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Effect of Parametric Changes on the Natural Frequency of Metallic Bellow for Constant Bellow diameter (d) to Cavity Diameter (D) Ratio

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Abstract: The noise is unwanted sound generated due the vibration and causes the pulsation of the air pressure. There are different methods to control noise. The Helmholtz Resonator is active noise control device used to reduce at low frequency noise. The neck potion of the HR is Metallic Bellow; its structural natural frequency plays an important role in the acoustic performance of the overall HR. In this paper, the existing metallic bellow was taken and the structural longitudinal modes along with respective frequencies were calculated. Further in the second part the significant parameters were selected for the parametric variation and their effect on the structural natural frequencies of the bellows was investigated. The graphical indication represented that the natural frequency of each proposed model follows the linear relation and these lines don't intersect at any point. One can customize the metallic bellow as per application and the range of natural frequency from the graph suggests the parametric relationship to be used.
Index Terms: Helmholtz Resonator, Metallic Bellow, Structural Frequency, Mode Shape, Parametric Variation, Bellow Diameter, Cavity Diameter, Normal Modal Analysis, Longitudinal Vibration, Acoustics.

I. INTRODUCTION

The noise is unwanted and unpleasant sound generated due to the vibration of the objects or fluids. It is generally causes due to the pulsation of the air pressure. The adverse effect of the noise ranges from irritation to the serious health issues. It also contributes to the general fatigue, hearing loss, and sometimes changes in the heart rate too. The Noise Control Systems are majorly classified as Active, Passive and Semi-active.

The Helmholtz Resonator (HR) is active noise control system in which it uses anti-noise to super impose with incident noise source to reduce noise and this method is suitable for low frequencies.

The basic HR is shown below which is also treated as 1D Spring-Mass-Damper system. The neck portion represents the mass of the system, whereas cavity portion represents spring-damper of the system.

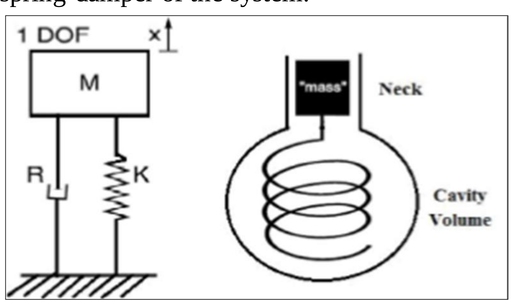


Fig. 1 - Basic Helmholtz Resonator

The schematic diagram of basic Helmholtz resonator is represented with Metallic Bellow in order to understand the role of Metallic Bellow. In HR, the arrow indicates the direction of incident sound wave, which passes through Neck portion and enters in cavity which is filled with the air in most commonly. The neck portion of the HR represents the Metallic Bellow. The general design parameters for HR are Cavity Diameter and Cavity Length, while for the general design of Metallic Bellow involves Neck Diameter, Neck Length & Convolution Pitch. The second image in schematics represents the cross-sectional view of Metallic Bellow.

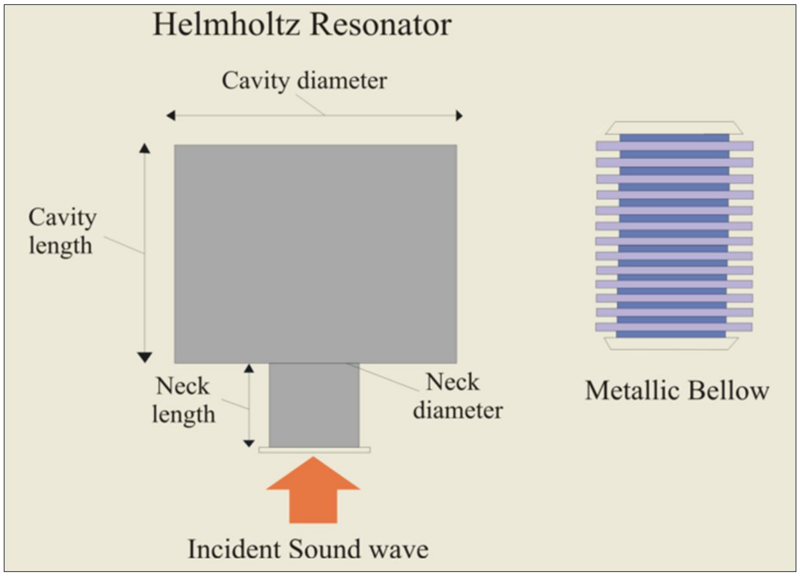


Fig. 2 - Schematic diagram of Helmholtz Resonator and Metallic Bellow [3]

