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Optimal Design & Analysis of Compression Helical Spring for Enhancement of Life

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ABSTRACT: *Springs are mechanical devices that are capable of storing mechanical energy because of their elasticity. Springs are often made of coiled, hardened steel, although non-ferrous metals such as bronze and titanium and even plastic are also used. There are various types of springs, the designs of which take advantage of different energy storage management. Springs are usually made of hardened steel that are formed into the shape of a helix which returns to its natural length when unloaded.*

Shot peening is done on the helical spring, which serves to increase the life of the component subjected to high cyclic stresses. These springs have been modelled and analysed using ANSYS 14.5 version.

These springs have been manufactured and one of the springs of each material has been shot peened. These springs are tested on Universal Testing machine for their deflection when subjected to different loads. It is observed that the spring that has been shot peened undergo less deflection for the same load applied when compared to spring to normal spring.

Spring steel is material used to manufacture. These materials have high yield strength and high ultimate strength but yield and ultimate are very close like brittle material but with high tensile strength.

Key words: *Spring, CATIA, spring steel, Shot peening, MPI, Ansys 14.5.*

I. INTRODUCTION

We are familiar with spring. Spring is a mechanical device which stores the energy in the form of compression of expansion and when releases this energy in the form of expansion or contraction whenever required.

Many components are in the field of mechanical working are subjected to cyclic loading and have to withstand it over a number of cycles beyond 10^7. This can be a result of a high frequency or a long service time. Designers & calculation engineers are becoming increasingly interested in considering this high cycle fatigue region in the assessment of their components. Fail with special failure mechanism can occur depends on the material, manufacture method, loading conditions and other influence factors. In most cases springs can be made of oil hardened and tempered. Spring steels have a high –purity, high young's modulus and an ultimate tensile strength of the wire of 1200 to 3000 MPa with high elastic limit. These properties are very sensitive to notches, which can be at the surface as scratches or roughness, or inside, as for instance oxide inclusions.

Type of springs

i) The gap between the successive coils is larger.

ii) It is made of round wire and wrapped in cylindrical shape with a constant pitch between the coils.

iii) By applying the load the spring contracts in action.

iv) There are mainly four forms of compression springs as shown in Figure3.

They are as follows:

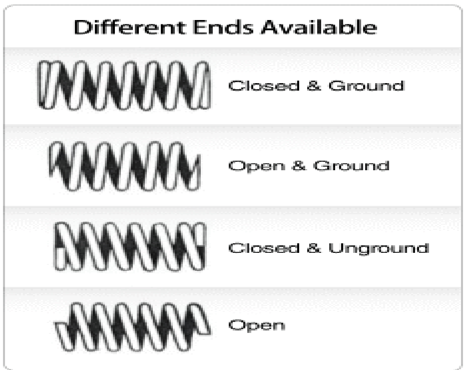

Figure 1: Types of Springs & Ends

a) Plain end
b) Plain and ground end
c) Squared end
d) Squared and ground end

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Among the four types, the plain end type is less expensive to manufacture. It tends to bow sideways when applying a compressive load.

Generally failure of spring occurs due to tension. When rod of spring steel gets bend into spring coils tension is induced into rod on outer surface of spring and compression is induced on inner surface of spring.

Figure 2: Tension leads to failure in bend rods

While in tension, small cracks get propagated one to another and fracture begins.

A study has done through the SAE Fatigue Design and Evaluation Committee and showedwhatever shot peened part can do for welds compared to welds. The study claimed that the regular welds would fail after 250,000 cycles when welds that had been shot peened would fail after 2.5 million cycles, and that failure would occur outside of the weld area. This is part of the reason that shot peening is a popular operation with aerospace parts. However, the beneficial pre-stresses can anneal out at higher temperatures.

Shot peening is very often used to impose compressive residual stresses in the surface region.Fatigue behavior of shot-peened mechanical components is characterized by uncertainty, where veteran approaches fail to exactly estimate the structural service life.

