A New Measurement Technique for Ducts Characterization

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Abstract: Devices such as silencers or filters are commonly used by the automotive industry to reduce the propagation of noise in ducts. The acoustical characterization of these devices is usually performed on transfer matrix measurement rigs equipped with microphone doublets. One drawback of this widespread technique is the difficulty of fitting of the test specimen to the test rig duct. It is required that the shape and cross-section of the test rig duct be as alike as possible as that of the test specimen. Such requirement complicates the testing and can become a source of uncertainty should the fitting be inadequate. When the qualification procedure does not require an air flow to blow through the test specimen, an alternate measurement technique is proposed. This measurement technique allows avoiding the issue of the mechanical fitting, and also requires a simplified test rig calibration phase. The measurement duration is then reduced. Said technique uses an acoustic impedance sensor developed by LAUM and CTTM. First the principles of this alternate technique are reminded, then some experimental results are discussed in order to highlight the pros and cons of both methods.

Keywords: Transmission Loss Measurement, Duct characterisation

1. Introduction

Acoustic ducts characterization is requested in several studies, either in industrial applications or in academic research. Many fields of activity are concerned: silencers qualification, poro-elastic material characterization, musical acoustics,.. Classical methods are well described in many studies [1, 2, 3]. They are generally based on “in-duct” measurement using two microphone doublets (with sometimes more microphones if the measurement frequency range must be extended). When the device to be characterised is not symetrical, the measurement must be done in two steps (multi-sources or multi-load methods).

These methods are nowadays widely used. However, some drawbacks are well known. The first one is associated to the calibration phase. If a good precision is requested, in particular at low frequencies, a relative calibration of the sensors must be done. With the four microphones simplest test bench (two microphones on each side of the device to be measured) it is then necessary to perfom three transfert function measurements. Moreover, an additionnal uncertainty is introduced by the fact that the calibration phase implies to mount and dismount the sensor from the duct. The second drawback is due to the mechanical adaptation that is requested between the device to be characterised and the measurement duct : if the input and output cross sections of the device are very differents from that of the measuring duct, it is necessary to manufacture a specific adaptator. Moreover, the discontinuity can have an unknown impact on the measurements results.

We propose here a new method which is an alternative to the classical ones when there is no need to have an air flow through the device. This method uses an impedance sensor developped by the LAUM and the CTTM [4,5]. Compared to the classical four microphones method, the proposed one features a quicker and simpler calibration phase, and reduce the constraints resulting from the mechanical adaptation.

2. Method Description

2.1 General principle

The principle of the method is described in Figure 1. The test bench contains three microphones: two are integrated in the impedance sensor, and the third one is flush mounted on a rigid back.

The measurement procedure is shared in three steps. In the first step, the test bench is calibrated. The output duct of the impedance sensor head is closed by the rigid back, with the third microphone acoustically connected to the impedance sensor. U1, U2 and U3 being the voltages provided by the microphone channels 1, 2 (impedance sensor) and 3 (rigid back), the frequency transfer functions $H_{12}=(U_2/U_1)$ and $H_{32}=(U_2/U_3)$ are recorded.

Then, the input of the device is placed over the impedance sensor head, while its output is closed by the rigid back containing the third microphone. The frequency transfer functions H_{12} and H_{32} are recorded again. The third step is identical to the previous one, but with the device turned over. For all of the three steps, it’s important to limit the leakages between the device and the test bench components.

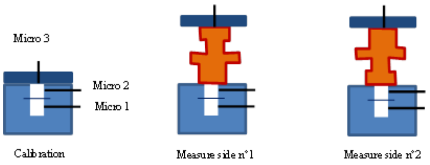

Figure 1: Measurement principle

2.2 Impedance matrix

With the conventions of the Figure 2, the acoustic magnitudes are defined as following:

- P_1 and P_2 are the acoustic pressures at the device input and output,
- Q_1 and Q_2 are the volume velocities,
- S_1 and S_2 are the cross sections at each side.

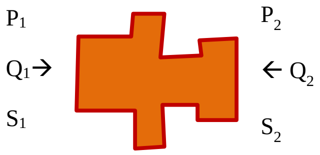

Figure 2: Acoustic magnitudes of the impedance matrix

The impedance matrix of the corresponding wave guide is then given by:

[1]

The first measurement is done with a volume velocity Q_2 equal to zero. Then, we obtain:

[2]

The second measurement, performed with a volume velocity Q_1 equal to zero, gives the two last coefficients of the impedance matrix:

[3]

The two input impedances of the wave guide Z_{11} and Z_{22} are given directly by the impedance sensor (see Figure 3 and [4] for more details on the impedance sensor principle).

