Lightweight Springs for Limited Life

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WEIGHT-REDUCTION efforts have caused aircraft designers to seek means of weight reduction that few other industries would find necessary. Some springs in aircraft mechanisms may operate only a few times each flight and, therefore, a life limited to 300,000 cycles may be entirely satisfactory. A method of spring design is presented that cuts spring weight to as little as 1/4 of the value obtained from standard spring design handbooks.

For example, a spring in the Constellation (749) main landing, gear drag, strut damper was redesigned as shown in Fig. 1 to save 17 lb. Being smaller, the housing weight was reduced and, with two required, a total weight saving of 55 lb per airplane was realized. Since then these springs have served well for over 20,000 service hr. This unusual weight saving was achieved by increasing the working stress more than 50%. Such a high working stress was made possible through the use of preset and stresspeen techniques applied to springs of unusually high quality.

It may not be economical to apply this method to small springs unless there are a sufficient number per airplane to justify the effort.

The following design principles can be used to reduce the weight of any spring, but service life may be greatly affected if the spring isn't used in the

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This unusual weight saving was achieved by increasing the working stress more than 50% over conventional design practice. A high working stress was made possible through the use of preset and stresspeen techniques on springs of unusually high quality.

Number of Active Coils – Knowing wire diameter, (d), mean coil diameter (D), and the volume of active steel required (V), we find it a simple matter to compute the number of active turns, (N), to give the required volume:

$$N = \frac{4V}{\pi^2 d^2 D}$$

Preset Operation

The purpose of presetting is to induce favorable residual stresses that will allow a greater range of working stress without producing permanent set. The spring is wound longer than desired in its final configuration. It is then deflected to its compressed height, producing a strain approximately double the yield strain and causing a permanent set. After presetting, the relaxed spring has the desired length called its set height.

It is recommended that preset deflection be twice that causing appreciable permanent set. Preset greater than this is permissible and will lock in higher beneficial residual stresses, but there is little further to be gained and the physical problems of performing the more extensive operations makes it impractical.

The spring will buckle and fly out of the press if not restrained and guided during presetting. It is imperative that the spring be well guided by a close-fitting tube or mandrel; otherwise it won't set evenly and will be crooked. Short of breaking the spring, it is not possible to preset too much.

Referring to Fig. 2 and using the assumed stress-distribution consisting of two straight lines *oab*, we find the internal moment within the torsion-bar under preset load is:

$$T_q = \int_{r/2}^{r} 2\pi X^2 F_{ps}\, dx + \int_{0}^{r/2} 2\pi X^3 \frac{F_{ps}}{r/2}\, dx$$

$$T_q = \frac{7}{12}\pi r^3 F_{ps} + 1/16\, \pi r^3 F_{ps}$$

$$T_q = 0.64\, \pi r^3 F_{ps}$$

Removing preset load reduces the internal moment to zero. However, since the recovery is elastic, the condition is equivalent to applying an equal and opposite moment producing a linear stress distribution, represented in Fig. 2 by the straight line *oc*. The ordinate *cr*, representing the change in surface stress due to removal of preset load can be found by equating the internal moments produced by the two stress-distributions. Thus:

$$0.64\, \pi r^3 F_{ps} = 1/2\,(F_{ps} + F_{rs})\, \pi r^3$$

and:

$$F_{rs} = 0.28\, F_{ps}$$

[1] See *Product Engineering*, Vol. 21, November, 1950, pp. 117-140: "Fatigue Weakness of Surfaces," by J. O. Almen.

Algebraic addition of stress distributions oab and oc in Fig. 2 gives the residual stress-distribution shown in Fig. 2, with $0.28\, F_{ps}$ the surface residual stress.

When the spring is compressed again it can now move a distance to cause an average stress change on the surface equal to $1.28\, F_{ps}$ without surface material yielding. This is the gain from the preset operation.

Effect of Wahl Factor

Stress distribution within the wire cross-section shown in Fig. 2 is only an average condition. Since the wire is wound into a coil, more stress is concentrated on wire surface nearest the axis of the coil. The factor by which this stress is increased is known as the Wahl factor, ψ, a sort of a stress-concentration factor. Fig. 3 illustrates the stress condition on the most highly stressed portion of the wire during and after preset.

Stresspeening

Almen says[1] that shotpeening leaves the surface in a state of biaxial compression equal to about ½ the yield strength of the material. This affects the surface material to a depth of only one or two thou-

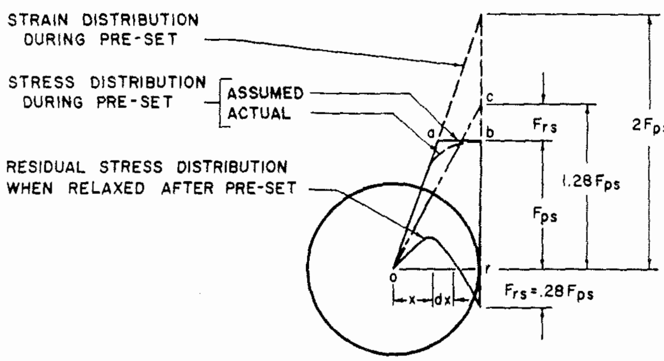

Fig. 2 – Average stress distribution within wire during and after preset. Wahl factor neglected

