Springs

Primary Functions of Springs

1. Control Motion and Apply Force:
   - Ensure proper contact between components (e.g., cam followers with cams).
   - Provide necessary pressure in mechanisms (e.g., clutches).
   - Restore components to original positions after load removal (e.g., brakes).
2. Store Energy:
   - As in mechanical systems like clockwork or watches.
3. Measurement:
   - Measure forces and weights, as seen in spring balances.
4. Vibration and Shock Absorption:
   - Minimize vibrations in machine mounts or flexible systems.
   - Cushion impacts and absorb shocks, such as in vehicle suspensions or railway buffers.

Classification of Springs

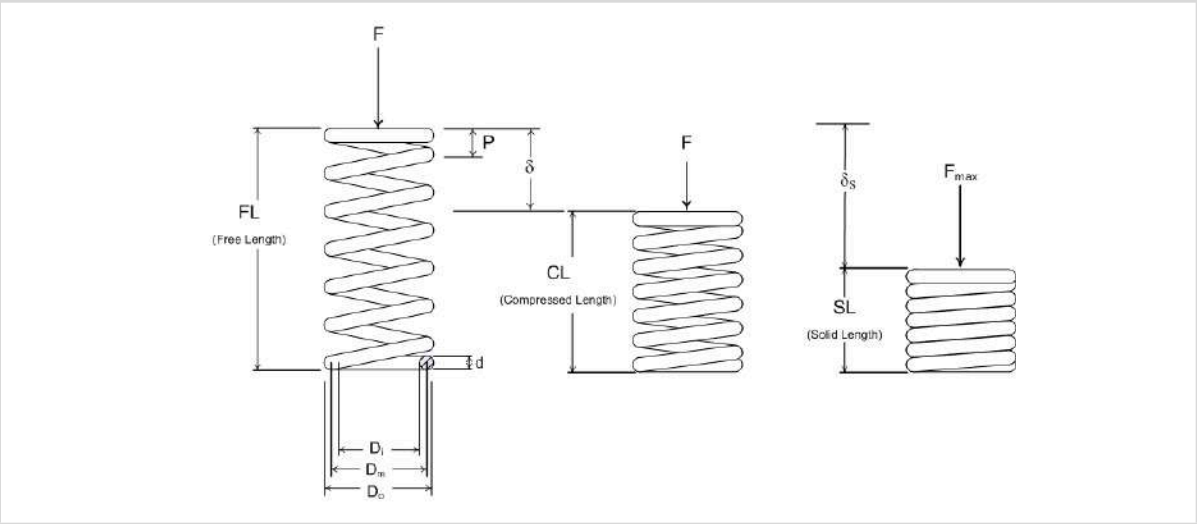
1. Wire Springs:
   - Includes helical springs with round, square, or rectangular cross-sections.
   - Handles compressive, tensile, or torsional loads.
2. Flat Springs:
   - Examples: cantilever springs and semi-elliptical leaf springs.
   - Commonly used in automotive suspension systems.
3. Special Springs:
   - Includes disk springs and custom-shaped springs designed for unique applications.

Design of Helical Springs

1. **Loading Modes:** Determine type (static or alternating) and operating conditions.
2. **Force-Deflection Characteristics:** Based on application.
3. **Space Restrictions & Economy:** Design within dimensional and cost constraints.
4. **Environmental Considerations:** Address temperature and corrosion effects.

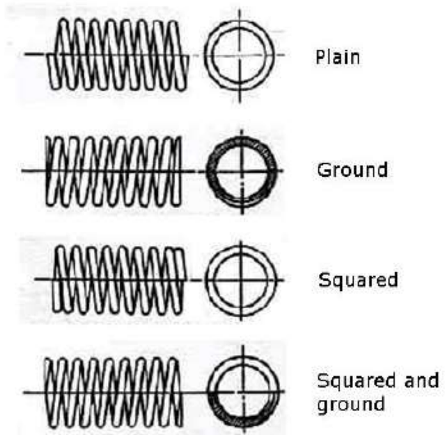
HELICAL SPRINGS

Helical springs are made of elastic material and are formed into a helix shape, which is used to store energy and subsequently release it when needed, absorb shock or maintain force between two contacting surfaces.



