# UNIT – IV
# DESIGN OF ENERGY STORING ELEMENTS

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# INTRODUCTION

**SPRINGS:**

Spring is an elastic body whose function is to distort when loaded and to recover its original shape when the load is removed.

**APPLICATION:**

1. To absorb energy – suspension systems, shock absorber, etc.
2. To store energy – watches, toys, etc.
3. To apply force – Brakes, clutches, safety valves etc.

# Continue…

4. To ensure position or contact in Ic engines valves & cam-follower.
5. To accommodate misalignment – Joining of railway compartment.

**SPRING MATERIAL:**

1. Oil – tempered carbon steel
2. Music wire
3. Phasphor Bronze
4. Beryllium Copper
5. Monel metal
6. Brass

# Continue…

**TYPES OF SPRING:**

1. Helical springs

    (a) Closed coil spring

    (b) open coil spring

2. Conical and volute spring
3. Torsion spring
4. Laminated (or)Leaf spring
5. Disc (or) Bellevile spring
6. Special purpose spring

# HELICAL SPRINGS

(*a*) Compression helical spring. (*b*) Tension helical spring.

| Open coiled helical spring | Closed coil helical spring |
|---|---|
| 1. The gap between sucessive turns is large | Small |

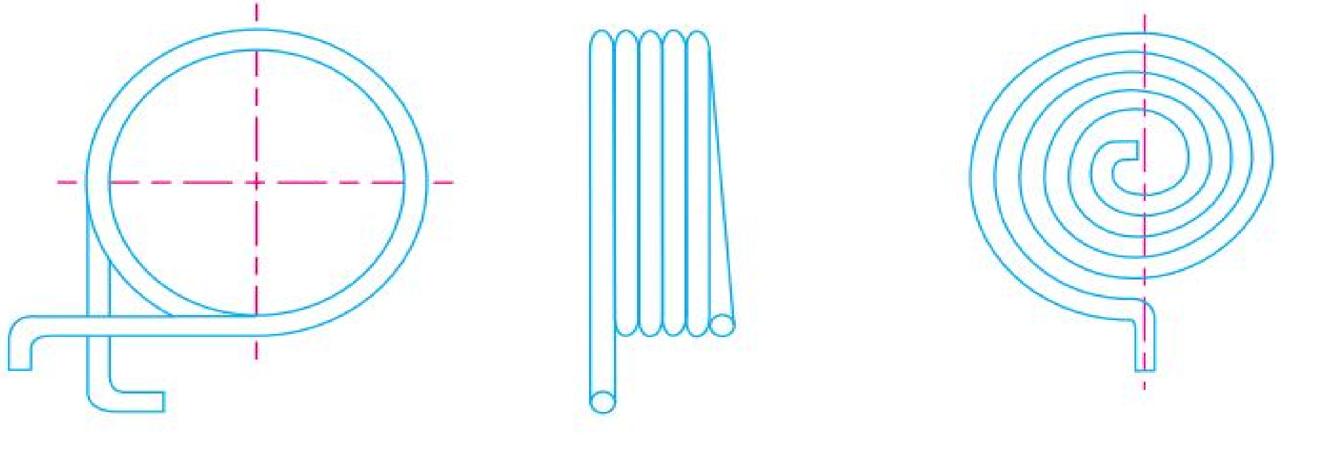
| | |
|---|---|
| 2. Helix angle is more than 10° | less than 10° |
| 3. It can take up tensile & compressive load | It can take up tensile load only |
| 4. Friction effect is less | Friction effect is more |

2. <u>Conical and volute springs:</u>

(*a*) Conical spring.

(*b*) Volute spring.

# 3. Torsional spring:



(*a*) Helical torsion spring.

(*b*) Spiral torsion spring.

# 4. Laminated (or) Leaf spring:

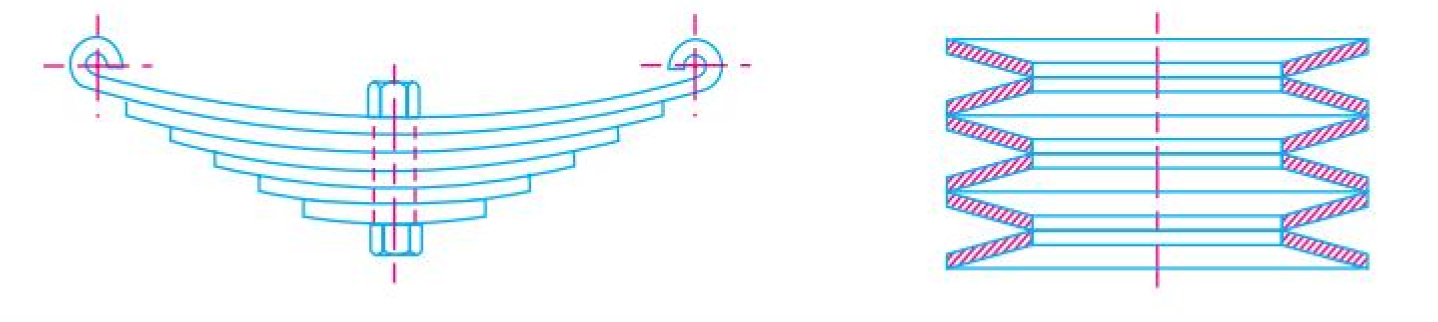


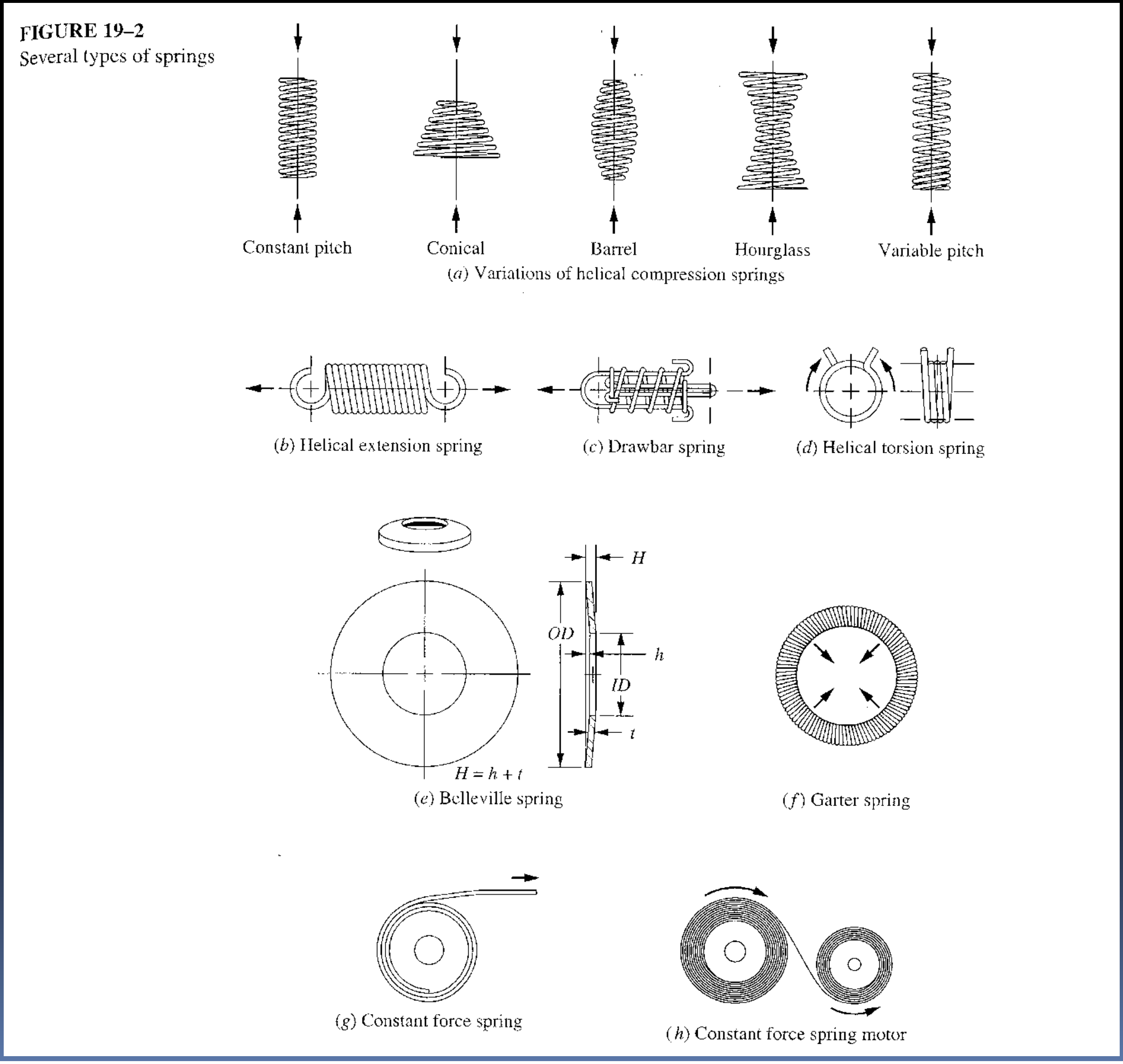
**Fig. 23.4.** Laminated or leaf springs.

