DESIGN OF HELMHOLTZ RESONATORS IN ONE AND TWO DEGREE OF FREEDOM FOR NOISE ATTENUATION IN PIPELINES

A thesis submitted to the department of Mechanical and Chemical Engineering (MCE), Islamic University of Technology (IUT), in the partial fulfillment of the requirement for the degree of Bachelor of Science in Mechanical Engineering.

PREPARED BY:

ANANTA KULDIP (091417)

HASAN MD. JUBAYER (091430)

Supervised by:

Dr. MD. ZAHID HOSSAIN

Dr. MIR MD. MARUF MORSHED

Department of Mechanical and Chemical Engineering

Islamic University of Technology

Organization of Islamic Cooperation (OIC)

Declaration

This is to certify that the work presented in this thesis is an outcome of the experiment and research carried out by the authors under the supervision of Dr. Zahid Hossain and Dr. Mir Md. Maruf Morshed

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Signature of the Candidates

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Ananta Kuldip	Hasan Md. Jubayer
(Author)	(Author)
Date-	Date-

Signature of the Supervisors

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Dr. Md. Zahid Hossain	Dr. Mir Md. Maruf Morshed
(Professor)	(Associate Professor)
Date-	Date-

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Although we tried our best to complete this thesis flawlessly, we seek apology if there is any mistake found in this report.

ABSTRACT

A thorough design methodology of one and two degrees of freedom Helmholtz resonators leading to optimized transmission loss is described and validated in this paper. Numerical simulations of acoustic wave propagation in pipelines fitted with designed resonators have shown great agreement with analytical modeling and experimental tests. The Helmholtz resonator concept has been analyzed in various configurations to evaluate the effect of the size and arrays on the overall noise attenuation performance. Using this method to directly dimension geometry aspects of the resonators followed by numerical computation of the sound pressure levels has shown that considerable sound attenuation could be achieved.

TABLE OF CONTENTS

LIST OF FIGURES

Figure Page

Chapter-1

INTRODUCTION

Excessive noise from compressors is a major concern in industries and refineries. The biggest impact of this noise is the discomfort to the personnel working at the facility as observed in practice. The primary concern is that the noise may drown/ hide the sound of the emergency alarms of the facility. The noise levels in compressors vary over a wide range from 70-120dB. As the compressor operates over its lifetime, the noise and vibration levels expectedly increase. Maintenance is periodic and stopping the operation every time noise levels exceed the desired threshold can be very expensive. Although the DR arrays give appreciable noise reduction since they are machined directly on the diffuser, the challenge lies in the manufacturing and application cost of this solution. The aim of this work is to formulate a design procedure for Helmholtz resonators that will be considered as an add-on device to existing pipelines to further reduce noise levels in a compressor line.

Two levels of noise reduction are usually requested in a compressor line i.e. compressor and pipeline. The first one is at the compressor level as introduced previously and the other one is within the pipelines. In this paper, the focus will be on the design of a fit resonator for pipelines bearing in mind that characteristics of the compressor are known. The objective is then to identify a design method to fit the right resonator in terms of shape and size on the current pipeline connected to a known compressor.

Chapter-2

BACKGROUND

Koopman and Neise (1980, 1982) studied the use of adjustable resonators to dampen the tone produced by blade passage of centrifugal fans. The volume of the Helmholtz resonator was changed by use of a moveable Teflon piston. Their experimental results showed that the amplitude of the tone of the blade passage frequency could be decreased up to 29 dB without generating a negative side effect on the fan frequency. However, no definitive methods were suggested for achieving the optimal condition of sound reduction by variation of the cavity depth.

Selamet, Dickey and Novak (1995) showed that the individual dimensions of a Helmholtz resonator can play a great role in determination of the resonant frequency and the transmission loss characteristics. An increase of the ratio of the length scale of the volume to the diameter decreases the predominant resonant frequency. This phenomenon is similar to the result of using an effective length, which includes a correction length. Experiments show agreement with the analytical expression and numerical simulation.

Tang (2003) investigated the effects of the taper and length of the resonator neck on the characteristics of a Helmholtz resonator. It was reported that an increase of the tapered length leads to improvement of sound reduction, and an increase of the cavity volume results in increased capacity for sound absorption of the Helmholtz resonator. These experiments showed that sound attenuation via the Helmholtz resonator of more than50% could be achieved by changing the length of the tapered neck, compared to the untapered neck. The increase of the resonant frequency is proportional to the tapered length and is decreased by expanding the cavity volume at a fixed slope of the tapered section. In addition, this investigation showed that the resonant frequency is proportional to the slope of the tapered section at constant volume of the Helmholtz resonance chamber.

The previous studies of the Helmholtz resonator have provided fundamental knowledge for the present experiments. Taking into account these investigations, sound reduction via the selected Helmholtz resonator can be pursued. The resonant frequencies of the Helmholtz resonator are evaluated by experiments and an analytical method, while changing the geometrical dimensions of the Helmholtz resonator, including the neck cross-sectional area, the length of the neck, and the magnitude of the volume.

Chapter-3

HELMHOLTZ PRINCIPLE

However in recent years, an add-on solution using the Helmholtz concept has been developed in the form of Helmholtz resonators. A Helmholtz resonator operates on the phenomenon of air resonance in a cavity, the pressure inside a cavity increases when air is forced into it. When the air source is removed, the air pressure inside the cavity flows outwards. This outward air pressure tends to overcompensate due to the inertia of the air in the neck, this causes the pressure inside the cavity lower than the outside letting the air to come back into the cavity. This continues with a decrement in the pressure magnitude every time.