Taking into account the sensor geometry, the two other impedances Z_{21} and Z_{12} can be calculated from the measured transfer functions. The analytical expressions of the four reduced impedances are given below:

[4]

[5]

with i and j=1 or 2,

and

- , are the frequency transfer functions recorded during the measurement phase “i” and during the calibration,
- , are the frequency transfer functions recorded during the measurement phase “i” and during the calibration,
- , are two functions only depending on the impedance sensor geometry (see Figure 3),
- S_c is the cross section of the impedance sensor output duct,
- L_{corr-i} is the added length associated to the discontinuity between the sensor output duct and the cross section S_i of the measured device,
- is the characteristic impedance of the ducts of cross section S_i.

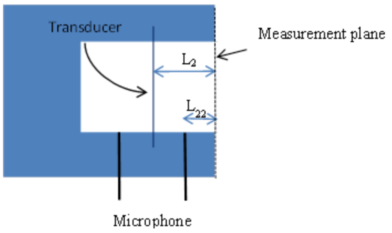

Figure 3: Simplified representation of the impedance sensor structure

2.3 Scattering matrix

The scattering matrix represents the wave guide by its reflection and transmission coefficients (Figure 4). It is defined as below:

[5]

where:

- T^+ and T^- are the direct (1 → 2) and reverse (2 → 1) transmission coefficients,
- R^+ and R^- are the reflection coefficients of the two sides.

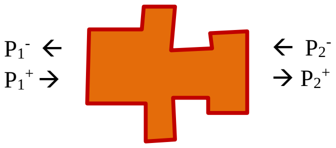

Figure 4: Acoustic magnitudes of the scattering matrix

Transmission coefficients are frequently expressed in terms of Transmission Loss (TL):

[6]

If the cross sections S1 and S2 are different, the following relations, which express the TL in term of transmitted energy, are used:

[7]

In that way, the two coefficients TL^+ and TL^- always remain identical.

The coefficients of the scattering matrix can be calculated from the ones of the impedance matrix by:

[8]

3. Quantitative Analysis of the Method

We firstly present an analysis of the intrinsic interest and limitations of the method. For this, we here consider a rigid circular duct of 29mm diameter and 124mm length. Measurements have been performed in a step sine mode.

3.1 Error due to ill-conditioned data

As the rigid duct is symmetrical, there is in practice no need to perform the step 3 of the measurement procedure. We firstly consider that and . In that way, we can study the intrinsic errors of the method without being impacted by handling errors. The Figure 5 presents the measured impedances and the Figure 6 shows the TL obtained from four different measurements. The theoretical TL of the rigid duct is also presented in Figure 6.

The estimations of the TL are in accordance with the theory excepted at some particular frequencies corresponding to an “infinite” value of the impedances (see figure 5). At these frequencies, depending on the accuracy of the measurement, the denominator could be close to 0 and then the value of the TL is undefined.

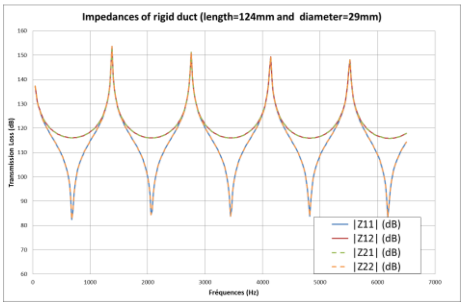

Figure 5: Impedance matrix coefficients

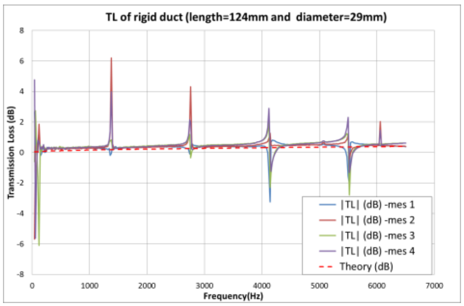

Figure 6: Transmission Loss of the duct – measurement in two steps

Now, if we estimate the scattering matrix coefficients from a complete three steps measurement procedure (that implies to switch the duct mounting between the steps 2 and 3), it appears that the errors on the TL coefficients (figure 7) are of the same order as what is shown in figure 6. We conclude that, in the case of an anti-symmetric device, the use of a three steps procedure shouldn't increase the intrinsic error of the method.