**Fig. 23.5.** Disc or bellevile springs.

5. Disc (or) bellevile springs

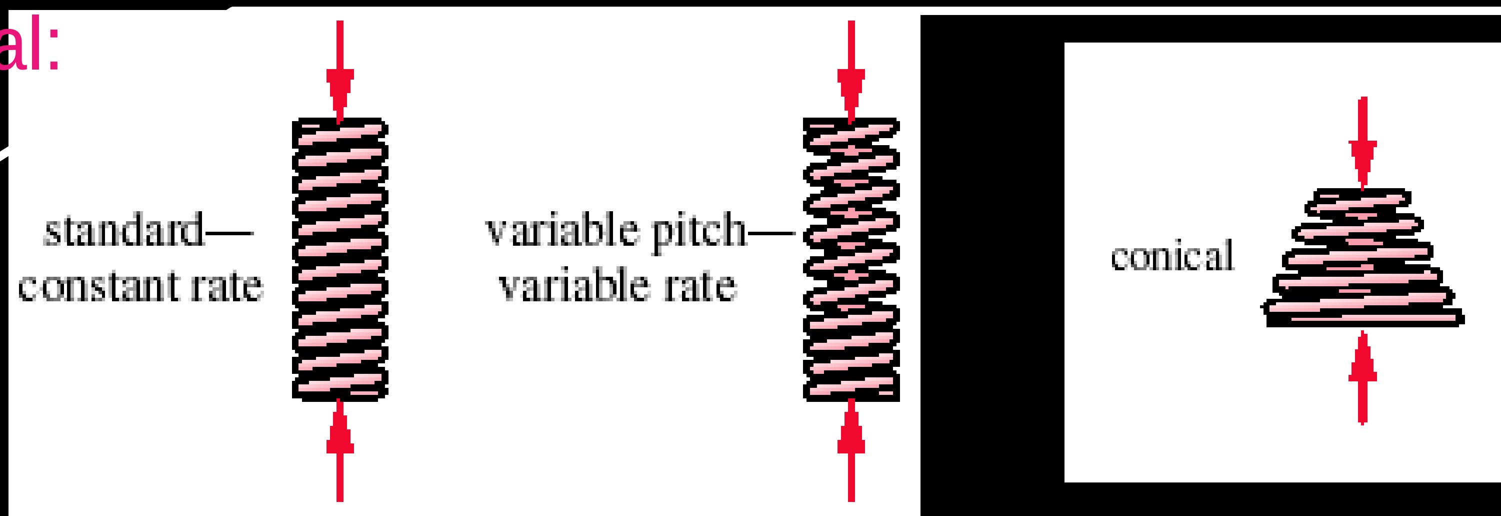
6. Special purpose spring

# Classification



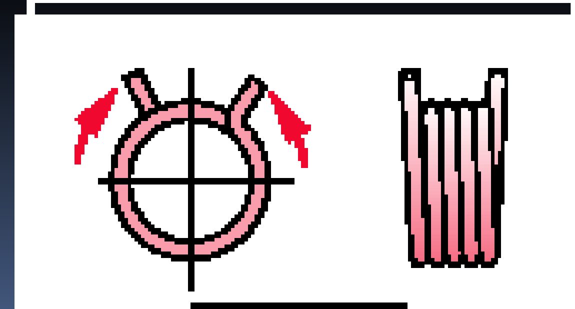
# Types of Springs

Helical:



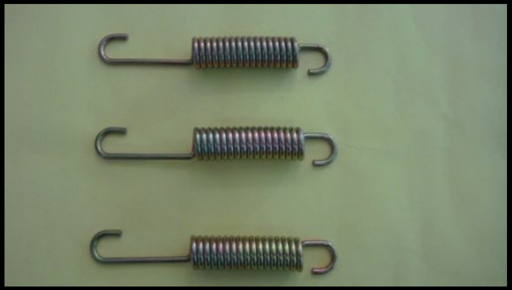

Compression

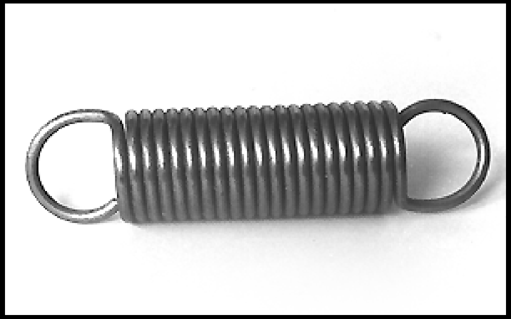
Extension



Torsion

# SPRING PRODUCTS



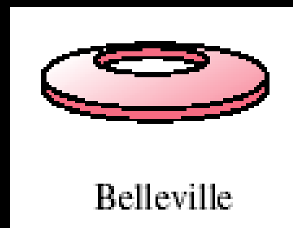


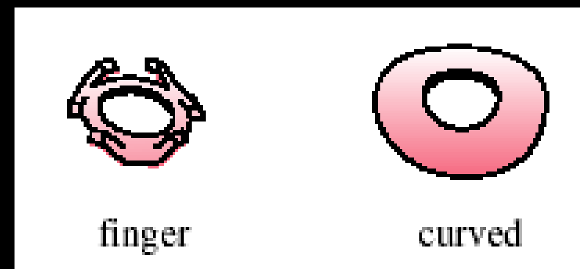
**Tension Spring**

**Compression Spring**

# More Springs

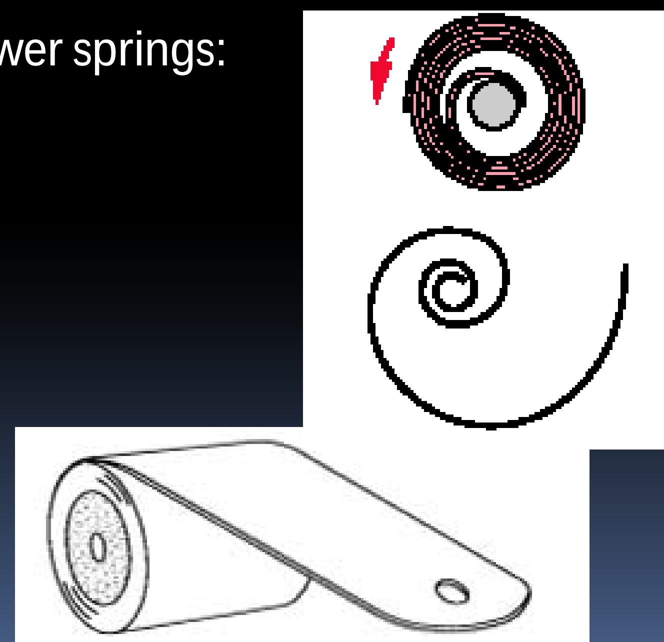
Washer Springs:




Beams:

Power springs:

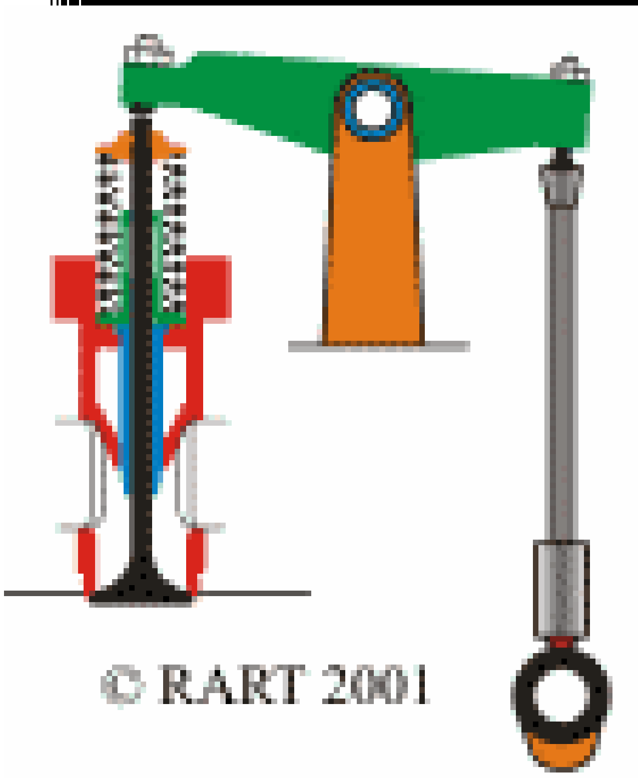


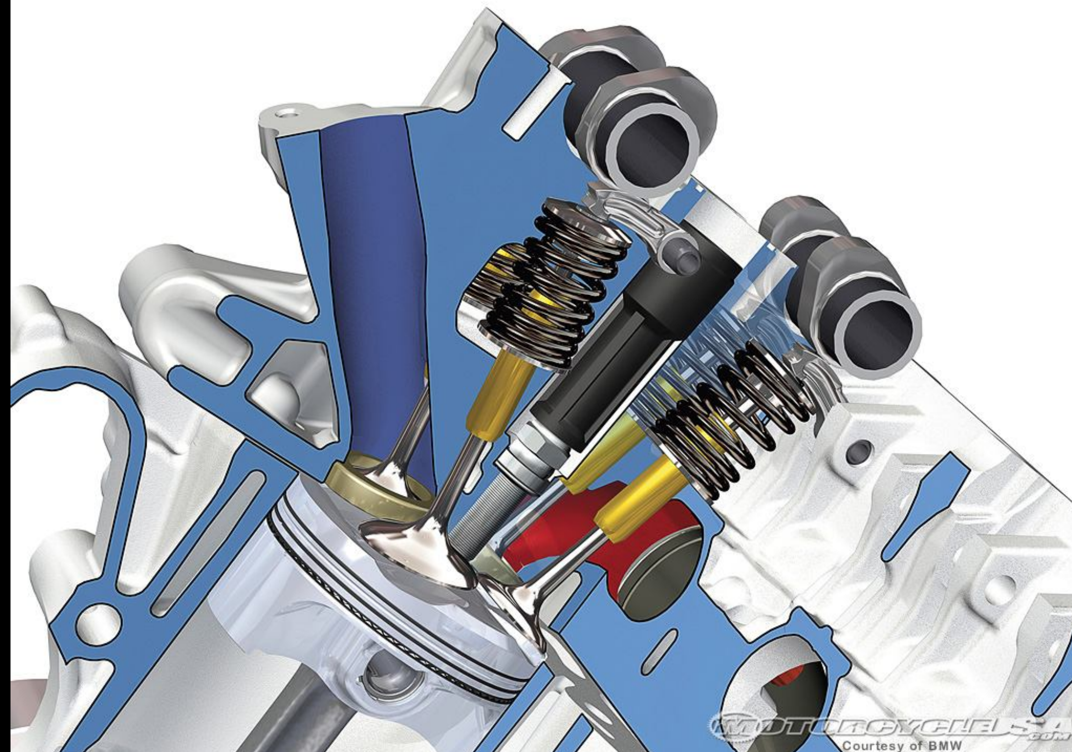
# Applications

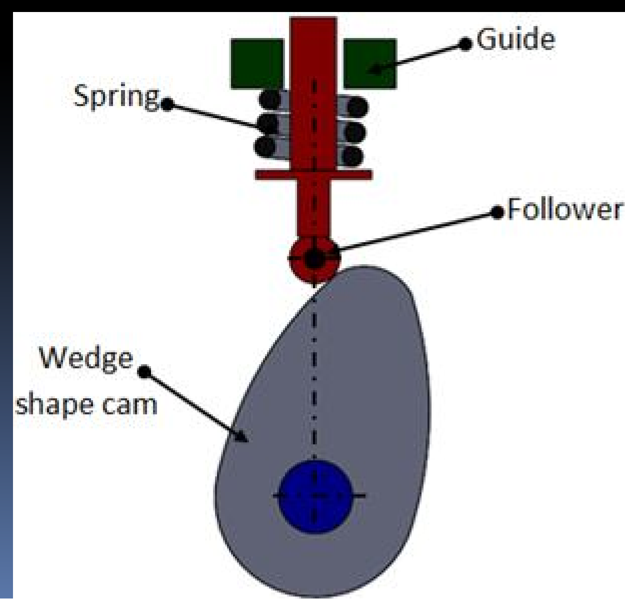
1. To cushion, absorb or control energy due to either shock or vibration as in car springs, railway buffers, air-craft landing gears, shock absorbers and vibration dampers.
2. To apply forces, as in brakes, clutches and spring-loaded valves.
3. To control motion by maintaining contact between two elements as in cams and followers.
4. To measure forces, as in spring balances and engine indicators.
5. To store energy, as in watches, toys, etc.

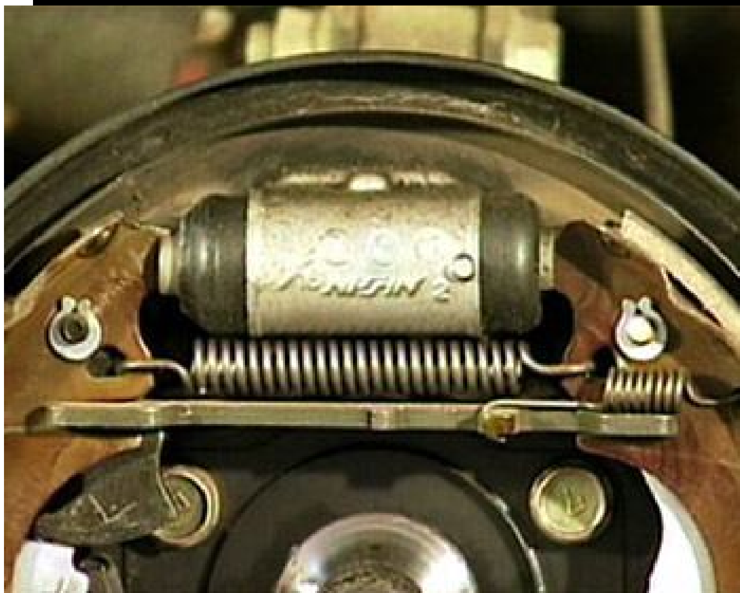
*In railway coaches strongs springs are used for suspension.*

