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Sound Transmission Loss Measurement Accuracy Requirement in Low Frequency Range

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Abstract- **The paper identifies the environmental requirements for accurate sound transmission loss (STL) measurement.STL resultsshow signal fluctuations in low frequency range up to 250 Hz measured in conventional room facility due to high back ground noise. This low signal to noise ratio (SNR) issue is resolved by measuring STL using an anechoic cone in an anechoic chamber where the back ground noise is low. In an anechoic chamber the SNR is equal to 1, this is one of the factors which helps eliminating the uneven spikes in the lower frequency range.The paper also discusses the effects of anechoic cone in STL measurementinstead of absorption spongeused for anechoic termination. The results without fluctuation in lower frequencies are highly helpful for evaluating reactive muffler performance. STL measurements of a reactive muffler and an absorption muffler are discussed. Analytical calculation of STL for a simple concentric chamber and correlation of experimental results from different measurement conditions are illustrated.**

Keywords-- **Anechoic chamber, Anechoic termination, Impedance tube, low frequency noise, Sound transmission loss.**

I. INTRODUCTION

Sound transmission loss (STL) is a fundamental guideline for designing a muffler for an internal combustion engine.STL is defined as the ratio between the incident sound energy entering the muffler to transmitted sound energy exiting the muffler.STL can be measured in various methods, in this paper two load method is used for the study. The four pole parameters are calculated by rigid and anechoic termination for deriving the transfer matrix equation for solving the STL[1] .Z. *Tao and A.F Seybert* [2] made a study on different test methods for measuring sound transmission loss for mufflers , the study shows two load method is one of the best technique for measuring accurate STL .

Automotive exhaust spectrum consists of strong exhaust tones of varying frequencies ranging from 30 Hz to 1000 Hz and above which have to becontrolled using mufflers.

The muffler is designed to control the exhaust noises from low to high frequencies by reflection & absorption methods. STL is used as a tool for designing a muffler. Higher the transmission loss better the performance of the muffler.

Conventionally STL is measured in a normal room with quiet environment for getting good results however the signal to noise ratio (SNR) will be lower due to vibrations, externalnoises; electric noises other environmental noisesetc...Due to these factors large fluctuation are observed in the STL result in the lower frequency range up to 250Hz which are very crucial range for exhaust applications. WhenSTL is measured inside the anechoic chamber the external noises are minimal so it will have reduced influence in the result due to higher SNR value. A anechoic room will not reflect noise to the source since it was perfectly architected with absorption wedges all over the chamber. The chamber is isolated from the ground by means of isolation springs thus making the chamber away from ground contact avoiding the noise entering the chamber through ground. The outer walls are lined with absorption material and constructed in such a way that it was within the chamber base making the whole chamber standing only on the isolation springs. The temperature is perfectly maintained at 22 ° C through air flow .The overall atmospheric noise level of anechoic chamber is less than 20 dB (A). A normal room has external noise influence and unsteady temperature which affects the accuracy of the results.

JianliangLi[3] made an intensive study on STL measurement with four pole parameters for improving the STL performance of acoustic silencer. In this study similar technique is employed for STL measurement.S-H Lee, J-GuonIh[4] made a study on a concentric resonator to find the acoustic and mechanical effects of perforation tubes and patterns, they used microphone array method to find the sound transmission loss performance of the concentric resonator.

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In this paper a simple concentric chamber is used without perforated pipe. Zheng, S. and Kleinfeld, C [5] made a study on STL measurement with different anechoic termination and analyzed the inaccuracy of results with imperfect anechoic termination through two load and source method. An acoustic model of glass wool is studied for constructing the perfect anechoic termination.

II. EXPERIMENTAL SETUP

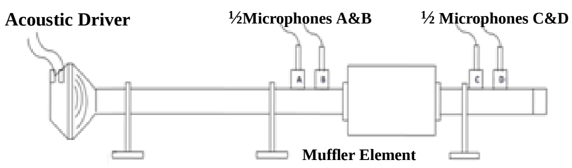

Fig1Schematic diagram- STL test setup

A data acquisition system is connected to the impedance tube setup Fig 1 with four pressure field microphones and a speaker which acts as acoustic source emitting white noise into the impedance tube. The speaker is connected to the upstream impedance tube and into the downstream impedance tube where the load conditions are changed in the tube end during measurement. Two microphones (A&B) are fitted in upstream impedance followed by the muffler and two microphones (C&D) are fitted in the downstream of the impedance tube. The acoustic element (Muffler) is fixed in between the two impedance tubes. A plunger is used as first load condition which acts as first load condition and an absorption sponge or an anechoic cone is used as second load condition.