A. Metallic Bellow

Bellow is an elastic membrane. The bellows are strong circumferentially and flexible along the length. It can be compressed and expanded by the application of external forces longitudinally. As bellows are loaded within elastic region (i.e. Induced stresses are well below yield strength) so, once the force is released it returns to its original shape.

Fig. 3 - Metallic Bellow Image

Basically, acoustic Metallic Bellow is the Flexible element of expansion joint. They are design for Strength and Flexibility. It should be strong in strength with circumferentially and should be flexible along the length. These are often subject to cyclic loading stresses. Higher stresses contribute to the premature failure.

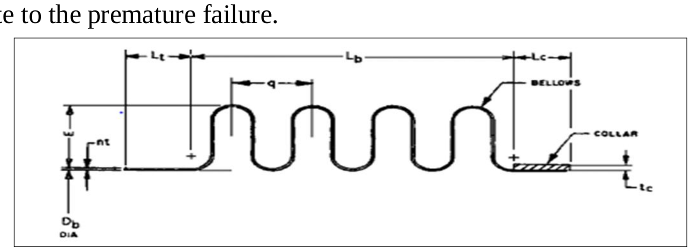


Fig. 4 - Metallic Bellow's Convolution Terminology

Where,

q	–	Convolution Pitch
w	–	Convolution Height
Lb	–	Bellows Convolution Length
Lc	–	Bellows Tangent Collar Length
Lt	–	Bellows Tangent Length

The broad objectives of the study

1) Study of existing Metallic Below to find out Structural Frequencies.

2) Effect of following Bellow parameters on the its structural natural frequencies -

a) Length of Metallic Bellow (L)

b) Pitch of Convolutions (P)

II. LITERATURE

M. Radhakrishna et al. [1] shared a methodology on the implementation of “Gerlach Method” for computing the Natural Frequencies of the Bellow. In which, convolutions are represented by identical masses connected by identical springs. Suppose, there are “N” convolutions are present in a current metallic bellow, which should be represented by “2N-1” identical masses connected to “2N-1” identical springs. The methodology can be implemented to verify the natural frequency of the component.

Brijesh M.et al. [2] in his paper mentioned the capabilities of the “Hydroforming” as compare to other conventional and modern manufacturing methodologies. The hydroforming can be implemented for complex shapes in a single step with varying cross-sections and free from the defects like the bursting, wrinkling or buckling etc. There few applications where it is required to design the customized metallic bellows, then the manufacturing through hydroforming can be one of the best alternatives to utilize design advantages.

A. Vinoth et al. [3] made a point about the additional design aspects needs to be considered based on application, a single design will not be best fit for all the applications like automotive, aerospace, marine etc. It shows that there is scope for the implementation of new design principles by all the three methods to solve engineering design problems i.e. Analytical, Simulation and experimental studies. He has mentioned the concept of Double Convolution Bellow and further he has shared the comparison chart for Single Convolution Bellow (SCB) and Double Convolution Bellow (DCB).

B. Kadam et al. [4] the paper is based on objective as to investigate the numerical and analytical approach on the effect of dynamic characteristics of metal expansion bellows. Mathematical approach is used to represent real life problem to find the natural frequency of the component by “Timoshenko Beam Theory” and further considered the case of longitudinal vibration of rod with respective boundary conditions has used.

E. Pavithra et al. [5] mentioned the need of flexible joints in marine, aerospace & nuclear applications due to its compactness and efficiency. Alternate material “Inconel 625 Alloy” is suggested over Stainless steel, Titanium, Brass, Copper and Aluminum etc. Inconel 625 alloy have better mechanical strengths, improved resistance to high temp, corrosion & oxidation environment and better surface stability.