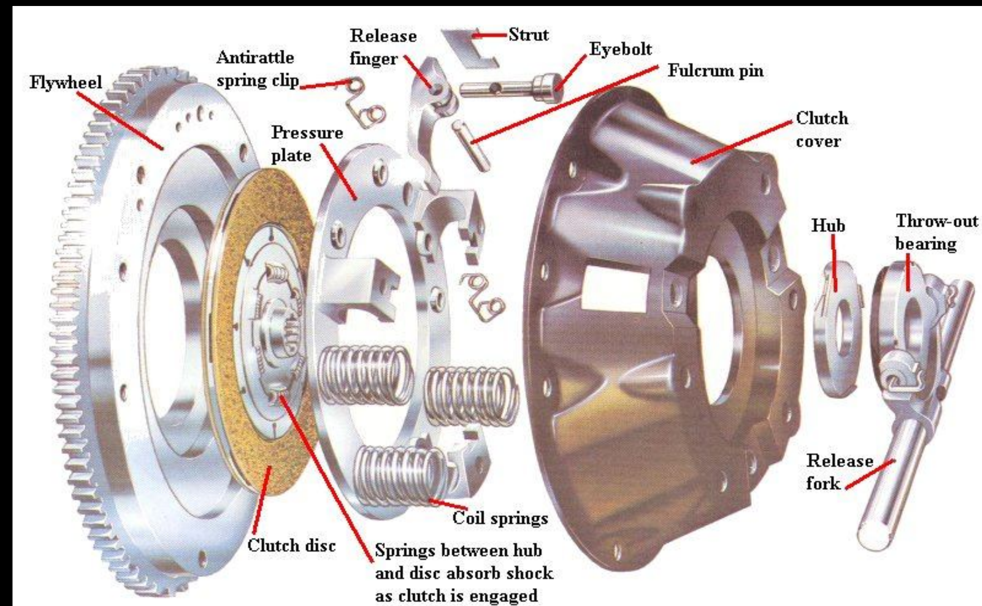

HPT

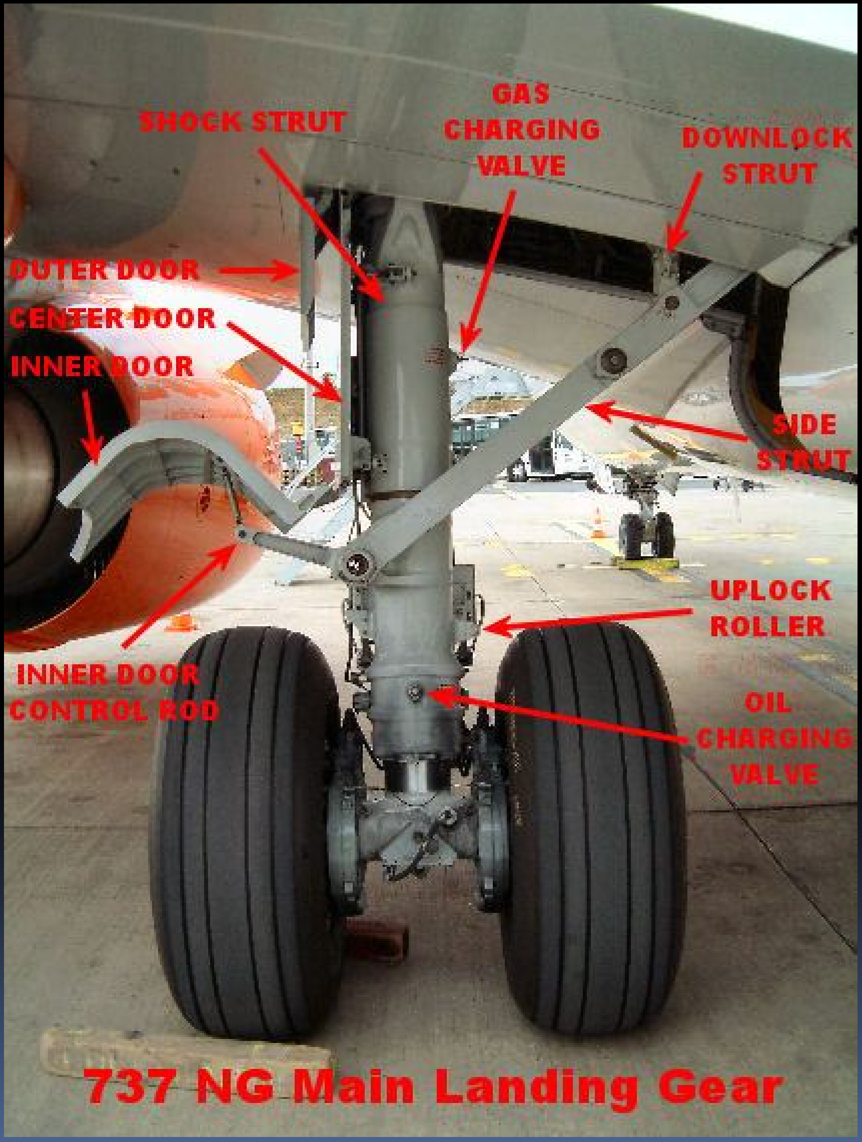

© RART 2001

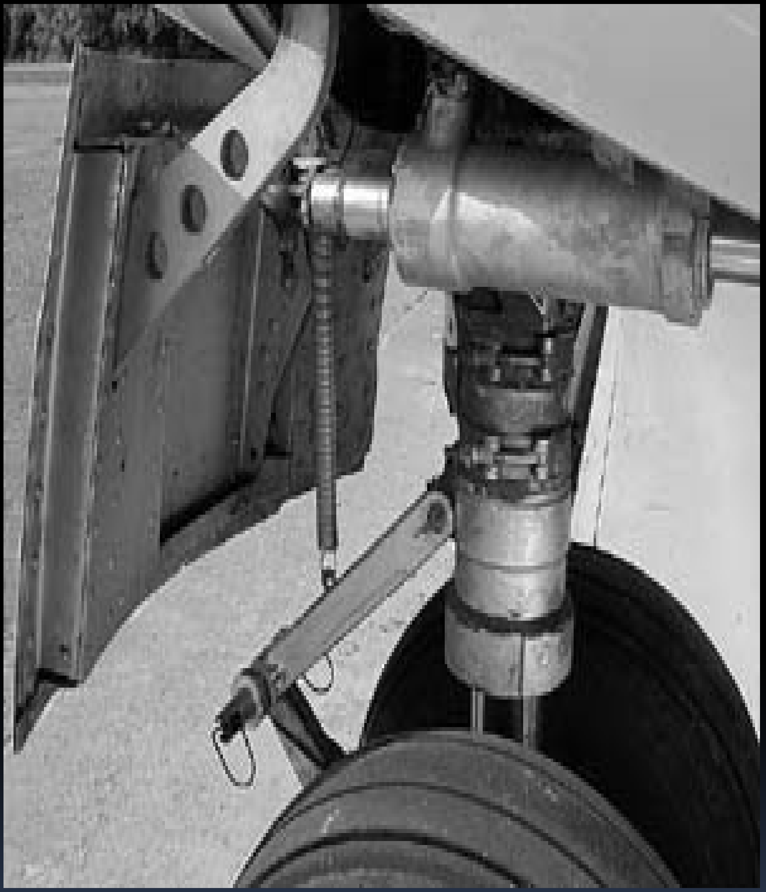

Courtesy of BMW


Guide
Spring
Follower
Wedge
shape cam




Flywheel
Antirattle spring clip
Release finger
Strut
Eyebolt
Fulcrum pin
Pressure plate
Clutch cover
Hub
Throw-out bearing
Release fork
Coil springs
Clutch disc
Springs between hub and disc absorb shock as clutch is engaged


SHOCK STRUT
GAS CHARGING VALVE
DOWNLOCK STRUT
OUTER DOOR
CENTER DOOR
INNER DOOR
SIDE STRUT
UPLOCK ROLLER
INNER DOOR CONTROL ROD
OIL CHARGING VALVE
737 NG Main Landing Gear



Tension springs are widely used in printing machines.