Types of coil end	Actual no. of coil	Solid length	Free length
Plain	n	(n + 1)d	nP + d
Ground	n	nd	nP
Squared	n + 2	(n + 3)d	nP + 3d
Squared and ground	n + 2	(n + 2)d	nP + 2d

Types of coil end:



Useful Equations:

1. Stress on spring material

$$S_S = K_W \frac{8FD}{\pi d^3}$$

2. Wahl Factor, K_W
Wahl Factor is used to correct for stress concentration in helical springs, particularly for torsional stresses that arise when the spring is compressed or extended. The Wahl Factor accounts for the non-uniform stress distribution in the coils, especially at the points of contact where the wire undergoes bending and twisting. Widely Used in Engineering Standards.

$$K_W = \frac{4c-1}{4c-4} + \frac{0.615}{c}$$

Where: c = spring index = $\frac{D}{d}$

3. Linear Deflection of spring, δ

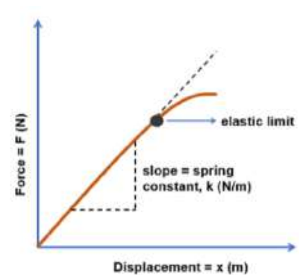
$$\delta = \frac{8Fc^3 n}{Gd}$$

4. Deflection of spring at solid force, δ_S

$$\delta = FL - SL$$

5. Spring rate, k_s

The **spring rate**, also known as the **spring constant** (denoted as k_s), quantifies a spring's stiffness. It represents the amount of force required to compress or extend a spring by a unit distance. In mathematical terms, it's defined as the ratio of the force applied to the displacement produced:



Hooke's Law states that the force required to compress or extend a spring is proportional to its displacement.

$$F \propto \delta$$

$$k_s = \frac{F}{\delta} = \frac{F_{min}}{\delta_{min}} = \frac{F_{max}}{\delta_{max}} = constant$$

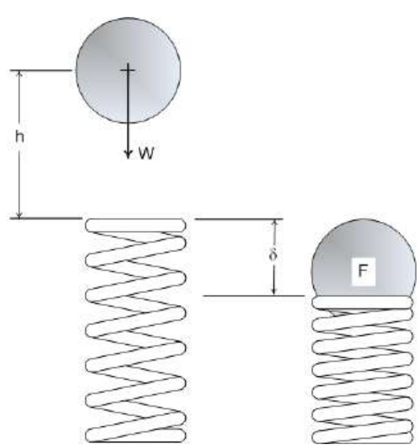
A higher spring rate (k_s) results in less deflection for a given force, meaning a stiffer spring.
A lower spring rate (k_s) results in more deflection, meaning a softer spring.

Key Factors Influencing Spring Rate and Spring Deflection:

- Wire Diameter: Thicker wires increase the spring rate, making the spring stiffer and more resistant to deformation.
- Spring Diameter: Larger coil diameters decrease the spring rate, resulting in a more flexible spring.
- Number of Coils: More coils reduce the spring rate, allowing for greater deflection under a given load.

Where:
F = axial load
G = modulus of rigidity
n = number of coils
P = pitch
d = wire diameter
D_i = inside diameter of coil
D_O = outside diameter of coil
D = mean diameter of coil = $\frac{D_O - D_i}{2}$

6. Impact load on springs
   This diagram shows a situation where an object is falling onto a spring, and we want to find out the maximum force that will act on the spring when the object lands on it.



