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Design of Accordion Spring for Automotive Application

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***Abstract*— Automotive field is demanding more of weight saving innovations without hampering the reliability of the product, this kind of innovations are carried out in developing special type of compression springs as well, which are mostly used in torque converters where space is a constraint. One such innovation is Accordion spring. This does the work same as that of conventional helical coil spring, with reduced weight and effective length.**

This paper discusses about the Accordion spring design philosophy, considerations & comparison with conventional helical coil spring. Design philosophy includes loads, stresses, and stiffness. The shape of Accordion spring is not regular and hence employability of classical formulations has limitations. Additionally, analysis using Finite Element Method is required to substantiate the design. The methodology is validated in design of torque converter

Keywords*— *Accordion spring; Compression spring; Torque converter; simulation;

I. INTRODUCTION

A spring can be defined to be an elastic member, which exerts a resisting force when its shape is changed. Mostly springs are assumed linear & obey hooks law, which states, Force is directly proportional to displacement with a constant called spring constant (k), please refer *Fig.1* [1]

$$F = k\Delta \qquad (1)$$

Where,

F= Force in N

k= spring constant/Spring rate in N/mm

Δ= Displacement in mm

Primary objective of the design is to keep k constant for Accordion spring, please refer *Fig.2* in comparison with helical coil spring. Accordion spring is flat spring form which usually looks like the accordion used in pianos. The same technique is used to design a spring which is shorter in effective length & lesser in weight when compared to that of conventional coil spring.

Basic principle of working of both the spring might be same. But, the amount of stress generated, stress fields, material used and stress relieving cycles varies. This will be discussed further in the coming sections of this article.

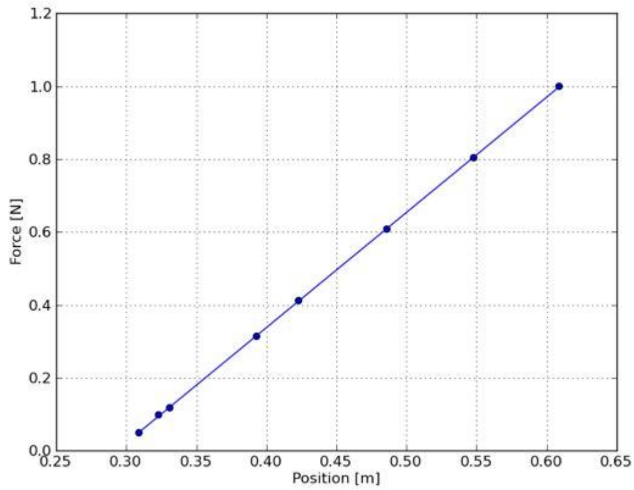

Fig. 1. Schematic of Force Vs Deflection graph

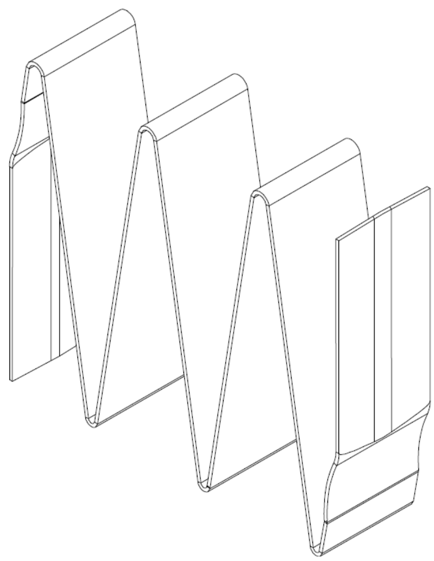

Fig. 2. Schematic view of Accordion spring

II. DESIGN CONSIDERATIONS FOR ACCORDION SPRING

Designing of compression accordion springs involves following aspects.

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- Spring rate required for given application & working condition
- Stresses developed at the corners during working in given environment and given condition.
- Material being used for the development

A designer would carefully integrate all these requirements in the design to achieve the desired result. Stresses generated depend solely on the material being used & the geometry of the spring that has been employed in the design. Fatigue stresses induced in the spring after few million cycles is taken empirically from the material properties.

