MODULE 4

MECHANICAL SPRINGS

ME/MD II

INTRODUCTION

- A spring is a resilient member capable of providing large elastic deformation.
- It is defined as an elastic body whose function is to distort when loaded and to recover its original shape when the load is removed.

INTRODUCTION

- Mechanical springs are used for a wide range of applications or uses. Their main applications are
- to exert force,
- to provide flexibility and
- to store or absorb energy.

TYPES OF SPRINGS- CLASSIFICATION

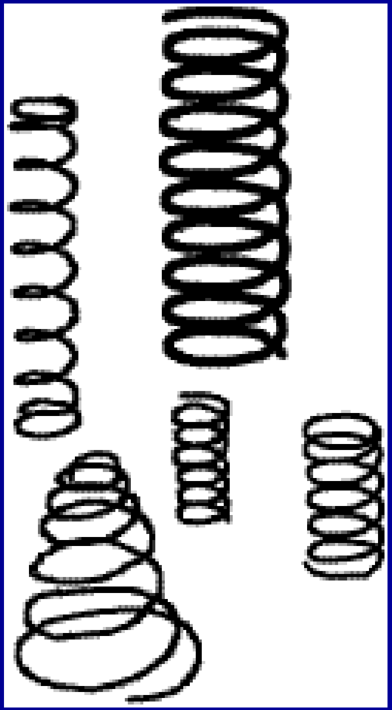
Springs are classified based on its shape or geometry, nature of stressing etc.

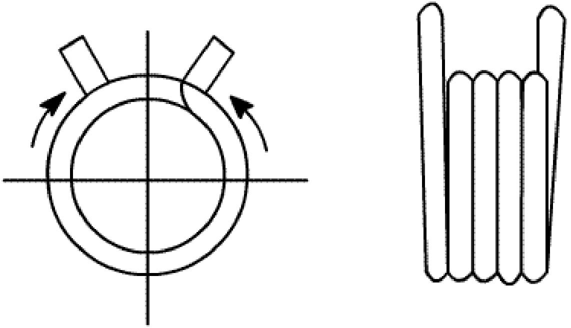
Based on the shape/geometry they fall under

1. wire springs,
2. flat springs, and
3. special-shaped springs

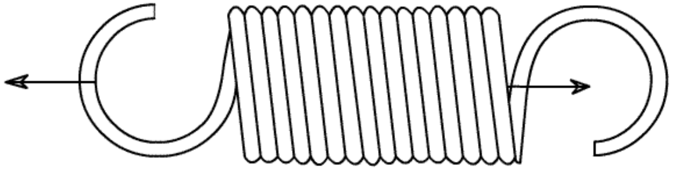
WIRE SPRINGS

- These include helical springs of round or square wire that are cylindrical or conical in shape.
- These are made to resist tensile, compressive, or torsional loads.