Petrol engine.

A car shock absorber.


An automobile suspension and shock-absorber. The two links with green ends are turnbuckles.

# PRODUCT APPLICATION

## Adjuster Spring

# TERMS USED IN COMPRESSION SPRING

SOLID LENGTH

When the compression spring is compressed until the coils come in contact with each other the spring is said to be solid. The solid length of a spring is the product of total number of coils and the diameter of the wire.

$$LS = n' \times d$$

n'- total number of coils

d- diameter of the wire

FREE LENGTH

It is the length of the spring in the free or unloaded condition. It is equal to the solid length plus the maximum deflection or compression of the spring and the clearance between the adjacent coils.

$$LF = n' \times d + \delta max + 0.15\ \delta max$$

## SPRING INDEX

It is defined as the ratio of the mean diameter of the coil to the diameter of the coil to the diameter of the wire.

$$C=D/d$$

D- mean diameter of coil

d- diameter of wire

## SPRING RATE

It is defined as the load required per unit deflection of the spring.

$q=W/\delta$

W- applied load

$\delta$ - deflection of the spring

## PITCH

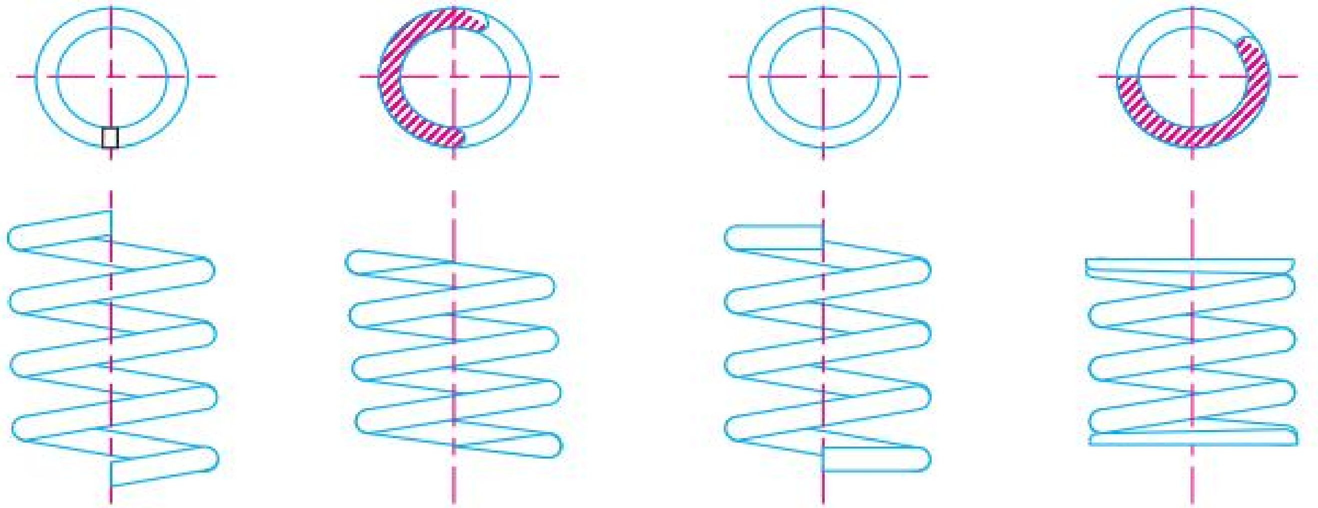
The pitch of the coil is defined as the axial distance between adjacent coil in uncompressed state.

Pitch length=free length/(n’-1)

Mostly square and ground ends condition is used for compressive spring.

$n' = n+2$

# ENDS FOR COMPRESSION HELICAL SPRING:



(*a*) Plain ends. (*b*) Ground ends. (*c*) Squared ends. (*d*) Squared and ground ends.

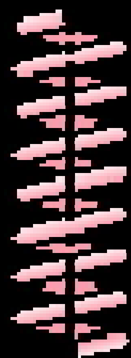
**Total number of turns, solid length and free length for different types of end connections.**

| *Type of end* | *Total number of turns (n')* | *Solid length* | *Free length* |
|---|---|---|---|
| 1. Plain ends | $n$ | $(n + 1)\, d$ | $p \times n + d$ |
| 2. Ground ends | $n$ | $n \times d$ | $p \times n$ |
| 3. Squared ends | $n + 2$ | $(n + 3)\, d$ | $p \times n + 3d$ |
| 4. Squared and ground ends | $n + 2$ | $(n + 2)\, d$ | $p \times n + 2d$ |

where $n$ = Number of active turns,
$p$ = Pitch of the coils, and
$d$ = Diameter of the spring wire.

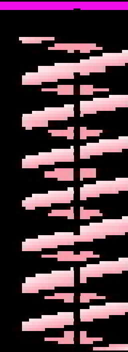
# End Conditions

Plain



$N_a = N_t$

Plain Ground

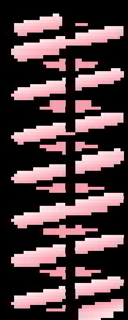


$N_a = N_t - 1$

$N_a$=

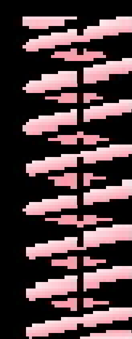
Active Coils

Square



$N_a = N_t - 2$

Square Ground



$N_a = N_t - 2$

# DESIGN OF HELICAL SPRINGS

There are two aspects of design of springs

1. Stress induced
2. Deflection of the spring

<u>Stresses induced</u>

1. (a) Direct shear stress

Consider a helical compression spring made of circular wire and subjected to an axial load *W*, as shown in Fig. 23.10 (*a*).

Let $D$ = Mean diameter of the spring coil,

$d$ = Diameter of the spring wire,

$n$ = Number of active coils,

$G$ = Modulus of rigidity for the spring material,

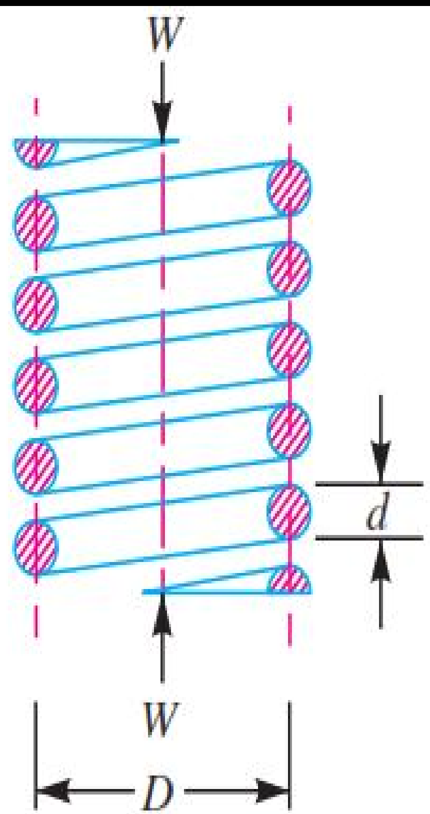
$W$ = Axial load on the spring,

$\tau$ = Maximum shear stress induced in the wire,

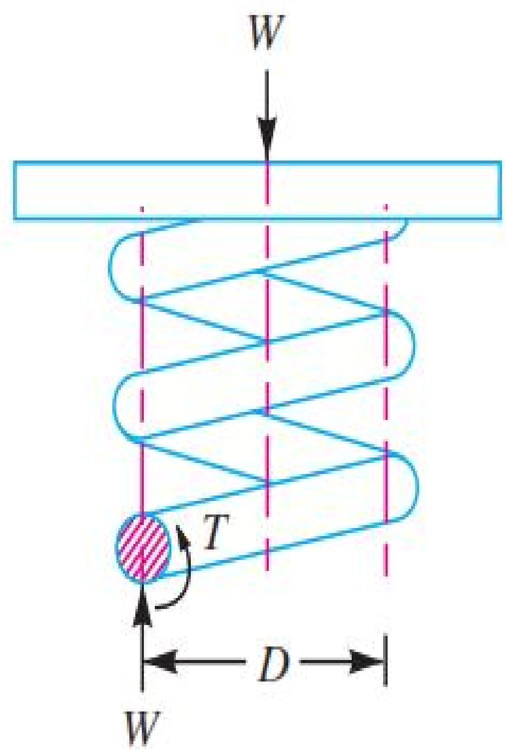
$C$ = Spring index = $D/d$,

$p$ = Pitch of the coils, and

$\delta$ = Deflection of the spring, as a result of an axial load $W$.