III. ANALYTICAL CALCULATION

A simple expansion chamber of dimension 101 mm diameter and 300 mm length is used for the experiment**.** The TL behavior of an expansion chamber with a large diameter is investigated, as shown in Fig. 2.

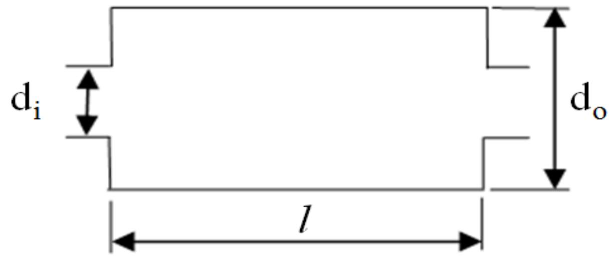

Fig 2 Expansion chamber dimensions (d_i = 0.043m, d_o = 0.101 m, l = 0.343 m)

The calculation of STL is typicaldone analyticallyfor measurement validation based on transfer matrix theory, considering the shell of the simple expansion chamber is round. The theoretical TL curve can be calculated by [3]

$$TL = 10\ Log_{10}\left[1 + 0.25\left(\left[m - \frac{1}{m}\right]^2 Sin^2\left(\frac{2\Pi f}{c}\right) l\right)\right]$$

Where, m-Expansion area (d_i/d_o),c- Speed of sound Propagation ,f- Operating frequency of the Engine (Hz)s, L – Length of the Muffler.

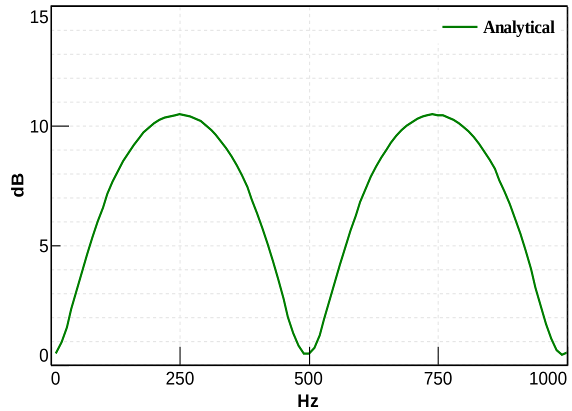

Fig 3 Theoretical transmission lossgraph foran expansion chamber

The STL value of a simple expansion chamber is shown in Fig 3 ,as the chamber is empty, the STL value is smooth and in a form of sine wave.

IV. STL EXPERIMENT IN TEST LAB CONDITION

I) STL Result with anechoic sponge

A prototype of a simple expansion chamber is made and it is put through to STL test using impedance tube .At first the STL is measured with an anechoic sponge as the second load condition. The test set up using anechoic sponge is shown in Fig 4.

Fig 4 Impedance tube setup with anechoic sponge

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In this experiment the STL is measured in normal room facility and an absorption sponge as second load condition where external noises are unavoidable .this noises penetrates through the anechoic sponge in impedance tube end and affects the measurement.

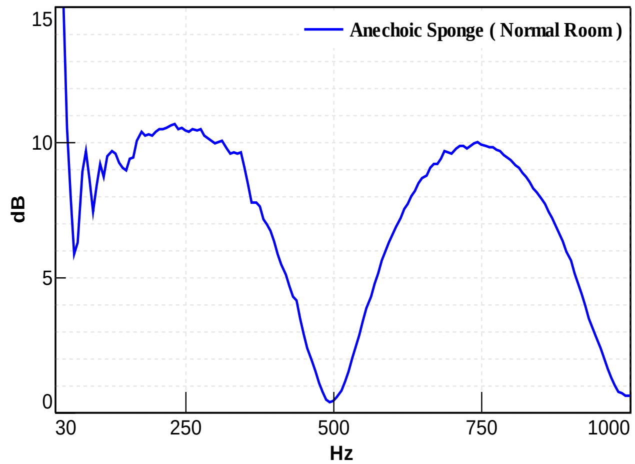

Fig 5 Transmission loss for simple expansion chamber with an anechoic sponge tested in normal facility

The result shown in Fig 5 indicates huge fluctuations in the lower frequency up to 200 Hz. The fluctuations are due to the external noise disturbance which the anechoic sponge could not absorb.