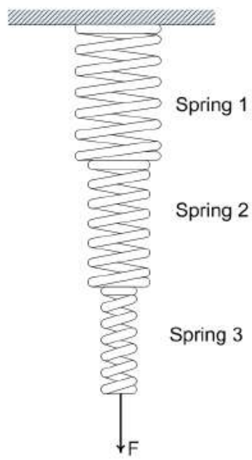
Weight of the Object:

$$W(h + \delta) = \frac{F}{2}\delta$$

Maximum force (F) acting on the spring

$$F = W\left[1 + \sqrt{1 + \frac{k_s h}{W}}\right]$$

7. Springs connected in series



Total Deflection:

$$\delta_T = \delta_1 + \delta_2 + \delta_3$$

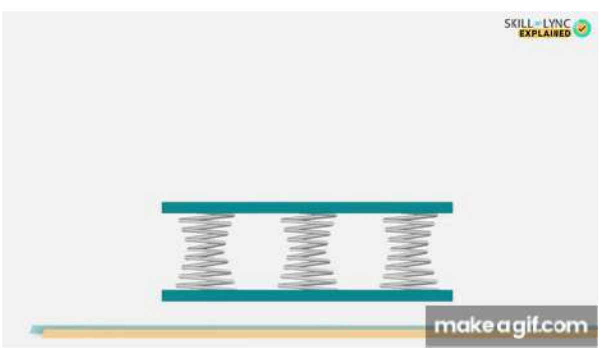
Total Load:

$$F_T = F_1 = F_2 = F_3$$

Spring Rate:

$$\frac{1}{k_s} = \frac{1}{k_{s1}} + \frac{1}{k_{s2}} + \frac{1}{k_{s3}}$$

8. Springs connected in parallel



Total Deflection:

$$\delta_T = \delta_1 = \delta_2 = \delta_3$$

Total Load:

$$F_T = F_1 + F_2 + F_3$$

If the springs are made of same material

$$\frac{F_T}{3} = F_1 = F_2 = F_3$$

Spring Rate:

$$k_s = k_{s1} + k_{s2} + k_{s3}$$

DESIGN OF HELICAL SPRINGS involves the factors engineers must consider to ensure that the spring performs reliably under different operating conditions.

1. Modes of Loading

- Springs are subjected to various types of forces:
  - **Static Loads**: Loads that do not change over time (e.g., a spring in a door hinge).
  - **Dynamic Loads**: Loads that change or fluctuate, such as in suspensions or engine valve springs.
  - **Variable Loads**: These include cyclic or periodic loads, such as in vibrating machinery.
- Proper design ensures the spring can handle the stresses from these loading conditions, including sudden impacts or repetitive cycling.

2. Material Selection

- Materials must be chosen to match the application's requirements:
  - **Load and Stress**: Stronger materials are needed for heavy loads.
  - **Operating Temperature**: Some materials, like stainless steel or Inconel, perform better at high temperatures.
  - **Environmental Exposure**: Corrosion-resistant materials, like phosphor bronze, are ideal for harsh environments.
- The right material ensures the spring doesn't fail prematurely due to environmental or mechanical factors.

3. Fatigue Resistance

- Springs under **repeated or cyclic loading** can fail due to fatigue over time.
- Techniques like **shot peening** (a process that introduces compressive residual stresses on the surface) improve resistance to fatigue by strengthening the material and preventing cracks from growing.

4. Stress Management

- High stress or improper design can cause failures:
  - Cracks or surface flaws can concentrate stress and lead to breakage.
- Careful design ensures stress is evenly distributed across the spring to prevent weak points.

5. Heat Treatment

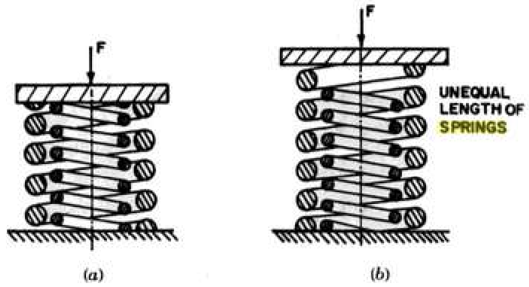
- Heat treatment processes (e.g., annealing, quenching, tempering) are used to:
  - Relieve internal stresses that arise during manufacturing.
  - Improve strength, ductility, and toughness for better performance.
- Heat-treated springs last longer and perform better under demanding conditions.