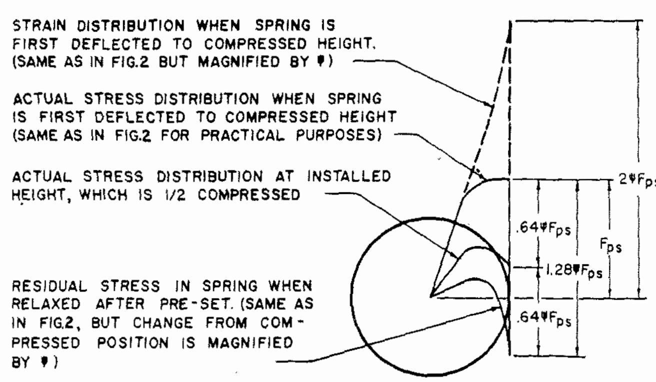

Fig. 3 – Stress distribution at inner face of coils during and after preset, including effects of Wahl factor

tion). Thus:

$$\frac{F_{ps}}{1.28\,\psi\,F_{ps}/2} = \frac{1.56}{\psi}$$

Special Notes

1. Satisfactory springs have been made from SAE 9260 steel heat-treated to 320,000 psi.

2. Ends may be squared and ground after heat-treatment. Under no circumstances can other grinding or cutting be performed beyond this stage.

3. Springs must be guided during presetting to prevent buckling. Adequate guides will permit uniform set along the length of wire.

4. Load at installed height before stresspeening should be about 5% greater than finally desired after stresspeening. Stresspeening will cause load at installed height to drop about 5%. Some "cut and try" with heat-treatment may be necessary in order to raise or lower the load at installed height to the desired value.

5. Fixtures to hold spring compressed during stresspeening must allow shot to get to all parts of the spring. The inner face of the coils must have complete coverage as well as the rest of the wire.

6. No plating or electrolytic treatment is permissible. Corrosion protection can be obtained if spring runs in oil or is covered by heavy grease.

7. Spring steel must be of high quality with no laps, seams, or gouges. Care must be taken during winding not to gouge the wire, or early service failures will result.

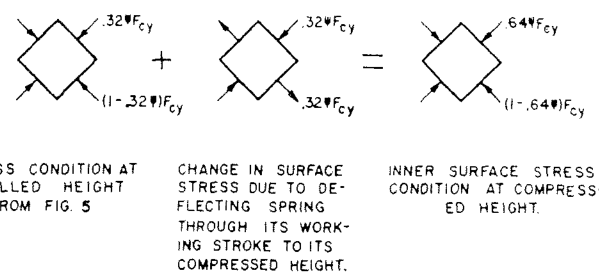

Fig. 6 – Inner surface stress conditions at compressed height

8. Decarburization cannot be permitted if a 300,000-cycle service life is desired. Decarburization has a very harmful effect on fatigue life.

9. Carburization of the surface cannot be tolerated because it causes cracking or failure during presetting. There is some danger that spring fabricators may carburize the surface in their efforts to avoid decarburization during heat-treatment.

10. Spring manufacturers may not be easily convinced of the soundness of this design. It may be necessary to relieve them of any responsibility for the spring before they agree to such specifications. It will be difficult to find a manufacturer who is able to produce such high-quality springs, but it has been and is being done.

DISCUSSION

Infinite Life Possible at Reduced Nominal Stress

by J. O. Almen

General Motors Corp.

I AM pleased to learn from this paper that Lockheed is continuing its progress in the application of prestressed hard steel in highly loaded, dynamically stressed structural parts. This work is additional confirmation of theories advanced in an earlier paper.[a]

Mr. Spaulding's title implies that the springs he describes are useful only in the finite region of fatigue. I see no reason why they cannot have an infinite life by operating at slightly reduced nominal stress.

The springs described were heat-treated to 320,000 psi, which corresponds to a Rockwell C hardness of 58-59. Tests of even harder coil springs[b, c] (RC 61-63) were made a number of years ago. They also showed that by avoiding brittleness (surface weakness) through prestressing it is possible to utilize the potential strength of very hard steel. These harder springs were not strainpeened because that process[d] was not applied until some time after the spring tests.

Regarding the precautions listed by Mr. Spaulding under "Special Notes," I offer the following:

1. I doubt the necessity for prohibiting all electroplating, and particularly soft plating commonly used for corrosion protection, provided cleaning by grit blasting follows plating.

2. Cracking or failure during presetting can be mitigated by (a) presetting at an elevated temperature, perhaps not greater than tempering temperature, and/or (b) shotpeening before presetting to reduce surface-fracture vulnerability.

3. Carburizing is not necessarily bad. Buick has long formed its "Crown" clutch spring from low carbon sheet carburized to develop spring quality steel in the highly stressed surfaces. Carburizing can, no doubt, be beneficial in restoring lost carbon, provided the process is properly applied. But until carburizing is better understood, I will support Mr. Spaulding in prohibiting its use.

[a] See SAE Transactions, Vol. 51, (July) 1943, pp. 248-268: "Shotblasting to Increase Fatigue Resistance," by J. O. Almen.

[b] See National Defense Committee of OSRD, War Metallurgy Division, Final Report, Part 1, OSRD No. 3274 (1944), pp. 46-47: "Effect of Shotpeening on the Physical Properties of Steel," by R. L. Mattson and J. O. Almen.

[c] See *Product Engineering*, Vol. 24, July, 1953, pp. 189-191: "Residual Compressive Stress Strengthens Brittle Materials," by J. O. Almen.

[d] See National Defense Committee of OSRD, War Metallurgy Division, Final Report, Part 2, OSRD No. 4825, 1945, pp. 108-109: "Effect of Shotpeening on Physical Properties of Steel," by R. L. Mattson and J. O. Almen.