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Research Paper

Design And Finite Element Analysis of 65mn Steel Disc Spring

Le Quang Duy*
Faculty of Vehicle and Energy Engineering, Thai Nguyen University of Technology,
Thai Nguyen, Viet Nam

Abstract
This study presents the design procedure and finite element investigation of a 65Mn steel disc spring. Mechanical behavior of the spring was evaluated through analytical calculations, experimental testing, and numerical simulation. A three-dimensional spring model was created using NX 12 software and analyzed under axial compression loading conditions. Experimental measurements were performed to determine the force–deformation relationship of the manufactured spring. The numerical simulation results were compared with theoretical calculations to evaluate the accuracy of the finite element model. The comparison demonstrates that finite element analysis can effectively predict the deformation characteristics and stress distribution of the disc spring. The obtained results provide a useful basis for improving spring reliability and optimizing structural design.

Keywords: *disc spring, finite element, cone spring, Von-Mises stress …*

I. INTRODUCTION

Disc springs are widely used in the fields of metal forming. This type of spring is suitable when large loads and small deformations are required . Springs are usually installed and arranged in layers. This type of spring has the ability to self-damp vibrations like leaf springs: Vibrations are quickly damped after compression. The conical disc of this type of spring has the cross-sectional dimensions and load as shown in Figure 1. The shape of the force-deformation curve depends mainly on the coefficient of free cone height h and thickness. The advantages of disc springs include small mounting space in the direction of the force, the ability to withstand lateral forces, and the force-deflection characteristics can be changed by adding or removing discs. .

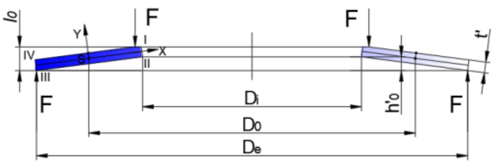

Figure 1. a single disk spring

Previous research has extensively investigated the mechanical behavior of disc springs and elevator safety systems through both numerical and experimental methods. Dębski et al [12]. together with Ozaki et al. applied finite element analysis to evaluate the load–deflection response of disc springs under various friction conditions, showing that friction plays an important role in spring deformation characteristics. Atxaga et al. [11] studied the influence of elevated temperature and saline environmental conditions on the durability and operational reliability of stainless-steel disc springs.

Kayaoglu and co-workers [16] analyzed the stress distribution and deformation behavior of elevator safety gear brake blocks using Abaqus/CAE software. Their numerical predictions were validated through experimental measurements, and good agreement was observed between the two approaches.

In addition, studies conducted by Jong and Feng et al. [14] used finite element methods to evaluate the stiffness and structural strength of elevator car frames. Their investigations mainly emphasized structural optimization and safety improvement of elevator systems and safety gear components.

II. DESIGNING OF DISC SPRING

The design of disc spring requires iteration. Trail values of R_0 and h/t ratio must be chosen. It is possible to estimate thickness required to obtain a particular force at the flat position from [2]

$$t = \frac{1}{10}\sqrt[4]{\frac{F_{flat} * D_0^{\ 2}}{132.4 * h / t}}$$

Generally we choose h/t ratio 1.414 for approximate constant value, centered around flat position [2]. h/t=1.414. Small and medium-sized work machines typically weigh from 100 kg to 500 kg and are supported by four legs, each with a vibration-damping cushion. The average weight supported by each cushion ranges from 25 kg to 125 kg. In Figure 1 different disc springs have different load-deformation curves and stiffness characteristics. As a vibration isolation component, a disc spring must have an equivalent stiffness of zero and nonlinear stiffness [23]. Therefore we choice dics spring made of 65Mn steel has parameters as Table 1

D_e (mm)	D_i (mm)	t (mm)	H (mm)	h_0 (mm)	h_0/t	μ	E (N/mm^2)
50	25,4	1,25	2,85	1,8	1.44	0,3	2,06*10^5

Table1- Parameter of a single disk sping

Steel	C	Si	Mn	P	S	Cr
65Mn	0.62÷0.70	0.17 ÷ 0.37	0.90 ÷ 1.20	< 0.035	< 0.035	< 0.25

Table 2 - Chemical composition of the spring material.

Figure 2. Heat treatment disc spring

[21, 22], the load-deformation characteristic curve is nonlinear. When the material, inner diameter Di, outer diameter De, and thickness t are fixed, the curve depends solely on and is most affected by h0/t.

When h0/t < 0.5, the deformation relationship is linear; otherwise, it is nonlinear. Furthermore, stiffness decreases as deformation increases. When , the stiffness of the disc spring is zero if deformation ; when , and the load increases to a critical value, a region of negative stiffness appears. Deformation gradually increases as the load decreases.

