Experimental and Numerical analysis of Metallic bellow for acoustic performance

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***Abstract*—Noise will concern about the work environment of industry.Machinery environment has overall noise which interrupts communication between the workers. This problem of miscommunication and health hazard will make sense to go for noise attenuation.Modification in machine setup may affect the performance of it. Instead of that, Helmholtz resonator principle will be a better option for noise reduction along the transmission path. Resonator has design variables which gives resonating frequency will help us to confirm the frequency range. This paper deals with metallic bellow which behaves likeinertial mass under incidentsound wave. Sound wave energy is affected by hard boundary condition of resonator and bellow. Metallic bellow is used in combination with resonator to find out Transmission loss (TL). Microphone attachment with FFT analyzer will give the frequency range for numerical analysis. Numerical analysis of bellow and resonator is carried out to summarize the acoustic behaviour of bellow. Bellow can be numerically analyzed to check noise attenuation criteria for centrifugal blower.An impedance tube measurement technique is performed to validate the numerical results for assembly. Dimensional and shape modification can be done to get the acoustic performance of bellow.**

Keywords—Noise attenuation, Metallic Bellow, Helmholtz resonator, white noise

I. INTRODUCTION

Noise is an unwanted sound; unpleasant to hear mayalso damage the environment. Many industries have pronounced effect on human health like hearing loss, change in heart and respiration rate.Noisy environment in industry has to become healthy one by controlling the overall noise. Noise control can be achieved by including aspects like type of application and cost constraints. Several techniques have been used for noise attenuation like installation of reactive silencers and use of passive noise control devices. Helmholtz resonator is the effective way of noise reduction, works on principle of resonator frequency. Classical HR can attenuate only single designed resonator frequency noise. Real applications involvemultiple resonator frequencies may varies with speed.Frequency span will be another approach to study acoustic behaviour of resonator.Type of application can decide frequency span for which modification in resonator will be done. Modification in resonator may give better solution to overcomethe problem.

This paper will include noise reduction achieved byresponse of bellow. Bellow response will include acoustic parameter responsible for noise attenuation.Transmission loss (TL) and Sound Pressure Level(SPL) have major effect on acoustic behaviour of resonator. Same acoustic parameter will be considered for bellow performance. Bellow performance will be done with consideration of frequency range.A noise attenuation criterion for bellow will become novel approach of research includes numerical and experimental analysis. Helmholtz resonator and bellow have schematic diagram shown in fig.1.

II. LITERATURE REVIEW

Helmholtz resonator and bellow have a different acoustic characteristicmay depend upon design variables of individual.

A. Overview

S. Nudehi et. al.[1] have discussed about the modification in resonatorin order to get multiple resonant frequencies. They developed the resonator which contains flexible plate at the cavity end. They have performed analytical calculation using receptance coupling approach. The researchers were used LABVIEW software to excite the speaker through an amplifier which simplifies the data collection from microphone. Experimental measurement was done by them to obtain the receptance of the resonator and assembly. Validation result would give the good agreement useful to confirm the resonator parameters.D. Yang et. al.[2] have considered about the sound absorption materials filled inside the neck. They proposed a sound absorption model in which incident sound wave propagates partly by reflection and transmission, whereas remaining sound wave immersed into the resonator. The sound absorption model was based on mass conservation equation which contains neck impedance and characteristic impedance. Whereas, the theoretical model may predict the neck impedance with consideration of nonlinear resistance offered by neck near resonance frequency.H. Kurdi[3]would describe the process to design a small volume resonator correspond to get high transmission loss.In this paper, the multiobjectiveoptimization problem formulated with weight function, which simplifies the design process as a single objective problem. On the same basis second objective was formulated as a constraint. The method was calculated the Pareto set with solutions known as ε-constraint method.M. Munjal and J.Vinay [4] were discussed the acoustic performance of conical shaped bellow. The performance of bellow was evaluated on basis plane wave propagation.The paper introduced a transfer matrix method for bellowusing successive multiplication of expanding and contraction portions. The researchers weresubstituted a rigid conical chamber with an equivalent expansion chamber. On a basis of that they discussed the effect of slope parameters on transmission loss of bellow.

B. *Outcome*

Flexible end plate assembly would give higher transmission loss than Unmodified Helmholtz resonator.Multiple frequencies can be attenuated using flexible end plate in combination with Helmholtz resonator. Nonlinear effect near resonant frequency will be more dominant with increase in perforation diameter at neck portion. The fundamental characteristics of sound absorbing material may broaden the frequency range with variation in perforation diameter. Multiobjective optimization process was considered to comparethe two objectives to get increased transmission loss. In this process, Optimization formulation was solved using gradient-based search method.