My work is on optimal design and analysis of compression helical spring. Here optimal refers to stiffness and fatigue life of the spring. This can be done by the process called SHOT PEENING.

Shot peening is a cold working process, produces the compressive residual stress to modify the mechanical properties (such as to avoid surface micro cracks because these don't propagate under compressive stress. Shot peening is also replace tensile stresses with compressive stress.

Shot peening process replaces the tension on outer surface of spring with compression and eliminates surface cracks.

Figure 3: Inducing residual compression stress on both sides

After shot peening, on the surface of the material compression is induced on both sides. Hence occurrence of tensile failure decreases. Only surface defects propagates tensile, but on surface crack are closed in cold working process.

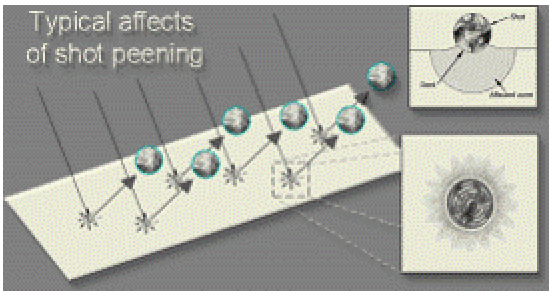

Figure 4: Shot peening process

If one imagines a stream of spherical particles leaving a blast nozzle or a centrifugal blasting machine and striking a metal surface, the work has done to the surface depends on a number of factors. Size and material of the spherical shot is important, as is its velocity and the rate and angle at which the blast pattern sweeps across the surface. The relative work done to the surface is called the 'Peening intensity'. Obviously it is impractical to count and weigh the particles and measure their velocity, so a simpler comparative method has been devised to measure peening intensity. If a flat strip of metal is shot peened on one side only it will slightly curl away from the side which has be treated and produce a convex surface. If a standard strip is used, the degree of curvature is a measure of the peening intensity, the stripe curling more at higher intensities. The standard strip is called an 'Almen Strip' after the man who first formalized this method. It is made from spring steel of carefully controlled quality to a size within close tolerances. It is used in three thickness called C, A and N. The C strip is thickest and N strips the thinnest. The curvature or are height, of the strip is measured with the aid of a dial gauge Fig.1 after the strip is placed and retained magnetically against two 0pairs of ball contacts a fixed distance apart. The gauge is zeroed with the unpeened strip in position. After peening the strip is replaced against the contacts with the unpeened side towards the dial gauge stem and the Almen are height is read directly in thousands of an inch or millimetres. The three different strip thicknesses are to cater for different extremes of peening intensity. For most applications an A strip would be used, and if this gave a deflection after peening of 0.015 in this would be expressed as 0.015 in A, lighter peening, giving less than 0.006 in A, an N strip would be used. The C strip is for heavy peening of intensity, greater than 0.23 in A. Generally, are height N is three times are height A and C reading is 0.3 of that on an A strip. In practice, 80% of all peening requirements lie between 0.012 in A and 0.020 in A.

- **"A" type** is predominantly used for shot peening with cast shot.
- **"N" type strips** are used usually for glass bead peen and ceramic bead peen, these strips are usually very thin.
- **"C" type strips** are used more rarely and are thicker than the other types.

When peening intensity is measured it is important to subject one side of the Almen strip to exactly the same blast conditions as the object to be peened. To do this the strip is clamped by the heads of four screws to a heavy flat block of hardened tool steel, called an Almen block, Fog. On irregularly shaped components often more than one strip is used, each one positioned on a difference face requiring treatment.

After shot peening these are tested for cracks in MPI (magnetic particle inspection test). In these test, under MPI machine rods are applied at the voltage of 180 to 240 V and dipped into the magnaflux florescent powder which is mixed with carrier liquid. Rods under these liquid, the magnaflux florescent powder gets penetration into the cracks under the applied voltage. Whenever UV light is projected on to the rods the magnaflux florescent powder glow where the power is accumulated like cracks. The inspection can done only cracks whose depth should be greater than the 0.5mm otherwise cracks and scratches are looks like same. Voltage supplied should not be greater than X20 times of size if it is more even small depth cracks increase their size due to high voltage.The magnaflux florescent powder should mixed properly with carrier liquid ensure that no stones formed otherwise flow powder into cracks is not sufficient or may accumulate at cracks.