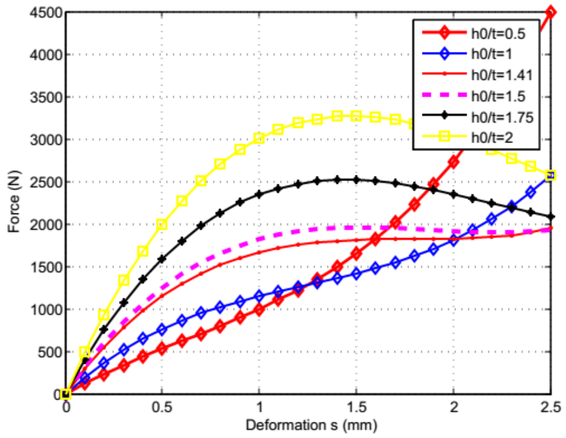

Figure 3 Load-deformation characteristic curve.

The relationship between the applied load on the disc spring and deformation can be described as follows [23]:

$$\mathrm{F} = \frac{4E}{1-\mu^2}\cdot\frac{t^4}{\mathrm{K_1 D_e^2}}.K_4^2.\frac{s}{t}.\left[K_4^2.(\frac{h_0}{t}-\frac{s}{t}).(\frac{h_0}{t}-\frac{s}{2.t})+1\right] \qquad (1)$$

In which:

μ is the Poisson's ratio of the material

δ is the spring diameter coefficient:

$$\delta = \frac{D_e}{D_i} \qquad (2)$$

K_i and C_1, C_2 are calculation constants.

$$K_1 = \frac{1}{\pi}\cdot\frac{\left(\frac{\delta-1}{\delta}\right)^2}{\frac{\delta+1}{\delta-1}-\frac{2}{\ln\delta}} \qquad (3)$$

$$K_2 = \frac{6}{\pi}\cdot\frac{\frac{\delta-1}{\ln\delta}-1}{\ln\delta} \qquad (4)$$

$$K_3 = \frac{3}{\pi}\cdot\frac{\delta-1}{\ln\delta} \qquad (5)$$

$$K_4 = \sqrt{-\frac{C}{2}+\sqrt{\left(\frac{C_1}{2}\right)^2+C_2}} \qquad (6)$$

$$C_1 = \frac{\left(\frac{t'}{t}\right)}{\left(\frac{1}{4}.\frac{l_0}{t}-\frac{t'}{t}+\frac{3}{4}\right)\left(\frac{5}{8}.\frac{l_0}{t}-\frac{t'}{t}+\frac{3}{8}\right)} \qquad (7)$$

$$C_2 = \frac{C_1}{\left(\frac{t'}{ft}\right)}\left[\frac{5}{32}\left(\frac{l_0}{t}-1\right)^2+1\right] \tag{8}$$

And then we have:

$$\delta = \frac{D_e}{D_i} = 1,969 \tag{9}$$

$$K_1 = \frac{1}{\pi}\cdot\frac{\left(\frac{\delta-1}{\delta}\right)^2}{\frac{\delta+1}{\delta-1}-\frac{2}{\ln\delta}} = 0,688 \tag{10}$$

$$\mathrm{F} = \frac{4E}{1-\mu^2}\cdot\frac{t^4}{\mathrm{K_1 D}_e^2}.K_4^2.\frac{s}{t}.\left[K_4^2.(\frac{h_0}{t}-\frac{s}{t})(\frac{h_0}{t}-\frac{s}{2.t})+1\right] = 1550\ (N) \tag{11}$$

III. MODELING AND FINITE ELEMENT ANALYSIS

A three-dimensional model of the disc spring was developed using NX 12 software. The spring profile was first sketched in two dimensions and then revolved around the central axis to obtain the complete conical geometry.

Finite element analysis was carried out to investigate stress concentration and deformation behavior under axial compression. The mesh model was refined in regions expected to experience high stress gradients. Boundary conditions were applied by fixing the lower surface of the spring while applying compressive force on the upper surface.

The simulation focused on evaluating equivalent stress, total deformation, and the load–displacement relationship of the spring.