(a) Axially loaded helical spring.




(b) Free body diagram showing that wire is subjected to torsional shear and a direct shear.

$$T = W \times \frac{D}{2} = \frac{\pi}{16} \times \tau_1 \times d^3$$

$$\tau_1 = \frac{8W.D}{\pi\, d^3}$$

$$\tau_2 = \frac{\text{Load}}{\text{Cross-sectional area of the wire}}$$

$$= \frac{W}{\frac{\pi}{4} \times d^2} = \frac{4W}{\pi\, d^2}$$

We know that the resultant shear stress induced in the wire,

$$\tau = \tau_1 \pm \tau_2 = \frac{8W.D}{\pi\, d^3} \pm \frac{4W}{\pi\, d^2}$$

Maximum shear stress induced in the wire,

$$= \text{Torsional shear stress} + \text{Direct shear stress}$$

$$= \frac{8W.D}{\pi d^3} + \frac{4W}{\pi d^2} = \frac{8W.D}{\pi d^3}\left(1 + \frac{d}{2D}\right)$$

$$= \frac{8W.D}{\pi d^3}\left(1 + \frac{1}{2C}\right) = K_S \times \frac{8W.D}{\pi d^3} \quad \text{...(iii)}$$

... (Substituting $D/d = C$)

where $K_S$ = Shear stress factor $= 1 + \frac{1}{2C}$

The wall factor after the account for the curvature effect

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

Using the above equation, wire diameter is to be found.

**Deflection of the spring (δ (or) y:**

$$\delta = 8WD^3n/Gd^4$$

# Problems:

1. A helical spring is made from a wire of 6 mm diameter and has outside diameter of 75 mm. If the permissible shear stress is 350 Mpa and modulus of rigidity 84 $kN/mm^2$, find the axial load which the spring can carry and the deflection per active turn.

# Continue…

2. Design a spring for a balance to measure 0 to 1000 N over a scale of length 80mm. The spring is to be enclosed in a casing of 25 mm diameter. The approximate number of turns is 30. The modulus of rigidity is 85 $kN/mm^2$. Also calcualte the maximum shear stress induced.

# Continue…

3. A helical compression spring made of oil tempered carbon steel is subjected to a load which varies from 400 N to 1000 N. The spring index is 6 and design factor of safety is 1.25. If the yield shear stress 770 Mpa and the endurance shear stress is 350 Mpa.

   (i) Size of the spring wire

   (ii) Diameter of spring

   (iii) Number of turns of spring

   (iv) Free length of spring. The compression spring maximum load 30 mm. Take G = 80 $kN/mm^2$.

**Example 23.1.** *A compression coil spring made of an alloy steel is having the following specifications :*

*Mean diameter of coil = 50 mm ; Wire diameter = 5 mm ; Number of active coils = 20.*

*If this spring is subjected to an axial load of 500 N ; calculate the maximum shear stress (neglect the curvature effect) to which the spring material is subjected.*

**Given:** Given : *D = 50 mm ; d = 5 mm ; *n = 20 ; W = 500 N*

**Find:** Maximum Shear Stress ( ) $\tau$

**Solution:**

Spring index $C = \frac{D}{d} = \frac{50}{5} = 10$

Shear stress factor $K_S = 1 + \frac{1}{2C} = 1 + \frac{1}{2 \times 10} = 1.05$

Maximum Shear stress

$$\tau = K_S \times \frac{8W.D}{\pi d^3} = 1.05 \times \frac{8 \times 500 \times 50}{\pi \times 5^3} = 534.7 \text{ N/mm}^2$$

$= 534.7$ MPa **Ans.**

PSG 7.100

# Continue…

5. Design a close – coiled helical spring of silicon – manganese steel for the valve of an IC engine capable of exerting a net force of 65 N when the valve is open and 54 N when the valve is closed. The internal and external diameters are governed by space limitations, as it has to fit over bushing of 19 mm outside diameter and go inside a space of 38 mm diameter. The valve lift is 6 mm. **(N/D 2010)**

6. A helical compression spring made of circular wire is subjected to an axial force, when varies from 2.5 kN to 3.5 kN over this range of forces, the deflection of the spring should be approximately 5mm. The spring index can be taken as 5. The spring has square and ground ends. The spring is made of patterned and cold drawn steel wire and ultimate strength of 1050 $N/mm^2$ and modulus of rigidity 81370 $N/mm^2$. The permissible shear stress for the spring wire should be taken 50% of the ultimate strength. Find, (i)wire diameter (ii) mean coil diameter (iii) number of active coils (iv) total number of coils (v) solid length of the spring (vi) free length (vii) required spring rate (viii) actual spring rate.

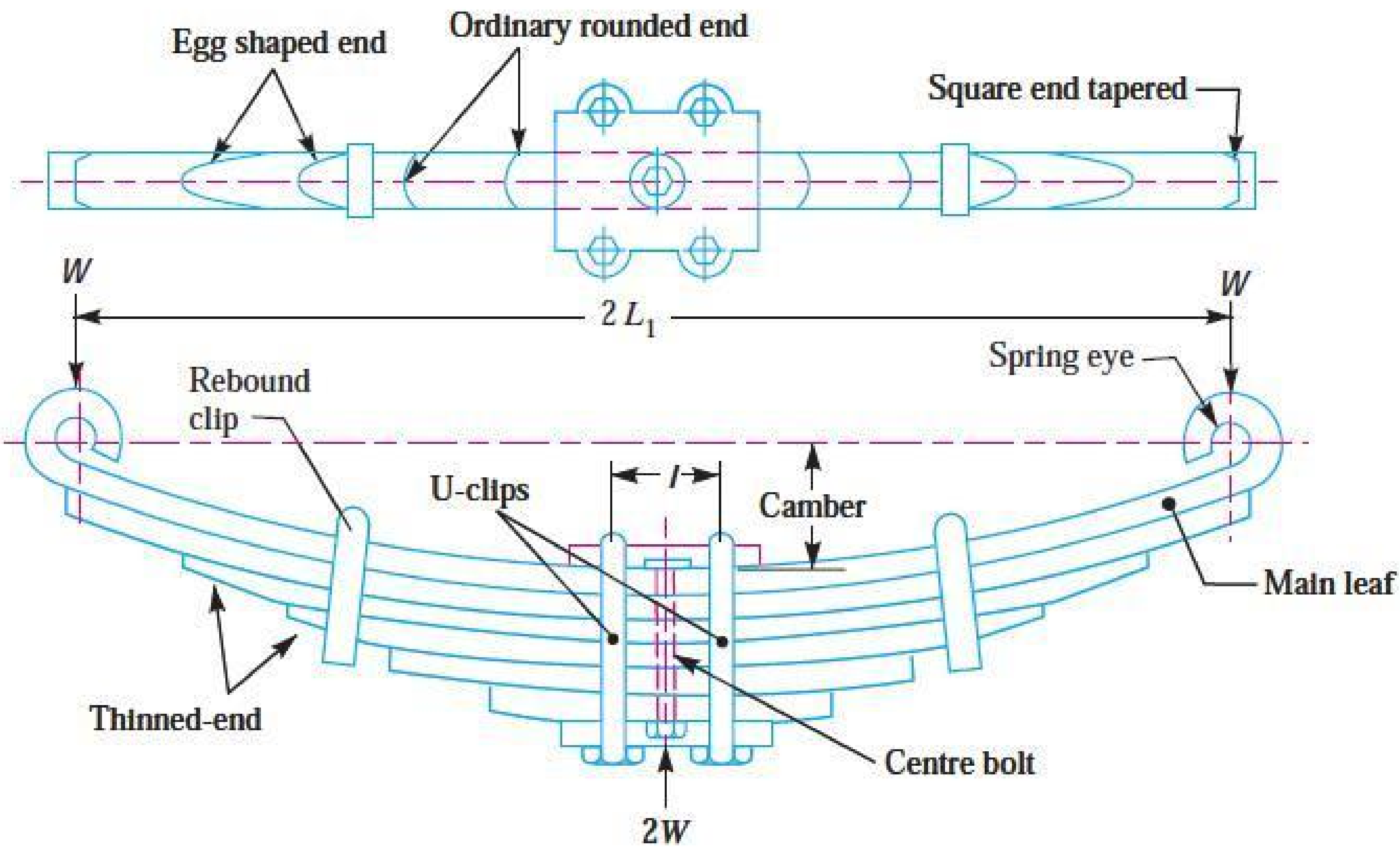
7. Design a close coiled helical springs for a service load ranging from 2250 N to 2750 N. The axial deflection of the spring for the load range of 6mm. Assume a spring index of 5. The permissible shear stress intensity is 420 Mpa and modulus of rigidity G = 84 $kN/mm^2$. Neglect the effect of concentration. Draw a fully dimensioned sketch of the spring. Show spring details the finish end coils.

