hook.

Modulus of elasticity. The ratio of stress to strain within the elastic range.

NOTE. The modulus of elasticity in tension or compression is also known as Young's modulus and that in shear as the modulus of rigidity.

Open end. The end of an open coiled helical spring in which the helix angle of the end coil has not been progressively reduced.

Outside coil diameter. The diameter of the cylindrical envelope formed by the outside surface of the coils of a spring.

Permanent set (set). The permanent deformation of a spring after the application and removal of a force.

Pitch. The distance from any point in the section of any one coil to the corresponding point in the next coil when measured parallel to the axis of the spring.

Prestressing (scragging). A process during which internal stresses are induced into a spring.

NOTE. It is achieved by subjecting the spring to a stress greater than that to which it is subjected under working conditions and higher than the elastic limit of the material. The plastically deformed areas resulting from this stress cause an advantageous redistribution of the stresses within the spring. Prestressing can only be performed in the direction of applied force.

Rate (stiffness). The force that has to be applied in order to produce unit deflection.

Relaxation. Loss of force of a spring with time when deflected to a fixed position.

NOTE. The degree of relaxation is dependent upon, and increases with, the magnitude of stress, temperature and time.

Safe deflection. The maximum deflection that can be applied to a spring without exceeding the elastic limit of the material.

Screw insert. A plug screwed into the ends of a helical extension spring as a means of attaching a spring to another component. The plug has an external thread, the diameter, pitch and form of which match those of the spring.

Shot peening. A cold working process in which shot is impacted on to the surfaces of springs thereby inducing residual stresses in the outside fibres of the material.

NOTE. The effect of this is that the algebraic sum of the residual and applied stresses in the outside fibres of the material is lower than the applied stress, resulting in improved fatigue life of the component.

Solid length. The overall length of a helical spring when each and every coil is in contact with the next.

Solid force. The theoretical force of a spring when compressed to its solid length.

Space (gap). The distance between one coil and the next coil in an open coiled helical spring measured parallel to the axis of the spring.

Spring seat. The part of a mechanism that receives the ends of a spring and which may include a bore or spigot to centralize the spring.

Stress (bonding stress, shear stress). The force divided by the area over which it acts. This is applied to the material of the spring, and for compression and extension springs is in torsion or shear, and for torsion springs is in tension or bending.

Stress correction factor. A factor that is introduced to make allowance for the fact that the distribution of shear stress across the wire diameter is not symmetrical.

NOTE. This stress is higher on the inside of the coil than it is on the outside.

Stress relieving. A low temperature heat treatment carried out at temperatures where there is no apparent range in the metallurgical structure of the material. The purpose of the treatment is to relieve stresses induced during manufacturing processes.

Variable pitch spring. A helical spring in which the pitch of the active coils is not constant.