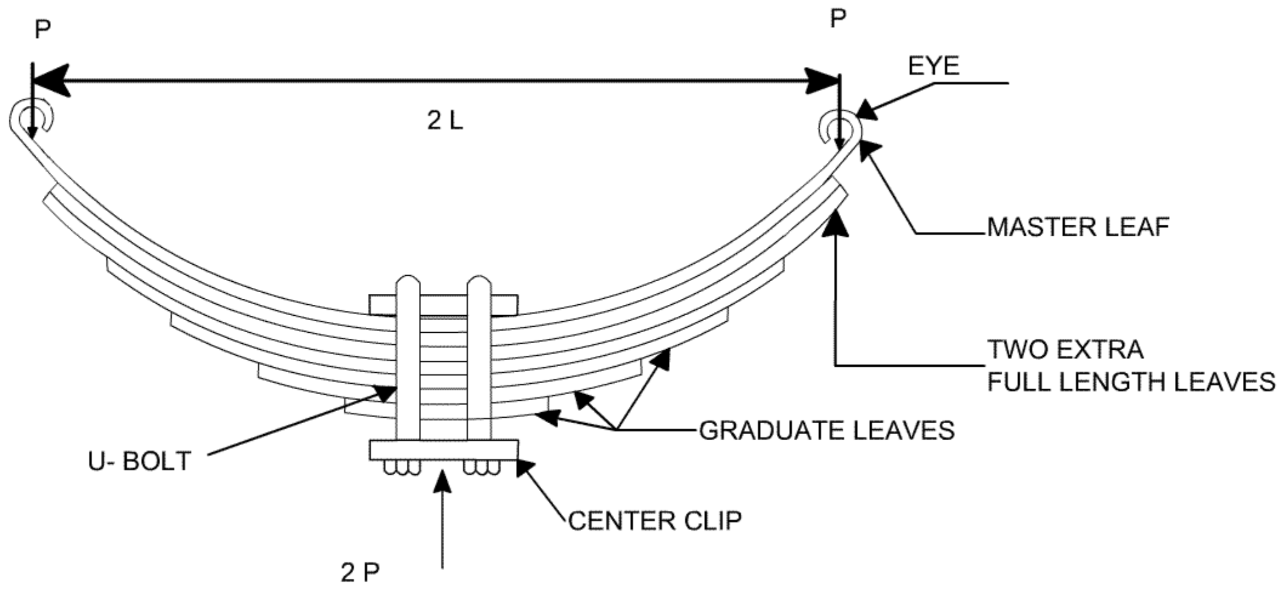




Torsion springs. Twist round or rectangular wire



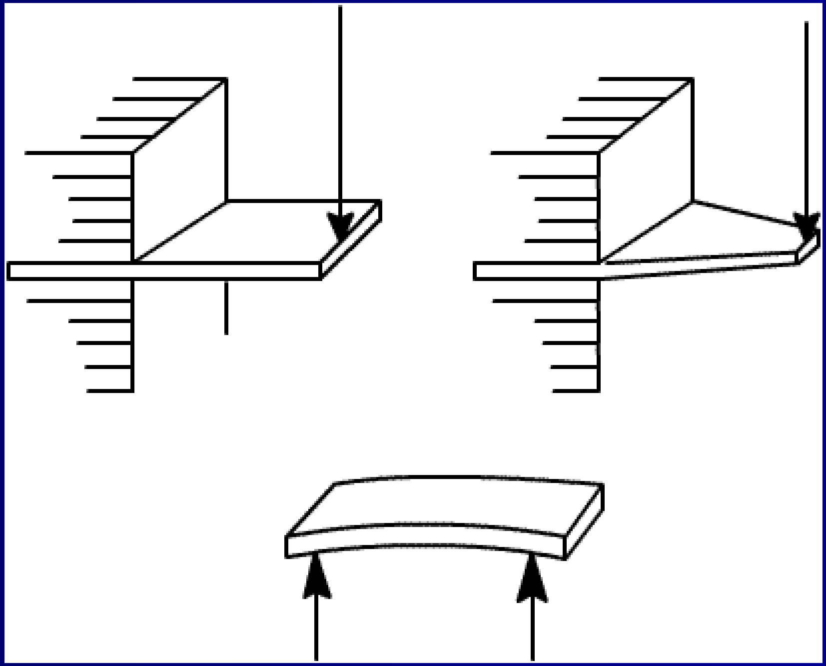
Helical extenstion springs



Semi-elliptic leaf spring

FLAT SPRINGS

These include the cantilever and elliptical type (leaf) springs, the wound motor-or clock type power springs and the flat spring washers, usually called Belleville springs.



COIL SPRINGS

- Among the various springs helical or coil compression springs are the widely used ones and hence discussions will be confined to the helical (coil) compression springs

DESING O F COIL SPRINGS

The design of a new spring involves the following considerations:

- Space into which the spring must fit and operate.
- Values of working forces and deflections.
- Accuracy and reliability needed.

DESIGN CONSIDERATION

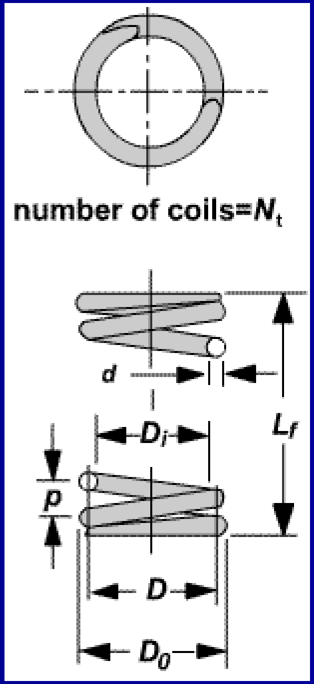
- The primary consideration in the design of the coil springs are that
- the induced stresses are below the permissible limits while subjected to or exerting the external force F

DESIGN CONSIDERATION

- Capable of providing the needed deflection or maintaining the spring rate desired

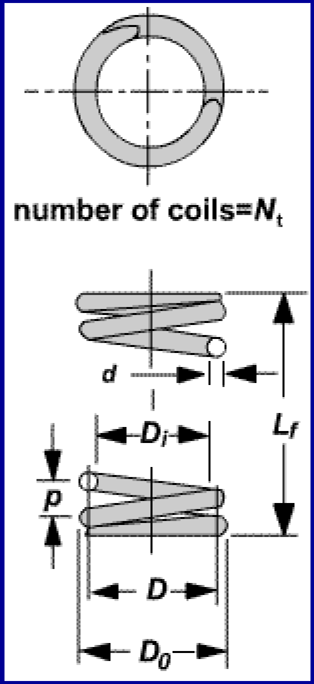
NOMENCLATURE

A	Material constant
C	Spring index=D/d
d	Wire diameter
D	Mean coil diameter
k	Spring rate or spring stiffness
L	Length
N	Number of coils
T	Torsional Moment



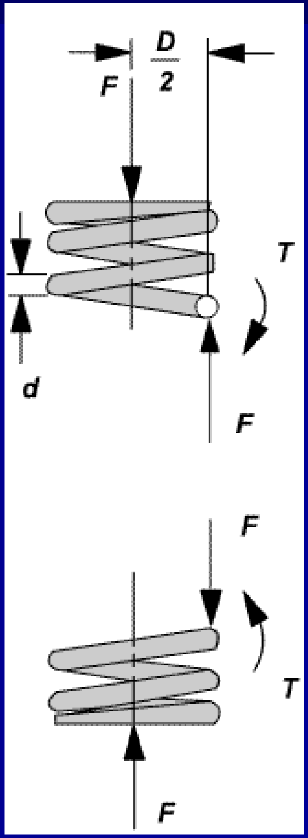
NOMENCLATURE

U	**Strain energy**
α	**Helix angle**
δ	**Deflection**
ρ	**Density**
τ	**Shear stress in spring**



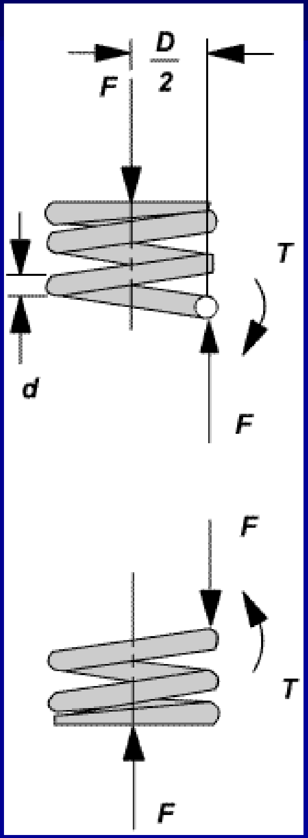
NOMENCLATURE

F	Force/Load
G	Shear Modulus (of Rigidity)
J	Polar Moment of Inertia
K	Stress correction factor



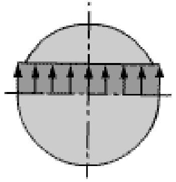
STRESSES IN HELICAL SPRINGS

The flexing of a helical spring creates torsion in the wire and the applied force also induces a direct stress. The maximum stress in the wire may be computed by super position.

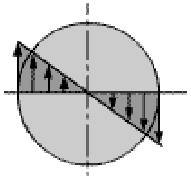


- **The result is**

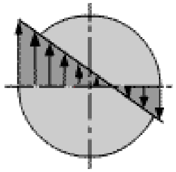
$$\tau_{\max} = \pm \frac{Tr}{J} + \frac{F}{A}$$



(a) direct shear stress distribution across section



(b) Torsional shear stress distribution



(c) combined direct shear and torsional stress

STRESSES IN HELICAL SPRINGS

Replacing the terms,

$$T=\frac{FD}{2},\ \ r=\frac{d}{2},\ \ J=\frac{\pi d^{4}}{32}\ and\ \ A=\frac{\pi d^{4}}{4}$$

And re-arranging,

$$\tau = K_s \frac{8FD}{\pi d^3} \quad or \quad \tau = K_s \frac{8FC}{\pi d^2}$$

K_s is the direct shear-stress correction factor and is defined as:

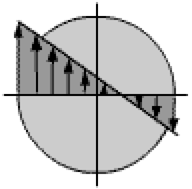
$$K_s = \frac{2C+1}{2C}$$

CURVATURE EFFECT

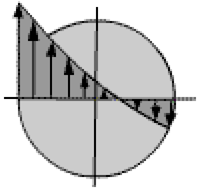
- The curvature of the wire displaces the neutral axis away from the center (geometric) axis and hence increases the stress on the inside of the spring, but decreases it only slightly on the outside.