SPRING MATERIALS

The choice of material is a critical factor in the design and performance of springs, as it determines their durability, strength, and resistance to environmental and operational stresses. Below is an overview of the materials commonly used for helical springs, non-ferrous springs, and flat springs, along with their characteristics and applications.

1. Helical Springs:
    - Made from steels and alloy materials for durability and performance.
    - Cold-Wound Springs:
        - For wires up to 10mm diameter.
        - Made using materials like music wire and oil-tempered wire.
    - Hot-Wound Springs:
        - For wires ≥10mm diameter.
        - Materials undergo preheating and stress-relieving processes.
    - Common Helical Spring Materials:
        - Music Wire:
            - High-carbon steel, strong and fatigue-resistant.
            - Used for small-diameter springs operating under high stress.
        - Oil-Tempered Wire:
            - General-purpose spring material; used in moderate stress applications.
        - Chrome-Vanadium Steel:
            - High shock resistance; used for aircraft engine valve springs.
        - Chrome-Silicon Wire:
            - Designed for high temperatures (up to 250°C); excellent for heavy-duty applications.
        - Stainless and Heat-Resistant Steels:
            - Resistant to corrosion and extreme temperatures (up to 500°C).
2. Non-Ferrous Spring Materials:
    - Spring Brass:
        - High conductivity but limited mechanical strength.
    - Phosphor Bronze:
        - Corrosion-resistant; good for electrical and underwater applications.
    - Beryllium Copper:
        - Excellent fatigue strength; used in electronics and corrosive environments.
    - Monel and Inconel:
        - High-temperature resistance; used in steam valves and turbines.
3. Flat Springs:
    - Carbon Steels:
        - Ranges from thin springs (0.48–0.55% C) to heavily loaded applications (0.68–0.8% C).
    - Alloy Steels:
        - Include vanadium and silicon additions for fatigue resistance and toughness.

Concentric Springs

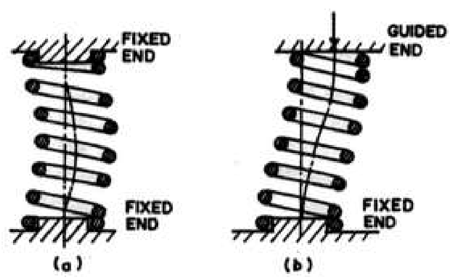


1. Improve space utilization and reliability.
2. Act as fail-safes if one spring breaks.
3. Help achieve load-deflection curve variation.

Equal stress distribution is crucial for effective performance.

Buckling or Instability of Compression Springs

When compression springs are very long, they can act like columns and may bend or buckle instead of compressing straight. This instability can happen in two main cases:



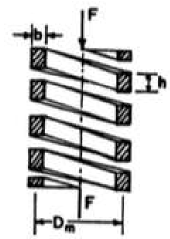
1. **Case (a): Fixed Ends**
   Both ends of the spring are fixed. The spring is constrained, which helps limit buckling but still makes the spring prone to instability under heavy loads.
2. **Case (b): One Fixed and One Guided End**
   One end of the spring is fixed, while the other is guided to ensure alignment. This setup is common for springs used as vibration isolators. The guiding mechanism prevents the spring from moving sideways or buckling excessively.

How to Prevent Buckling

- **Guide the Spring:** Use a sleeve or arbor to keep the spring straight during compression.
- **Divide into Smaller Sections:** For very long springs, separate them into smaller, "buckle-proof" sections using intermediate plates or supports.
- **Design for Stability:** Ensure the spring's design can handle the intended load without significant sideways deflection.

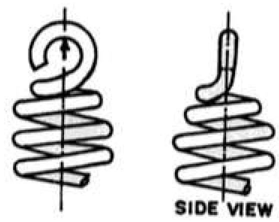
Square or Rectangular-Section Wire Springs

These springs are only used when **space limitations** demand it, as they are weaker and less flexible compared to circular-section wire springs.