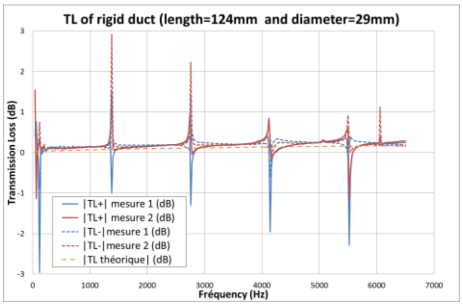

Figure 7: Transmission Loss of the duct – measurement in three steps

3.2 Impact of the device characteristics

Until now, the analysis has been done on a device featuring a very small TL, which is one of the worse configurations that can be measured. To conclude this preliminary study, we add some losses in the duct. A porous acoustic foam sample has been introduced in the duct. The foam is placed in the middle of the duct, so that the device remains symmetrical.

The two steps procedure is applied, and the result is shown in Figure 8.

When the losses of the studied device increase, the method becomes less sensitive to data conditioning. The results are better.

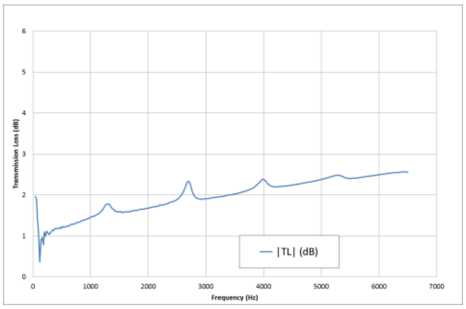

Figure 8: Transmission Loss of the duct with a porous material sample

4. Application to a small silencer

The proposed method is now applied to the characterization of a small silencer used in automotive industry (turbo engines). The experimental set-up is shown in Figure 9. The input and output diameter of the silencer are slightly different (42mm and 47mm).

Figure 9: Experimental setup with the small silencer

4.1 Results with the new measurement method

As the silencer is not symmetrical, the measurement uses the three steps procedure. The obtained scattering matrix coefficients are shown in Figures 10 and 11. The Figure 12 contains the "Den" coefficient (Equation 9). The frequency range is limited to [0-4.5kHz] which corresponds to the plane wave behavior of the silencer. The measurements are done at a low acoustic level.

The direct and reverse TL are almost identical. Some small accidents however exist, at about 1kHz and 1.85kHz for the direct TL, and at about 2.3kHz for the reverse TL. These accidents are due to ill-conditioned data. They correspond to

the "Den" curve peaks, and are therefore predictable. The reflection coefficients seem to be less sensitive to data conditioning.
Below 200Hz, the result quality decrease: this is due to the lack of acoustic level of the sensor at very low frequencies.

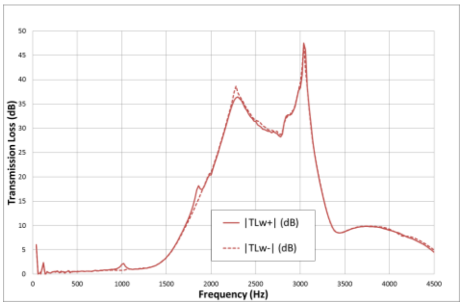

Figure 10: TL of the small silencer measured with the proposed method

Figure 11: Reflection coefficients of the small silencer measured with the proposed method

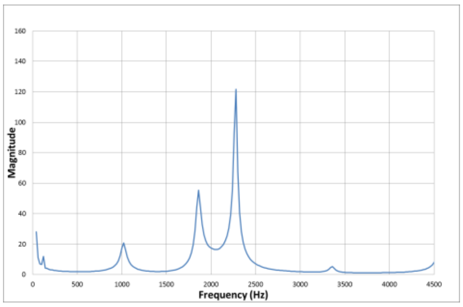

Figure 12: "Den" coefficient

4.2 Comparison with a classical method

The small turbo silencer is now measured with classical four microphones method. Two test benches are employed:

- A 40mm diameter duct with a two sources method. With this method, the sources are located on each side of the silencer, and the scattering matrix is obtained from two measurements. The silencer has been measured at a high acoustic level,
- A 30mm diameter duct with a one source method and an anechoic end (figure 13). With this method, the scattering matrix is obtained from only one measurement. The silencer has been measured at a low acoustic level.