C. *Bridging gap between literature and paper*

The paper will include acoustic performance of bellow, which contains unique part of study. Bellow performance can be studied for different types of application. Noise reduction using bellow will be the new area of research work.

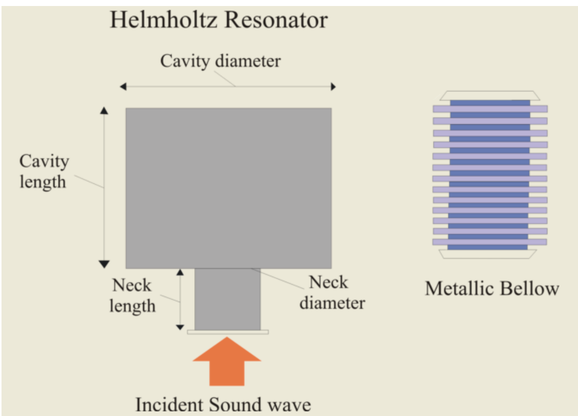


Fig.1 Schematic Diagram of Resonator and bellow

III. ANALYTICAL DESIGN

Metallic bellow has expansion and contraction portion which have significant effect on transmission loss. When bellow is attached below the resonator then it will act as extended neck of the resonator.Bellow has dependency on neck dimension which is decided from resonator frequency. Resonator frequency has beenrepresented in terms of neck lengthgiven as below.[5]

$$f_H = \frac{c_{air}}{2\pi}\sqrt{An/(Vc * l_{neck})} \quad \text{(I)}$$

Where,

f_H - Resonator frequency

c_{air}- Speed of sound in air

An - Neck area

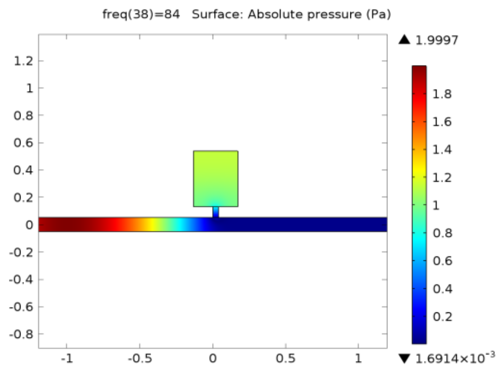
Vc - Cavity volume

l_{neck}- Neck length

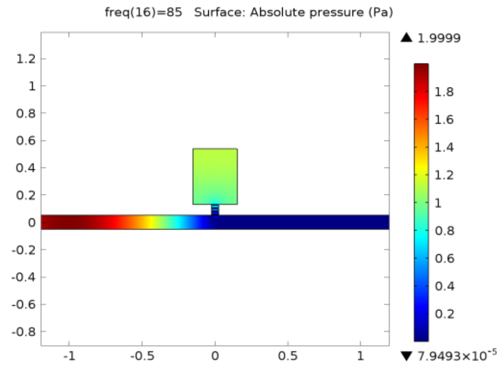
Bellow has different shapes with slope parameters which affects the transmission loss. Transmission loss is acoustic parameter required to getreduced noise level.Blower is subjected to forced passage of air responsible for noise generation. Centrifugal blower is working in frequency range of 140-600Hz. This frequency value will give the neck dimension using equation (I), designed for noise attenuation.

IV. NUMERICAL ANALYSIS

Helmholtz resonator and bellow are numerically analyzed to have upper hand in determination of acoustic performance. The analysis is based on propagation of pressure waves uses Helmholtz equation. Outer boundaries are acting as hard wall boundary condition during simulation. This condition is applied to achieve the resonance phenomena during wave propagation. The numerical analysis was done to get comparison between unmodified resonator and modified resonator. Modified resonator containsneck, designed with variable cross-sections like bellow coupled below the resonator. This numerical analysis is done on two-dimensional geometry represented in following figures.