II. STL Result with anechoic cone.

Fig 6 Impedance tube setup with anechoic cone in normal room facility

In this experiment the measurement is done in normal roomfacility but the absorption sponge is replaced by absorption cone for reducing the fluctuations. An absorption cone is 1 meter long cone filled with absorption materials such as glass wool. A perforated pipe inside the cone is connected to the impedance tube end. The external noises during the measurement are avoided because the cone absorbs the noise. The absorption perforce of cone is always better than a sponge since the cone has high absorption material and much larger in size than a small sponge.

However the low frequency noises less than 100 Hz can partially penetrate through the impedance tube since the cone has limitation to its length. For controlling low frequency noises the cone length should be much longer but it is not practical to use. The experiment setup is shown in Fig 6.

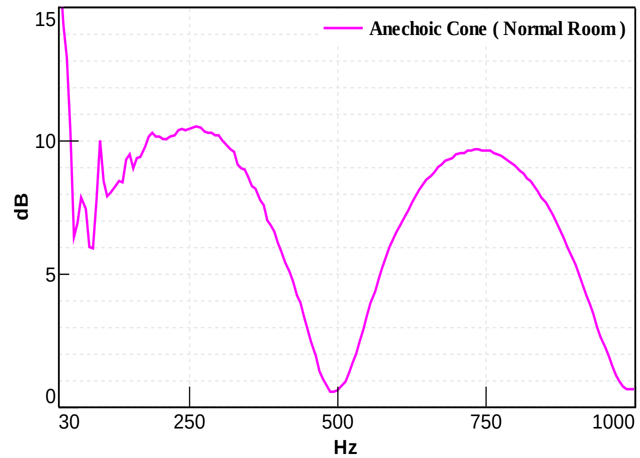

Fig 7 Transmission loss for simple expansion chamber with an anechoic cone tested in normal facility

The result shows the fluctuation is reduced a little but still the results in the lower frequencies are not clear.

V. STL Measurement In Anechoic Room Condition

I) STL Result with anechoic sponge

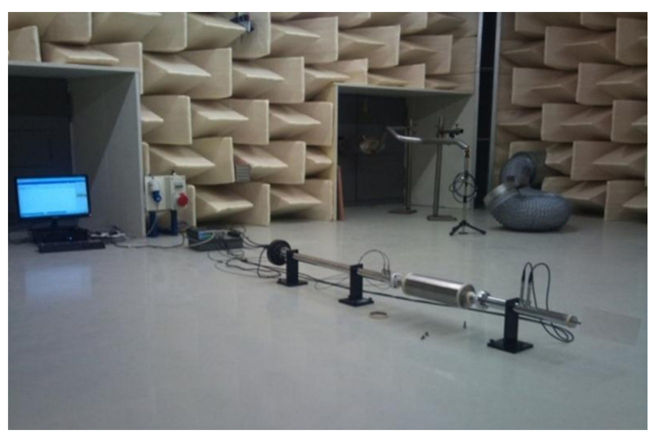

Fig 8 STL Test setup in anechoic lab with anechoic sponge

In the third test.it is made inside an anechoic chamber Fig 8 for avoiding the external noises influncing the measurement.

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In this experiment the STL is measured in anechois room and a absorption sponge as second load condition.

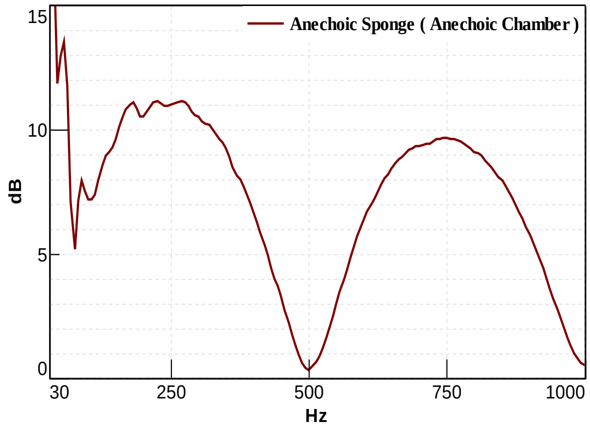

Fig 9 Transmission loss for simple expansion chamber with an anechoic sponge tested in anechoic chamber

This experiment result shows less fluctuation in the result but there is a sharp spike visible in 30 Hz. Because the cut off frequency of the anechoic room is below 80Hz. Still the results in the lower frequency need to be improved.

