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Stress and Deflection Analysis of slotted Belleville Spring

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Abstract- A Slotted conical disk spring is a modification of the regular conical disk spring or Belleville spring as it has regularly arranged slots extending from the inside diameter. A single slotted disk undergoes large deflection at a smaller loads than the regular disk with comparable dimensions . This report gives stress and deflection analysis of a Belleville Spring with slots and without slots using finite element method. For a particular dimension of its outer diameter and inner diameter i.e. (OD/ID), diameter between slots and outer diameter (TD/OD) and its Height to thickness i.e. (H/T) have been considered to investigate the Von-misses stresses in the spring along with the deflections. Finite element method is used for analysis. The FE results are compared with existing analytical results.

Index: spring1, Von-misses 2, Finite element method 3

1. INTRODUCTION

A Belleville Spring is a conical shaped disc that will deflect (flatten) at a given spring rate when subjected to an axial load Fp. This rate is usually very high relative to a coil spring, which makes a Belleville an excellent candidate where large loads must be delivered through a short movement. Some applications where Belleville are commonly found are: clutch and brake mechanisms in heavy equipment, punch and die sets, bearing assemblies, switchgear, and anywhere bolt pre-load must be maintained over time. A Belleville Spring's geometry can be characterized by four dimensions:

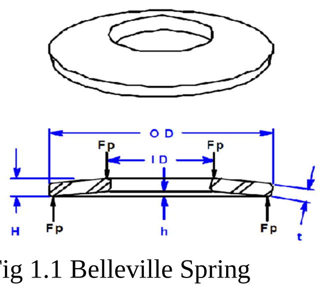

Fig 1.1 Belleville Spring

ID = inside diameter, t = material thickness, OD = outside diameter , h = deflection-to-flat

Some manufacturers use the parameter H (free height t+h) in lieu of h. In a bolted joint the spring is normally loaded at the upper-inside edge by the nut or bolt head and the lower-outside edge by the joint. Manufacturers also use a parameter called "flat-load" or "load-to-flat" (FW) in their description of a Belleville Spring. This is the force required to "push" the spring into the flat position. As the nut in a bolted joint is torqued the spring starts to deflect (flatten) and the bolt begins to stretch. The Belleville will be in its flat position when the preload in the bolt equals the flat-load1 since the spring will be clamped between the flat joint and the nut, any additional torque applied to the nut will only stretch the bolt. Higher loads (than FW) will normally not damage the spring if the load cannot deflect it past the flat position (as in most bolting applications). Therefore, the maximum force that can be applied to a Belleville mainly depends on the limitations of the bolt or joint designs. The spring rate of a Belleville depends on geometry, material, and loading conditions

1.1. *A Slotted Belleville Spring*

The slotted conical disk spring is a modification of the regular conical disk spring or Belleville spring in as much as it has regularly arranged slots extending from the inside diameter. A single disk of the slotted type undergoes a larger deflection at a smaller load than a regular disk spring of comparable dimensions, thereby combining some of the advantages of the disk spring and the cantilever type spring in a single unit. It is used, where stacking is undesirable, a relatively large outside diameter is tolerable, and a regressive load-deflection-characteristic is desired, like in clutch applications. The analytical equations for the slotted Belleville spring have been taken from[3]—The Slotted Conical Disk Spring, as shown in Figure

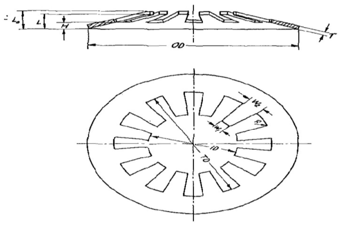

Fig 1.2 Slotted Belleville Spring.

2. LITERATURE REVIEW

Many researchers have carried out stress and deflection analysis of a Belleville spring. Monica Carfagn.[1] carried out the stress and deflection analysis to prepare a CAD method for the checkout and design of the Belleville springs. The method eliminates the need to resort to conventional trial-and-error techniques. In a matter of seconds, it rapidly and accurately checks out and designs Belleville springs, outputting the load deflection characteristics in graphic and table formats and can generate a dimensioned drawing. G. Schrfmmer [2] carried out the stress and deflection analysis of a slotted Belleville spring to develop a analytical relationship for deflection and stress of a slotted conical spring.