FLOW PROCESS IN HELMHOLTZ RESONATOR

Excitation of a fully-coupled resonance in a Helmholtz resonator involves two principal components, a source, which is the unstable shear flow along the mouth of the cavity; and, a resonator, in the form of a cavity of defined volume terminated by an open neck or orifice, such that resonance in a Helmholtz mode can occur. A schematic of a typical Helmholtz resonator geometry is shown in Fig-

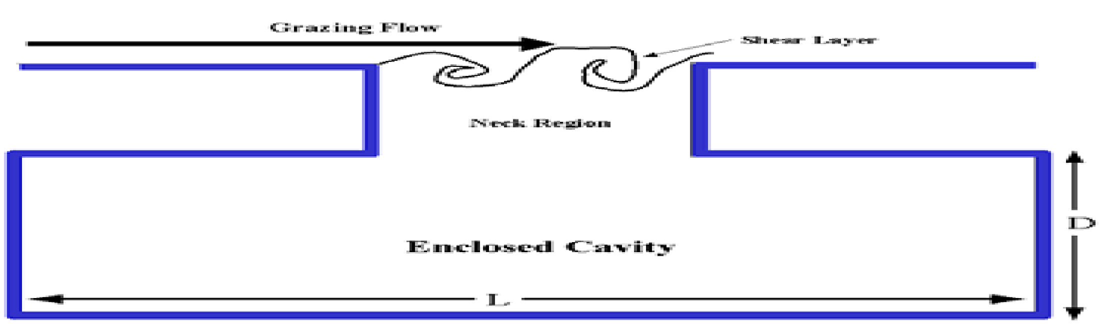


Fig-1: Schematie of helmholtz resonator (one DOF)

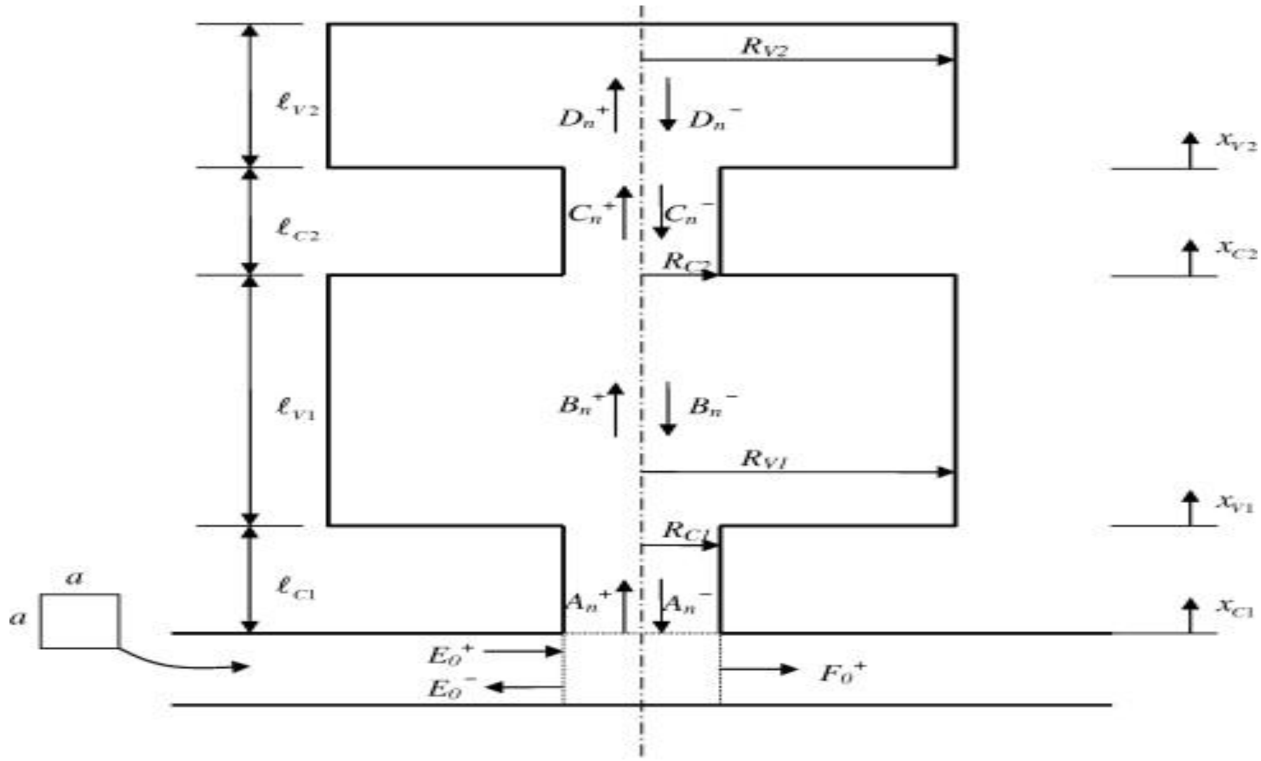


Fig-2: Schematie of helmholtz resonator (two DOF)

