Silencer measurements in the manufactory hall

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1. Abstract

When calculating the expected dB(A)-weighted sound level at the requirement point the procedure always starts with the estimated (calculated or measured) Sound Power spectra for the engine. When designing an exhaust system for diesel engine it is important to have the correct source spectrum for the engine. But without the correct silencer attenuation curve no precision design of the total exhaust system is possible. To measure the attenuation curve of the silencer according to international standard is time-consuming, difficult to achieve during production and quite expensive. There is an evident need for a new method.

The target was to investigate a new method for measuring the Transmission Loss (TL) of silencers directly in the manufacturing hall. TL is the power-based damping spectra of the silencer which shows the attenuation of the silencer with 100% upstream traveling waves through the silencer (no downstream reflected waves).

The measurement setup must therefore be built with acoustic termination acting like the tail pipe would be infinity long. This is the reason why a long (broadband acting) absorber is needed at the end of the tail pipe in a geometrical finite test rig for measurements. Also the waves position before and after the silencer affects the result, especially in the most important low frequency region. The SESAM method (Silencer & Exhaust Systems Acoustic Measurement) handles this by averaging the measured sound pressure levels taking the geometry into account. (spatial averaging).

Measuring the transmission loss of a silencer you need; first a relevant source covering the necessary frequency range, a inlet duct with the silencer inlet dimension, the silencer itself, an outlet duct, Tail pipe, with the silencer outlet dimension and a relevant acoustic termination.

2. The acoustic system for a diesel exhaust has the following main parts:

1. Source strength of the engine
2. Applied attenuation (damping) i.e. the silencer added to the system
3. End reflection and directivity at the exhaust duct end
4. Damping caused by the distance to the requirement point

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The interesting characteristic for the silencer is always the Transmission Loss, TL which is the power-based damping over the silencer (not to be mixed with the *Insertion Loss* which is related to a changing before/after at any point and any acoustic descriptor). Transmission Loss is a spectrum which shows the attenuation of the silencer with 100% upstream traveling waves through the silencer (no downstream reflected waves). The measurement setup must therefore be built with acoustic termination acting like the tail pipe would be infinity long. This is the reason why a long (broadband acting) absorber is needed at the end of the tail pipe in a geometrical finite test rig for measurements.

Measuring the transmission loss of a silencer needs first a relevant source covering the necessary frequency range, an inlet duct with the silencer inlet dimension the silencer itself, an outlet duct, tail pipe, with the silencer outlet dimension and a relevant acoustic termination.

- The source - which ought to be the real engine but must be substituted with loudspeaker sources. Theoretical corrections are available in literature.
- The system temperature - which normally is 300-400 degrees Celsius must be substituted with 20 degree Celsius during the measurements. Theoretical corrections for this are also available in literature.
- The acoustic termination - ought to be an infinity long duct with no end reflections and consequently no standing wave phenomena. This is substituted with an efficient dissipative end termination which means an absorbent part at the duct end with a length equal to at least ¼ wave length for the lowest interesting test frequency.

3. Measurement Setup

The 6 tubes needed for the SESAM Probe was installed before and after the Silencer. Since the measurements were done in cold condition the spacing between the holes becomes less than on a hot system, see fig 1 and 2.