II. STL Result with anechoic cone

Fig 10 STL Test setup on anechoic lab with anechoic cone

In this experiment the measurement is done in anechoic room but the absorption sponge is replaced by absorption cone as second load condition Fig 10 for reducing the fluctuations in the lower frequency. Here the long absorption cone helps to reduce the spike in the lower frequency by absorbing it.

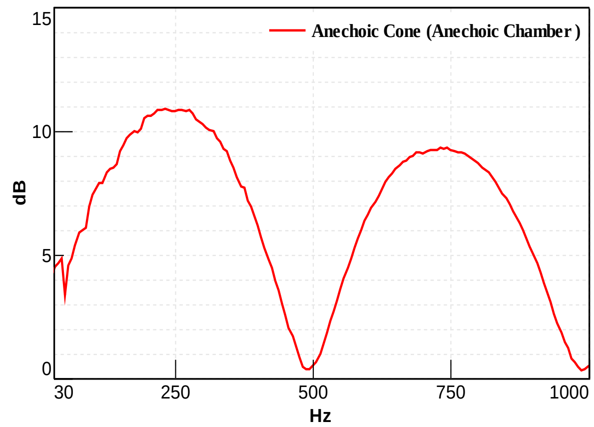

Fig 11 Transmission loss for simple expansion chamber with an anechoic cone tested in anechoic chamber

The result in Fig 11 shows improved STL result. The spike in 30 Hz is eliminated and over all the fluctuation is much reduced in all low frequency regions.

VI. Results Comparison

I. Result comparison with all measurement condition

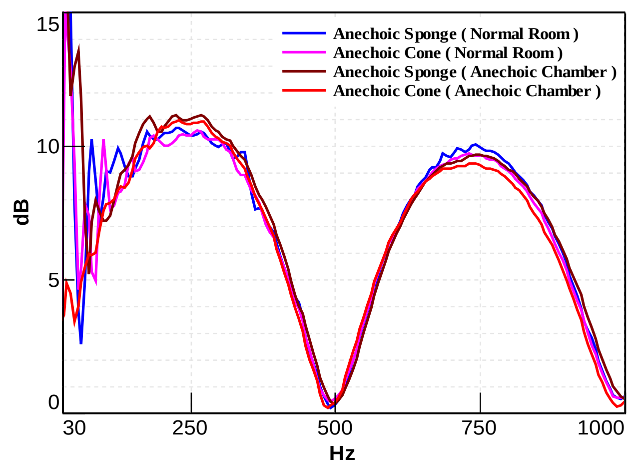

Fig 12 Transmission loss graph comparison for a simple expansion chamber with various test conditions

The comparison graph in Fig 12 shows the fluctuation reduction variation in different STL measurement condition .The measurement condition of absorption cone in anechoic chamber has lowest fluctuation and withoutany spike in the graph. So this measurement condition canbe used to measure mufflers for effective performance evaluation.

II. Result comparison with analytical calculation

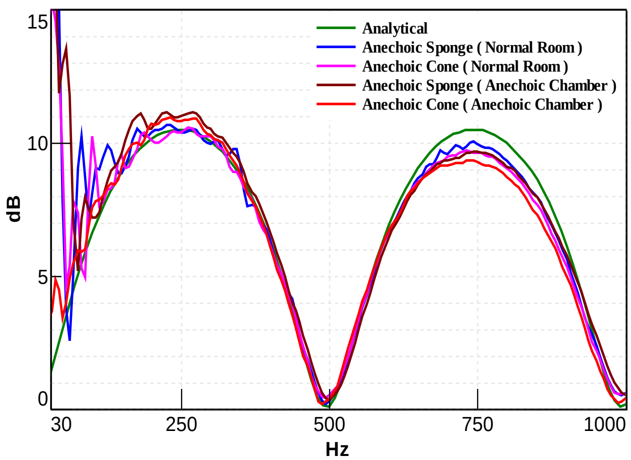

Fig 13 Transmission loss graph comparison for simple expansion chamber measured in various test conditions with analytical result

The analytical result compares well with STL graph obtained from absorption cone in anechoic chamber measurement condition as shown in fig 13. The other results from other three measurement condition have poor correlation with analytical result due to fluctuations in low frequency up to 200 Hz. All the graphs matches well in higher frequencies with analytical measurement after 200 Hz.