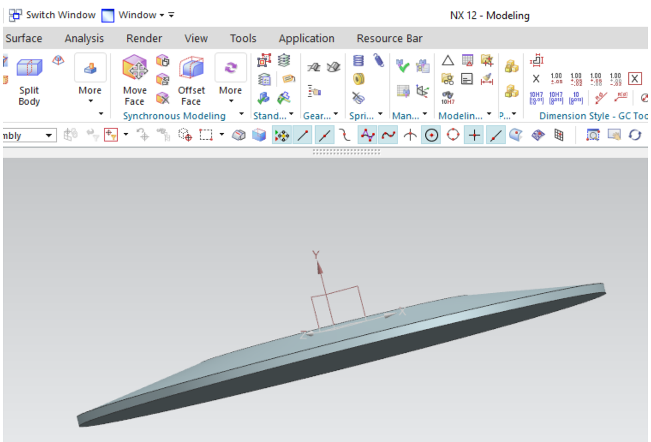

Figure 4 3D Model in NX12

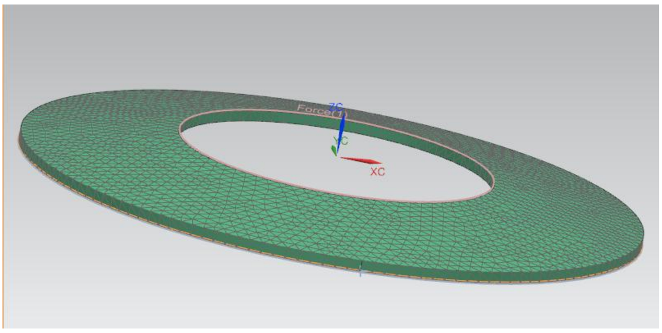

Figure 5 Mesh model

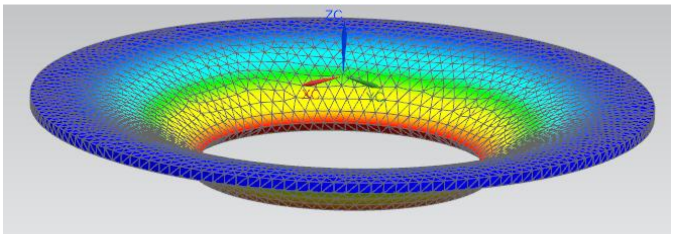

Figure 6 Deformation model

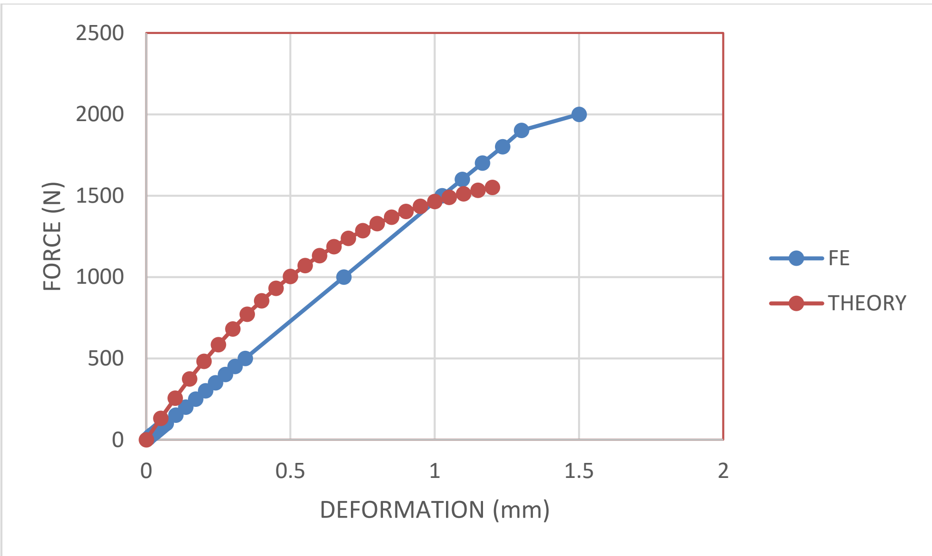

Figure 7 Force-Deformation curve

IV. RESULTS AND DISCUSSION

Experimental tests were conducted to determine the load–deformation behavior of the manufactured spring. The experimental results were compared with analytical calculations and finite element simulation results.

The comparison showed that the overall trend of the numerical force–displacement curve was consistent with theoretical predictions. Small differences between experimental and numerical results may be caused by manufacturing tolerances, friction effects, and simplifications used in the simulation model.

The finite element model successfully predicted the deformation characteristics and stress distribution of the spring. The maximum stress values remained within the allowable range of 65Mn steel, indicating that the proposed design is structurally safe.

V. CONCLUSION

A 65Mn steel disc spring was successfully designed and analyzed using analytical calculations, finite element simulation, and experimental validation.

The developed finite element model accurately represented the deformation behavior of the spring under axial loading conditions. Numerical simulation results showed good agreement with theoretical calculations and experimental measurements. The study confirms that finite element analysis is an effective method for evaluating spring performance and optimizing spring geometry before manufacturing.
Future work may include fatigue analysis, dynamic loading investigation, and optimization of stacked disc spring configurations for vibration isolation systems.

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