Advanced Production and Industrial Engineering
R.M. Singari and P.K. Kankar (Eds.)


doi:10.3233/ATDE220721

# Design and Analysis of Conical Spring Isolator

K Ujwal[1] Leeladhar Nagdeve[1] Harish Kumar[1]
National Institute of Technology[1], Delhi

**Abstract:** An ideal vibration isolation system should have low transmissibility, extensive isolation range, and stiffness to support any static load. Isolators are designed and developed for various applications where vibrations in the system become a bane to it, we find that most of the isolators use rubber as an electrostatic element while other designs also adopt wire rope and springs. The spring-type isolators are metallic and offer better flexibility in addition to the longevity of their performance as rubber loses its elasticity over the period. Helical springs are extensively used in many applications where the isolator is intended to perform for longer periods. In this paper, we present a detailed design and analysis of the metallic spring conical isolator that finds its application in airborne systems.

**Keywords** - Isolator, Conical Spring, Damper, Deflection

## 1. Introduction

The design of an isolator is complex as its structure is defined by multiple parameters. Vibration among structures is of great concern to the structural rigidity of the system. It is always a need and challenge to reduce the vibration and to that extent, even a reduction of 0.01 percent of transmission of vibration could lead to a revolution in the industry. It is desirable to design an efficient isolator to address the vibration. For an external force F(t), the dynamic parameters such as displacement(x), velocity(v) and acceleration(a) are related by the energy equation[1]

$$\mathrm{ma} + \mathrm{cv} + \mathrm{kx} = \mathrm{F(t)} \quad (1)$$

The main components of an isolator here are the spring and damper. When a vibrational force is applied to the body, the spring stores energy in it, and the damper converts the stored energy from low grade to high-grade energy. During the storage and conversion of power, the time delay becomes crucial in designing an isolator. The time delay is measured from the frequency as it is inversely proportional to time. The frequency can either be calculated dynamically or analytically. Few isolator designs adopt certain elastic materials like rubber or wires. Particularly in applications where the shelf life of the systems is long, usage of rubber-based isolators poses problems. The elastic nature of the rubber is lost due to oxidation which results in powder. On the spring-based isolators which are metal based do not succumb to such scenarios. Springs in isolators are found in various configurations like helical, torsional, conical springs as shown in Fig.2.[4]

(a) (b) (c)

Figure 1: Various configurations of springs (a) Helical (b) Torsional (c) Conical

In applications where space is a constraint, conical springs are more suitable. On compression, the helical and torsional springs, the minimum length would be the product of the wire diameter and the number of turns. Whereas in conical springs, irrespective of the number of turns, the minimum length would be as small as the wire diameter itself. Conical Spring has other advantages compared to helical such as variable force rate and stability In this paper, the detailed conical spring design is presented. The optimum dimensions of the spring are arrived for a specific frequency and mass.

## 2. Literature review

Rivin[1] discussed various types of isolators and classified them based on their applications by mentioning their frequency ranges and a brief design of each isolator is mentioned. Isolators can be differentiated by the elastomeric element in them .These elastomeric elements include wire rope ,Rubber and Springs . Many authors have developed different type of isolators with different elastomeric elements and investigated their behaviours [16]. A survey regarding the recent developments in the isolators is conducted by Ibrahim[15] which reveals that the introduction of nonlinear damping and stiffness in the isolator would yield better results. Such nonlinear damping and stiffness would be possible if we use metallic elastomeric elements instead of rubber. The study of isolator involving rubber as an elastomeric element was conducted by Schemit [20.] which shows linearity behaviour in the stiffness and damping, and rubber gets deformed during high temperatures. Wire rope isolators shows nonlinear behaviour but it can be made for either high frequencies or very low frequencies[4] .The last and the available elastomeric element is spring . Yamada [2] emphasized the need of the quality requirements such as load, deflection, elastic modulus, rigidity modulus, spring shape, wire diameter in the design of an isolator. Design and analysis of helical spring [13] is carried out for different applications where height is not a constraint. The optimal design for the conical spring in which the height of the spring becomes almost equal to wire diameter is shown by Manueal pardes [18]..The difference in the analysis of helical spring and conical spring is given by Pratik sharma[3].These studies of different elastomeric elements focused much on higher frequencies and helical springs. In this paper, we will be taking a conical spring into consideration and design for the lowest frequencies i.e from 8-10 Hz for the isolator.