VII. Reflection Coefficient Of Anechoic Sponge And Anechoic Cone

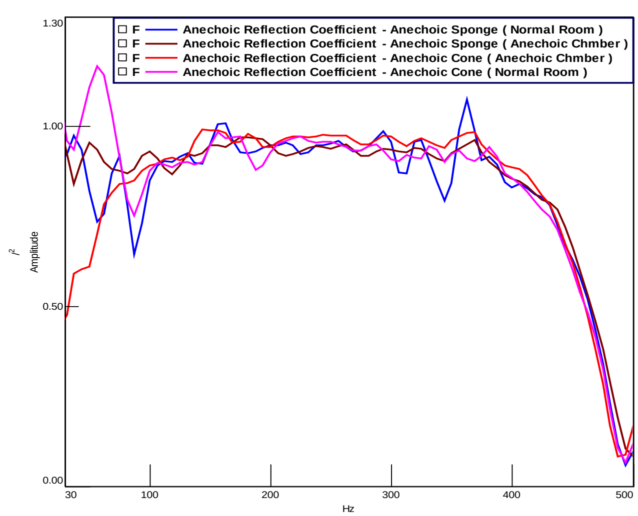

Fig 14 Reflection coefficient graph of different measurement conditions

The reflective coefficient of different measurement condones are shown in fig 14. it clearly shows the noise reflection is very low in measurement four i.e. absorption cone in anechoic chamber measurement condition because of higher SNR level due to low noise reflection inside the anechoic chamber.

VIII. Flow Velocity For Fluctuation Distribution Comparison

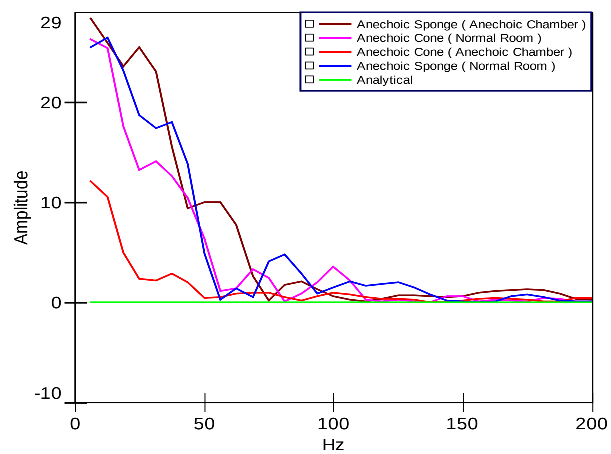

Fig 15 Flow velocity for fluctuation distribution graph

This graph shown in Fig 15 shows the flow velocity of noise levels in different measurement condition absorbed during measurement .The flow noise velocity amplitude is zero because noise flow is not taken into consideration in analytical calculation where as in actual measurement there are some flow velocity disturbance absorbed during measurement However the flow velocity disturbance is absorbed only in the lower frequency up to 150 Hz after 150 Hz the flow velocity amplitude is almost zero. The measurement four has the lowest flow velocity amplitude thus it has lower fluctuation in the tested result thus it is found that the flow velocity is one of the factor which affects the STL measurement and lower the flow velocity amplitude better the accuracy of the result.

IX. Reflective Muffler

I. STL Reflective resonator

An example reflective muffler of a passenger car Fig 20 is measured for its STL performance with through the best measurement condition i.e. with anechoic cone in anechoic chamber combination where the low frequency fluctuations are very low and it is compared with the measurement taken in normal room for seeing the difference.

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Fig 20 Reflective muffler

II. Main Muffler Test in Normal Room facility

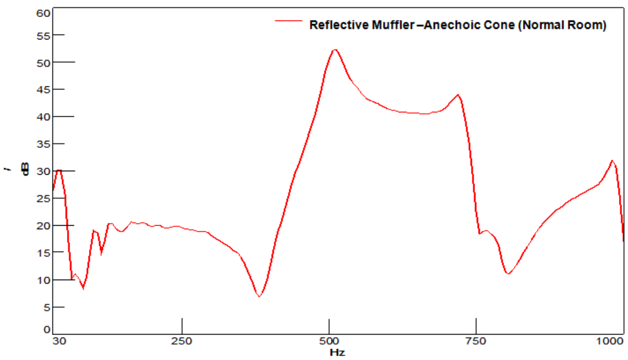

Fig 16 Transmission loss for reflective muffler with an anechoic cone tested innormal room facility

The result shown in Fig16 has a huge spike in the low frequency region. we cannot analyze the value in the low frequency area where the reactive muffler are critical .