III. DESIGN METHODOLOGY

As discussed earlier the spring is assumed to obey Hooks law as stated in Equation (1).
Accordion spring consists of serpentine shaped bends which are called as folds, please refer *Fig.3* for nomenclature.

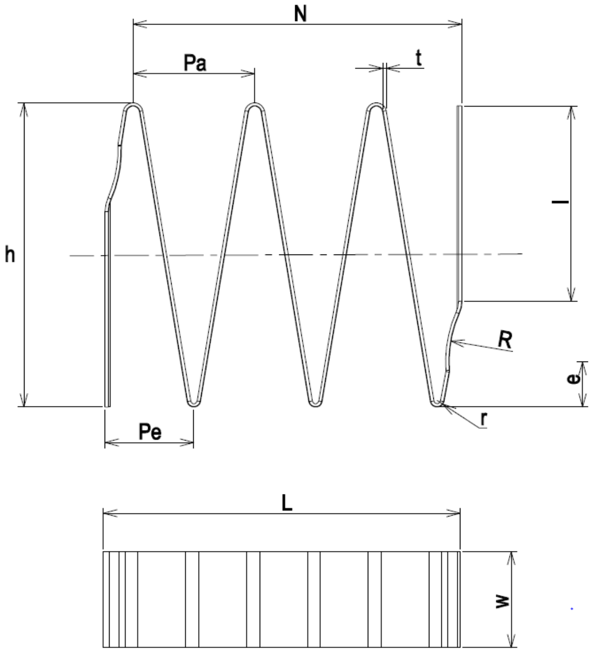

Fig. 3. Nomenclature of Accordion spring

Where,

N= Number of folds

Pa= Actual pitch

Pe= Relaxed pitch

h= Height

t= Thickness of material

L= Free length

w= Width

l = Straight length

r= Radius of bend

R= Radius of curvature

e= Eccentric center of R

Depending on height & free length required for packaging condition the following formulas holds good in selecting appropriate dimension of the spring.

A. *Design Calculations*

Pitch, $P = L/N$ (1)

Actual pitch, $P_a = P - 0.1 \times P$ (2)

Eccentric pitch, $P_e = (P + 0.2 \times P) / 2$ (3)

Eccentric center of R, $e = 0.148 \times h$ (4)

Radius of curvature, $R = 0.4 \times L$ (5)

Radius of bend, $r = 4 \times t$ (6)

The above equations forms pre-requisite for designing of the spring,

Solid length, $Ls = n' \times t + (N \times 2 \times r)$ (7)

Where,

n'= No. of strips = $(N+4)$ (8)

Since, the shape is irregular the stress analysis using classical formulations is tedious Finite Element Analysis is used to determine the stresses generated in static & dynamic conditions.

B. *Analogy to select number of folds and thickness of material*

As a thumb rule it is evident that if strips are connected in series then the spring becomes stiffer for the given load. Also, the thickness of material plays a significant role in determining the stiffness of the spring.

By simulating the model using appropriate tool & checking for the required stiffness gives the approximate number of folds & thickness of the material.
As a thumb rule, it is evident that lesser the number of folds & lesser the thickness more sensitive the spring will be. Usually it is recommended to keep the thickness below 0.4mm for sensitive spring i.e. for low stiffness.

C. *3D Modeling using CAD tool Pro-E /Creo*

After calculating the required data from known entities, the spring is modeled in any appropriate 3-D CAD tool using Sheet metal forming module.
Here, this module is used since the spring is a flat form.
This modeling helps us to determine the developed length of the spring; this will help in manufacturing of the spring for consistency. Please refer *Fig.4*

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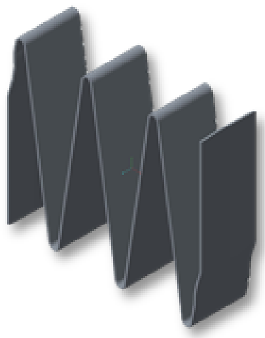

Fig. 4. 3D CAD Model of Accordion Spring

It is recommended to form the spring with top & bottom die arrangement. Sheet metal extrusion gives rise to uneven metal distribution since; the profile extrudes material in a single side & there will be considerable amount of mismatch in the symmetricity of the profile. This must be addressed carefully because the same model will be used for analysis. An inappropriate model directly means unsatisfactory analysis & simulation.