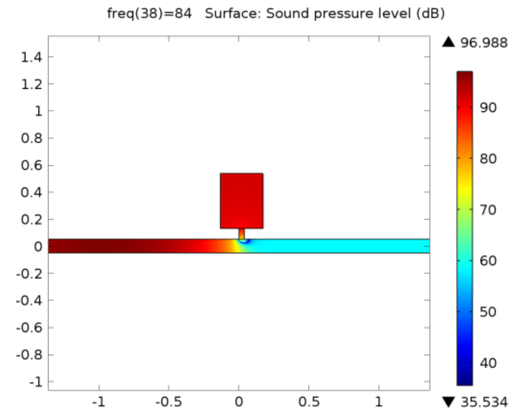
(a)



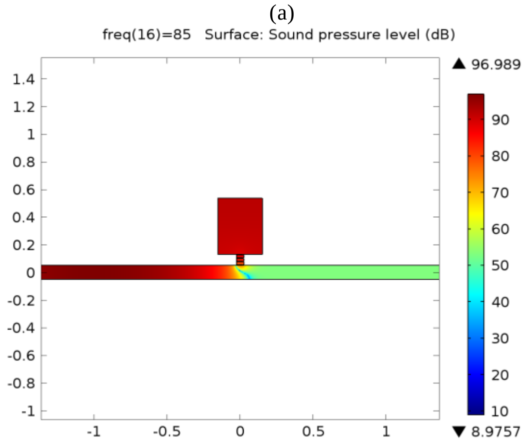
(b)

Fig.2 Acoustic pressure response of resonator
(a) without bellow (b) with bellow

The fig. 2 shows that, Acoustic pressure is more for modified resonator than the unmodified one.This will conclude that modified resonator isapplicable for higher acoustic pressure.



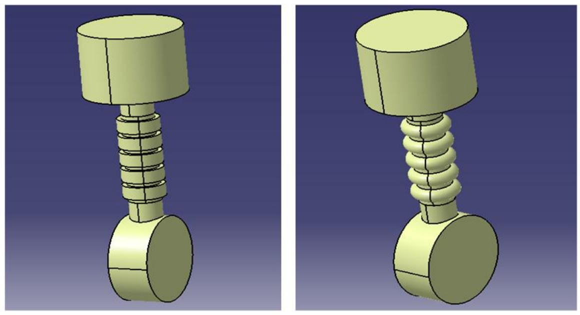
(a)



(b)

Fig.3 Sound pressure response level of resonator
(a)without bellow (b) with bellow

Simulation represented in above figure shows the Sound pressure level inside the resonator and duct tube. Modified resonator [case (b)] will shows the more capability of noise reduction evaluatedfrom SPL results. These results will showthat the approach for bellow was correct.Shape of bellow is taken into account to study acoustic performance of it. Resonator is coupled with a bellow was modelled in CATIA represented in fig.4. Meshing of assembly was done by assigning element size as tetrahedral mesh.



Resonator with rectangular bellow Resonator with circular bellow

Fig.4 CAD design of resonator with bellow

Bellow shape has effect on simulation result suggested to go for nonlinear response. To compare this effect, numerical response was performed for those types of bellow. Simulation was done for frequency domain with incident sound wave pressure of 1Pa. Thenormal velocity of wave incidenton outer boundary has zero value. The simulation results are analyzed using boundary condition applied toacoustic wave energy.

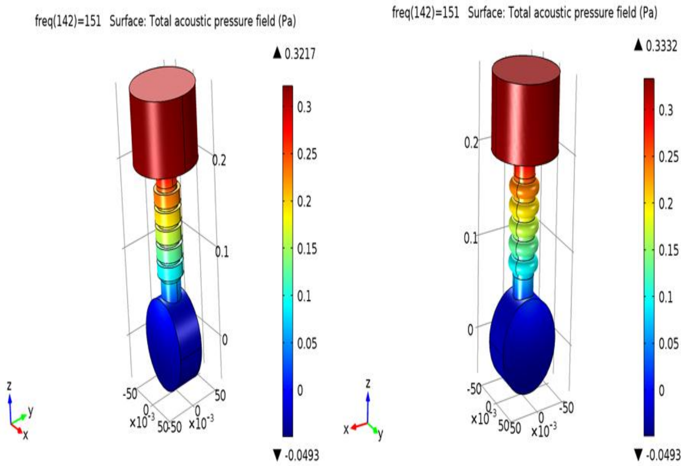


Fig.5Acoustic pressure of rectangular and circular shape bellow

Acoustic pressure value will give the wave energy inside the system at resonance condition.