Kaishu Guan a et al. [6] this paper describes the study representing the cause of accident which resulted into the damage of the bellows made of austenitic stainless steel. Post study it is observed that presence of large amount of martensite contributing to the increase in the material hardness.

A. Literature Summary

From the literature survey we came to know the importance of Metallic Bellow in Helmholtz resonator. There are few major finding which are found by above literature survey.

1) Implementation of “Gerlach Method” for computing Natural Frequencies of Bellow.

2) Hydroforming can be implanted for custom design with variable cross-section in single step free-from any defects.

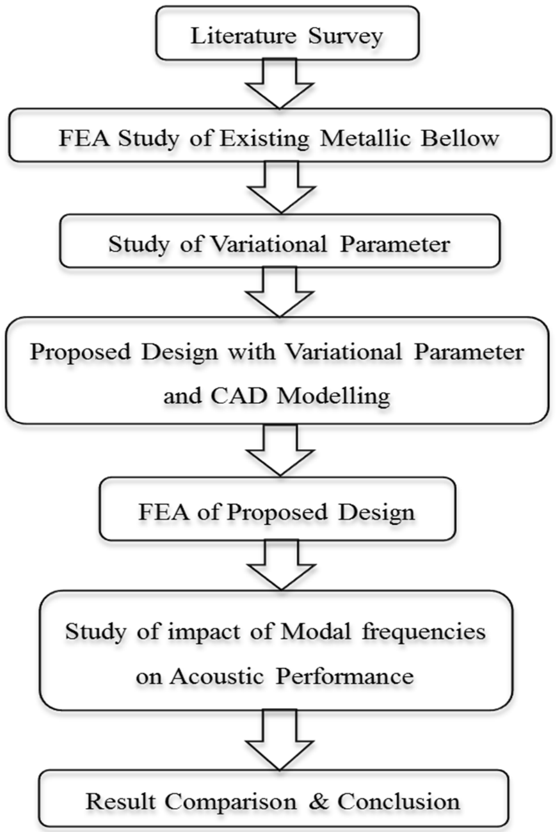
3) Scope for new design aspects for respective applications using Experimentation & FEA Methods.

4) Analytical calculations can be performed with assumptions by using “Timoshenko Beam Theory” considering Longitudinal Vibration of solid bar.

5) Inconel 625 alloy can be considered as alternate material due to better mechanical properties.

III. METHODOLOGY

The respective block outlines the work in the respective stages:



IV. NUMERICAL ANALYSIS

FEA is the method which can be implemented to study the effects of parametric changes on the natural frequency of the metallic bellow by keeping constant bellow diameter (d) to cavity diameter (D) of the metallic bellow under the study.

A. Existing Metallic Bellow CAD Model

The prime dimensions which were required for modeling 3D CAD model are overall length of the bellow, number of convolutions, pitch of convolutions, inner, outer diameter & thickness of the bellow, tabulated below –

Table 1 - Metallic Bellow Dimensions

Sr. No.	Bellow Parameters	Dimension/Value
1	Outer Diameter (D)	42 mm
2	Inner Diameter (d)	34 mm
3	Over-all length (L)	76.8 mm
4	Convolution Pitch (P)	2.32 mm
5	Height of attachment column (H)	6.5 mm
6	Number of convolution (N)	14

The scope of this paper is to focus on the following two parameters only. Those are discussed below –

1) Length of Metallic Bellow (L)
2) Pitch of Convolutions (P)

B. Model Building Activity

The model building activity is done in the market leading pre-processor with 2D Shell element – Quad4 for better interpolation function.

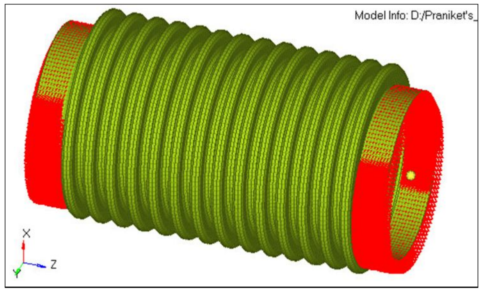


Fig. 5 – Metallic Bellow Model with BCs

The stringent quality parameters were followed during the model building activity, which includes the warpage, aspect ratio, minimum angle, maximum angle, Jacobian and skewness. This makes sure that the interpolation of the results will be accurate and smoother.