CURVATURE EFFECT

- The curvature stress is highly localized that its effect can not be neglected particularly when fatigue is present.



(c) combined direct shear and torsional stress



(d) effects of stress concentration

Whal's correction factor

- The combined effect of direct shear and curvature correction is accounted by Wahl's correction factor K_w and is given as:

$$K_w = \frac{4C-1}{4C-4} + \frac{0.615}{C}$$

DEFLECTION AND STIFFNESS OF THE SPRING

- **According to Castigliano's theorem,the total strain energy for a helical spring is composed of torsional component and a shear component.**

  i.e

DEFLECTION AND STIFFNESS OF THE SPRING

- The total strain energy for a helical spring is composed of torsional component and a shear component.

- **Strain energy per unit volume**

$$u=\frac{T^2}{2G}\frac{l}{J}+\frac{F^2}{2A}\frac{l}{G}$$

Substituting

$$T=F\frac{D}{2};\ 1=\pi.D.N;\ J=\pi.\frac{d^4}{32}\ \ and\ \ A=\frac{\pi d^2}{4}$$

$$U = \frac{4F^2D^3N}{G.d^4} + \frac{F^2DN}{Gd^2}$$

- Where N is the number of active coils
- The deflection in the spring, using Castigliano’s theorem

$$y = \frac{\partial U}{\partial F} = \frac{8FD^3N}{Gd^4} + \frac{4FDN}{Gd^2}$$

- Substituting C= D/d and rearranging

y =

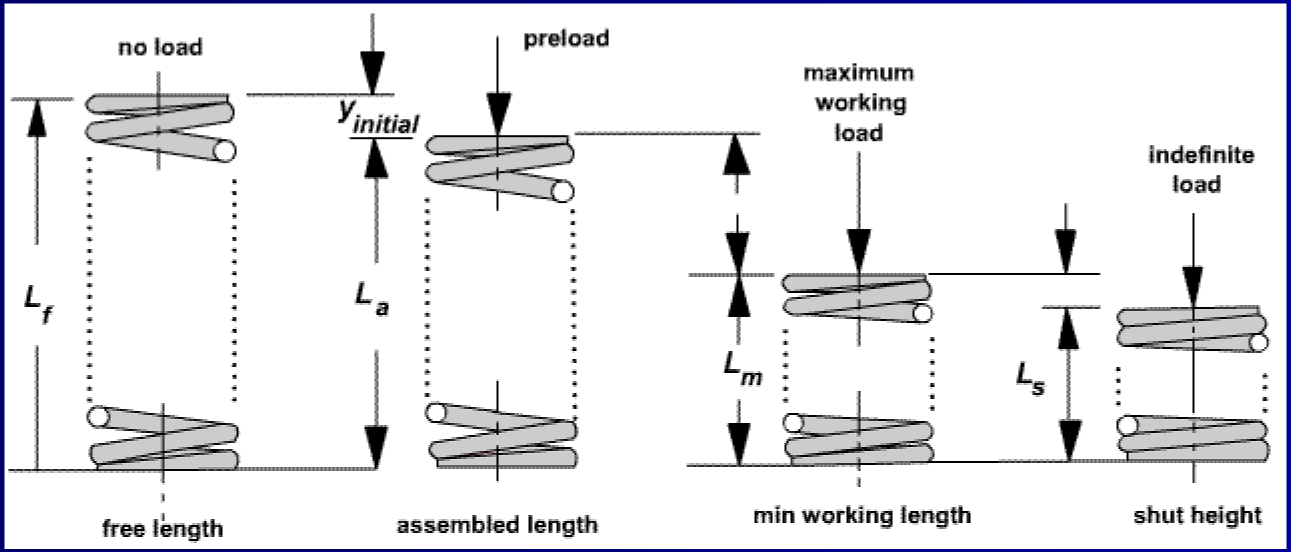
$$y = \frac{8FD^3N}{Gd^4}\left(1 + \frac{1}{2C^2}\right)$$

For normal range of C, the term within bracket (contribution of direct shear) is so negligible we can write

$$y = \frac{8FD^3N}{Gd^4} \quad or \quad \frac{8FC^3N}{Gd}$$

and

$$k = \frac{F}{y} = \frac{G.d}{8C^3N} = \frac{Gd^4}{8D^3N}$$


no load
preload
maximum working load
indefinite load
$y_{initial}$
L_f
L_a
L_m
L_s
free length
assembled length
min working length
shut height

DEFLECTION AND STIFFNESS OF THE SPRING

The spring stiffness or springs rate,

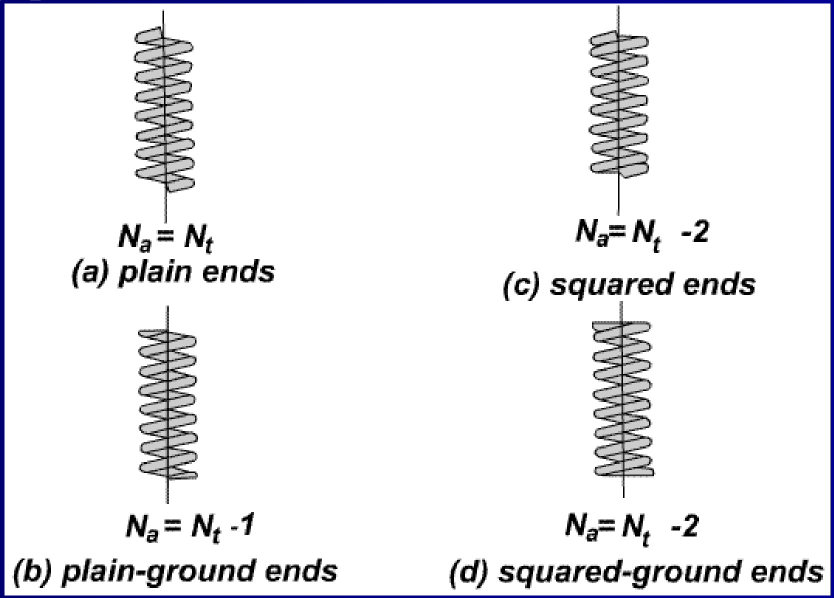
$$k = \frac{F}{y} = \frac{G.d}{8C^3 N} = \frac{Gd^4}{8D^3 N}$$