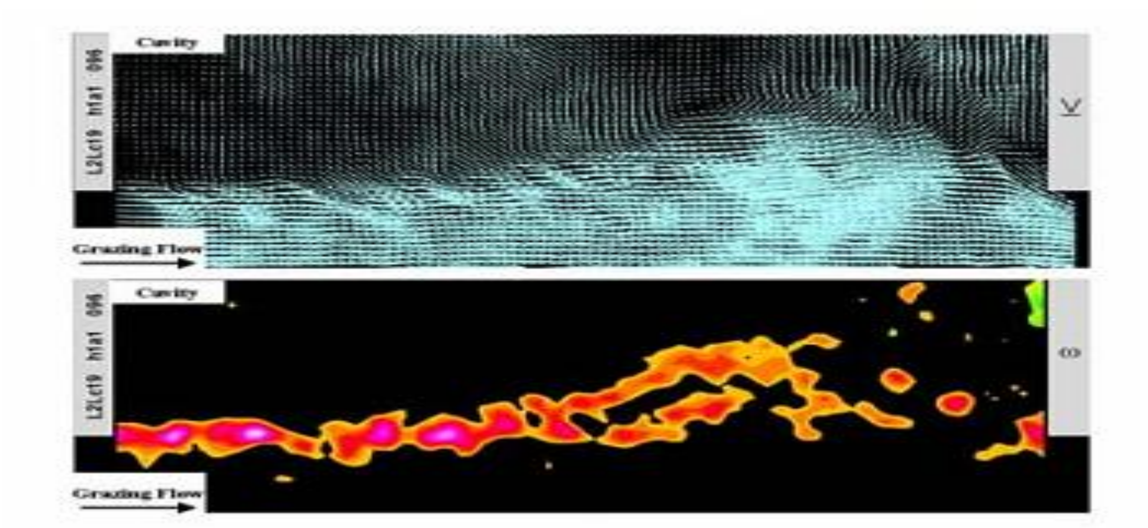


Fig-3: Instantaneous structure of the shear layer along the opening of a deep cavity. Top and bottom images show patterns of velocity and vorticity.

LUMPED ELEMENT MODEL OF THE HELMHOLTZ RESONATOR

The Helmholtz resonator acts as an acoustic filter element. The dynamic behavior of the Helmholtz resonator can be modeled as a lumped system if the dimensions of the Helmholtz resonator are smaller than the acoustic wavelength. The air in the neck is considered as an oscillating mass and the large volume of air is taken as a spring element. Damping appears in the form of radiation losses at the neck ends and viscous losses due to friction of the oscillating air in the neck.

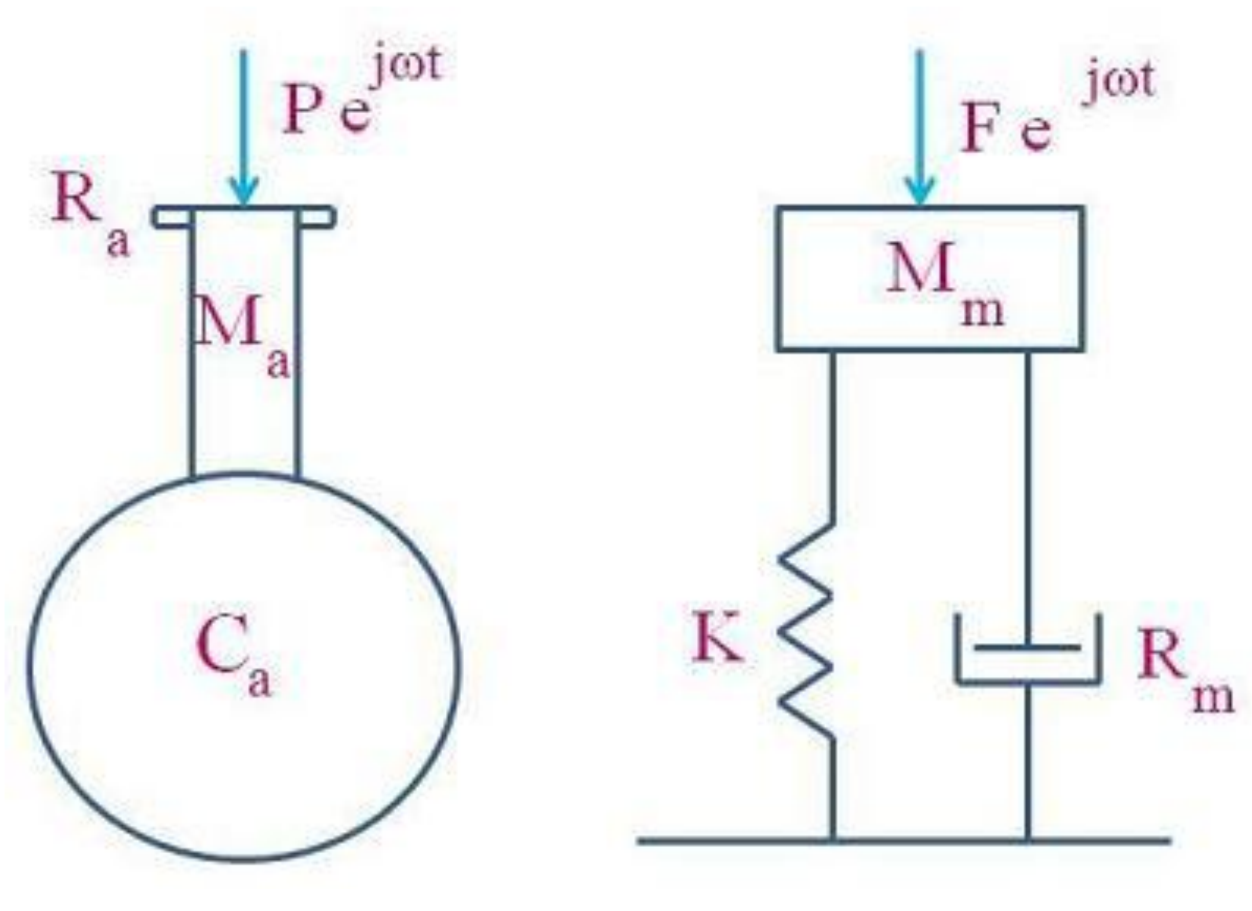


Fig-4: Helmholtz resonator and vibration absorber

Chapter-4

DESIGN OF ONE AND TWO DOF HELMHOLTZ RESONATOR

One degree of freedom Helmholtz resonator:

There are four design parameters corresponding to Ln,Lc,An and Ac that represent the cavity and corrected neck lengths and the cross sections, respectively as shown in figure-