Spring materials - Summary table ... Continued overleaf

Material		Size	Min UTS	Surface	Heat Treatment	Max	Corrosion	Fatigue
Specification	Grade/Type	Range (mm)	Range (N/mm²)	Qualities	After Coiling	Serv. Temp	Resistance	Resistance
	1	0.2 - 9.0	370 - 940	NS			Poor	NS,HS:N/A (2)
BS 5216	2 + 3	0.2 - 13.2	2640 - 1040	HS, ND, HD	SR (1) 300/375°C	150		HD:Excellent
	M4	0.1 - 4.0	3020 - 1770	M, Ground M	1.5 hr			M: V Good
	M5	0.1 - 3.0	3400 - 2000	M				Gr.M: Excellent
	095A65			NS				NS, HS: N/A
	094A65	0.25 - 12.5	1910 - 1240	HS, ND		170		ND; Good
	093A65			HD				HD; V Good
BS 2803	735A654	1.0 - 12.5	1970 - 1360		SR 350/450°C	200		
	735A65		1910 - 1350		1.5 hr			HS; N/A
				HS, ND, HD			Poor	ND; Good
								HD; Excellent
	685A55:R1	1.0 - 12.5	1950 - 1460			250		
	685A55:R2		2100 - 1610					
	090A65							
	070A72					170		
	060A69				H/T (3) to			NS; N/A
BS 1429		1.0 - 16.0	1740 - 1290	NS, ND, HD	hardness		Poor	ND; Good
	735A50				required	200		HD; V Good
	685A55					250		
BS 970:Pt 1	080A67	12.0 - 16.0	1740 - 1290	Black Bar	H/T to hardness	170	Poor	Black Bar; Poor
	060A78			Ground Bar	required			Ground Bar; Good
	251A58	12.0 - 16.0						
	250A60	12.0 - 25.0				170		
	525A58	12.0 - 25.0						
	525A60	12.0 - 40.0				170		
	525A61	12.0 - 54.0		Black Bar,				Black Bar; Poor
	685A57	12.0 - 40.0	1740 - 1290	Peeled or,		250	Poor	Peeled or
				Turned Bar,	H/T to hardness			Turned Bar; Good
BS 970:Pt 2				Ground Bar	required			Ground Bar; Good
	704A60	12.0 - 80.0				170		
	705A60							
	735A51	12.0 - 40.0				200		
	735A54	12.0 - 54.0						
	925A60	12.0 - 80.0				170		
	805H60	12.0 - 80.0				200		
	302S26;GrI	0.08 - 4.0	1880 - 1230					
	302S26;GrII	0.08 - 10.0	2160 - 1230					
	301S26;GrI	0.08 - 6.0	1920 - 1200	As drawn				
BS 2056 (austenitic)	301S26;GrII	0.08 - 10.0	2200 - 1250	or	SR 450°C ½ hr	300	Good	Poor
				As drawn				
	316S33	0.08 - 10.0	1680 - 860	& polished				
	316S42	0.08 - 10.0	1680 - 860					
	305S11	0.08 - 10.0	1680 - 860					
	904S14	0.08 - 10.0	1600 - 1150					

Material: Specification	Material: Grade/Type	Size Range (mm)	Min UTS Range (N/mm²)	Surface Qualities	Heat Treatment After Coiling	Max Serv. Temp	Corrosion Resistance	Fatigue Resistance
BS 2056 (pcpn.harden)	301S81	0.25 - 10.0	2230 - 1470	As drawn	A[4] 480°C 1hr	320	Good	Poor
BS 2056 (martensitic)	420S45	5.00 - 10.0	2000 - 1740	As drawn & softened	H/T to hardness required	300	Good	Poor
BS 970: Pt 1	402S29	10.0 - 70.0	1650 - 1470	Bright Bar	H/T to hardness required	320	Good	Poor
BS 3075 GrNA19	Cold Drawn Sol Treated	0.45 - 10.0 0.45 - 10.0	1540 - 1310 1080	As drawn	A.650°C: 4hrs A.750°C: 4hrs	350 350	Excellent	Poor
ASTM B166-84	Spring Temper	0.30 - 14.3	1275 - 965	As drawn	SR 450°C: 1hr	340	Excellent	Poor
AMS 5699D AMS 5698D	Spring Temper No. 1 Temper	0.30 - 15.5 0.30 - 12.5	1515 - 1240 1140 - 1070	As drawn	A.650°C: 4hrs A.735°C: 16hrs	370 550	Excellent	Poor
BS 3075 GrNA18	Cold Drawn	0.45 - 8.0	1240 - 1170	As drawn	A.590°C: 8hrs	260	Excellent	Poor
ASTM B164-84	Spring Temper	0.30 - 14.3	1140 - 830	As drawn	SR 310°C: ½hr	200	Excellent	Poor
BS 2786	CZ 107: ½H CZ 107: H CZ 107: EH	0.50 - 10.0 0.50 - 10.0 0.50 - 6.0	460 min 700 min 740 - 695	As drawn	SR 180/230°C: ½hr	80	Good	V.Poor
**BS 2873	PB 102: ½H PB 102: H PB 102: EH PB 103: ½H PB 103: H PB 103: EH	0.50 - 10.0 0.50 - 10.0 0.50 - 6.0 0.50 - 10.0 0.50 - 10.0 0.50 - 6.0	540 min 700 min 850 - 800 590 min 740 min 900 - 850	As drawn	SR 180/230°C: ½hr	80	Good	Poor
	CB 101WP CB 101W(H)P	0.50 - 10.0 0.50 - 3.0	1050 min 1240 min	As drawn	A.335°C: 2hrs	125	Good	Poor