III. Main Muffler Test in Anechoic Chamber

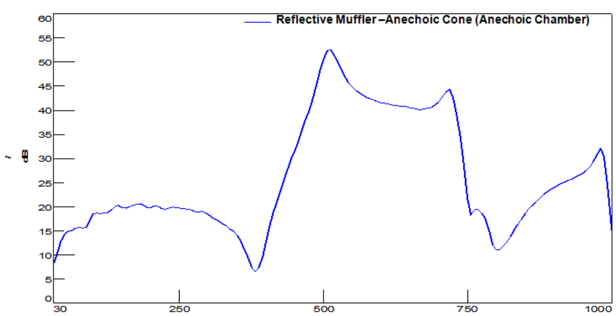

Fig 17 Transmission loss for reflective muffler with an anechoic cone tested in anechoic chamber

The graph shown in fig 17 indicates the STL value of reactive muffler measured with anechoic cone inside anechoic chamber which proved to give real STL values. The huge spike in low frequency area is not visible the muffler gives 15 to 20 dB STL from 50 to 250 Hz this is the real STL performs of the reactive muffler.

III. Main Muffler STL Test Result Comparison Measured in Normal Room and Anechoic Chamber

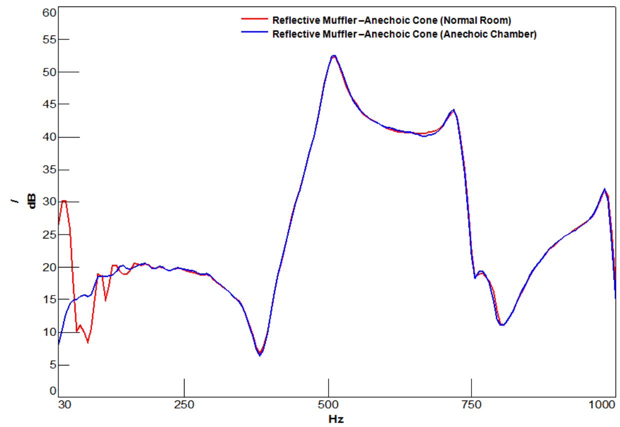

Fig 18Transmission loss graph comparison for Reflective muffler in normal facility and anechoic chamber test conditions

The comparision graph of two measurement conditions are shown in Fig 18 where we can clearly see the fluctuation in the low frequency area measured in a normal room which is not real but the blue graph measured in anechoic room is smooth in lower frequency with out fluctation.After 200Hz both measurements gives same values.

X. Absorptive Resonator

I. STL Absorptive sub resonator

Fig 19 Absorptive resonator (muffler)

In the second example an absorption sub resonator of an passenger carFig 19 is measured for its STL performance with the best measurement condition i.e. with anechoic cone in anechoic chamber combination where the low frequency fluctuationsare very low and it is compared with themeasurement taken in normal room for understanding the difference.

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I. Sub Resonator STL Test on Normal Room

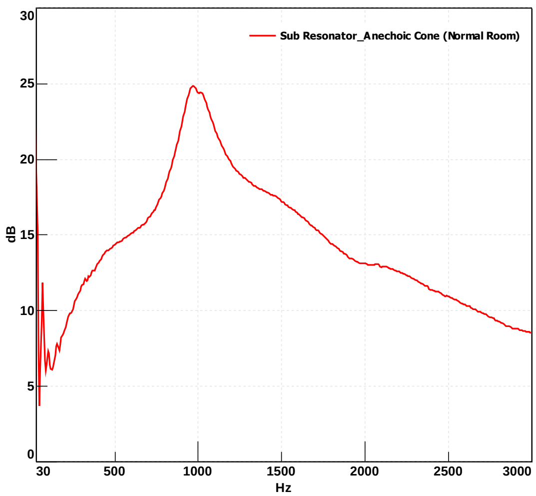

Fig 20 Transmission loss for simple absorptive resonator with an anechoic cone tested innormal room facility

The result shown in Fig 20 has a huge spike in the low frequency region. we cannot analyze the value in the low frequency area due to the fluctuations.