Disc springs are conical ring washers whose shape changes under axial loads, based on the approximated rotation of the generally uniform rectangular cross-section of the disc around a circle of inversion. This forms the basis for Almen and Laszlo's * equations for spring force and mechanical tension. The calculation method specified today by DIN 2092 assumes almost identical conditions. It has shown to be sufficiently precise in practical application and is generally taken as the accepted standard.

3. THEORY

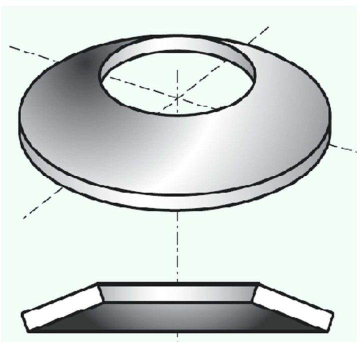

Fig 3.1 3D Model of Belleville Spring

Compared to other types of springs, the disc spring can be categorized as having a "small spring deflection coupled with high spring force" However, this restriction is circumvented by the ability to form stacks of multiple disc springs. Arranging the discs in parallel or nested formation multiplies the spring force, alternating or series arrangement multiplies the spring deflection. Both these stacking methods can be used in combination.

One of the outstanding characteristics of the disc spring is doubtless its capacity for variation of the characteristic force-deflection curve over a wide range. Alongside practically linear characteristics, digressive force-deflection characteristics can also be implemented, even those in which spring force diminishes in certain ranges with increasing spring deflection. Many disc springs feature contact surfaces. These are predominantly large parts which in any case involve a high degree of production complexity. In this case, modified calculation methods are used. Contact surfaces improve the guidance properties of disc springs. In some applications, the guiding element of the disc spring stack can have a disturbing influence. A number of examples illustrate how this problem can be successfully overcome by using self centered disc spring arrangements. Slotted disc springs assume a special role. The slotting process changes the force-deflection range of the individual disc springs, resulting in greater spring deflections coupled with lower spring force. As well as the materials stipulated in DIN 2093, which we use for our disc springs manufactured to generally applicable and also works standards, a wide range of other materials are also available nowadays to fulfill wide-ranging requirements. The most commonly used materials are described in brief and their most important characteristics summarized in table form. For components made of high-strength materials, corrosion represents a special hazard. A description of methods shown by present experience to combat corrosion in spring steel is attached. This compendium of data contains an extensive table section covering all disc springs to DIN 2093 and CB works standards. These tables contain the mechanical characteristics in both graph and table form. This is followed by a corresponding collection of disc springs made of stainless materials to DIN EN 10 151.

The compendium is completed by a section dealing with disc springs for ball bearings and a section on fastener Belleville's to DIN 6796. It should also be mentioned in passing that, alongside the hundreds of springs listed here, our production range also encompasses a wide selection of non-standard disc springs. Our advisory team is at your service at any time to discuss the design of your specific disc spring.

4. CASE STUDY

4.1. *Finite Element Analysis Of A Slotted Belleville Spring*

In this work a simple slotted Belleville Spring analysis has been done. For a particular dimension of its various parameters given below the force has been calculated. The specifications of the Slotted Belleville spring considered are as follows.