C. Material

The existing Metallic Bellow is made up of SS 304 and the respective mechanical properties have taken in the study.

V. SIMULATION APPROACH (OFFSET BARRIER)

Normal Modal Analysis (NMA) is carried out of the existing Metallic Bellow in order to find the mode shapes and the natural frequencies. To longitudinal mode shapes along with respective frequencies have taken to understand the behavior of existing bellow.

The given table enlists longitudinal models with the frequency values –

Table 2 - First Four Longitudinal Modes

Sr. No.	Overall Mode No.	Longitudinal Mode No.	Frequency (Hz)
1.	Mode 1	Mode 1	865.568
2.	Mode 4	Mode 2	1732.60
3.	Mode 7	Mode 3	2602.73
4.	Mode 10	Mode 4	3477.79

A. Proposed Parametric Models

The proposed models are based on following variational parameters –

1) *Case 1:* Keeping Same Overall Length (L) & by varying Convolution Pitch (P)
   - *a)* Keeping same overall length, L = 76.80 mm
   - *b)* Pitch Variation: 80% & 60% of the Current Pitch
   - *c)* Number of Convolution: 14 for both

2) *Case 2:* Keeping Same Convolution Pitch (P) & by varying Overall Length (L)
   - *a)* Keeping same convolution Pitch, P = 02.32 mm
   - *b)* Overall Length Variation: 80% & 60% of the Current Length (L)
   - *c)* Number of Convolution: 11 for 80% of current length & 8 for 60% of the current length.

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VI. RESULT DISCUSSION

The result table enlisted the values of the Longitudinal Modes for both the cases. Further these values are represented on graphical scales as well in order to understand the behavior of the metallic bellow for various parametric changes.

Table 3 - Proposed Models' Results

METALLIC BELLOW (CASE I & II)						
Sr. No	Longitudinal Modes	For 100% Length, L = 63.8 mm	Same Thread count & Variable Pitch		Same Pitch & Variable Thread Count	
			For 80% Length	For 60% Length	For 80% Length	For 60% Length
1	Mode 1	874.87	865.568	953.89	1185.615	1630.908
2	Mode 2	1753.189	1732.6	1906.21	2364.881	3246.47
3	Mode 3	2638.834	2602.73	2855.66	3532.331	4835.87
4	Mode 4	3535.229	3477.79	3801.4	4684.232	5546.469

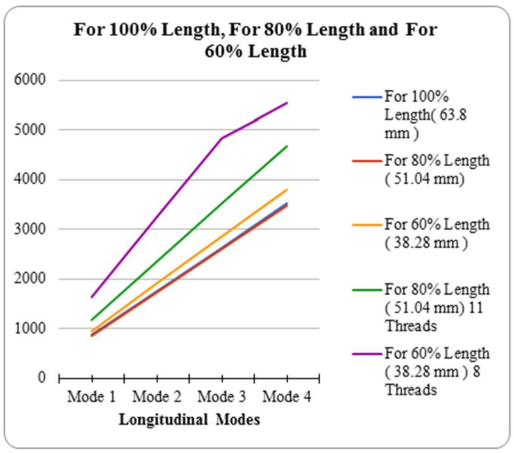

Fig. 1 – Graphical Representation of Results

VII. CONCLUSION

The graphical indication represents that the natural frequency of each proposed model follows the linear relation and these lines don't intersect at any point. One can customize the metallic bellow as per application and the range of natural frequency from the graph suggests the parametric relationship to be used.

VIII. FUTURE SCOPE

In this seminar topic, the Cavity diameter to Metallic Bellow diameter ratio is kept constant and further study can be carried out in future for various ratios of Cavity diameter to Bellow diameter and its effect on natural frequency.

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