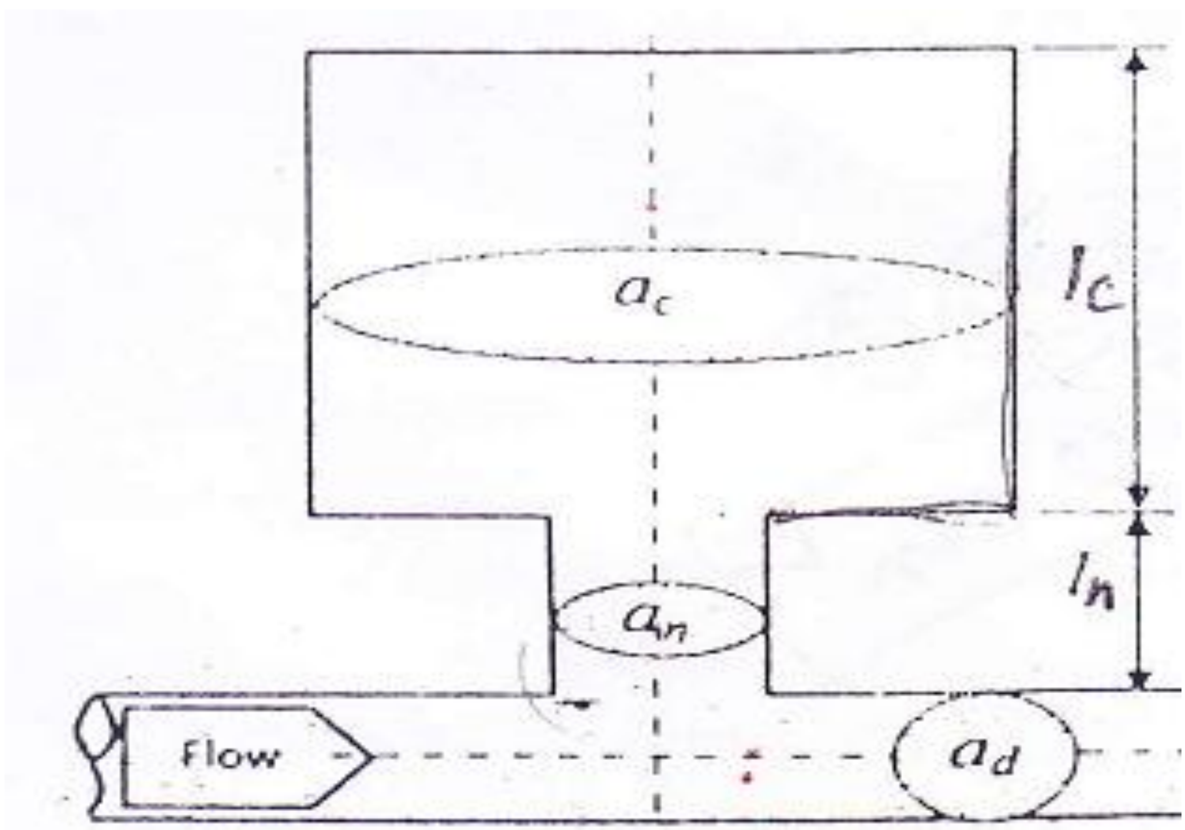


Fig-5: One degree of freedom Helmholtz resonator

The resonating frequency and transmission loss for a one DOF Helmholtz resonator are represented by-

$$f = \frac{c}{2\pi}\sqrt{-\frac{3L_n + L_cA}{2L_n^3} + \sqrt{\left(\frac{3L_n + L_cA}{2L_n^3}\right)^2 + \frac{3A}{L_n^3 L_c}}}$$

$$TL = 10\log_{10}\left[1 + \left(\frac{a_n}{2a_d} \times \frac{(1/A)\tan(kL_c) + \tan(kL_n)}{(1/A)\tan(kL_n) + \tan(kL_c)-1}\right)^2\right]$$

where k is the wave number.

The condition on the frequency is given by the following equation-

$$f < 0.2756\,\frac{c}{L_c}$$

The sections ratio A is given by-

$$A = \frac{a_c}{a_n} = \tan(kL_n).\tan(kL_c)$$

Two degree of freedom Helmholtz resonator:

The transmission loss for a dual Helmholtz resonator can be calculated by-

$$TL = 20\log_{10}\left|1 + \frac{\alpha}{\left[2a_d\left(ik + \frac{\alpha}{ikV_1}\left(1 - \frac{V_2}{V_2 + V_1 - \frac{V_2V_1k^2}{\beta}}\right)\right)\right]}\right|$$