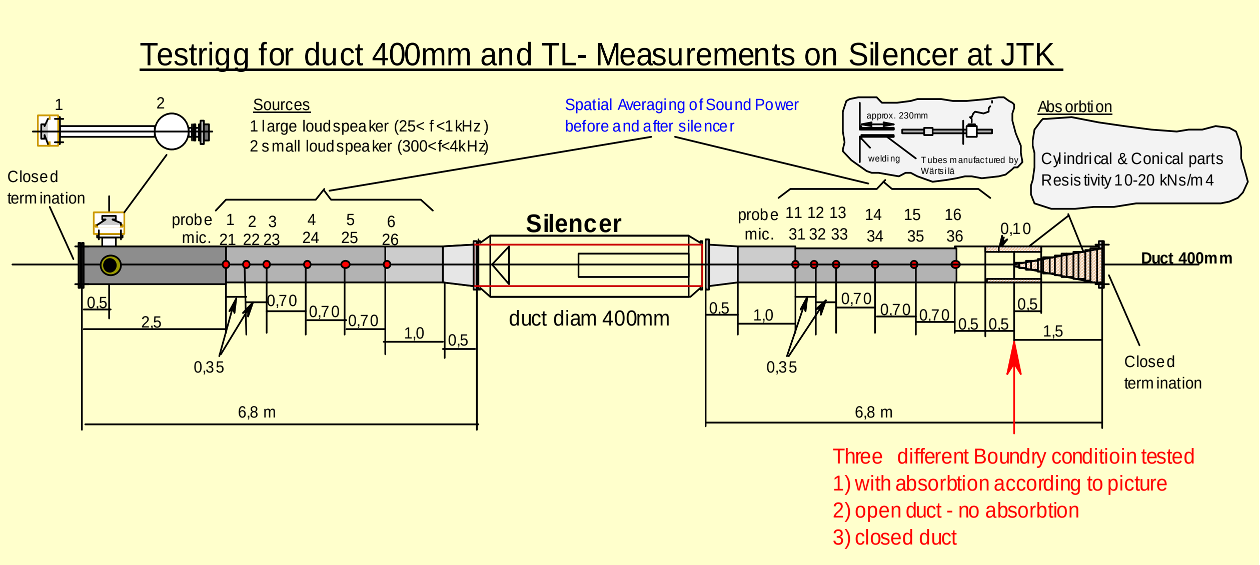


fig 1. *Geometry and principal schematic of the measurement setup*

fig 2. *Photo for duct before and after silencer*

3.1 Excitation

Excitation was done using a Noise Generator BK1405 giving signal to a Power Amplifier that fed two loudspeakers. Both loudspeakers were mounted at 90 degree angle from the duct. The first (A) directly on the duct and the second (B) at the end of a quarter-wave resonator attached to the duct. The resonator was tuned to give extra power at low frequency, fig 3.

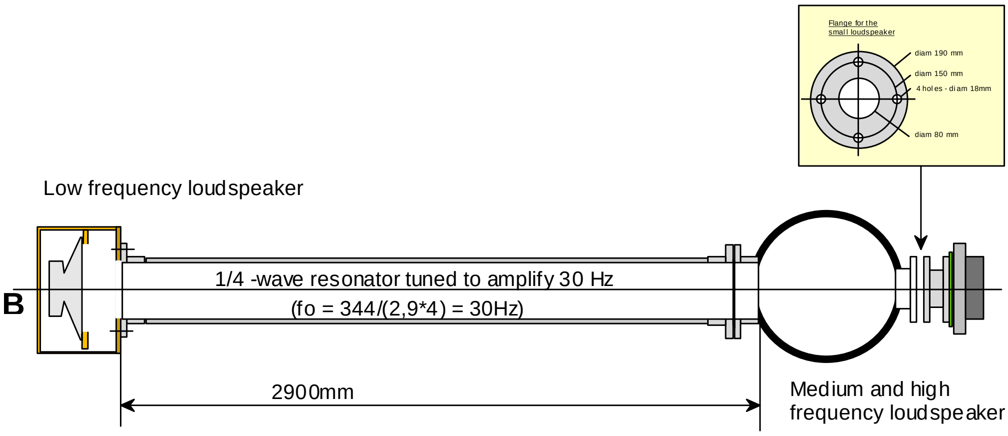
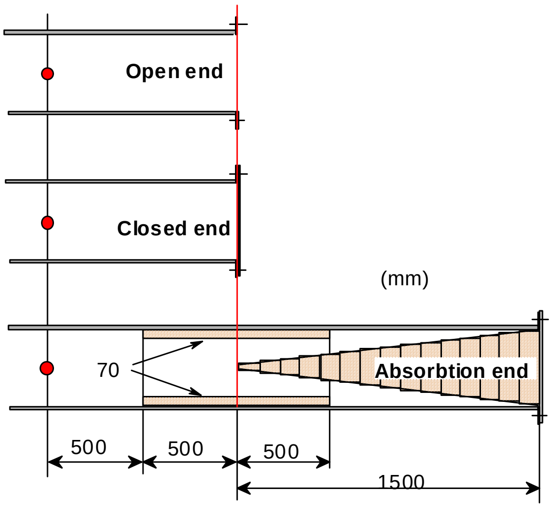


fig 3. *Two loudspeakers used as input source in the test rig*

3.2 Acoustic Infinity



To estimate TL spectrums that are as independent of the total system as possible, an Absorption Cone is introduced at the end of the tail pipe, so that the sound waves propagate as if the pipe would be infinitely long.