- OD = 144mm
- TD= 124.8mm
- ID= 72mm
- T= 1.92mm
- Modulus of Elasticity (E) = 206.7×10^3 N/mm²
- Poisson's Ratio (μ) = 0.3
- LO = 12mm
- L=10.08mm
- W1 = 8.4mm
- Z= 12

The analysis is done by imposing boundary conditions such that the spring could deflect only along X&Z-direction. The analytical equations for the deflection and stresses for a slotted Belleville spring are given from equation (1) to (7)

$$P=\frac{E}{1-\mu^2}\times\frac{T^3}{OD^2}K_1\times F_1\left[1+\left(\frac{H}{T}-\frac{F_1}{T}\right)\left(\frac{H}{T}-\frac{F_1}{2T}\right)\right]\left[\left(1-\frac{TD}{OD}\right)\div\left(1-\frac{ID}{OD}\right)\right] \quad \text{.... (1)}$$

$$S=\frac{E}{1-\mu^2}\times\frac{T}{OD^2}\times\frac{TD}{OD}K_2\times F_1\left[1+K_3\left(\frac{H}{T}-\frac{F_1}{2T}\right)\right] \quad \text{.... (2)}$$

Where K_1, K_2, K_3 are Constants.

$$K_1=\frac{2\times3.14}{3}\frac{(OD/TD)^2\ln(OD/TD)}{[(OD/TD)-1]^2} \quad \text{.... (3)}$$

$$K_2=\frac{2(OD/TD)^2}{[(OD/TD)-1]} \quad \text{.... (4)}$$

$$K_3=2-2\left[\frac{1}{\ln(OD/TD}-\frac{1}{(OD/TD)-1}\right] \quad \text{.... (5)}$$

$$H=\frac{1-(TD/OD)}{1-(ID/OD)}\times L \quad \text{.... (6)}$$

$$W_2=(TD/ID)\times W_1 \quad \text{.... (7)}$$

Where,
P= Force
F1 = Deflection of the spring
OD= Outside surface Diameter
ID= Inside surface diameter
TD= Diameter between two slots
E= Modulus of Elasticity
μ = Poisson's ratio
H= Height of the spring,
T= thickness of the spring
L0 = Vertical distance from upper inner surface to the bottom outer surface
L= Vertical distance from Lower inner surface to the bottom outer surface
Z= Number of tongues (i.e. slots provided in the spring)
W1 & W2= width of the slots on upper and lower side.

The representation of the stress and deflection contours for the above said dimensions of the Belleville spring with slots and without slots are shown in figures 2&3 as illustration. Further the load-deflection characteristic and load stress characteristic have been studied by varying the load obtained in the above case. The results are presented in forthcoming section.

The FE analysis revealed the Von-misses stresses along with the deflections for a particular dimension of a Belleville spring with slots and without slots. The analytical calculations for the above dimensions are in very close approximation with the FE values thereby validating the correctness of the analytical equations. Substituting the given values the constants are found to be: - K1 =16.8, K2= 17.3, K3=1.024 Now substituting these values of constants in Eq (1) & Eq (2) mentioned above to calculate the respective Load (force) and the stress.

$$P=\frac{206.7\times10^3}{1-0.3^2}\times16.8\times\frac{1.92^3}{144^2}\times2.68\times\left[1+\left(\frac{2.68}{1.92}-\frac{2.68}{1.92}\right)\left(\frac{2.68}{1.92}-\frac{2.68}{2\times1.92}\right)\right]\left[\left(1-\frac{124.8}{144}\right)\div\left(1-\frac{72}{144}\right)\right]$$

P= 1074 N.

$$S=\frac{206.7\times10^3}{1-0.3^2}\times\frac{1.92}{144^2}\times\frac{72}{144}\times17.3\times2.68\times\left[1+1.024\times\left(\frac{2.68}{1.92}-\frac{2.68}{2\times1.92}\right)\right]$$

S= 1453.229 Mpa.

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CONCLUSION

1. The comparison between the conical springs with & without slots reveals that, deflection drastically increases due to the presence of slots . Thus slots are recommended to decrease the stiffness of spring for similar dimensions. This can be very well observed in figure 4.4 and table 4.1

2. The comparison of the stresses reveals that the stresses, in slotted spring are very high as compared to conical spring without slot and this can be observed very clearly from figure 4.5 and table, which shows the drastic difference of the Von-misses stress between the two cases i.e. with slots and without slots. This is due to the effect of stress concentration at the corners of the slots. This effect can be significantly reduced by providing suitable fillet at the slot corners, hence slotted springs are recommended for lower load values and greater flexibility.

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