8. Design a helical spring for a spring loaded safety valve (Ramsbottom safety valve) for the following conditions: Diameter of valve seat = 65 mm, operating pressure = 0.7 $N/mm^2$, maximum pressure when the valve blows off freely = 0.75 $N/mm^2$, maximum lift of the valve when the pressure rises from 0.7 to 0.75 $N/mm^2$ = 3.5 mm, maximum allowable stress = 550 Mpa, modulus of rigidity = 84 $kN/mm^2$, spring Index = 6. Draw a neat sketch of the free spring showing the main dimensions.

# Leaf spring

- It is used in automobile suspension systems. These are called graduated (or) laminated springs, because number of flat plates are stacked together. By geometry they are semi-elliptical in shapes.

# Continue…


Egg shaped end
Ordinary rounded end
Square end tapered
W
W
2 L1
Spring eye
Rebound clip
U-clips
l
Camber
Main leaf
Thinned-end
Centre bolt
2W

# Problems:

A locomotive semielliptical laminated spring has an overall length of 1m and sustains a load of 70 kN at its centre. The spring has 3 full length leaves and 15 graduated leaves with a central band of 100 mm width. All the leaves are to be stressed to 400 Mpa, when fully loaded. The ratio of the total spring depth to that of width is 2. Take young modulus is 210 kN/mm$^2$. Determine (i) the thickness and width of the leaves (ii) the initial gap that should be provided between the full length and graduated leaves before the band load is applied and (iii) the load exerted on the bank after the spring is assembled.

# Continue…

Design a leaf spring for the following specifications: Total load 140 kN, Number of springs supporting the load = 4, maximum number of leaves 10, span of the spring = 1000 mm, permissible deflection = 80 mm, Take young’s modulus (E) = 200kN/mm$^2$ and allowable stress in the spring material as 600 Mpa.

A semi elliptical laminated spring is made of 50 mm wide and 3 mm thick plate. The length between supports is 65 cm and the width of band is 6 cm. The spring has 2 full length leaves and 5 graduated leaves. If the spring carries a central load of 2 kN. Find (i) maximum stress in full length leaves and graduated leaves, for a initial condition of no stress in the leaves. (ii) maximum stress if the initial stress is provided to cause equal stress when loaded.

# Practice:

- A closed – coiled helical compression spring has plain ends and is to fit over a 25 mm diameter rod. When a compressive force of 100 N is applied to the spring it compresses by 50 mm. If the spring has a preferred wire diameter of 4 mm, and the spring material has a maximum allowable shear stress of 180 $MN/m^2$ and a modulus of rigidity of 81 $GN/m^2$, determine

(i) The mean coil diameter of the spring

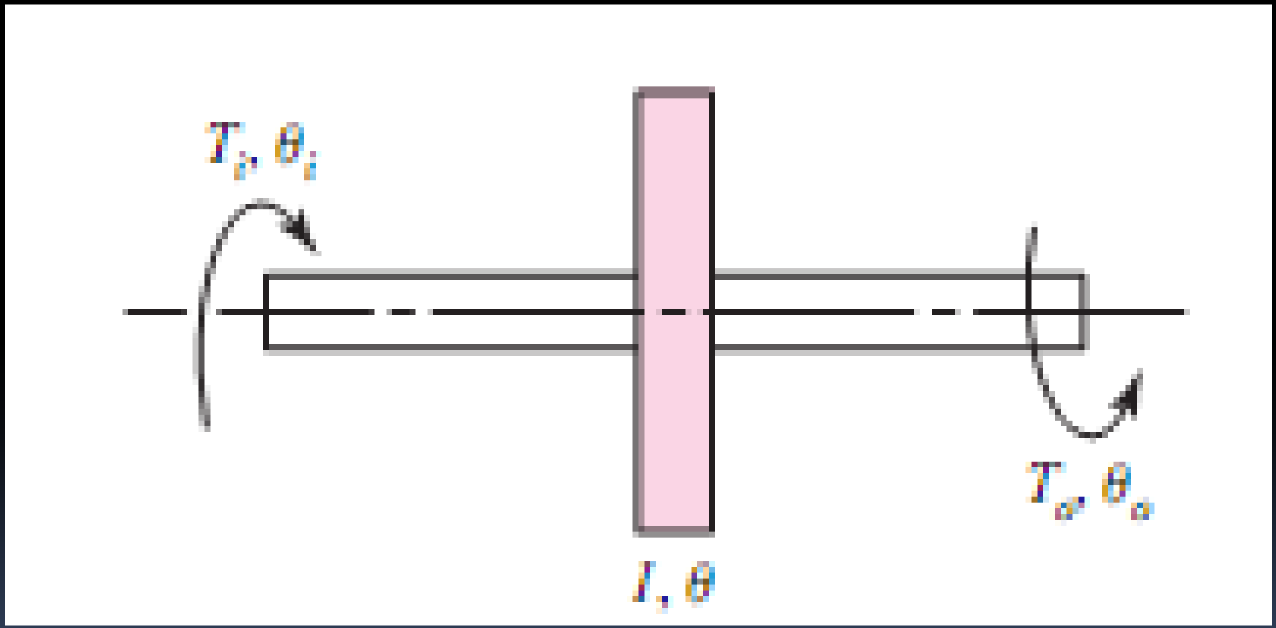
(ii) The number of coil in the spring

(iii)The solid length of the spring **(M/J 2014)**

# Continue…

Design a closed coiled helical spring subjected a tensile load of magnitude varying from 2500 N to 3000 N and axial deflection of spring for the range of load is 65 mm. Design the spring, taking the spring index as 6 and safe shear stress for material equal to 465 Mpa. **(N/D 2014)**

# DESIGN OF FLYWHEELS



# Flywheel

- A rotating mechanical device that is used to store rotational energy.
- A flywheel is used in machines , serves as a reservoir which stores energy during the period where the supply of energy is more than the requirement.
- Conversely, a flywheel releases stored energy by applying torque to a mechanical load, thereby decreasing the flywheel's rotational speed.

# Flywheel

- In other words it can be defined as "it stores energy during power stroke and delivers during idle strokes".