KEY

1. SR = Stress Relieve
2. N/A = Not Applicable
3. H/T = Harden and Temper
4. A = Ageing (Precipitation Hardening)
5. Corrosion Ratings = Poor, Good, Excellent
6. Fatigue Ratings = V Poor, Poor, Good, V Good, Excellent

**Now BS EN 12166: 1998

Maximum permissible stresses for springs - Static applications

Material	Specification	Maximum Static Stresses			
		Unprestressed Compression and Extension Springs	Prestressed Compression Springs	Unprestressed Torsion Springs	Prestressed Torsion Springs
		% R_m	% R_m	% R_m	% R_m
Patented cold drawn spring steel wire	BS 5215, BS 1408	49*	70	70	100
Prehardened and tempered carbon steel and low alloy wire	BS 2803	53	70	70	100
Steels hardened and tempered after coiling carbon & low alloy	BS 1429, BS 970 Parts 1&2	53	70	70	100
Austenitic stainless steel wire	BS 2056 Gr 302S25	40*	59	70	100
Martensitic stainless steel wire	BS 2056 Gr 420S45	53	70	70	100
Precipitation hardening stainless wire	BS 2056 Gr 301S81	53	70	70	100
Spring brass wire	**BS 2873 Gr CZ107	40	59	70	100
Extra hard phosphor-bronze wire	**BS 2873 Gr PB102/103	40	59	70	100
Beryllium-copper wire	**BS 2873 Gr CB 101	40	59	70	100
Monel alloy 400	ASTM B164-90	40	53	70	100
Monel alloy K 500	BS 3075 Gr NA18	40	53	70	100
Inconel alloy 600	ASTM B166-91	42	55	70	100
Inconel alloy X 750	AMS 5699C	42	55	70	100
Nimonic alloy 90	BS 3075 Gr NA19	42	55	70	100
Ni-span alloy C902		40	53	70	100

***N.B.** For unprestressed compression and extension springs in static applications the LTHT (low temperature heat treatment) after coiling may be omitted only for BS 5216 and BS 2056 austenitic stainless materials. In this case, the maximum solid stress is reduced to 40% R_m for BS 5216 springs and 30% R_m for austenitic stainless springs.
****Now** BS EN 12166: 1998

