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Impact of Modal Frequencies of Cavity on Acoustic Performance for Variational Bellow Diameter (d) to Cavity Diameter (D)

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***Abstract:** Helmholtz Resonator is widely known as the phenomenon of air resonance in the cavity. The intent of this paper is to find out the effects of various geometric parameters of the cavity models. The main objective of this work piece is to investigate the effect of acoustic natural frequency on structural natural frequency for the given cavity model.*
The design of experiment method is chosen to investigate the relation. It was found that variation in the cavity diameter will not much affect the acoustic performance. The noise cancellation signal which consisting of acoustic and structural frequency, their peaks are apart by quite long span, providing vary broad width of the band of frequencies for noise cancellation or attenuation.
Index Terms: Helmholtz Resonator, Acoustic Performance, Cavity Design, Design of Experiment, Normal Modal Analysis, Longitudinal Vibration, Acoustics.

I. INTRODUCTION

The noise is pollution can cause adverse effects on the both mental and physical health of the animals. According to studies, it is observed that the noise pollution is associated with faster cognitive decline. The current need of the industry is to reduce the instrumental noise. There are different ways to control noise depending upon application and the costs associated with it are the major constraints. There are different techniques to control the noise transmission, such as use of barriers, reactive silencers and costlier active noise control devices.

The noise can be effectively reduced by the use of HR. There are versatile usages of the HR in order to mask, reduce or suppress the acoustic pressure inside any defined volume. The main problem associated with HR is that it can attenuate only single one designed frequency. In real life world, the resonant frequencies of the machines will vary according to its operating conditions. In such cases traditional HR becomes ineffective. For instance, if we have designed HR for a specific resonance frequency of blower, then it will only induce one peak to attenuate the noise for that specific frequency only. Further, if there is speed variation in the blower due to load variation, then the conventional HR will not be useful. In order to rectify this limitation associated with classical HR, the new approach was suggested by changing the neck shape in order to reduce the noise in real life applications.

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.

A. The broad objectives of the Study

1) Study of existing Cavity volume to find the structural natural frequency.
2) To find the dominant set of parameters for the cavity volume design by design of experiments.
3) To study and investigate relation between the acoustic resonance frequencies and the structural frequencies of the cavity model design.

During the literature study, it was found that the work implementation of this topic covers a specific direction like “Acoustic Performances or Resonances”, so there is need to study and summaries the interaction of acoustic and structural performances. The proposed work of this paper discusses about relation between the structural natural frequencies of cavity frame and acoustic natural frequencies of cavity. This will be helpful understand the required cancellation frequency signal to attenuate the noise.

The scope of this paper is limited to the variable Cavity to Bellow Diameter (D/d ratios) under different conditions mentioned below:

a) Keeping “d” Constant and varying “D”
b) Keeping “D” Constant and varying “d”

II. LITERATURE

Helmholtz resonator consists of different parameters on which noise attenuation phenomenon can be tested. Cavity Volume design is an essential part of this study, also considered while designing Helmholtz resonator.

Akira S. et al.; [1] discusses the method in which he had proposed two-degree-of-freedom HR, to enhance the effect of the sound absorber which can enable the HR to work in wide frequency range. In its arrangement, the resonator is fixed with the panel in the cavity region, so whenever the sound wave will incident on this panel will vibrate and resonator acting as 2-dof system. Further the respective arrangement is done in order to spit the resonant frequency peak into two.

Chenzhi Cai et al. [2] In this paper the focus is given on the improvement of overall acoustic performance by increasing noise attenuation of HR operating at low frequencies where the space is constraint. The suggestions related to shape have been proposed to study and analyze the acoustic performance.

The spiral neck and extended neck were proposed instead of conventional neck of HR. In the overall process the performance was studied by theoretical and numerical approach. The respective changes have been carried out by converting it to one dimensional approach by introducing equivalent straight neck. There is reasonable accuracy in the results by theoretical and numerical analysis method.

Final, outcome of this experiment suggests that resonance frequency of HR system by increasing extended or spiral neck length and without changing cavity volume.

Mohammad Kurdi et al. [3] describe a simulation based design process which is capable of producing a small volume HR which can provide the higher value of transmission loss across a specific range of frequencies. The design of HR with the flexible plate at the end was achieved by multi-objective optimization formulation. Pareto curve was referred to quantify the tradeoff between the objectives of the optimization. Finally, gradient based approach was used to get optimum design solution.

M.B. Xu et al. [4] presented dual-HR.

The construction of such dual HR consists of two back to back HR connected in series. The arrangement is such that cylindrical shape neck and cavity volume are connected to another neck and cavity volume of the HR. The respective attempt was made in order to improve the performance related to attenuation of sound.