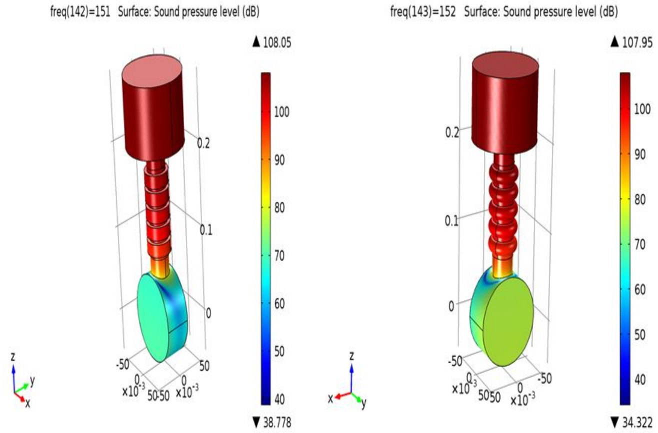
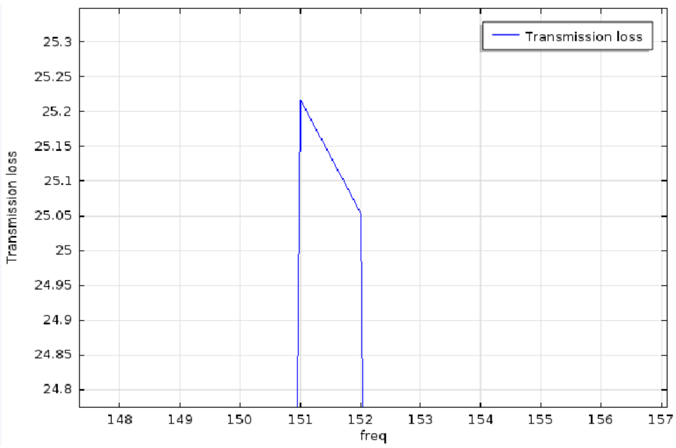
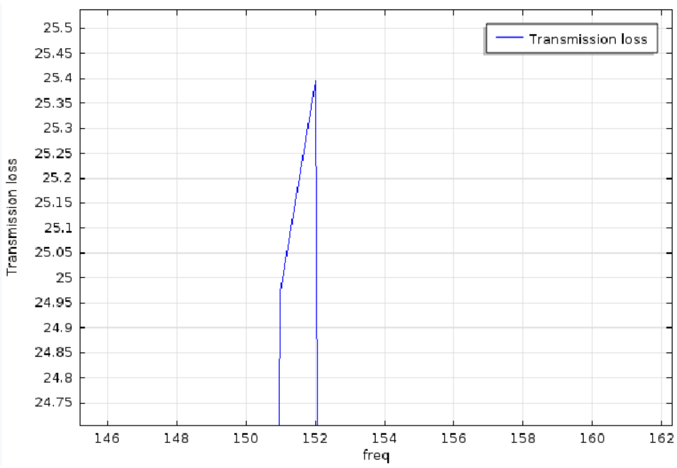


Fig.6 Sound pressure level of rectangular and circular shape bellow

Fig.6 shows the Sound pressure level for rectangular and circular bellow was plotted at resonance frequency of system.Similarly, Acoustic wave energy is useful for finding out the transmission loss which was shown in below figure.



Rectangular bellow



Circular bellow

Fig.7 Transmission loss in case of rectangular and circular shape bellows

Transmission loss (dB) is calculated to get noise attenuation level for the particular setup dependent on surrounding environment.

V. EXPERIMENTAL ANALYSIS

An impedance tube is available to conduct an experiment on it. Experimental setup includes microphone attachment for measurement of wave pressure shown in fig.(8). Sound source is generated from speaker connected at the end of measurement tube. Resonator assembly was installed vertically in between themicrophone attachment. Metallic bellow is mounted on tube to get wave response in frequency domain. To get this frequency-based response of bellow FFT analyzer is used.