Influence of shot peening
Stiffness of normal spring K= 120 N/mm
Stiffness of shot peened spring K= 131 N/mm

After shot peening stiffness of the spring is increased i.e. load carrying capacity is increased for same spring. Hence these springs can use as large spring where ever required whose stiffness is 131N/mm is required. This can be used as to reduce space occupied by the spring in the sense that by doing shot penning on smaller spring to increase theStiffness of the small spring up to required level.

In these work, spring steel is the material consider for design, manufacturing, testing, and analyzing. Spring steel low alloy, medium-carbon steel with high yield strength (1000 to 1300 MPa).

Design refers to – Design the spring model in CATIA with the required dimensions.

Manufacturing refers to – Manufacturing of two Spring according to design done.

Preprocessing refers to – One spring is oil quenched, tempered and another one is oil quenched and shot peened.

Testing refers to

– Both springs are tested under UTM to find deflection under various loads.

-Shot peened material also tested for various material properties.

- Yield strength(tension)
- Ultimate strength (tension)
- Compressive strength

Material Type:- Spring Steel (ASTM A 228)

Design of spring

- Type of spring:- Closed & Grounded ,Compression type Helical Spring
- Wire diameter d : 12 mm
- Mean diameter D : 58 mm
- Outer diameter OD : 70 mm
- Free length L free : 270 mm
- Solid height L solid : 132 mm
- Number of coils N : 9
- Pitch : 30 mm
- Length of wire required : 2.004 m
- Rise angle of coils : 8.53^0
- Spring index C : 4.833
- Wahl correction factor W : 1.323

Material Properties

- Density : 7.8g/c^3
- Young's modulus : 210 GPa
- Poisson's ratio : 0.313
- Bulk Modulus : 1.87e^11
- Yield strength : 1132Mpa
- Ultimate strength : 1236Mpa
- Elongation : 8 – 15 %

SPRING DESIGN:

1. Solid length. When the compression spring is compressed until the coils come in contact with each other, then 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. Mathematically, Solid length of the spring,

LS = n' x d

Where n' = Total number of coils, and

d = Diameter of the wire.

2. Spring index. The spring index is defined as the ratio of the mean diameter of the coil to the diameter of the wire.

Mathematically, spring index, C = D / d

Where D = Mean diameter of the coil, and

d = Diameter of the wire

3. Spring rate. The spring rate (or stiffness or spring constant) is defined as the load required per unit deflection of the spring. Mathematically,

Spring rate, k = W / δ where W = Load, and δ = Deflection of the spring.

4. Pitch: The pitch of the coil is defined as the axial distance between adjacent coils in Uncompressed state. Mathematically,

Pitch of the coil, $P = \frac{Lf - Ls}{n'} + d$

Where

L_{free} = Free length of the spring,

Ls = Solid length of the spring,

n' = Total number of coils, and

d = Diameter of the wire.

In choosing the pitch of the coils, the following points should be noted:

(a) The pitch of the coils should be such that if the spring is accidently or carelessly compressed, the stress does not increase the yield point stress in torsion.

(b) The spring should not close up before the maximum service load is reached.

5. Stiffness of Spring: Stiffness of the spring or spring rate,

$K = \text{Load /Deflection} = \frac{W}{\delta} = \frac{Gd}{8C^3 n}$

6. Frequency of Helical Spring: Natural frequency of spring should be at least twenty times the frequency of application of a periodic load in order to avoid resonance with all harmonic frequencies up to twentieth order. The natural frequency for springs clamped between two plates is given by

$$f = \frac{d}{2\pi D^2 n}\sqrt{\frac{6G.g}{\rho}}$$

d = Diameter of the wire,
D = Mean diameter of the spring,
n = Number of active turns,
G = Modulus of rigidity,
g = Acceleration due to gravity, and
r = Density of the material of the spring.