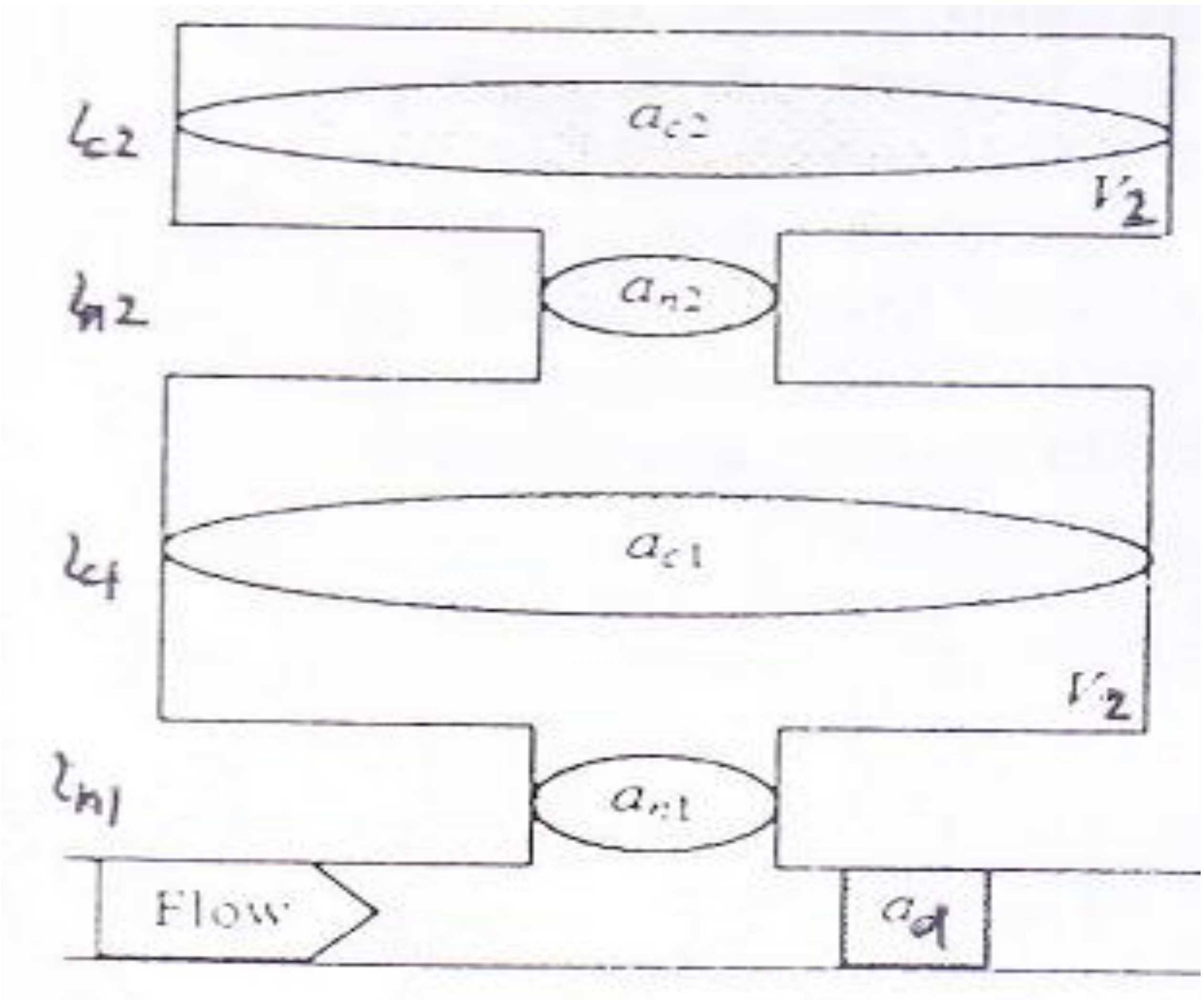
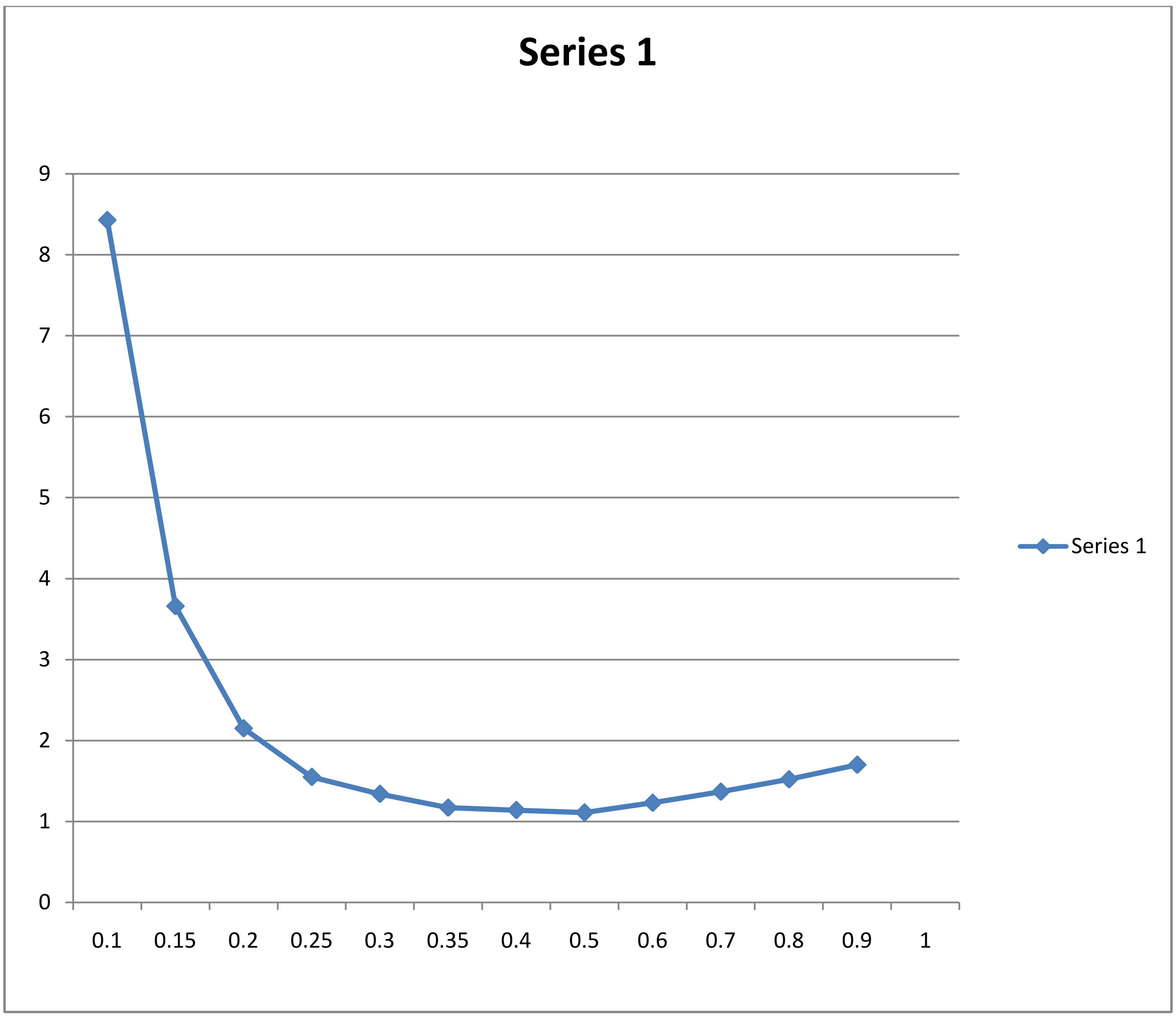