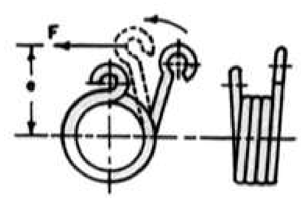
Helical Extension Springs

These springs are designed to carry tensile loads and extend under tension. They are commonly used in applications where pulling forces are needed, such as in garage doors or trampolines.



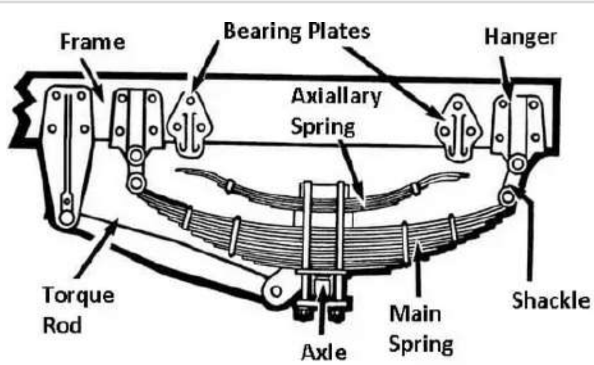
Torsion Springs

Designed to twist rather than compress or extend.
Commonly used in applications like door hinges and vehicle suspensions, where rotational forces are needed



LEAF SPRINGS

Leaf springs consist of several layers of thin metal springs joined together to perform as a single unit. Leaf springs are widely used as suspensions in automobiles.



Design of Leaf Springs

- **Structure and Components**:
  - Leaf springs are made of multiple metal leaves, typically rounded or chamfered at the ends.
  - **Interleaf Friction**: Clips and lubrication between leaves improve load capacity (by 2–12%) and reduce deflection.
  - A **central bolt** holds the leaves together but can weaken the spring. **U-bolts** secure the spring to its support, ensuring stress is not concentrated at the central bolt.
  - **Rebound Clips**: Prevent leaves from separating and protect against excessive stress during rebound.
- **Curvature and Loading**:
  - Unloaded leaf springs are curved (cambered). Under full load, the camber flattens to ensure even stress distribution.

Shackles and Safety Factors:

- Shackles on one or both ends allow flexibility and compensate for spring length changes during deflection.
- For **static loads**, use a safety factor of 1.5; for **fluctuating loads**, a safety factor of 2–2.5 is recommended.

Materials for Leaf Springs

- **Common Materials**:
  - **Carbon Steel (0.5% C)**: Moderate strength, suitable for general use.
  - **Cr-V Steel**: High strength, up to 30% better endurance with shot peening.
  - **Si-Mn Steel**: High endurance, commonly used in vehicles.