fig 4. *Three different boundary conditions after the silencer*

fig 5. *End duct absorption – part of the acoustic infinity*

4. Estimating Transmission Loss, TL

Since the measurements (before and after the silencer) are relative we do not in this report make any distinction between Sound Pressure, Lp, and Sound Power, Lw.
To get to Sound Power only Duct Area influence needs to be added in the Plane Wave Region. Above f_0, in the Transition Region and above also Wave Mode Attenuation needs be added.
Both these factors are constants and therefore cancel out when doing relative measurements. Because of this we regard the sound power behaving exactly the same as sound pressure.

4.1 Logarithmic Average

The most straight forward way of analyzing the data would be to make a Logarithmic average of all measurement points before and after. This is done for *n* number of holes *H* using the formula:

$$LogAvr(n) = 10*Log((10^{H1/10}+10^{H2/10}\ldots+10^{Hn/10})/n)$$

Adding up the Total Sound Pressure Level we consider the values from each 1/3 octave band as being a contributing source:

$$LpTot(n) = 10*Log(10^{H1/10}+10^{H2/10}\ldots+10^{Hn/10})$$

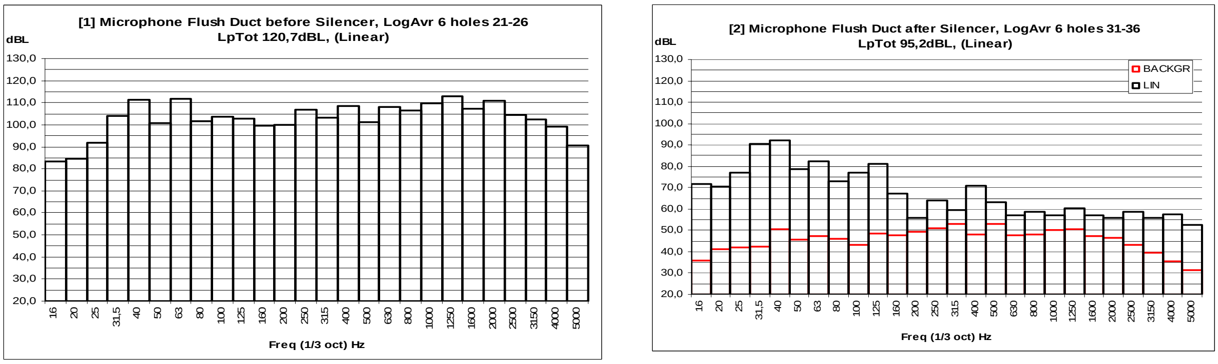
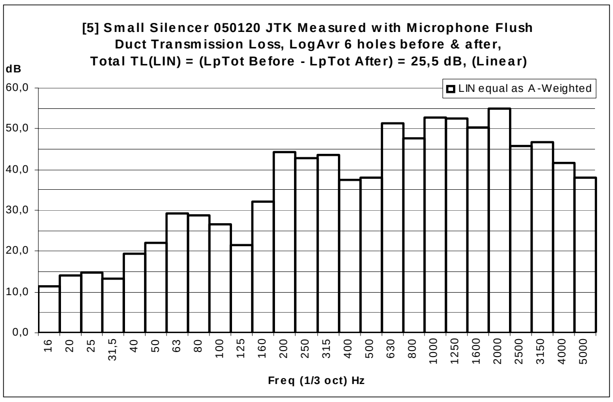