Fig-6: Dual Helmholtz resonator

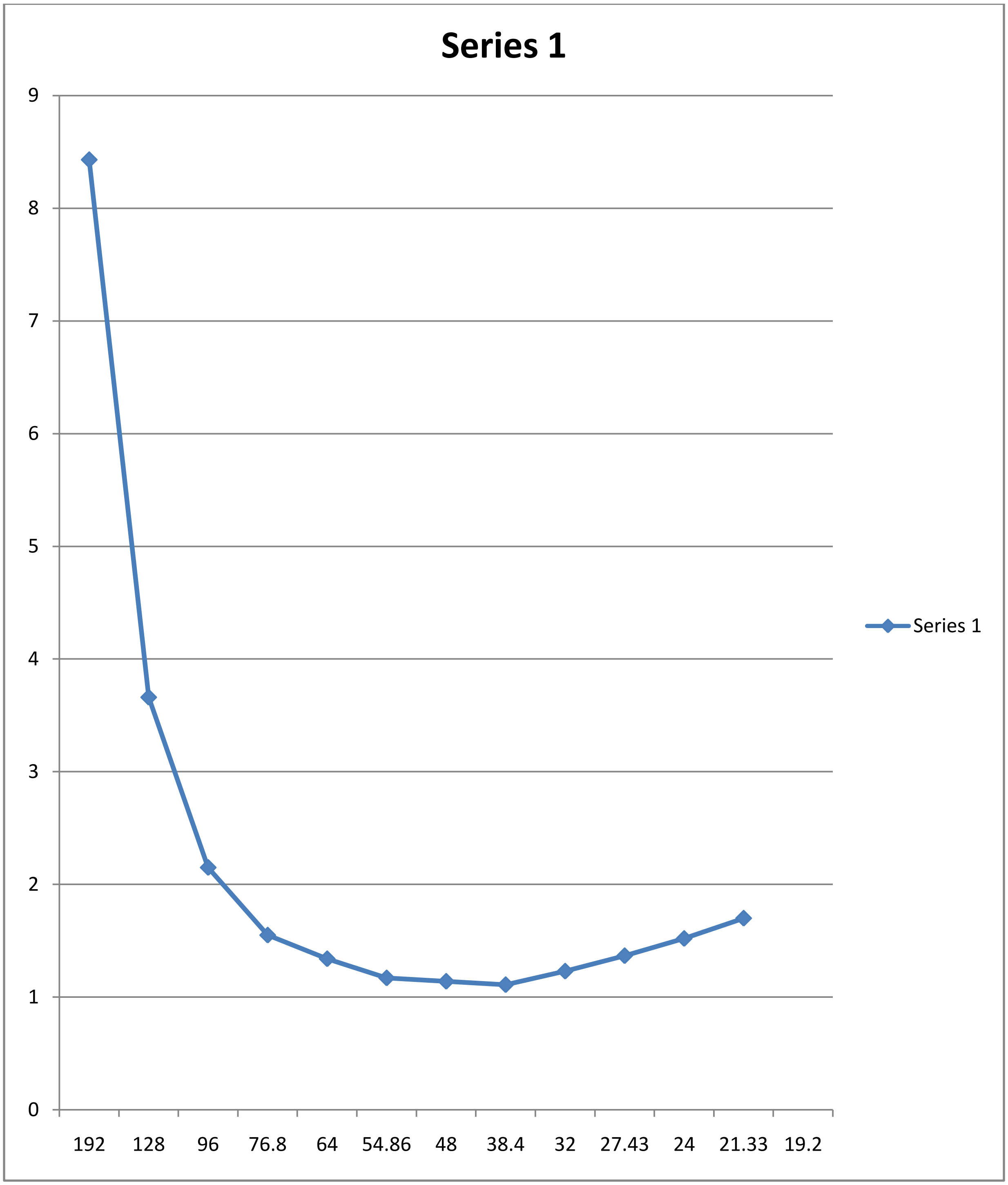
Chapter-5

RESULTS

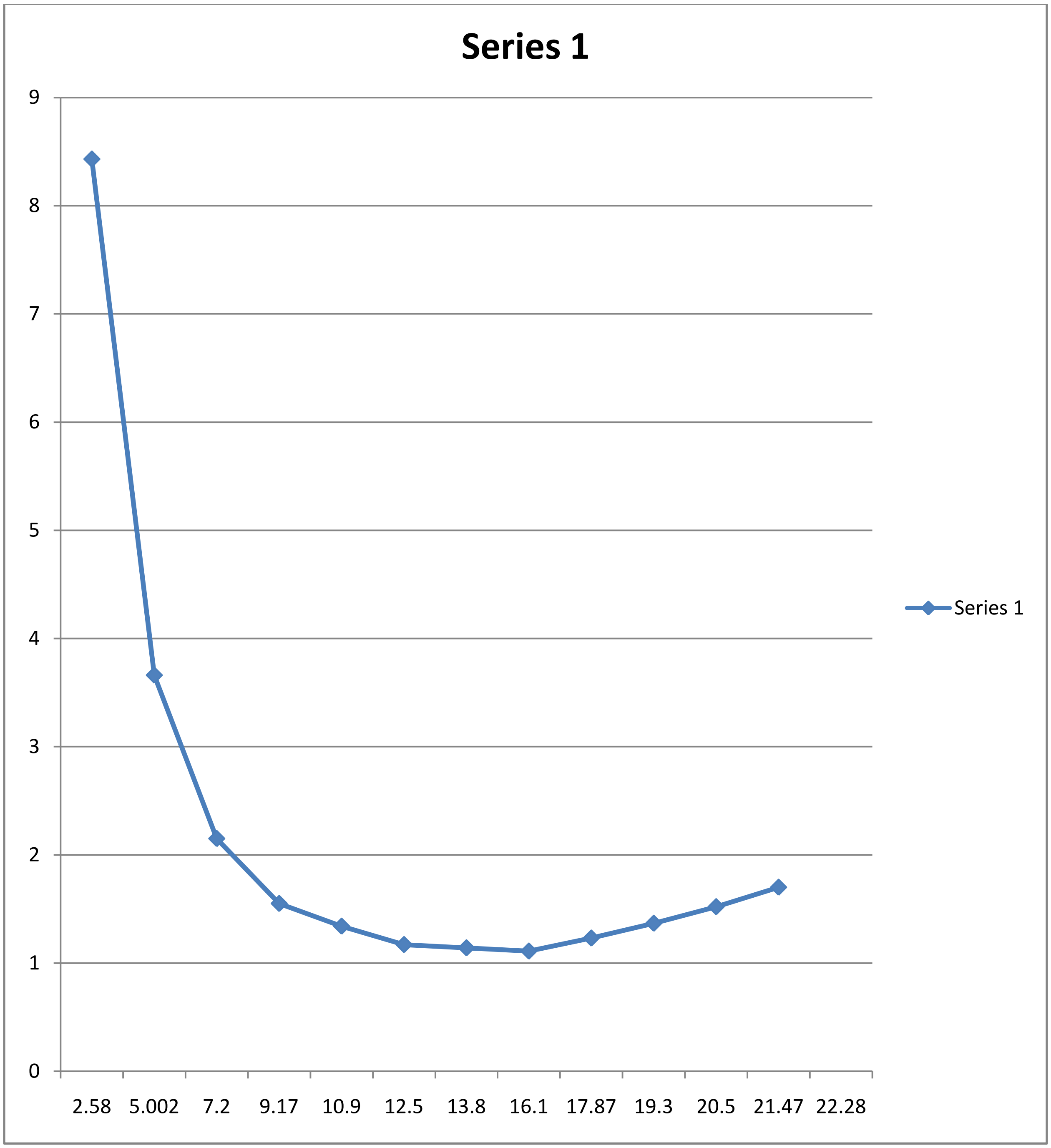
