Design of Helical 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.
- Tolerances and permissible variations in specifications.
- Environmental conditions such as temperature, presence of a corrosive atmosphere.
- Cost and qualities needed.

The designers use these factors to select a material and specify suitable values for the wire size, the number of turns, the coil diameter and the free length, type of ends and the spring rate needed to satisfy working force deflection requirements. The primary design constraints are that the wire size should be commercially available and that the stress at the solid length be no longer greater than the torsional yield strength. Further functioning of the spring should be stable.

Stability of the spring (Buckling)

Buckling of column is a familiar phenomenon. Buckling of column is a familiar phenomenon. We have noted earlier that a slender member or column subjected to compressive loading will buckle when the load exceeds a critical value. Similarly compression coil springs will buckle when the free length of the spring is larger and the end conditions are not proper to evenly distribute the load all along the circumference of the coil. The coil compression springs will have a tendency to 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 (Lf) of the spring . The critical length is the ratio of free length (Lf) to mean coil diameter (D)

The critical deflection is a function of critical length and has to be below a certain limit. As could be noticed from the figure absolute stability can be ensured if the critical length can be limited below a limit.

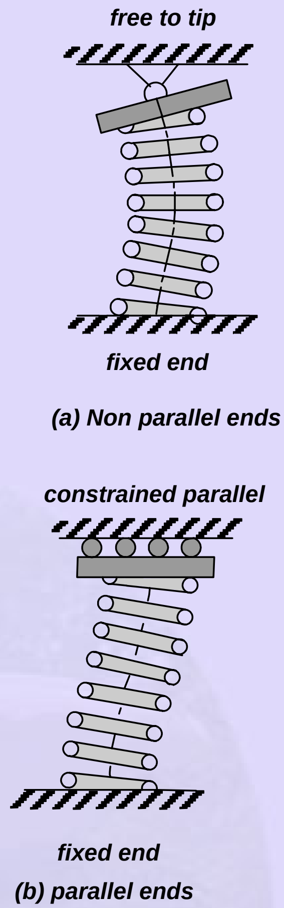

Figure 4.16

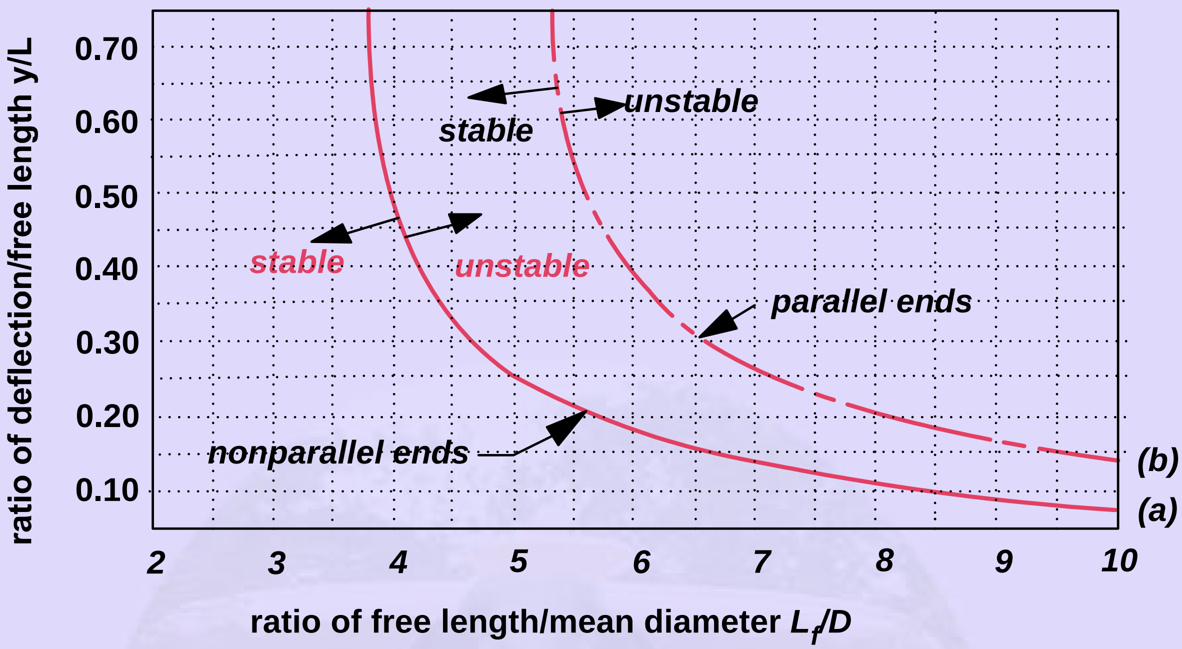

Figure 4.17

Similarly compression coil springs will buckle when the deflection (for a given free length) becomes too large. 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 exactly like the swimming pool wave. 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. 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 in applications requiring a rapid reciprocating motion, the designer must be certain that the physical dimensions of the spring are not such as to 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:

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

The fundamental critical frequency should be from 15 to 20 times the frequency of the force or motion of the spring in order to avoid resonance with harmonics. If the natural frequency is not high enough, the spring should be redesigned to increase k or decrease the weight W.

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. 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,

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

Certain applications like the valve spring of an automotive engine, the springs have to sustain millions of cycles of operation without failure, so it must be designed for infinite life. Unlike other elements like shafts, helical springs are never used as both compression and extension springs. In fact 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,

Then the stress amplitude and mean stress values are given by: if we employ the Goodman criterion, then

The best data on torsional endurance limits of spring steels are those reported by Zimmerli. He discovered the surprising fact that the size, material and tensile strength have no effect on the endurance limits (infinite life only) of spring steels in sizes under 10mm(3/8 inches). For all the spring steels in table the corrected values of torsional endurance limit can be taken as: = 310 Mpa (45.0 kpsi) for unpeened springs= 465 Mpa (67.5 kpsi) for peened springs.

The stress amplitude and mean stress values are given by:

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

If we employ the Goodman criterion, then

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

The design or resulting factor of safety will depend on the spring material selected and their endurance strength. In the absence of data on the endurance limit, the best data on torsional endurance limits of spring steels are those reported by Zimmerli. He discovered the surprising fact that the size, material and tensile strength have no effect on the endurance limits (infinite life only) of spring steels in sizes under 10mm(3/8 inches). For all the spring steels the corrected values of torsional endurance limit can be taken as:

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