- **Using the equation the number of active coils needed to maintain the desired deflection or spring stiffness will be determined.**
- **In order to maintain proper contact and align the force along the spring axis the ends are to be properly shaped.**

COIL COMPRESSION SPRINGS

End Construction

Different types of ends used are shown in the figure



$N_a = N_t$
(a) plain ends

$N_a = N_t - 2$
(c) squared ends

$N_a = N_t - 1$
(b) plain-ground ends

$N_a = N_t - 2$
(d) squared-ground ends

PRE-SETTING OR SET REMOVAL

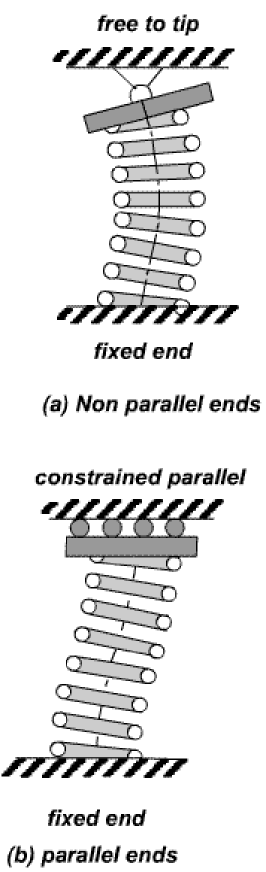
- Pre-setting or set removal is a process used in the manufacture of compression springs to induce useful residual stresses.
- It is done by making the spring longer than needed and compressing it to its solid height for few times till the designed length is attained

PRE-SETTING OR SET REMOVAL

- Set removal increases the strength of the springs
- It is useful when the spring is used for energy storage purposes.
- However, this should not be used when springs are subjected to fatigue.

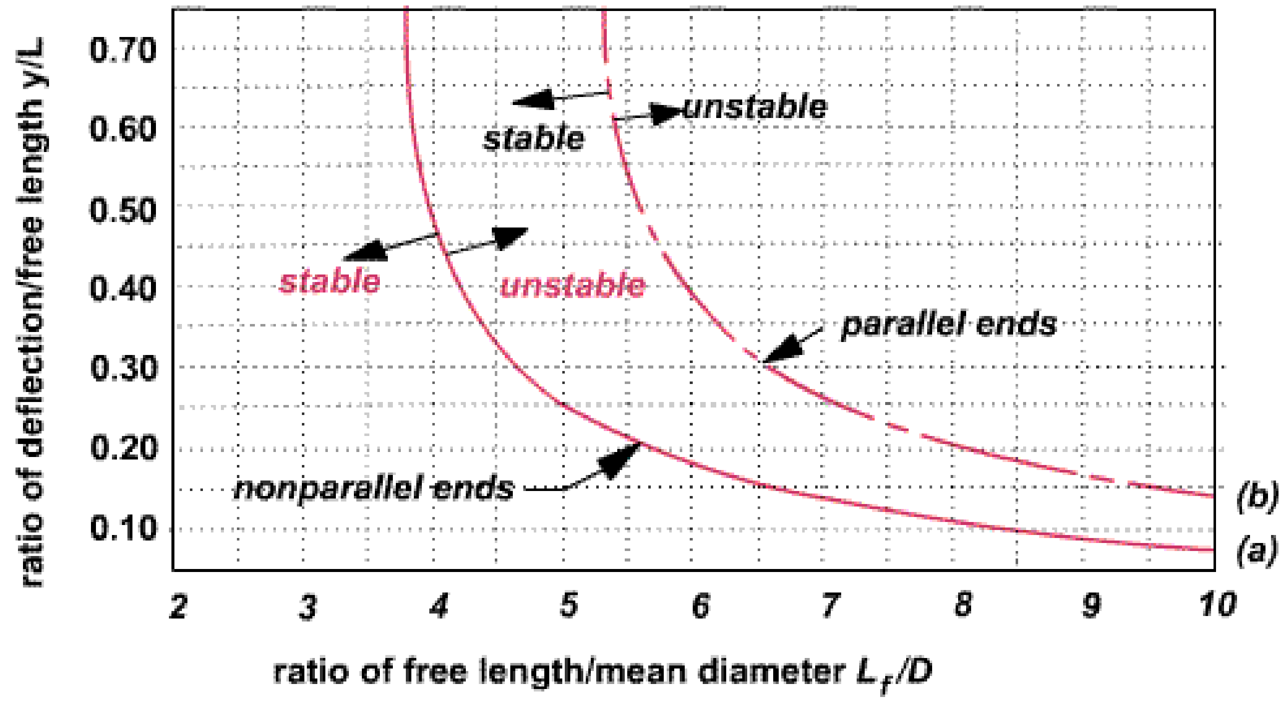
STABILITY OF THE SPRING (BUCKLING)

- Buckling of column is a familiar phenomena.
- Similarly, compression coil springs will buckle when the deflection (for a given free length) becomes too large.



- Buckling can be prevented by limiting the deflection of the spring or the free length of the spring.
- The behavior can be characterized by using two dimensionless parameters, critical length and critical deflection

- Critical deflection can be defined as the ratio of deflection (y) to the free length (L_f) of the spring
- The critical length is the ratio of free length (L_f) to mean coil diameter (D)
- The critical deflection is a function of critical length and has to be below a certain limit.


ratio of deflection/free length y/L
0.70
0.60
0.50
0.40
0.30
0.20
0.10
stable
unstable
stable
unstable
parallel ends
nonparallel ends
(b)
(a)
2
3
4
5
6
7
8
9
10
ratio of free length/mean diameter L_f/D

- As could be noticed from the figure absolute stability can be ensured if the critical length can be limited below a limit.