Graph- Transmission loss vs sections ratio (for one DOF):



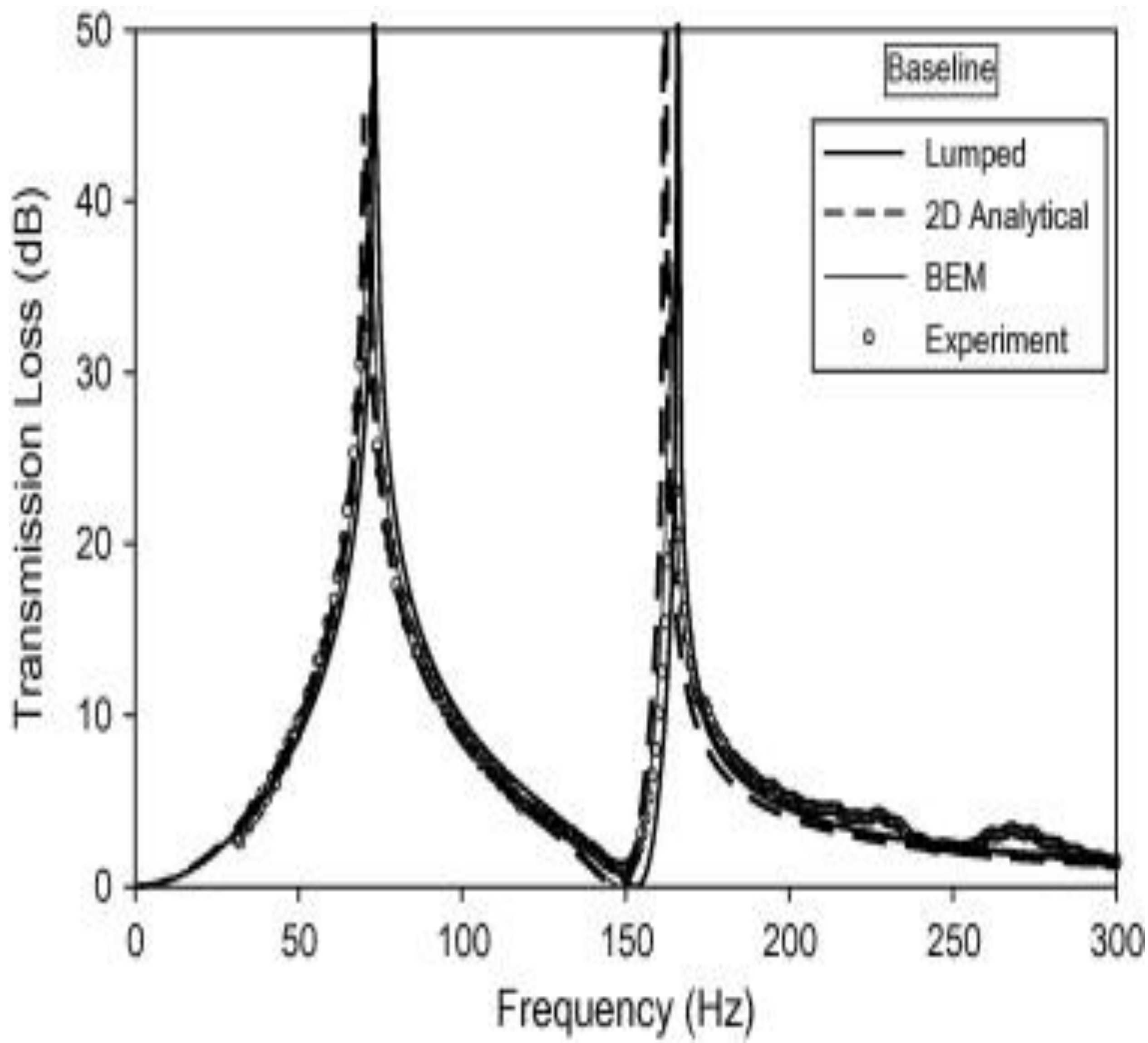
Graph- Transmission loss vs cavity area (for one DOF):