7. Maximum shear stress : Maximum shear stress induced in the wire,

$\tau = K \, \frac{8WC}{\pi d^2}$,

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

8. The length of wire needed to make the spring is found from

$$L_{wire} = \pi D \left(\frac{n_a}{\cos\theta} + 2 \right)$$

Result:

1. Tensile yield strength of normal spring rod = 1200 Mpa
2. Tensile yield strength of shot peened spring rod = 1292.7 Mpa
3. Ultimate strength of normal spring rod = 1289 Mpa
4. Ultimate strength of shot peened spring rod = 1315 Mpa
5. Stiffness of normal spring = 120 N/mm
6. Stiffness of shot peened spring = 131 N/mm
7. Deformation of compression helical spring

Deflection (mm)	Load on normal spring(KN)	Load on shot peened spring(KN)
10	1.18	1.36
20	2.30	2.43
30	3.60	3.93
40	4.92	5.18
50	6.10	6.23
60	7.34	7.69
70	8.55	8.98

In ANSYS, deformation is

Load (N)	Deflection (mm) of normal spring	Deflection (mm) of shot peened spring
1000	8.911	8.162
2000	17.727	16.238
3000	26.542	24.312
4000	3.5357	32.387
5000	44.173	40.461

8. normal spring for 131 Nmm design required is

normal spring for 131 Nmm		
N	dia of wire	mean dia
3	9.5	59.5
3	10.5	68
3	18	139.5
4	14.5	95
4	19.5	141
5	17	1.9
6	14.5	83
6	19	119
7	19.5	117
8	8.5	37
9	14.5	72.5
10	13	60.5

10	14.5	70
10	15.5	76.5
12	15.5	72
13	6.5	22
13	9.5	36.5
15	8.5	30
15	12	47.5
16	12	46.5
16	17	74
17	17	72.5
18	19	82.5
19	14.5	56.5
20	13.5	50.5
20	16.5	66

9. shot peened spring for 120 Nmm design required is

shot peened spring for 120 N/mm		
n	wire dia	mean dia
3	15	116
4	10.5	65.5
4	19.5	149.5
5	9	49.5
5	13.5	85
5	14.5	93.5
6	13.5	80
6	14.5	88
7	8.5	41
7	18	11.5
10	18	99
12	7.5	29
12	13.5	63.5
13	9	36
13	14.5	68
13	19	97.5
14	15.5	72.5
14	17	82
14	18	88.5
15	10	39.5
15	18	86.5
18	14.5	61
19	15.5	65.5
19	17.5	77
19	20	92
20	18.5	81.5

Conclusion

1. Influence of shot peening

Stiffness of normal spring K= 120 N/mm
Stiffness of shot peened spring K= 131 N/mm

After shot peening stiffness of the spring is increased i.e. load carrying capacity is increased for same spring. Hence these springs can use as large spring where ever required whose stiffness is 131N/mm is required.

This can be used as to reduce space occupied by the spring in the sense that by doing shot penning on smaller spring to increase the stiffness of the small spring up to required level.

2. Yield strength and ultimate tensile strength of spring material are very closed like Brittle material but with very tensile strength

Yield strength =1289MPa
Ultimate tensile strength =1315MPa

3. Tensile strength of shot peened spring rod is higher than normal spring rod.
4. Stress concentration due to sudden reduction in area is decreased due to shot peening process.
5. In tensile test, yield point and ultimate point are very close like brittle material but with high strength.
6. When deformation of both spring are compared for same design, load carrying capacity of shot peened spring have high higher stiffness then normal spring.
7. Because of having higher stiffness for shot peened spring, we can design a smaller or simpler shot peened spring to give normal spring design hence area decreases.

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