STABILITY OF THE SPRING (BUCKLING)

- The condition for absolute stability can be given as:

$$L_o < \frac{\pi D}{\alpha}\left[\frac{2(E-G)}{2G+E}\right]^{\frac{1}{2}}$$

For steels this can be simplified as:

$$L_o < 2.63\frac{D}{\alpha}$$

- Where α is a constant related to the nature of support of the ends simply referred as end constant

SPRING SURGE AND CRITICAL FREQUENCY

- If one end of a compression spring is held against a flat surface and the other end is disturbed, a compression wave is created that travels back and forth from one end to the other.

SPRING SURGE AND CRITICAL FREQUENCY

- **Under certain conditions, a resonance may occur resulting in a very violent motion, with the spring actually jumping out of contact with the end plates, often resulting in damaging stresses.**

SPRING SURGE AND CRITICAL FREQUENCY

- **This is quite true if the internal damping of the spring material is quite low. This phenomenon is called *spring surge* or merely *surging.***

- **When helical springs are used the physical dimensions of the spring should not create a natural vibratory frequency close to the frequency of the applied force.**

- The final equation for the natural frequency, derived from the governing equation of the wave motion, for a spring placed between two flat parallel plates is given by:

$$f = \frac{d}{\pi D^2 N_a} \sqrt{\frac{G.g}{32.\rho}}$$

- **For steels this can be simplified as:**

$$f = 38.5 \times 10^4 \frac{d}{N_a D^2}$$

FATIGUE LOADING

- The springs have to sustain millions of cycles of operation without failure, so it must be designed for infinite life.
- Helical springs are never used as both compression and extension springs.

FATIGUE LOADING

- They are usually assembled with a preload so that the working load is additional. Thus, their stress-time diagram is of fluctuating nature.

Now, for design we define,

$$F_a = \frac{F_{\max} - F_{\min}}{2}$$

$$F_a = \frac{F_{\max} + F_{\min}}{2}$$

The stress amplitude and mean stress values are given by:

$$\tau_a = K_c \frac{8F_a D}{\pi d^3} \quad and \quad \tau_m = K_s \frac{8F_m D}{\pi d^3}$$

If we employ the Goodman criterion, then

$$\frac{\tau_a}{S_{se}} + \frac{\tau_m}{S_{su}} = \frac{1}{n} \quad or \quad n = \frac{S_{se}.S_{su}}{\tau_a.S_{su} + \tau_m.S_{su}}$$

Extension Springs

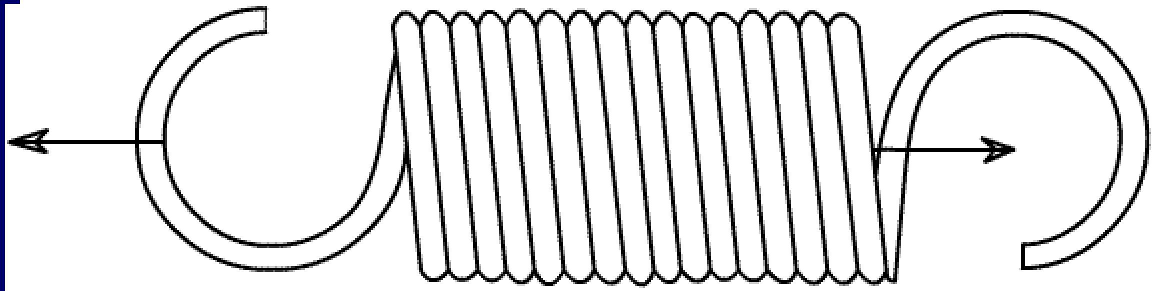
- Extension springs must necessarily have some means of transferring the load from the support to the body of the spring.
- In designing the spring with a hook end, the stress concentration effect must be considered as failure, predominantly occurs here.

Extension Springs

- Extension springs must necessarily have some means of transferring the load from the support to the body of the spring.
- Most widely used means for transfer of load is through hook construction

- In designing the spring with a hook end, the stress concentration effect must be considered as failure, predominantly occurs here
- Further as the spring elongates when loaded, no built in safety is available, as in coil compression springs and very often spring fails or loses its resilience when the extension exceeds a limit.

- To mitigate this problem, the springs are initially wound with certain pre-stressing and consequently will have closed coils.
- The initial pre stress and the stress due to external loading should not exceed the permissible strength.
- The stress concentration effect further limits the useful load range for a given size.

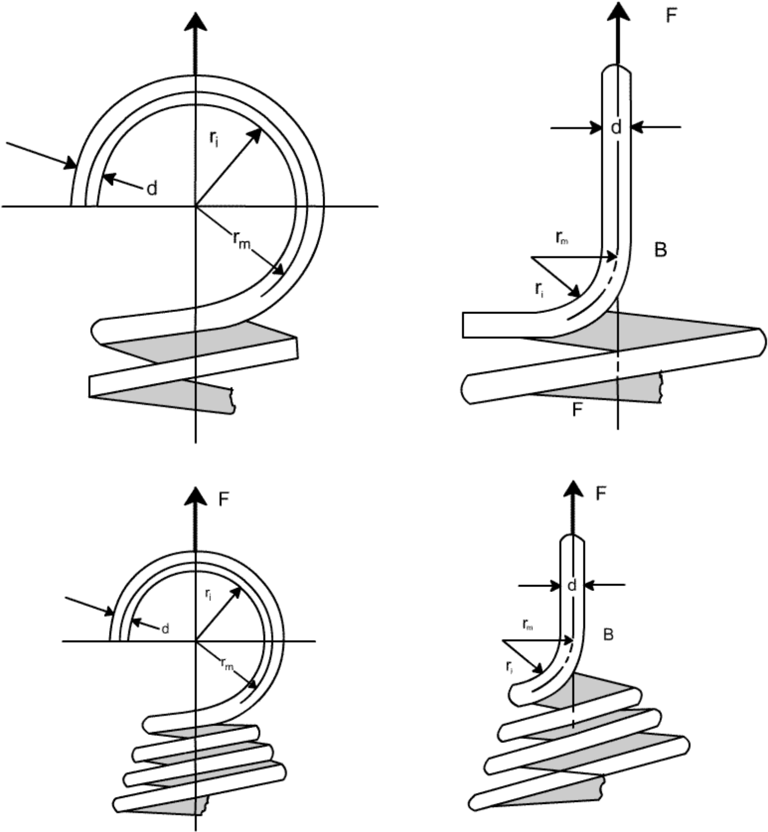


Helical extenstion springs

Extension Springs

- Tests as well as analysis show that the stress-concentration factor is given approximately by