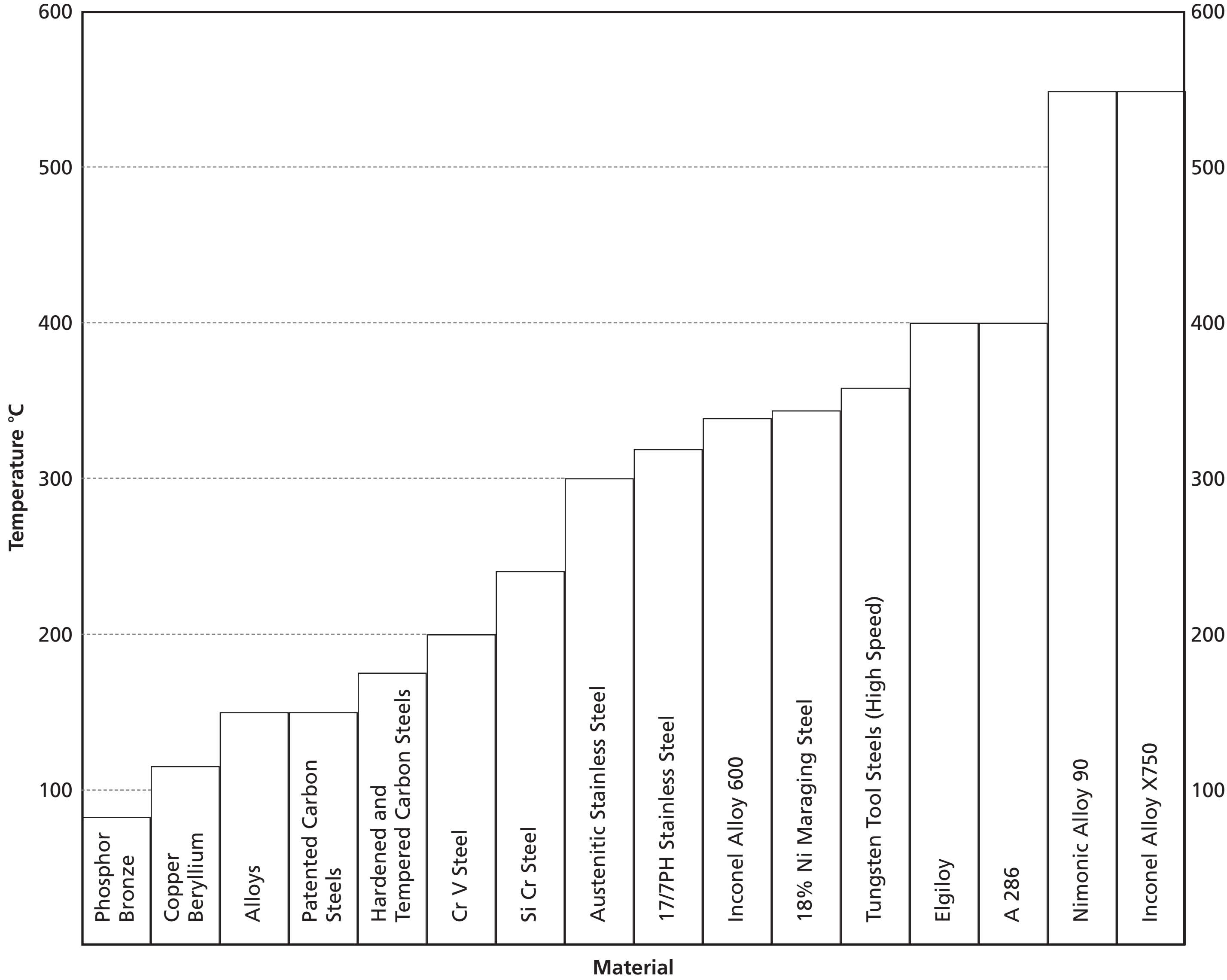
Elastic modulus values for spring materials

MATERIAL	E kN/mm²	G kN/mm²
Cold drawn carbon steel	207	79.3
Hardened and tempered carbon steel	207	79.3
Hardened and tempered low alloy steels	207	79.3
Austenitic stainless	187.5	70.3
Martensitic stainless	207	79.3
Precipitation hardening stainless	200	76.0
Phosphor-bronze	104	44.0
Spring brass	104	38.0
Copper-beryllium	128	48.3
Monel alloy 400 + K500	179	65.5
Inconel 600 + X750	214	76.0
Nimonic alloy 90	224	84.0
Titanium alloys	110	37.9
Ni-span alloy C902, Durinval C	190	65.0

NOTE: The above are average room temperature values. With some materials these values can vary significantly with metallurgical conditions.

As a guide to change in modulus with temperature value of 3% change per 100°C will give sufficient accuracy for all the above materials except Ni-span C902 which has a constant modulus with temperature. For all the other spring materials modulus decreases with increasing temperature.