An attempt was made in order to form a relationship between resonance frequency range and transmission loss of this 2 dof by following lumped mass approach. Post 2D analytical approach, experimentation and simulation by BEM methods shows an acceptable agreement.

The effects of constituents of HR like neck and cavity volume have been studied; the resonance frequency can be decreased by following parameters (a) increasing the overall cavity volume (b) increasing neck length (c) decreasing neck radius, whereas the changes shape changes in second cavity volume remains infinitesimal. It has been observed that multiple solution paths can be achieved for the same acoustic performance

Amit Panchwadkar et al. [5] paper implements HR principle for the reduction of noise along the transmission path. The resonator frequency range can be determined by the by using design parameters. The paper explains the use of metallic bellow acts like the inertial mass in the HR setup.

The transmission loss was found by the metallic bellow in combination with resonator. Similarly, the FFT in combination with microphone yielded to find the operating frequency. Further the acoustic behavior of metallic bellow was studied by the numerical analysis of bellow and the resonator with help of earlier calculated operating frequency. The paper concludes that there is scope for parametric variations in the dimensions and modifications in the shapes to get the desired acoustic performance.

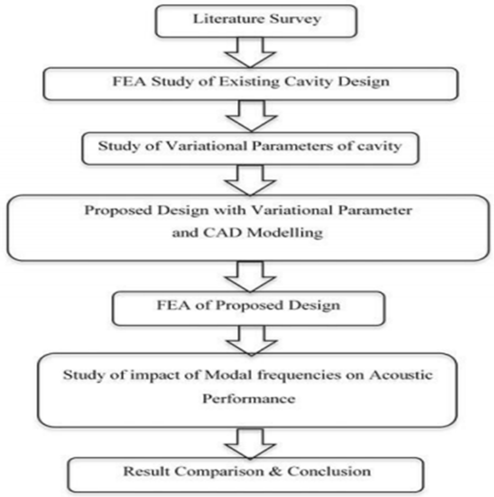
A. Literature Summary

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) The Classical HR principle can be implemented by using Newton's Second law to give single resonance frequency and a corresponding attenuation peak. This method is available for single dof system.
2) Extended neck cavity models can be used to reduce the resonance frequency instead of increasing volume.
3) The geometric modifications like extended neck length and overall shape can be one of the effective methods to control resonance frequency of HR for the same cavity volume.
4) Dimension and shape modifications can be implemented to get the desired acoustic performance of the bellow & system.

III. METHODOLOGY

The respective block outlines the work in the respective stages:



IV. ACOUSTIC NATURAL FREQUENCY OF CAVITY

The acoustic natural frequency of the Cavity is the HR is determined by the simple formula illustrated below:

$$f = \frac{C}{2\Pi}\sqrt{\frac{S}{VL}}$$

The above equation can be simplified for the ease of the calculation:

$$f = \frac{C}{2\Pi}\sqrt{\frac{\Pi r^2}{\Pi R^2 Ll}}$$

$$f = \frac{C}{2\Pi}\sqrt{\frac{r^2}{R^2 Ll}} \ldots\ldots\ldots\ldots\ldots 1$$

Where,

C = Speed of the sound, (m/sec)
S = Neck cross Section area, (m^2)
L = Cavity Length, (m)
l = Neck Length, (m)
V = Volume of the Cavity, (m^3)

A. Existing Cavity Volume CAD Model

The dimensional study of the existing model is conducted in order to form 3D model. The measurements were taken from the original (existing) model by using various metrological instruments. The prime dimensions which were required for modeling 3D CAD model are cavity diameter, bellow neck diameter, length of cavity, length of the neck & thickness.

Table 1 – Cavity Dimensions

Sr. No.	Cavity Parameters	Dimensions
1	Cavity Diameter (D)	114 mm
2	Cavity Length (L)	36 mm
3	Neck Diameter (d)	36 mm
4	Nek Length (l)	28 mm
5	Overall Modal Thickness (t)	1.25 mm

Acoustic frequency values of various Cavity Models are enlisted below in the Table 2 referring the formulation of the Equation 1 and Table 1 respectively.

Table 2: Acoustic Frequency of the Cavity Models

Acoustic Frequency of the Cavity Models			
Sr. No.	Parametric Variational Cases		Acoustic Frequency, (Hz)
1	For 100% Dimension, (D=114mm,d=36mm)		522.397
2	Case 1 - Keeping "D" Constant & Varying "d"	10% decrease in "d"	470.158
		20% decrease in "d"	417.918
		30% decrease in "d"	365.678
		30% increase in "d"	679.117
3	Case 2 - Keeping "d" Constant & Varying "D"	10% decrease in "D"	580.442
		20% decrease in "D"	652.997
		30% decrease in "D"	746.282
		30% increase in "D"	401.844

V. NUMERICAL ANALYSIS

A. Model Building Activity

The model building activity is done by the market leading pre-processor. Model building activity is followed by quality checks which include 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.