$$K = \frac{r_m}{r_i}$$

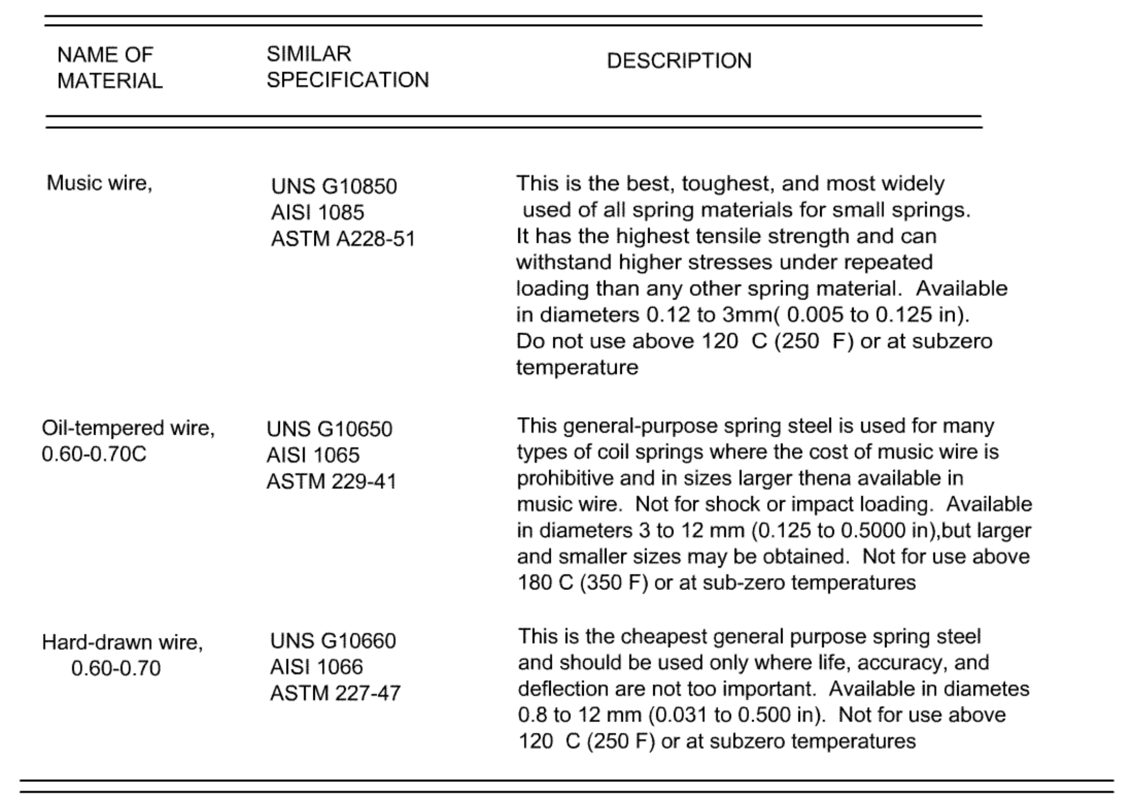

r_i
d
r_m
F
d
r_m
r_i
B
F
F
r_i
d
r_m
F
d
r_m
r_i
B

SPRING MATERIALS

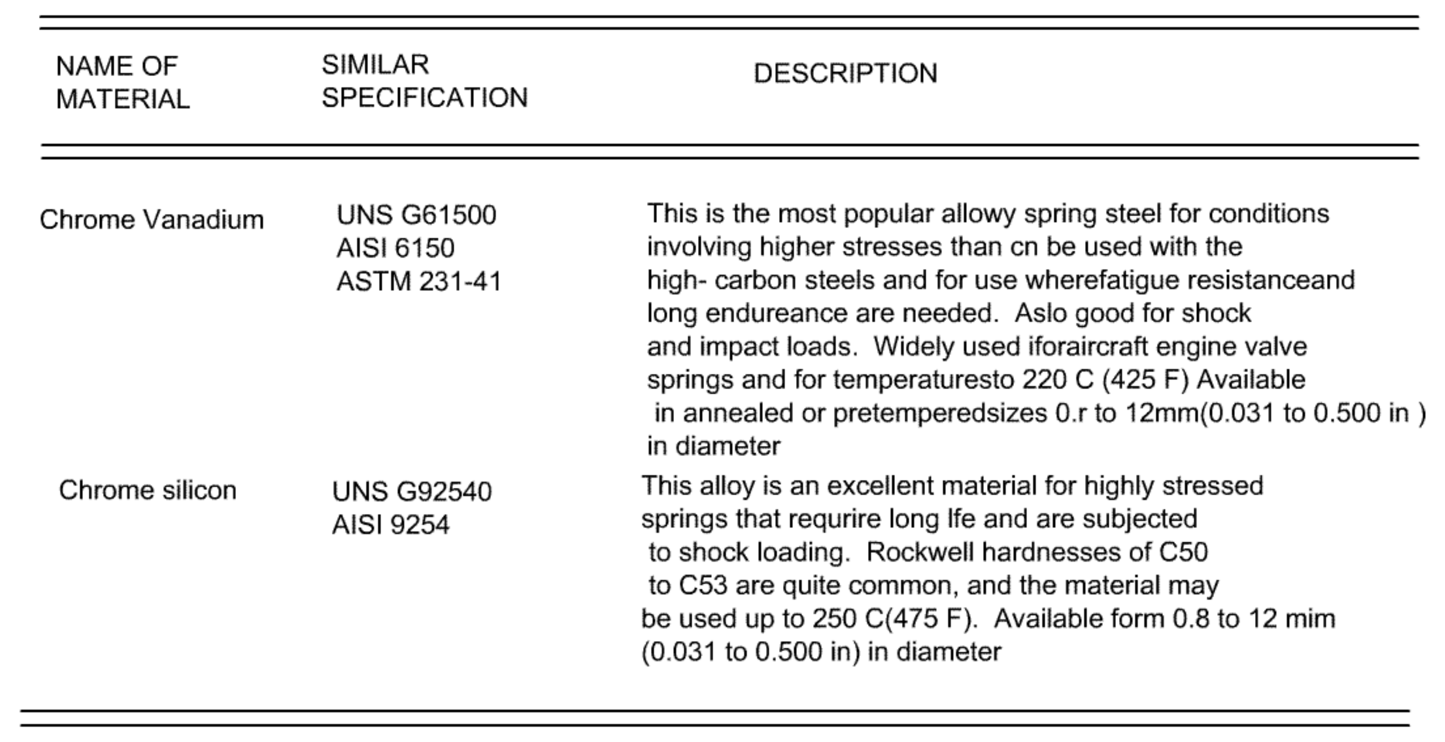
- The spring materials available are:
- Plain carbon steels,
- Alloy steels, and
- Corrosion resisting steels.
- Non-ferrous materials such as