D. Material selection

It is recommended to use AISI 302, AISI 304 stainless steel for this application since the mechanical properties are favorable for spring action.

IV. Finite Element Analysis and its Importance

As discussed before, classical formulations have their own set of limitations. Hence, Finite Element Analysis of Accordion spring would give designer an additional information to predict the required parameters & integrity. Here we discuss Finite Element analysis & simulation using Transvalor ForgeNxt Module to simulate the spring under dynamic condition.
Outcome of finite element analysis depends on:

- Quality of mesh (including refinement)
- Interface definition using contact settings [2]. (*Selection of contact & target component (Roller & Spring) is designer's prerogative. However, in present work, roller is used as contact & spring is used as target surface)*

Surface to surface contact pair definition was used to define the interface between the components.

Initial mesh size & re meshing factor is defined, please refer *Fig 5.*

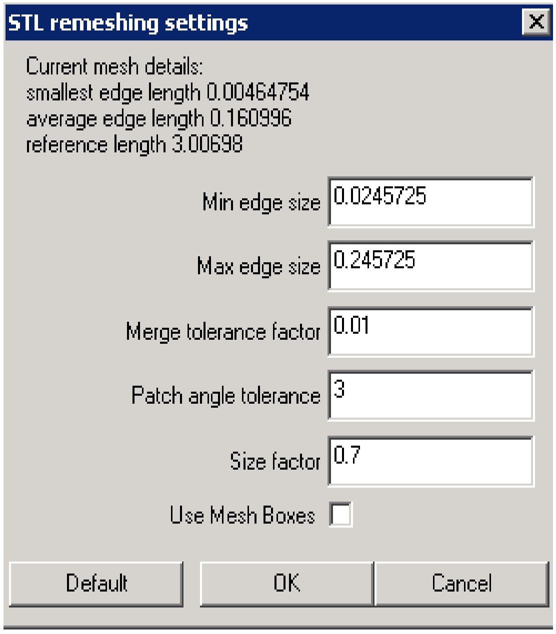

Fig. 5. Meshing details of the object

The maximum load is defined before the simulation is processed from the data of end application, please refer *Fig 6.*

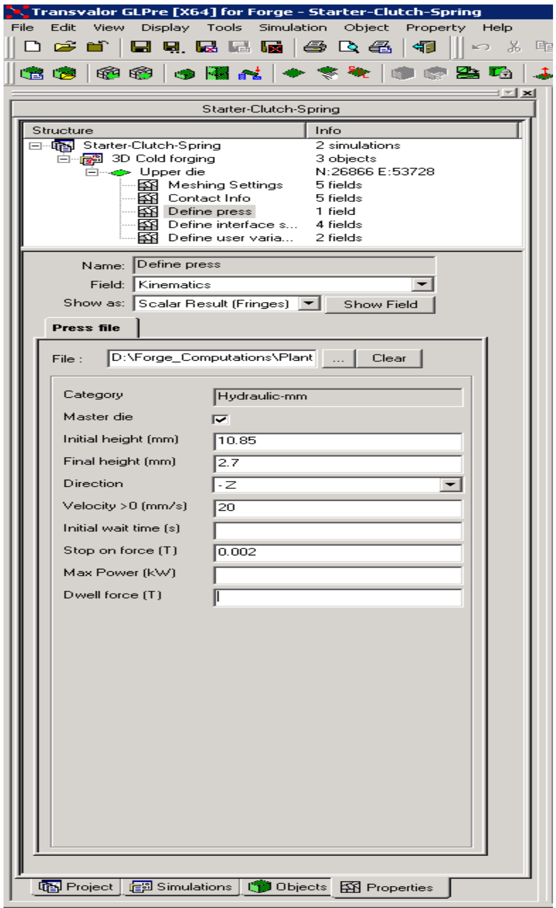

Fig. 6. Loading details on the spring

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After defining the parameters, simulation is carried out by simulating conditions that happens in the end application by defining appropriate boundary conditions