1) *Element Type* – Quad4 Shell Element
2) *Element Size* – 2 mm

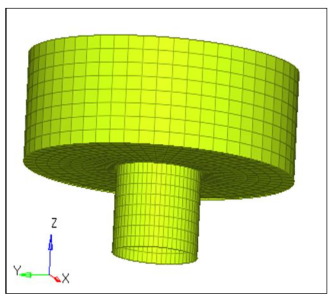


Fig. 1 – Meshed Model of the Cavity Model

B. Material

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

VI. SIMULATION APPROACH (OFFSET BARRIER)

Normal Modal Analysis (NMA) is carried out of the existing Cavity volume cover 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 3 - First Three Longitudinal Modes

Sr. No.	Longitudinal Mode No.	Frequency (Hz)
1.	Mode 1	332.084
2.	Mode 2	1000.501
3.	Mode 3	3494.145

A. *Proposed Parametric Models*

The proposed models are based on following Variational parameters –

1) *Case 1:* Keeping Cavity diameter (D) constant & Varying Neck diameter (d)
   a) Keeping Cavity Diameter Constant, D = 114 mm
   b) Varying Neck Diameter, by 10%, 20% & 30% of the original dimension.

2) *Case 2:* Keeping Neck Dia. (d) constant & Varying Cavity diameter (D)
   a) Keeping Neck Diameter Constant, d = 36 mm
   b) Varying Cavity Diameter, by 10%, 20% & 30% of the original dimension.

VII. RESULT DISCUSSION

The result table enlists 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 cavity volume for various parametric changes.

Table 4 - Proposed Design Result: Cavity Modeling Case 1

Sr. No	Longitudinal Modes, (Hz)	For original Dimension 100% Dim. (D=114mm, d=36mm)	Keeping "D=Const" & Varying "d"			
			10% Decrease in "d"	20% Decrease in "d"	30% Decrease in "d"	30% Increase in "d"
1	Mode 1	332.084	450.6336	605.892	865.781	431.64
2	Mode 2	1006.501	1235.453	1548.22	2003.97	1026.7
3	Mode 3	3494.114	4384.692	5541.93	7176.01	3988

Table 5 - Proposed Design Result: Cavity Modeling Case 2

Sr. No	Longitudinal Modes, (Hz)	For original Dimension 100% Dim. (D=114mm,	Keeping "d=Const" & Varying "D"			
			10% Decrease in "d"	20% Decrease in "d"	30% Decrease in "d"	30% Increase in "d"
1	Mode 1	332.084	450.6336	605.892	865.781	431.64
2	Mode 2	1006.501	1235.453	1548.22	2003.97	1026.7
3	Mode 3	3494.114	4384.692	5541.93	7176.01	3988

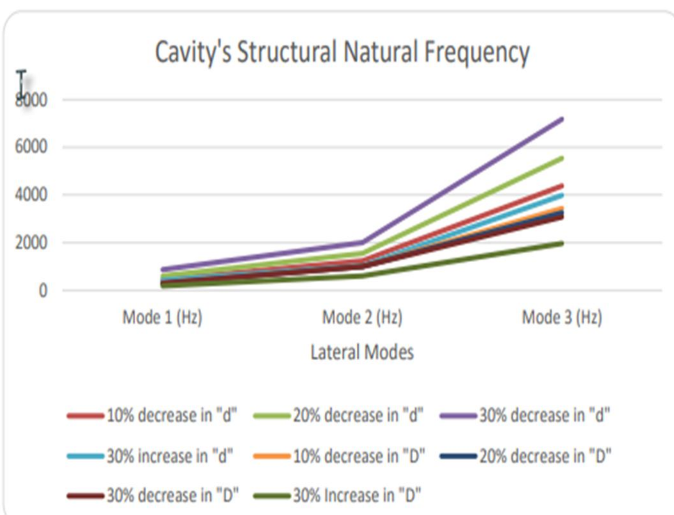


Fig. 2 – Graphical Representation of Results

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Table 6 – Acoustic and Structural Frequency Comparison Study of Cavity Models

Acoustic and Structural frequency Comparison		
Origimal Model	Acoustic Mode, (Hz)	Structural Modes, (Hz)
	522.397	332.084
Case 1 - Keeping "D" & Varying "d"		
10% Reduction in"d"	470.158	450.633
20% Reduction in"d"	417.918	605.89
30% Reduction in"d"	365.678	865.781
30% Increase in"d"	679.117	431.638
Case 2 - Keeping "d" & Varying "D"		
10% Reduction in"D"	580.442	326.904
20% Reduction in"D"	652.997	306.97
30% Reduction in"D"	746.282	288.846
30% Increase in"D"	401.884	190.417

VIII. CONCLUSION

The graphical indication states that the structural natural frequencies of the proposed cavity models are influenced by the variation in the neck diameter, for the cavity diameter its frequency band is narrow, so in order to attenuate a certain frequency signal any of the combination will serve the purpose.