SPRING MATERIALS

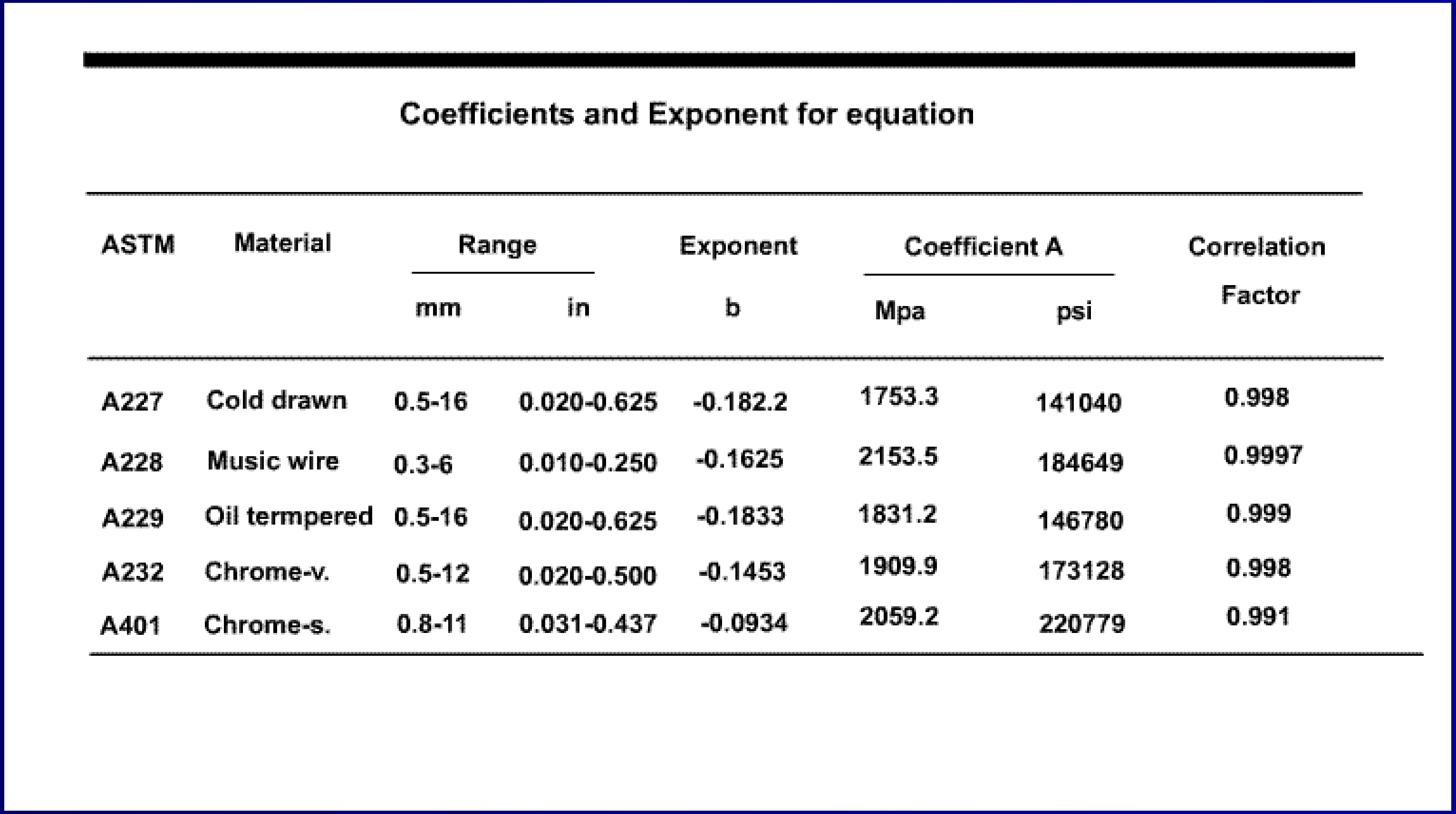
- Phosphor bronze,
- Spring brass,
- Beryllium copper, and
- Various nickel alloys.
- Table



NAME OF MATERIAL	SIMILAR SPECIFICATION	DESCRIPTION
Music wire,	UNS G10850 AISI 1085 ASTM A228-51	This is the best, toughest, and most widely used of all spring materials for small springs. It has the highest tensile strength and can withstand higher stresses under repeated loading than any other spring material. Available in diameters 0.12 to 3mm(0.005 to 0.125 in). Do not use above 120 C (250 F) or at subzero temperature
Oil-tempered wire, 0.60-0.70C	UNS G10650 AISI 1065 ASTM 229-41	This general-purpose spring steel is used for many types of coil springs where the cost of music wire is prohibitive and in sizes larger thena available in music wire. Not for shock or impact loading. Available in diameters 3 to 12 mm (0.125 to 0.5000 in),but larger and smaller sizes may be obtained. Not for use above 180 C (350 F) or at sub-zero temperatures
Hard-drawn wire, 0.60-0.70	UNS G10660 AISI 1066 ASTM 227-47	This is the cheapest general purpose spring steel and should be used only where life, accuracy, and deflection are not too important. Available in diametes 0.8 to 12 mm (0.031 to 0.500 in). Not for use above 120 C (250 F) or at subzero temperatures