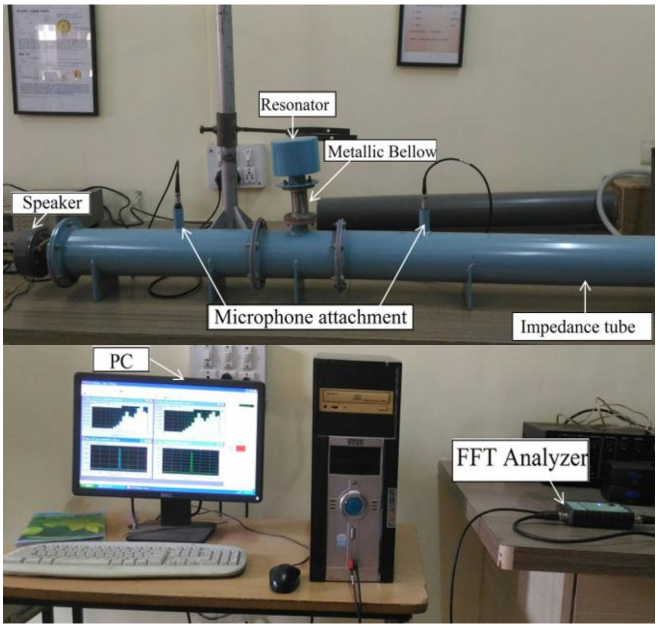
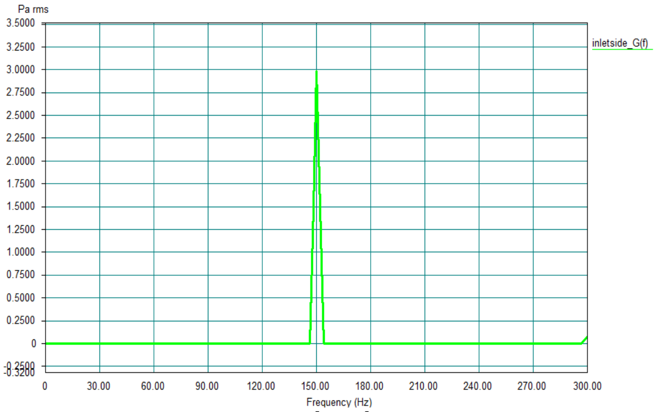
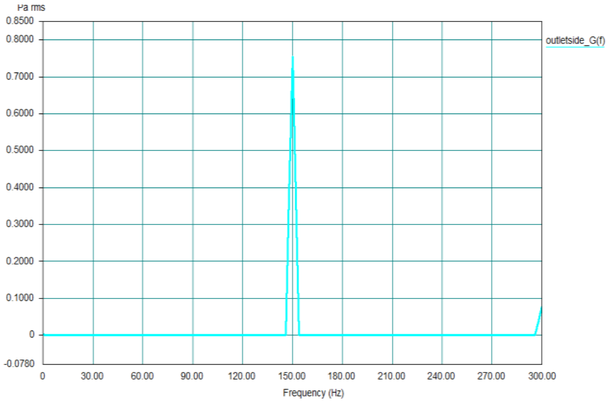


Fig.8 Experimental setup

Signal generation is done by connecting FFT analyzer to the speaker. Swept sine signal is given for measurement of sound wave pressure. Microphone fitted inside the tube also connected to the analyzer for measurement. Experimental results of assembly are shown in following figures.

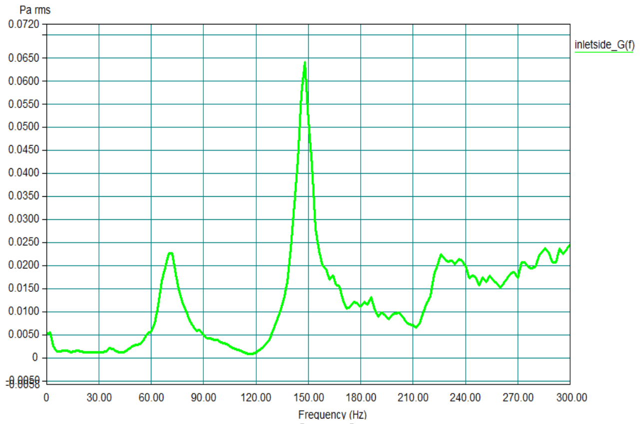


Inlet side

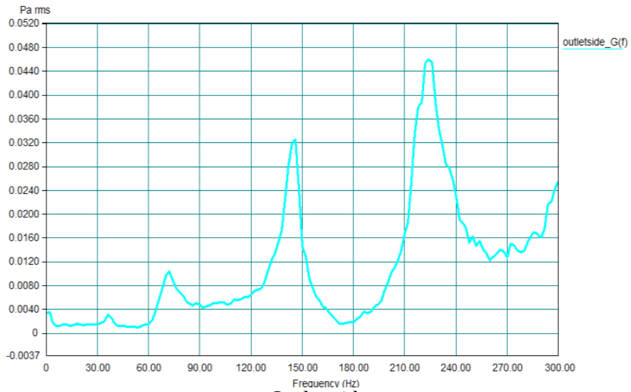


Outlet side

Fig.9 Sound wave pressure at inlet and outlet side for swept sine waveform



Inlet side



Outlet side

Fig.10 Sound wave pressure at inlet and outlet side for white noise

Experimental Measurement on Centrifugal blower:

Measurement of pressure at exhaust section was done to get noise level. Microphone was hold at a distance of 1m from exhaust section.These readings were shown in below figure.