## 3. Design Methodology

A detailed design of the conical spring-based isolator is presented in this section. For the reasons mentioned in section I, the design of the isolator is carried out for a minimum frequency range of 8 to 10 Hz and a bearable mass of 2kg.The schematic of the conical spring is shown in Fig 2.

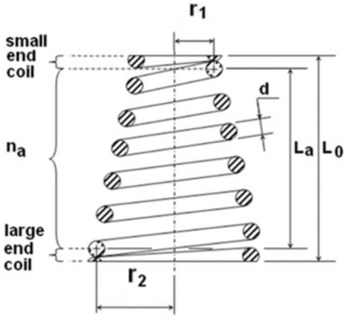


Fig 2. Nomenclature of a conical spring

The governing equation for the designing of the conical spring isolator is given in equation ( 2) [18] .

$$\boldsymbol{K} = \frac{\boldsymbol{Gd^4}}{\boldsymbol{16n_{a}(r_1 + r_2)(r_1{}^2 + r_2{}^2)}} \tag{2}$$

$n_a$ = Number of active turns
d = wire diameter
$r_1$ = minor radius
$r_2$ = major radius
K = stiffness
G = rigidity modulus

The design is aimed at calculating the major and minor radii of the conical spring, i.e, $r_1$, and $r_2$.

### *3.1 Stages of Design*

For the frequency range of 8 to 10Hz, the stiffness is calculated based on the formula shown in Equation(3)

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{3}$$

$f_n$ = natural frequency
k = stiffness
m = mass =2 kg

The stiffness values vis-à-vis the frequency is shown in table (1). Since the frequency of interest is between 8-10 Hz, the stiffness, k, ranges from 5.0535 to 7.895.

Table 1. Stiffness corresponding to different Frequencies

| *Frequency (Hz)* | *stiffness(N/mm)* |
|---|---|
| 30 | 71.06 |
| 28 | 62.08 |
| 24 | 45.6 |
| 20 | 31.58 |
| 16 | 20.212 |
| 15 | 17.765 |
| 12 | 11.36 |
| 10 | 7.895 |
| 9 | 6.395 |
| 8 | 5.0535 |

*3.1.1 Selection of number of turns*

The number of turns, $n_a$ of the isolator is dependent on the maximum length, $L_0$ and pitch, S of the spring. For a fixed length of the spring, the number of turns is inversely proportional to the pitch. The proposed designed isolator is intended to be placed in an existing system that allows a maximum length of 24mm. Hence $L_0$ is considered to be 24mm in the succeeding design equations.

$$S = \frac{L_0}{n_a} \tag{4}$$

where $L_0$ = maximum spring length
$n_a$ = number of active turns

The pitch is dependent on the wire diameter, d of Equation( 4). Pitch should increase accordingly with wire diameter, if not there will be surging in the spring. The. realizable minimum wire diameter is 660µm. As the diameter is increased, the value of stiffness increases to the fourth power. Increase in stiffness, in turn, increases the frequency and reduction in time delay. Reduced time delays minimize the rate of absorption.

Table 2. Dimensions of springs

| Mass (kg) | Stiffness (N/mm) | Radius (mm) | Deflection Theoretical | Deflection Analysis |
|---|---|---|---|---|
| 2 | 7.89 | $R_1 = 8.178$ $R_2 = 10.54$ | 2.484 | 2.751 |
| 2.5 | 9.869 | $R_1 = 7.6$ $R_2 = 9.75$ | 2.484 | 2.6419 |
| 3 | 11.84 | $R_1 = 7.19$ $R_2 = 9.15$ | 2.484 | 2.50 |
| 4 | 15.79 | $R_1 = 6.57$ $R_2 = 8.27$ | 2.484 | 2.660 |

Considering only the real values, the values of $r_1$ and $r_2$ are obtained as 8.178 and 10.54 respectively. The 3D model of the designed spring with these parameters is shown in Fig.3.