Maximum operating temperatures for spring materials



Finishes

Springs made from carbon and alloy steels are particularly subject to corrosion. As well as spoiling the appearance of the spring, rusting can lead to pitting attack and can often result in complete failure of the component.

To prevent rusting, the steel surface should be isolated from water vapour and oxygen in the atmosphere at all stages of spring processing, storage and service, by application of a suitable protective coating.

Several temporary protective coatings are available to prevent corrosion in springs during processing and storage. The term 'temporary' does not refer to the duration of corrosion protection, but indicates only that the protective coating can be easily applied and removed as required. Nevertheless, temporary coatings are not suitable for long term protection of springs against corrosion in damp, humid or marine environments.

More durable coatings are therefore needed to protect springs throughout their service life.

Electroplated zinc and cadmium coatings have been used for many years to protect springs against corrosion during service. These metallic coatings act sacrificially to protect the spring, even when the coating is breached to expose the steel surface. However, electroplated springs can break due to hydrogen embrittlement introduced during the plating process.

New methods have now been developed for depositing zinc rich coatings onto the steel surface without introducing hydrogen embrittlement. The zinc can be mechanically applied during a barrelling process, or can be contained within the resin base with which the spring is coated during a dip/spin process, to give uniform coverage, even over recessed surfaces.

Paint and plastic coatings can also be used to protect springs against corrosion in service, neither of which protect the springs sacrificially. As a result, the success or failure of these coatings is critically dependent upon their ability to prevent the corrosive environment from reaching the steel surface. Good adhesion to the steel surface, flexibility and resistance to the environment are therefore required for paints and plastic coatings used to protect springs against corrosion.

Developments in coating technology have produced several new coatings which can be used to protect springs against corrosion at various stages of manufacture and service.

The IST (Institute of Spring Technology) has evaluated temporary coatings, metallic coatings, paint and plastics coatings in detail and results are available from them or ask you supplier.