Blade passing frequency (f_b) is calculated from blower specification stated as follows.

- Power-7.5HP
- Air flow- 0.5 m^3/sec
- Speed- 2880rpm
- No. of radial blades-12

$$f_b = \text{No. of blades} * \left(\frac{\text{Revolution per minute}}{60}\right) \quad \text{(II)}$$

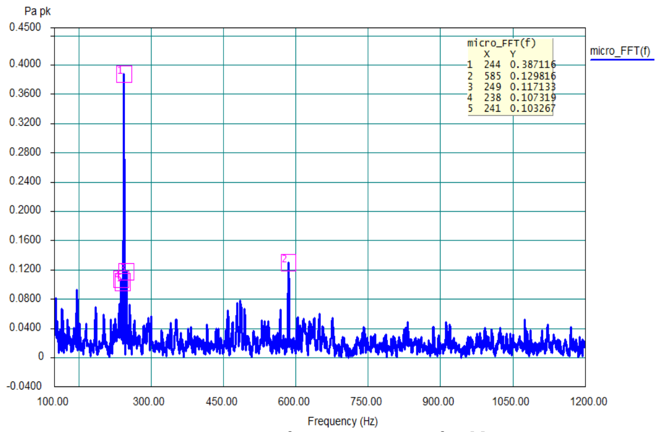


Fig.11 Resonatorfrequency range for blower

Blade passing frequency is calculated from above formula found as 576Hz. Numerical and experimental results are discussed in next section to get Transmission loss in dB.

VI. RESULTS

Acoustic parameters are compared on basis bellow structure at neck with different shapes of bellow. The comparisons of these results are represented in below tables.

TABLE I. ACOUSTIC PERFORMANCE OF MODIFIED AND UNMODIFIED RESONATOR

Type of resonator	Absolute(surface) pressure (Pa)	Sound Pressure Level (dB)
Unmodified resonator	1.997	96.988
Modified resonator	2.0	96.989

TABLE II. ACOUSTIC PERFORMANCE OF RECTANGULAR AND CIRCULAR BELLOW

Type of bellow	Acoustic pressure (Pa)	Sound Pressure Level (dB)	Transmission loss (dB)
Rectangular bellow	0.3217	108.05	25.2
Circular bellow	0.3332	107.95	25.4

Transmission loss has been increased by 16.66% due to insertion of bellow andAcoustic pressure decreases by 16.81% for modified resonator.To study the noise attenuation characteristics Modified resonator is applied.Rectangular bellow creates lesser pressure inside the resonatorwith higher SPL.Less acoustic pressure with more SPL will serve the noise attenuation criteria. Transmission loss of circular bellow is represented with slight change in dB level when compared with rectangular bellow.Table II shows that bellow shape changes the acoustic pressure value by 10%. This discussion will suggest that, rectangular bellow is betterone instead of circular bellow. Experimental results are included the sound wave pressure at inlet and outlet side. Swept sine signal was incident on inlet side enters in resonator assembly would result into decrease in sound wave pressure at outlet side. Resonator assembly was installed on tube reduces the acoustic pressure by 50% for white noise. Numerical and experimental results are evaluated on basis of noise reduction.

VII. CONCLUSION

The present work discusses about the noise attenuation using resonator and bellow. Numerical analysis of bellow was carried out forstudies of acoustic performance.Modified resonator has shown a better numerical solution in comparison with unmodified resonator.Shape modification result shows that Rectangular bellow is suitable for reducing the noise level.

Experimental result was carried out on impedance tube to get pressure variation due to insertion of resonator and bellow.Experimental measurement was done to get a pressure of exhaust air came from blower. Numerical and experimental results are done to get an acoustic performance of bellow.This study will give proper approach about noise attenuation involved in following conclusions.

- Effect of bellow shape and variable neck area are studied numerically in comparison with constant neck.
- Acoustic performance is done to understand the parameters responsible for noise reduction.

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