- A little considerations will show that when the flywheel absorbs energy, its speed increases and when it releases, the speed decreases. Hence a flywheel does not maintain a constant speed, it simply reduces the fluctuation of speed.

- The flywheel's position is between the engine and clutch patch to the starter.

# How is it used?

- A rotating mechanical device that is used to store rotational energy.
- It acts like a reservoir and stores the energy in mechanical form
  - It Supply energy when required.
  - Releases it when it is more then required.
- Energy is stored by the formula

$$E = \frac{1}{2} I\omega^2$$

  - Where "I" is the moment of inertia and it can vary for different shapes of wheels. For solid disk the "$I=Mr^2/2$".
  - "$\omega$" is the rotational velocity and it is in (rad/sec).

# Functions and Operation

- Fly wheel smoothen out variations in the speed of a shaft caused by torque fluctuations if source of driving torque is fluctuating.
- It is also used to provide continuous energy in system.
- It is also used to supply intermittent pulses of energy at transfer rates that exceed the abilities of its energy source.

# How to Design Flywheel?

**Design Approach:-**

There are two stages for it

- The degree at which energy is required to smoothen and its moment of inertia.
- The geometry of flywheel.

**Design Parameters:-**

- It depend upon acceptable changes in the speed.

**Speed fluctuation:-**

- The change in the shaft speed during a cycle is called the speed fluctuation and it is given by

$$\mathbf{Fl = \omega_{max} - \omega_{min}}$$

# Flywheel in automotives

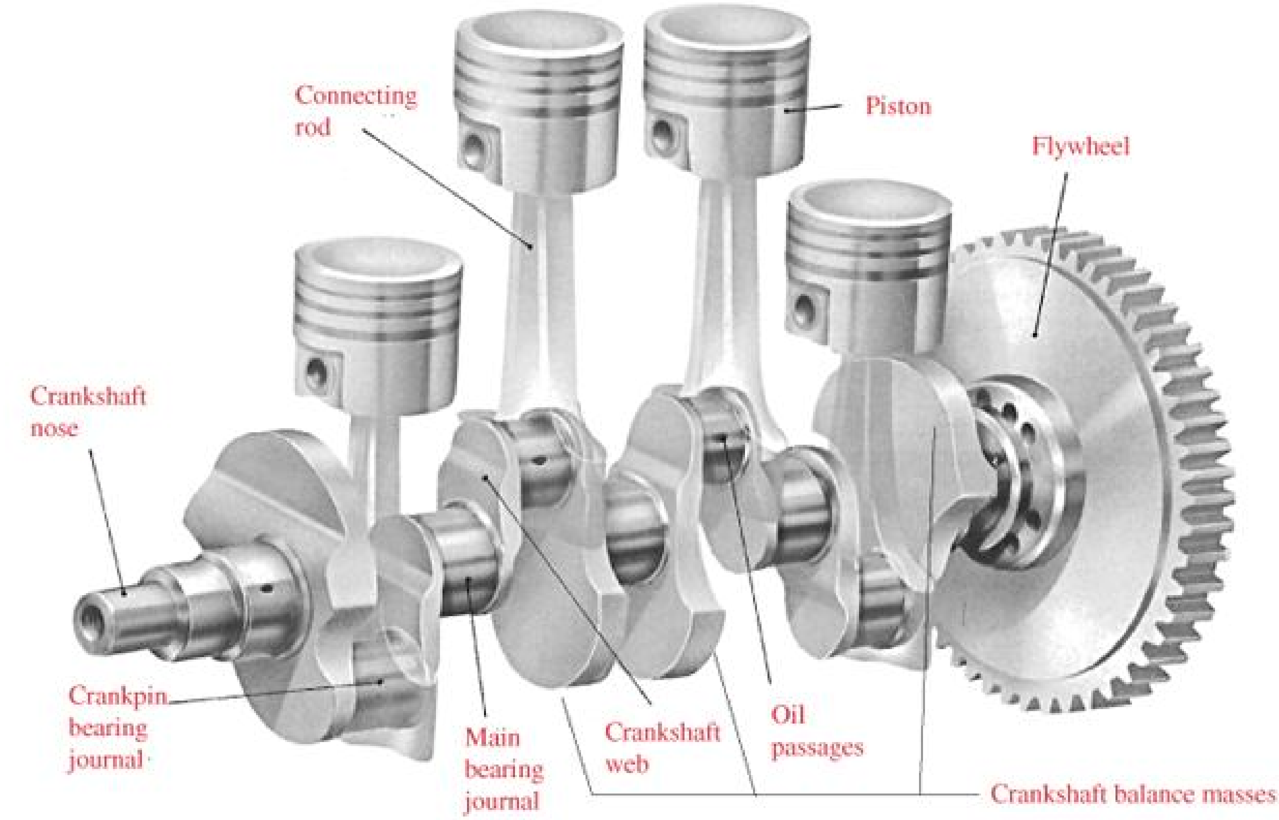



**FIGURE 14-3**

Crankshaft from an inline four-cylinder engine with pistons, connecting rods, and flywheel

- A Flywheel is used to maintain constant angular velocity of the crankshaft in a reciprocating engine.
- In this case, the flywheel—which is mounted on the crankshaft—stores energy when torque is exerted on it by a firing piston and it releases energy to its mechanical loads when no piston is exerting torque on it.

# Problems

The intercepted areas between the output torque curve and the mean resistance line of a turning moment diagram for a multi cylinder engine, taken in order from one end are as follows:

-35,+410, -285, +325, -335, +260, -365, +285, -260 $mm^2$.

The diagram has been drawn to a scale of 1mm = 70 N-m and 1mm = 4.5º. The engine speed is 900 rpm and the fluctuation in speed is not to exceed 2% of the mean speed.

Find the mass and cross-section of the flywheel rim having 650 mm mean diameter. The density of the material of the flywheel may be taken as 7200 $kg/m^3$. The rim is rectangular with the width 2 times the thickness. Neglect effect of arms etc.

The areas of the turning moment diagram for one revolution of a multi cylinder engine with reference to the mean turning moment, below and above the line, are -32, 408, -267, 333, -310, 226, -374, 260, -244 $mm^2$. The scale for abscissa and ordinate are: 1 mm = 2.4º and 1mm = 650 N-m respectively. The mean speed is 300 rpm with a percentage speed fluctuation of ±1.5%. If the hoop stress in the material of the rim is not to exceed 5.6 Mpa, determine the suitable diameter and cross section for the flywheel, assuming that the width is equal to 4 times the thickness. The density of material may be taken as 7200 $Kg/m^3$. Neglect the effect of the boss and arms. **(N/D 2014)**

A multi-cylinder engine is to run at a constant load at a speed of 600 rpm. On drawing the crank effort diagram to a scale of 1mm = 250 N-m and 1 mm = $3^{o}$, the areas in sq. mm above and below the mean torque line are as follows:

160, -172, 168, -191, 197, -162 sq. mm. The speed is to be kept within ± 1% of the mean speed of the engine. Calculate the necessary moment of inertia of the flywheel. Determine suitable dimensions for cast iron flywheel with a rim whose breadth is twice its radial thickness. The density of cast iron is 7250 $kg/m^3$, and its working stress in tension is 6 Mpa. Assume that the rim contributes 92% of the flywheel effect. **(N/D 2011, M/J 2014)**

## Practice:

An engine runs at a constant load at a speed of 480 rpm. The crank effort diagram is drawn to a scale 1mm = 200 N-m torque and 1 mm = 3.6º crank angle. The areas of the diagram above and below the mean torque line in sq.mm are in the following order: +110, -132, +153, -166, +197, -162. Design the flywheel if the total fluctuation of speed is not to exceed 10 rpm and the centrifugal stresses in the rim is not to exceed 5 Mpa. Assume that the rim breadth is approximately 2.5 times the rim thickness and 90% of thee moment of inertia is due to rim. The density of the material of the flywheel is 7250 $kg/m^3$. **(M/J 2012)**

END