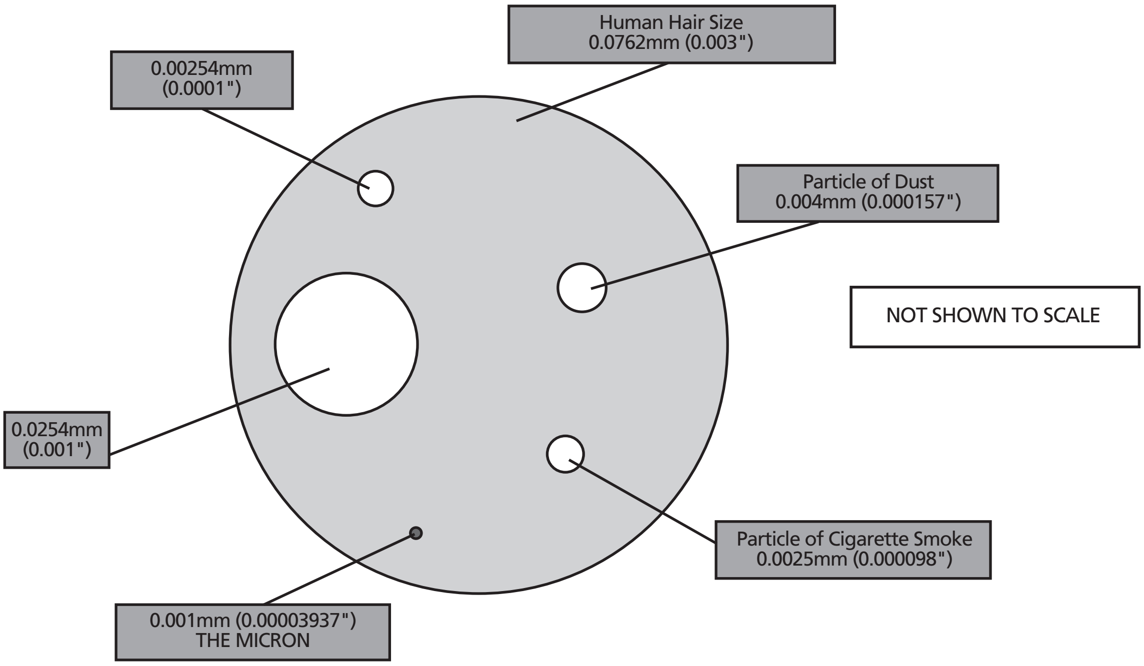
Conversion data

Quantity	To convert from	To	Multiply by
Length	Feet (ft)	Metres	0.3048
		Millimetres	304.8
	Metres (m)	Feet	3.2808
		Inches	39.3701
	Inches (in)	Metres	0.0254
		Millimetres	25.4
Area	Square Inches (in^2)	Square Millimetres	645.16
	Square Millimetres (mm^2)	Square Inches	0.00155
Volume	Cubic Inches (in^3)	Cubic Millimetres	16387.064
	Cubic Millimetres (mm^3)	Cubic Inches	0.000061024
Force	Pounds Force (lbf)	Newtons	4.4498
		Kilograms Force	0.4536
	Newtons (N)	Pounds Force	0.2247
		Kilograms Force	0.102
	Kilograms Force (kgf)	Newtons	9.81
		Pounds Force	2.2046
Rate	Pounds Force per Inch (Ibf/in)	Kilograms Force per Millimetre	0.017858
		Newtons per Millimetre	0.17519
	Newtons per Millimetre (N/mm)	Pounds Force per Inch	5.7082
		Kilograms Force per Millimetre	0.102
	Kilograms Force per Millimetre (kgf/mm)	Newtons per Millimetre	9.81
		Pounds Force per Inch	55.997
Torque	Pound Force-inch (Ibf/in)	Kilogram Force-Millimetre	11.52136
		Newton-Metre	0.11302
	Newton-Metre (Nm)	Pound Force-inch	8.84763
		Ounce Force-inch	141.562
		Kilogram Force-Millimetre	101.937
	Kilogram Force-Millimetre (kgf/mm)	Pound Force-inch	0.086796
		Newton-Metre	0.00981
		Ounce Force-inch	1.3887
	Ounce Force-inch (ozf/in)	Pound Force-inch	0.0625
		Newton-Metre	0.007064
		Kilogram Force-Millimetre	0.72

Standard wire gauge

SWG	IMPERIAL	METRIC
0000000	0.5000	12.7000
000000	0.4640	11.7856
00000	0.4320	10.9728
0000	0.4000	10.1600
000	0.3729	9.4488
00	0.3480	8.8392
0	0.3240	8.2296
1	0.3000	7.6200
2	0.2760	7.0104
3	0.2520	6.4008
4	0.2320	5.8928
5	0.2120	5.3848
6	0.1920	4.8768
7	0.1760	4.4704
8	0.1600	4.0640
9	0.1440	3.6576
10	0.1280	3.2512
11	0.1160	2.9464
12	0.1040	2.6416
13	0.0920	2.3368
14	0.0800	2.0320
15	0.0720	1.8288
16	0.0640	1.6256
17	0.0560	1.4224
18	0.0480	1.2192
19	0.0400	1.0160
20	0.0360	0.9144
21	0.0320	0.8128
22	0.0280	0.7112
23	0.0240	0.6096
24	0.0220	0.5588
25	0.0200	0.5080
26	0.0180	0.4572
27	0.0164	0.4166
28	0.0148	0.3759
29	0.0136	0.3454
30	0.0124	0.3150
31	0.0116	0.2946
32	0.0108	0.2743
33	0.0100	0.2540
34	0.0092	0.2337
35	0.0084	0.2134
36	0.0076	0.1930
37	0.0068	0.1727
38	0.0060	0.1524
39	0.0052	0.1321
40	0.0048	0.1219
41	0.0044	0.1118
42	0.0040	0.1016
43	0.0036	0.0914
44	0.0032	0.0813
45	0.0028	0.0711
46	0.0024	0.0610
47	0.0020	0.0508
48	0.0016	0.0406
49	0.0012	0.0305
50	0.0010	0.0254