fig 6: *Log average after Silencer*

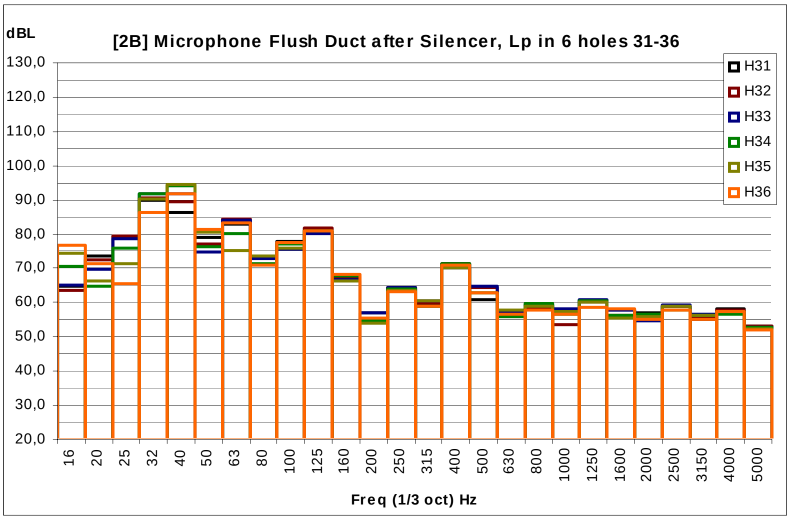
Thanks to the ¼ wave resonator we have a lot of energy in the low frequency region and a reasonably flat spectrum.



Finally the attenuation curve for exhaust silencer, Total attenuation is linear scale in 26 dB.

fig 7: *The TL spectra based on Log average Lp (Before and After)*

4.2 Spatial Average



As we could see in fig 8 above the levels of individual 1/3 octave bands after Silencer differ quite a lot in the Low Frequency Region depending on measurement hole. The High frequency region, above the *Plane Wave Region*, it is OK to average Logarithmically, as described earlier.

fig 8. *The measured sound pressure levels in different holes after silencer*

But using only logarithmic averaging would not give as accurate results in the low frequency region as one could get. It is possible to treat the measured data more correctly to achieve better accuracy. This is the reason for the technique of spatial averaging, also called spatial RMS. Using the fact that two measurement points can always give the exact value for a certain frequency if those points are ¼ of a wavelength apart.

The measurement points 1 and 2 gives the sound pressure levels Lp1 and Lp2. No matter where on the curve we move the points this results in the same RMS Level as long as the distance between the points are the correct distance for the wanted frequency.
In other words, the value you get when using calculating the Spatial RMS value for a certain frequency is the correct value for that frequency no matter if the wave is propagating (traveling) or standing in the pipe and it does not matter how that wave is standing if it is.

We then use different combinations of holes to pick the values for each 1/3 octave band up to 500Hz. Some of the distances matches a 1/3 octave band frequency directly. The others are weighted together as combinations of the above. Analyzing the measured values using this technique we get the following results.

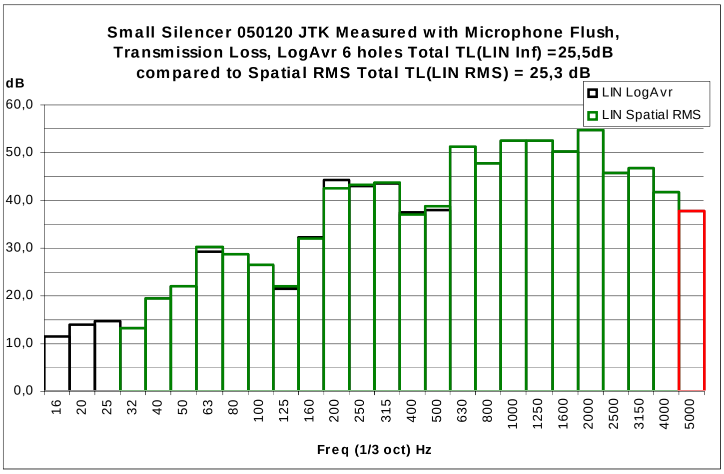


Fig 9. *TL spectra based on Spatial RMS compared with TL spectra based on Log average.*

From fig 9 above we can conclude that when measuring on this Silencer the TL spectra was relatively equal using Spatial RMS or not, almost no difference in the Total TL either.

When making relative measurements like this the absolute sound pressure level is not so interesting. But working with source spectrums and measuring sound power in different positions in an exhaust system it is vital to have a correct measurement method.

5. Conclusions

The target was to investigate a new method to estimate Transmission Loss (TL) directly in the manufacturing hall was successfully fulfilled. The comparison with the earlier measured silencers at Helsinki in VTT showed almost equal result.