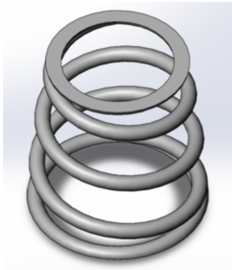

Fig 3. Designed Model of Conical Spring

## 4. Design of Conical Isolator

The discussion of what is inside the isolator is one of the central aspects of this article. Without complete knowledge of it, we cannot design an isolator. Every part of an isolator has its significance and role in absorbing vibration

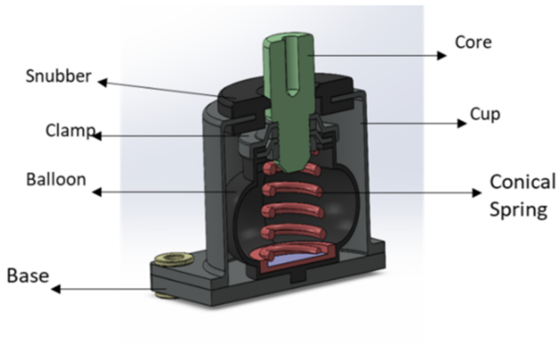


Fig.4: Solid Model of Conical Spring Isolator

The parts of the isolator are
1. Conical spring
2. Balloon
3. Balloon Cap
4. Balloon clamp
5. Core
6. Snubber
7. Cup and Baseplate

Conical spring is the main component in the isolator as stiffness and damping are related to it.

## 5. Results and discussions

Conical spring is an important part of the isolator. An appropriate selection of it would lead to better isolation. We have already fixed three constraints i.e length, wire diameter, and a number of turns but the behaviour of the spring changes with different masses, and there would also be a change in dimensions as the mass increases. From the Table, we get the values to design a conical spring with variable masses acting on it. The solid models of each and every spring are analyzed and checked for deflection. The results are given below for the deflections of springs with variable masses The Deflection almost remains the same with the increasing mass. This is shown using a graph for the theoretical and analytical values of deflection

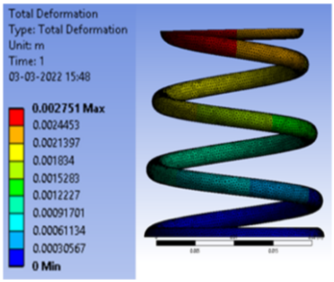


Figure 5 Deflection spring with mass 2kg

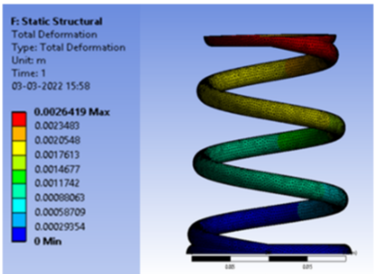


Figure 6 Deflection of spring with mass 2.5 kg

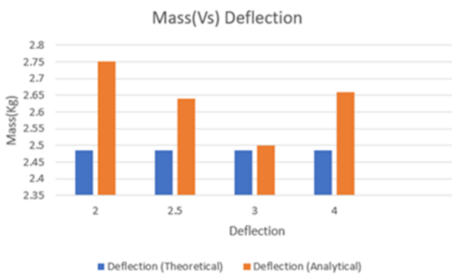


Figure 7 The graph between Mass and Deflection

## 6. Conclusions

A conical isolator for a frequency of 10 Hz is designed and presented. This isolator is capable of bearing 2kg, 2.5kg, 3kg, 4 kg loads. Details of each and every component of the isolator are discussed and also their characteristics along with their analysis have been shown.

## 7. Future scope

The designed conical isolator is assembled with all the components and all the dimensions are also mentioned. The manufacturing of the isolator would give a clear view of the isolator. Rubber can be completely avoided if we find a solution to eliminate the rubber balloon and snubber.

## Acknowledgments

The authors express their sincere thanks to the management of RCI for providing the facilities.

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