Using microns



Geometric solutions

The Diameter of a Circle equal in area to a given Square - multiply one side of the Square by 1.12838
The Side of a Hexagon inscribed in a Circle - multiply the Circle Diameter by 0.5
The Diameter of a Circle inscribed in a Hexagon - multiply one side of the Hexagon by 1.7321
The Side of an Equilateral Triangle inscribed in a Circle - multiply the Circle Diameter by 0.866
The Diameter of a Circle inscribed in an Equilateral Triangle - multiply one Side of the Triangle by 0.57735
The Area of a Square or Rectangle - multiply the base by the height
The Area of a Triangle - multiply the Base by half the Perpendicular
The Area of a Trapezoid - multiply half the sum of Parallel sides by the Perpendicular
The Area of a Regular Hexagon - multiply the square of one side by 2.598
The Area of a Regular Octagon - multiply the square of one side by 4.828
The Area of a Regular Polygon - multiply half the sum of Sides by the Inside Radius
The Circumference of a Circle - multiply the Diameter by 3.1416
The Diameter of a Circle, multiply the Circumference by 0.31831
The Square Root of the Area of a Circle x 1.12838 = the Diameter
The Circumference of a Circle x 0.159155 = the Radius
The Square Root of the area of a Circle x 0.56419 = the Radius
The Area of a Circle - multiply the Square of the Diameter by 0.7854
The Square of the Circumference of a circle x 0.07958 = the Area
Half the circumference of a Circle x half its diameter = the Area
The Area of the Surface of a Sphere - multiply the Diameter Squared by 3.1416
The Volume of a Sphere - multiply the Diameter Cubed by 0.5236
The Area of an Ellipse - multiply the Long Diameter by the Short Diameter by 0.78540
To find the Side of a Square inscribed in a Circle - multiply the Circle Diameter by 0.7071
To find the Side of a Square Equal in Area to a given Circle - multiply the Diameter by 0.8862

References:

BS 1726 : Parts 1, 2 & 3. These standards have been superceded. See inside front cover.
Institute of Spring Technology.

Conversion data

Stress	Pound Force per Square Inch (lbf/in^2)	kgf/mm^2	0.000703
		hbar	0.000689
		N/mm^2	0.006895
		$tonf/in^2$	0.000446
	Kilogram Force per Square Millimetre (kgf/mm^2)	lbf/in^2	1422.823
		hbar	0.981
		N/mm^2	9.81
		$tonf/in^2$	0.635
	Hectobars	lbf/in^2	1450.38
		N/mm^2	10
		kgf/mm^2	1.019368
		$tonf/in^2$	0.6475
	Newton per Square Millimetre (N/mm^2)	lbf/in^2	145.038
		kgf/mm^2	0.101937
		hbar	0.1
		$tonf/in^2$	0.06475
	Ton Force per Square Inch ($tonf/in^2$)	lbf/in^2	2240.0
		kgf/mm^2	1.5743
		hbar	1.54442
		N/mm^2	15.4442

Length	1 cm	= 0.3937 in	1 in	= 25.4 mm	1 m	= 3.2808 ft
	1 ft	= 0.3048 m	1 km	= 0.6214 mile	1 mile	= 1.6093 km
Weight	1 g	= 0.0353 oz	1 oz	= 28.35 g		
	1 kg	= 2.2046 lb	1 lb	= 0.4536 kg		
	1 tonne	= 0.9842 ton	1 ton	= I.0I6 tonne		
Area	1 m^2	= 1.196 $yard^2$	1 in^2	= 645.2 mm^2		
	1 hectare	= 2.471 acre	1 $yard^2$	= 0.8361 m^2		
	1 acre	= 0.4047 hectare	1 sq mile	= 259 hectare		