Figure 13: Experimental setup for the "one source + anechoic end" method

4.2.1 Small discontinuity configuration

The comparison of the previous results with the ones obtained on the 40mm test bench is presented on Figures 14 and 15. With the 40mm diameter test bench, the discontinuity between the silencer and the bench duct is small, but the acoustic level is greater than the one applied in the measurements with the impedance head.
The TL curves are similar. Some differences exist at the maximum attenuation (and also above 3.5kHz). These discrepancies can be due to the small discontinuity between the silencer and the duct, but they probably result from the different acoustic excitation level employed on the two experiments. The reflection coefficients are similar.

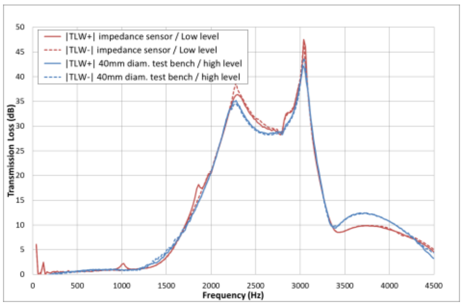

Figure 14: TL of the small silencer – comparison to classical method with small discontinuity

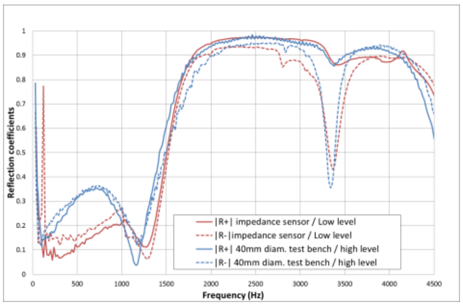

Figure 15: Reflection coefficients of the small silencer – comparison to classical method with small discontinuity

4.2.2 Significant discontinuity configuration

The comparison of the previous results with the ones obtained on the 30mm test bench is presented on Figures 16 and 17. With the 30mm diameter test bench, the acoustic level is similar to that applied in the measurements with the impedance head, but the discontinuity between the silencer and the bench duct is higher. Some ripples are visible on the curves coming from classical method measurements: they are due to the anechoic end which is not perfectly anechoic.

The TL curves are similar even at the maximum attenuation. This confirms the impact of acoustic excitation level previously discussed. But some discrepancies are here visible at low frequencies that can be related to the discontinuity between the measurement duct and the silencer. The reflection coefficients are similar excepted at low frequencies: again, the impact of discontinuity is suspected.

In that configuration, the results obtained by our method are better than the one given by the classical measurement procedure.

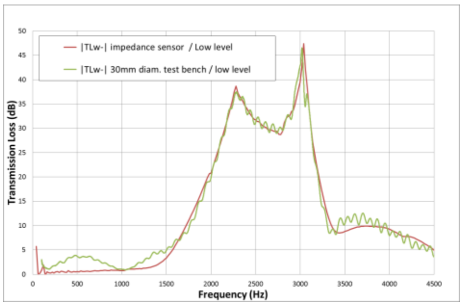

Figure 16: TL of the small silencer – comparison to classical method with significant discontinuity

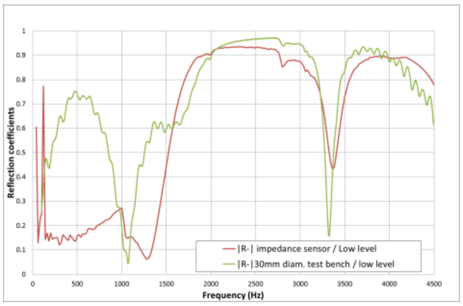

Figure 17: Reflection coefficients of the small silencer – comparison to classical method with significant discontinuity

5. Conclusion

A new measurement method for wave guide has been presented. This method can be applied when the wave guide is tested without air flow. It is based on an impedance sensor developed conjointly by the CTTM and the LAUM. The new method provides accurate results that are similar to the one given by the classical test setups.

When the required output is the scattering matrix, some local discrepancies can appear and they are due to ill-conditioned experimental data. It has been shown that the frequencies at which the discrepancies occur can be identified.

The advantage of the proposed method is that it makes easier the mounting of the device to be tested. Moreover, the calibration phase is shortened compared to the one of a classical four microphones measurement.

6. References

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Commenté [D1]: Demander à Eric une référence pour ses mesures.