Based on requirement different load conditions where simulated to check the amount of load spring can withstand without undergoing plastic deformation at the corners. The points that are studied critically include first principal stress, Von mises stress, and Strain rate. Please refer *Fig.7, Fig.8, Fig.9.*

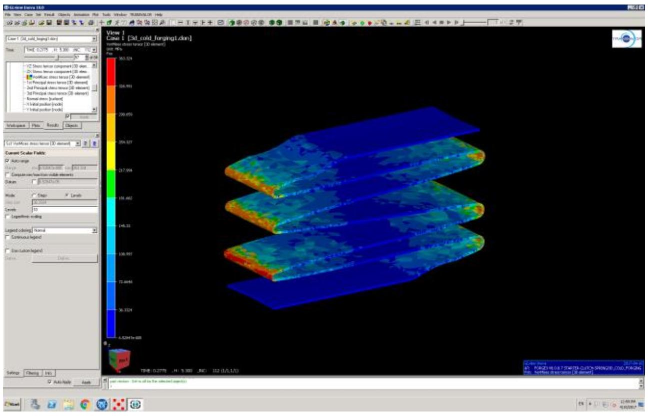

Fig. 7. Von Mises stress field

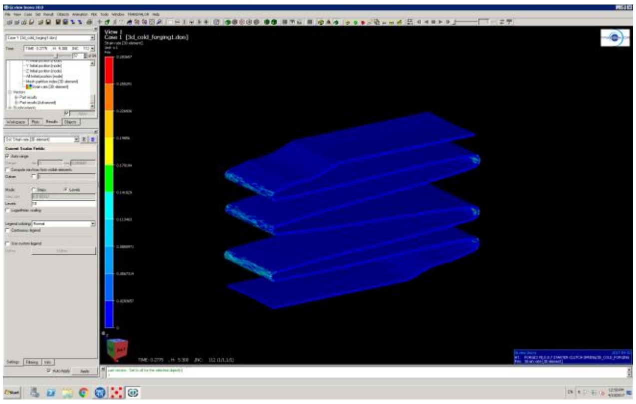

Fig. 8. Starin rate

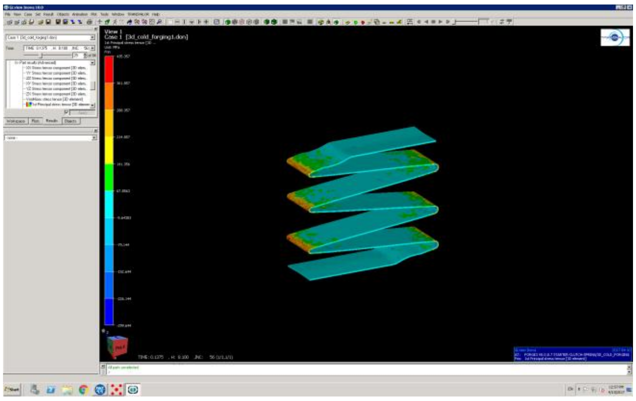

Fig. 9. 1st Principal stress tensor (3D-Element)

The stresses generated should be less than that of the material used, this proves whether the design will sustain for long cycle run or not. And can also be computed.

Also, End effects (or) localized stress raisers can also be observed from the finite element model unlike the classical formulation in relevant cases.

V. APPICATION OF DESIGN PROCESS IN A RECENT PROJECT

For a recent project on torque converter the above said spring is used as a replacement to conventional helical coil spring through the above established process. Post design, the torque converter was tested successfully at factory works.

VI. CONCLUSION

Methodology for design of Accordion spring as a replacement for conventional coil spring is described. Design calculations, validation and analysis has been carried out via finite element software has been shared. A case of successful implementation of the procedure to design accordion spring for torque converter is also presented.

VII. REFERENCES

[1] SAE Spring design manual
[2] Standard handbook of machine design by Joseph.E. Shigley
[3] Text book of machine design by R.S.Khurmi