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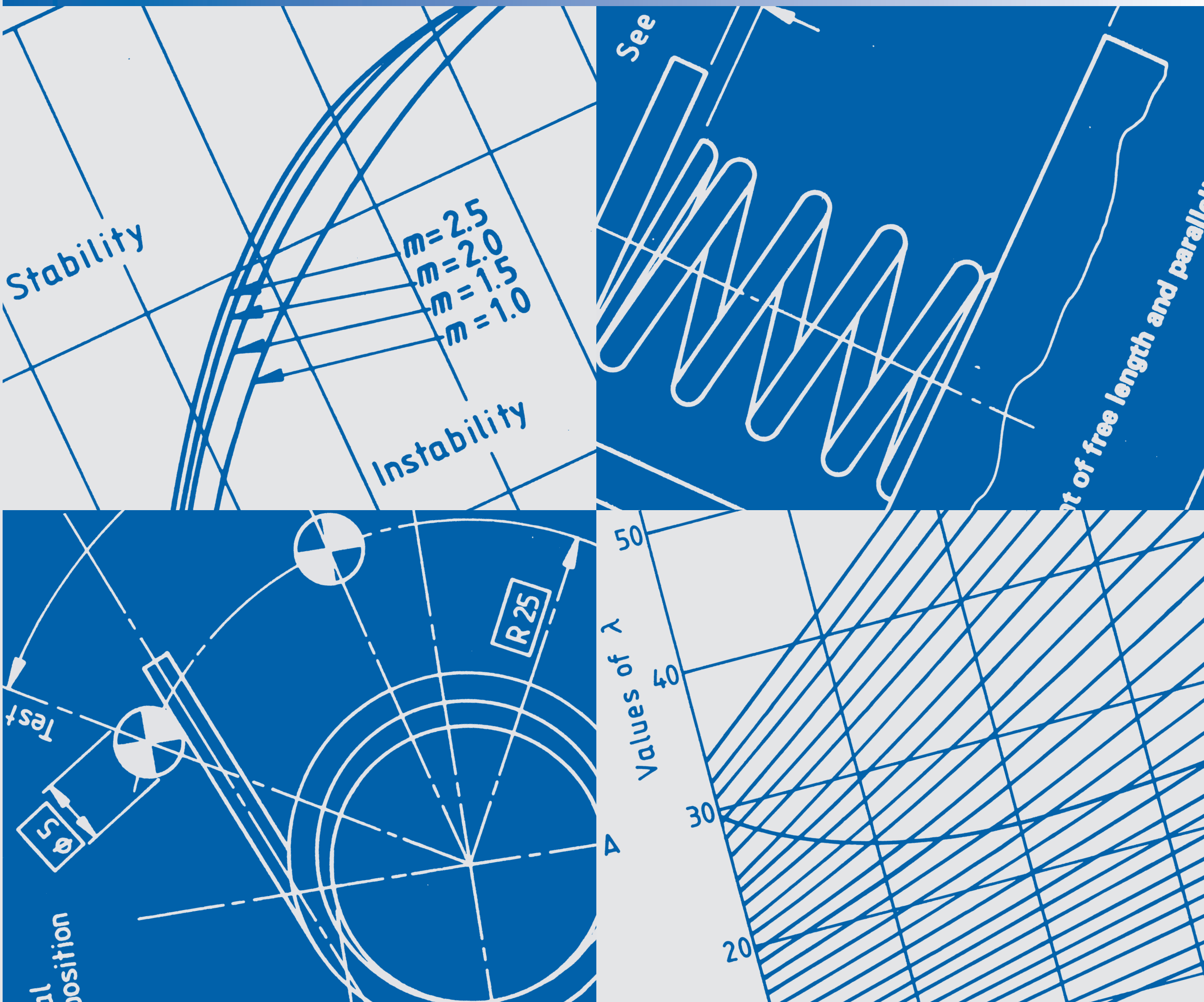
SPECIFIED THE WORLD OVER



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