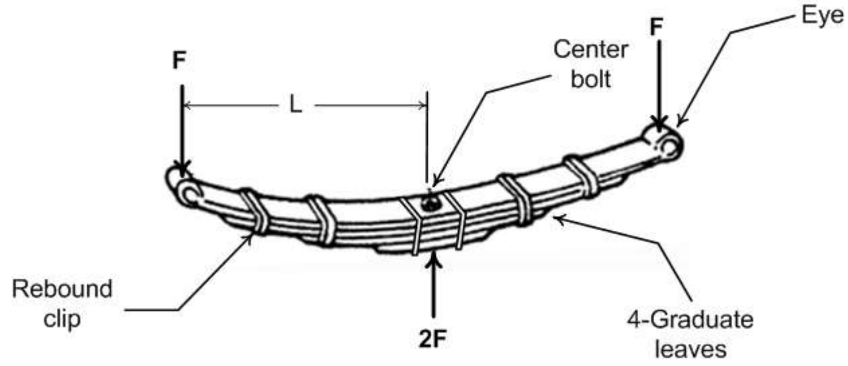
Design Considerations for Leaf Springs

1. **Key Dimensions**:
   - Thickness: Standard sizes range from 3.2 mm to 16 mm.
   - Width: 32 mm to 125 mm for different applications.
   - Eye Diameters: Standard sizes (19 mm to 55 mm).
   - Wall Thickness of Bushings: Typically 3 mm.
2. **Stress Analysis**:
   - Effective spring length and deflection are determined using standard formulas based on load, material properties, and leaf dimensions.
   - For example, for a spring with a load of 5 kN and specific dimensions, stress and deflection can be calculated step-by-step.
3. **Graduated Leaf Lengths**:
   - The length of each leaf decreases progressively (from smallest to full-length leaves). This improves load distribution.
4. **Camber and Deflection**:
   - The radius of curvature and deflection under load are calculated for uniform stress distribution.

Design Adjustments:

- To reduce bending stresses at the eye or pin, proper clearance and material selection are critical.
- Use shackle length adjustments to manage deflection effectively.

Useful Equations for semi-elliptic leaf spring:



Useful formula for Leaf Springs from Design of Machine Members:
By Venton Levy Doughtie, Page 237-238

1. Maximum stress: The maximum stress S_{fmax} occurs at the surface of the leaf and is given by:

$$S_{fmax} = \frac{18FL}{bt^2\left(2n_g + 3n_f\right)}$$

2. Deflection of the spring: The deflection δ of the leaf spring due to the applied load is given by:

$$\delta = \frac{12FL^3}{bt^3E\left(2n_g + 3n_f\right)}$$

Where:

F = load at the supports
L = distance of force to produce maximum moment
t = thickness of the plates
b = width of plates
E = modulus of elasticity
n = number of leaves

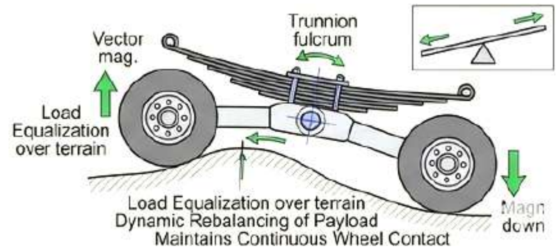
Subscripts g and f indicate the graduated leaves and full length (uniform section), respectively.

TYPES OF TRAILER SPRINGS

		In a **Straight Axle Overslung** setup, the leaf spring is mounted directly on top of a standard straight axle tube. This configuration pushes the vehicle's frame higher, making it the standard choice when you need maximum ground clearance for off-road vehicles, heavy-duty trucks, and utility trailers that must navigate rough terrain without scraping their undercarriage.
		The **Straight Axle Underslung** setup—places the leaf spring underneath that exact same straight axle. By moving the spring below the axle tube, the entire frame drops closer to the ground, which significantly lowers the vehicle's center of gravity. This design provides better handling, less body roll, and increased stability, making it ideal for street-focused trailers, lowered vehicles, and racing applications where ground clearance is not the primary concern.
		The **Drop Axle Underslung** configuration provides the absolute lowest possible ride height among the three. In this setup, the axle itself is specially manufactured with a "drop" (a structural bend causing the center tube to sit much lower than the wheel spindles), and the leaf spring is mounted underneath this dropped tube. This is perfect for specialized equipment like car haulers, horse trailers, or cargo trailers where a very low deck is required for easy loading ramps and maximized aerodynamic efficiency while towing.

INVERTED LEAF SPRINGS

In standard automotive design, a leaf spring is normally mounted with its ends attached to the chassis and its center resting on the axle. An **Inverted Leaf Spring**, however, reverses this load path. In this configuration, the thick center of the spring is mounted to the vehicle's chassis (often on a pivot), and the ends of the spring connect to the axles or wheel hubs. Additionally, the spring pack is literally turned upside down, with the longest master leaf sitting at the bottom of the stack instead of the top.



When the truck's front tandem wheel hits a hump and lifts up, the inverted spring pivots on the trunnion. As the front goes up, the spring mechanically pushes the rear wheel *down* to maintain constant contact with the road. This dynamically balances the payload, prevents the chassis from twisting, and reduces stress on the road surface.