Post comparison of the acoustic and structural frequencies, it has been found that the values of the frequencies are apart with quite huge margin indicating that in the noise cancellation signal there will be two different peaks which are separated by quite long span. It represents that the resultant signal can attenuate the noise with certain range of cancellation.

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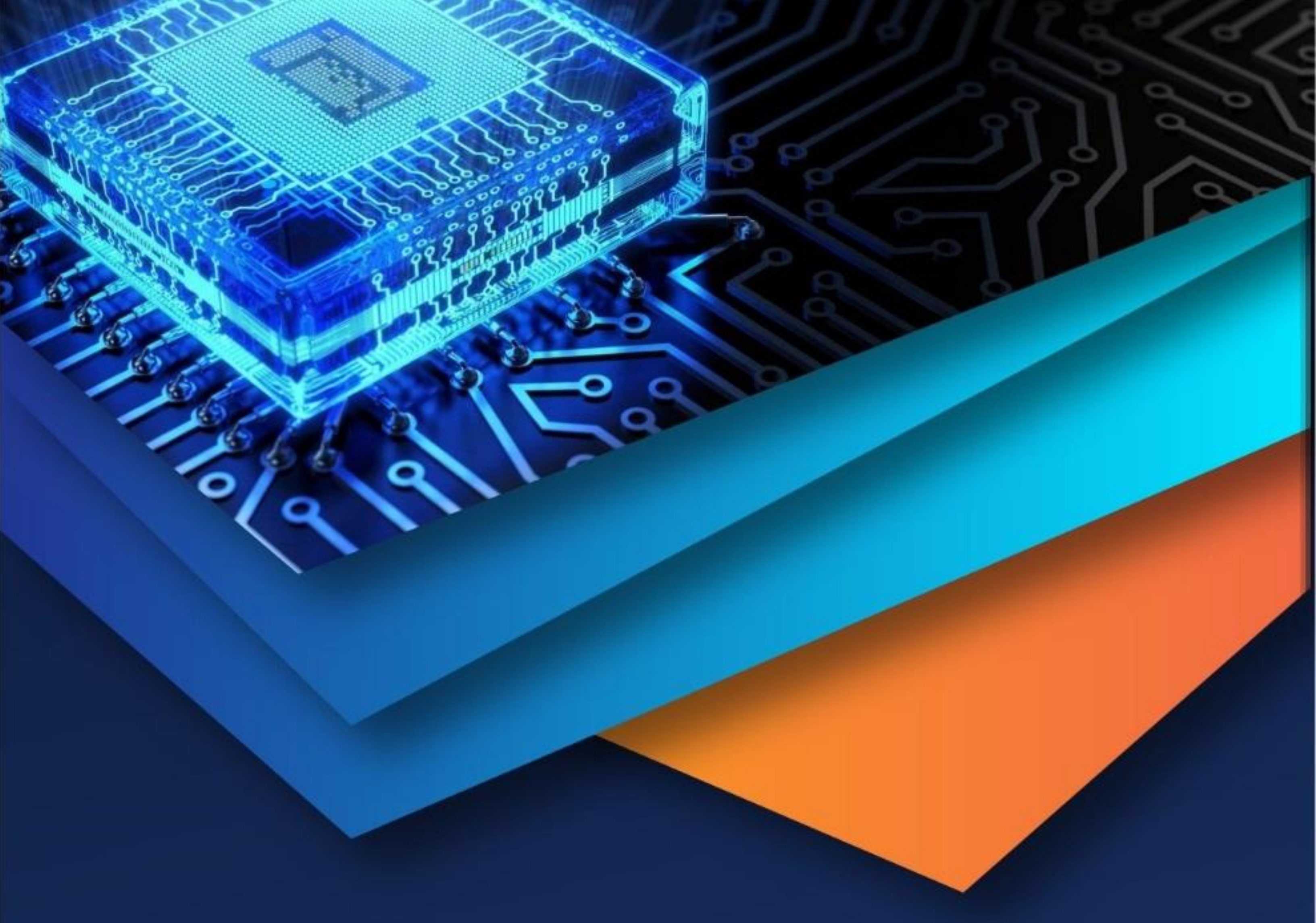

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