NAME OF MATERIAL	SIMILAR SPECIFICATION	DESCRIPTION
Chrome Vanadium	UNS G61500 AISI 6150 ASTM 231-41	This is the most popular allowy spring steel for conditions involving higher stresses than cn be used with the high- carbon steels and for use wherefatigue resistanceand long endureance are needed. Aslo good for shock and impact loads. Widely used iforaircraft engine valve springs and for temperaturesto 220 C (425 F) Available in annealed or pretemperedsizes 0.r to 12mm(0.031 to 0.500 in) in diameter
Chrome silicon	UNS G92540 AISI 9254	This alloy is an excellent material for highly stressed springs that requrire long lfe and are subjected to shock loading. Rockwell hardnesses of C50 to C53 are quite common, and the material may be used up to 250 C(475 F). Available form 0.8 to 12 mim (0.031 to 0.500 in) in diameter



Coefficients and Exponent for equation

ASTM	Material	Range		Exponent	Coefficient A		Correlation Factor
		mm	in	b	Mpa	psi	
A227	Cold drawn	0.5-16	0.020-0.625	-0.182.2	1753.3	141040	0.998
A228	Music wire	0.3-6	0.010-0.250	-0.1625	2153.5	184649	0.9997
A229	Oil termpered	0.5-16	0.020-0.625	-0.1833	1831.2	146780	0.999
A232	Chrome-v.	0.5-12	0.020-0.500	-0.1453	1909.9	173128	0.998
A401	Chrome-s.	0.8-11	0.031-0.437	-0.0934	2059.2	220779	0.991

- The wire diameter used apart from the materials and its processing,have an effect on tensile strength.
- It turns out that the graph of tensile strength versus wire diameter is almost a straight line for some materials when plotted on the log-log paper.

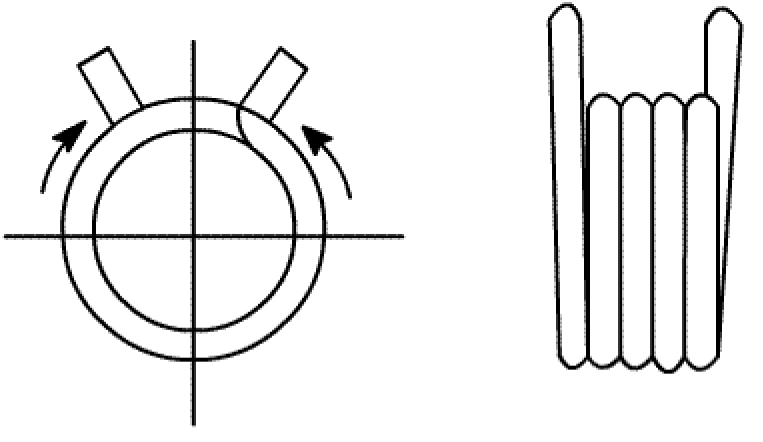
- Hence their tensile strength can be determined, writing the equation of this line as,

$$S_{ut} = \frac{A}{d^m}$$

- Springs are manufactured by hot or cold-working process, depending upon the size of the material, the spring index, and the properties desired.

HELICAL TORSION SPRINGS

Figure



Torsion springs. Twist round or rectangular wire

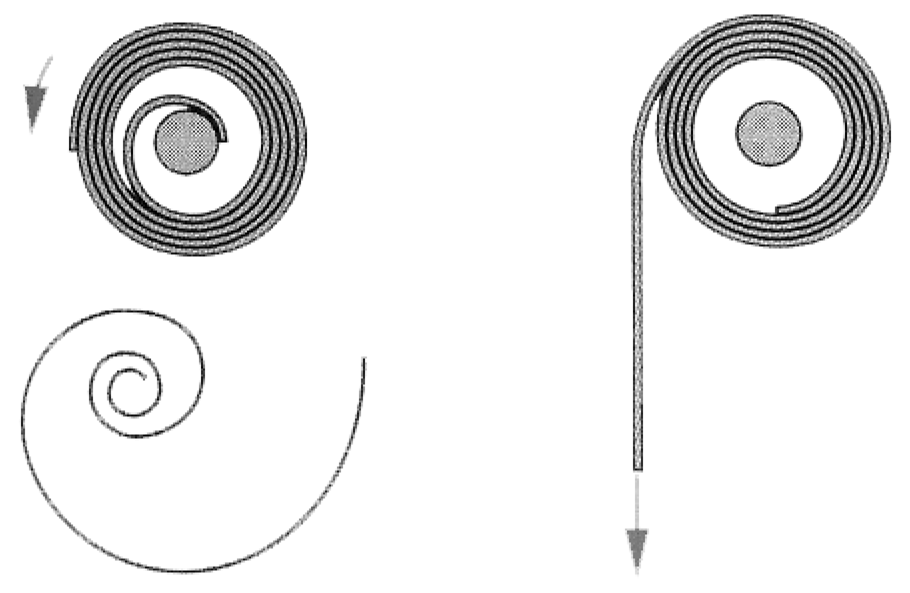
BELLEVILLE SPRINGS

Belleville

MISCELLANEOUS SPRINGS

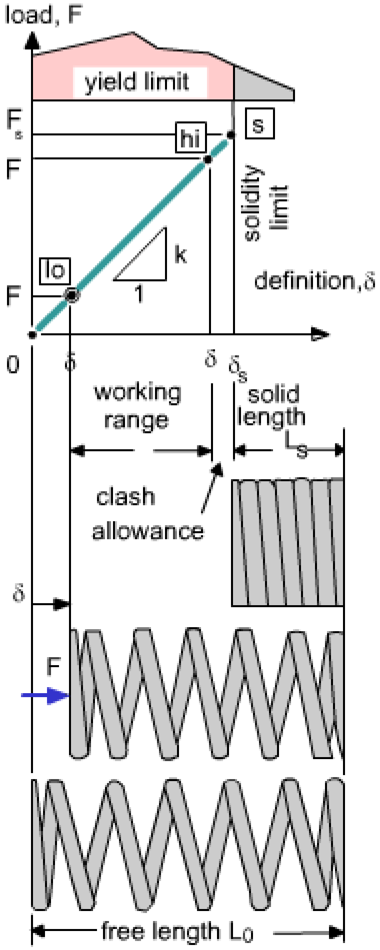
Flat stocks are used for a great variety of springs, such as:

- clock springs,
- power springs,
- torsion springs,
- cantilever springs and
- hair springs.



MISCELLANEOUS SPRINGS

It is specially shaped to create certain spring actions for fuse chips, relay springs, spring washers, snap rings and retainers.


load, F
yield limit
F_s
hi
s
F
solidity limit
k
1
lo
F
definition, δ
0
δ
δ
δ_s
working range
solid length
L_s
clash allowance
δ
F
free length L_0