II*) Sub Resonator STL Test on Anechoic Chamber*

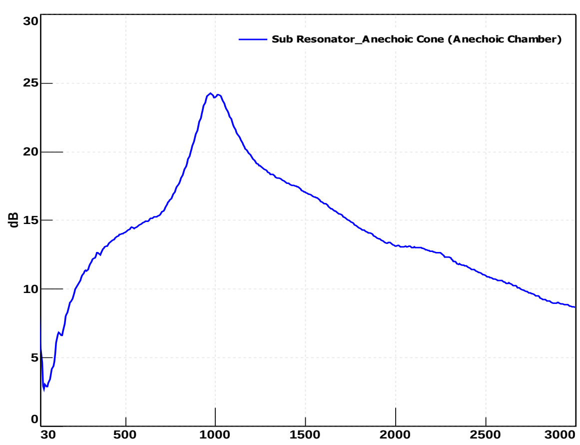

Fig 21 Transmission loss for simple absorptive resonator with an anechoic cone tested inanechoic chamber

The graph shown in Fig 21 indicates the STL value of absorption resonator measured with anechoic cone inside anechoic chamber which provides real STL values. The huge spike in low frequency area is not visible the muffler gives STL of 23 dB at 100 Hz. This is the real STL performs of the absorptive muffler.

III. Sub resonator STL Test Result comparison of normal room facility and Anechoic Chamber

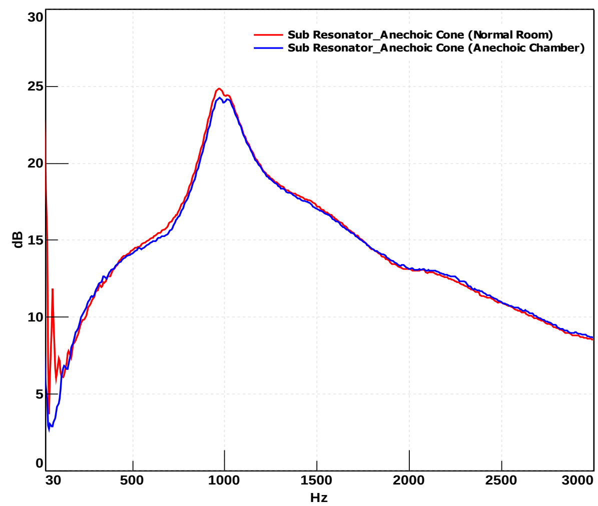

Fig 22 Transmission loss graph comparison for absorptive resonatorin normal facility and anechoic chamber test conditions

The comparision graph of two measurement conditions are shown in Fig 22 where we can clearly see the fluctuation in the low frequency area measured in a normal room which is not real but the blue graph measured in anechoic room is smooth in lower frequency with out fluctation which is the accurate result. After 200 Hz both measurement methods give same values.

XI. Conclusion

STL measurement for a simple expansion chamber is done for four different measuring conditions

a). Measurement in normal room with absorption sponge.

b. Measurement in normal room with absorption cone.

c). Measurement in anechoic room with absorption sponge.

d) Measurement in anechoic room with absorption cone.

During first measurement in normal room condition with absorption sponge there is a huge fluctuation in lower frequency due to lower signal to noise ratio because of external noises.duringsecond measurement with anechoic cone the fluctuation is reduced bur still the results are not accurate. In the third measurement with anechoic sponge in anechoic room the fluctuation is reduced in the low frequency but a spike in lower frequency still persists.

In the fourth measurement with absorption cone in anechoic room the spike is eliminated due to higher SNR value due to reduced external noise level and reduced reflection coefficient .Also the Flow velocity amplitude is lower in the fourth measurement compared to all other three measurements.Hence the measurement results accurately match with analytical result.

Thus with this experiments the environmental effects on STL measurement accuracy is clearly evident .It also proves that the results obtained from the anechoic chamber where external noise sources are eliminated produces greater accuracy in the tested result.

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Mathan Kumar born in Kanyakumariis working as an engineer in NVH testing & validation labrelated to automotive exhaust systems at Sharda Motor R&D. He has Practical experience in sound transmission loss measurement, vehicle noise testing & validation.