Graph- Transmission loss vs neck length (for one DOF)



Graph- Transmission loss vs frequency (for two DOF):



From the graph we can see that by using a one degree of freedom resonator it is possible to achieve upto 8-10dB transmission loss while a dual resonator will give upto 42-45dB.

Chapter-6

EXPERIMENTAL SETUP

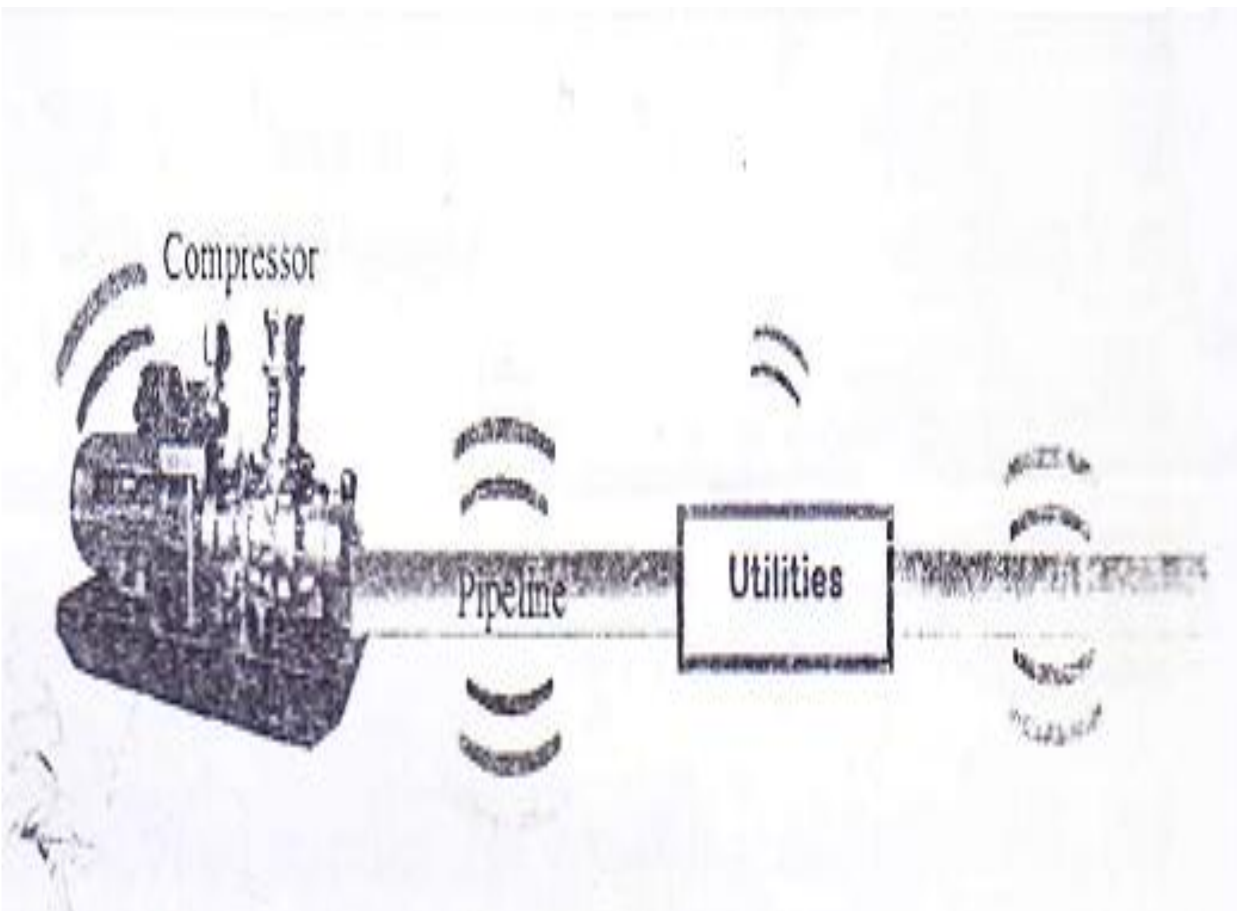


Fig-7: Source of noise reduction in a compressor line

Chapter-7

CONCLUSION

The goals of the present investigation were, first of all, to investigate the resonance characteristics of an isolated Helmholtz resonator, then to attenuate the oscillations in a deep cavity duct, i.e., a side branch, via attachment of the resonator to the wall of the duct.

The volume of the Helmholtz resonator, as well as the geometrical details of its neck and its opening (mouth), influence its resonance characteristics, as determined by spectral analysis of pressure fluctuations within the resonator. These variations can lead to a substantial increase or decrease of the resonant frequency. Furthermore, the theoretically predicted resonant frequencies are compared with those measured experimentally. In doing so, the role of end corrections at the opening (mouth) of the resonator is addressed.

When the resonator is attached to the wall of the deep cavity duct, i.e., side branch, the oscillation of the entire deep duct~ Helmholtz resonator system can be substantially attenuated. The manner in which variations of volume of the resonator influence the degree of attenuation of the various spectral components is characterized. An unexpected observation is a shift of the resonant acoustic mode of the attenuated system to a higher value of frequency, relative to that in the unattenuated system. This aspect deserves further investigation.

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