THE SIDE BRANCH RESONATOR DESIGN METHOD FOR TWO-STROKE ENGINE EXHAUST SYSTEM

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1.0 INTRODUCTION

The exhaust noise of a two-stroke engine is still a prior source of noise in recreational vehicle. Noise standard and consumers demand for noiseless vehicle require to find new solutions in exhaust noise attenuation. These solutions must be efficient in a large range of frequencies in order to reduce the noise at each engine RPM and load of the vehicle. Priorities like cost, weight, safety, reliability, packaging and performance need to be taken into account very seriously.

The purpose of this paper is to present an innovative approach to achieve the above target in term of noise and performance along the load line of the vehicle.

First, an experimental approach is developed to determine the exhaust noise along the load line. This approach allows the engineer to determine the problematic frequencies due to the exhaust system.

Then an analytical model developed by Bombardier is used in order to tune a set of side-branch resonators. This model, based on experimental data, allows to optimise the resonators design.

2. EXHAUST NOISE EVALUATION

First, the exhaust noise with typical muffler is measured from an engine running on a dynamometer. All the parameters representing the in field condition must be controlled, (engine rpm vs throttle opening following the load line, engine cooling flow and temp, exhaust temp., water injection (if applicable), etc ...) A schema of the apparatus is showed in figure 1.

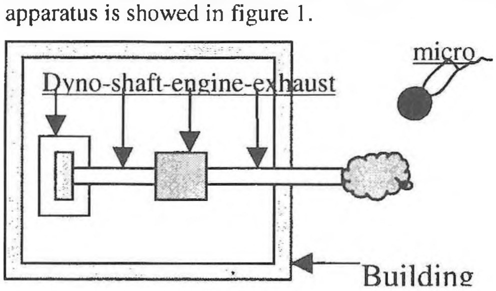


Figure 1.

Measurements are made at each RPM of the load line of the vehicle. Typically, it requires around 13 measurements at different engine speed. In order to pin-point all the different resonance in the exhaust noise, all the measurements are logarithmically averaged.

Typical exhaust noise spectra are showed in figure 2. The thick curve represents the averaged data. All the resonance can be clearly identified. It is important to work on each of these peaks in order to reach a good sound quality of the vehicle.

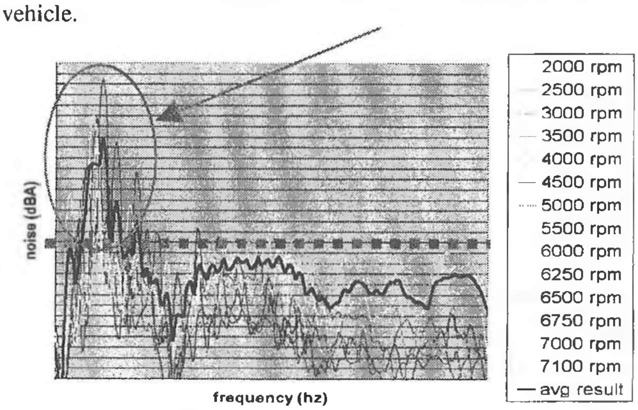


Figure 2: Exhaust noise without resonators

3. SIDE-BRANCH RESONATORS

As vehicles get smaller, there is less room for big expansion chamber. At the same time, expansion chambers create more restriction and back pressure in the exhaust line, which affect the engine efficiency. This lead to a new approach in order to control the exhaust noise.

The side branch resonator has no flow going through it. The principle of attenuation is that the reflective plane wave cancel the coming plane wave. The frequency efficiency of these resonators is selective. The length of the tube corresponding to the frequencies to be cut can be calculated by the following equation.

$$L = C.n/2f \quad n=0.5\text{-}1.5\text{-}2.5\text{-}3.5\text{-}4.5\ldots$$

C=speed of sound
f=frequency to be cut

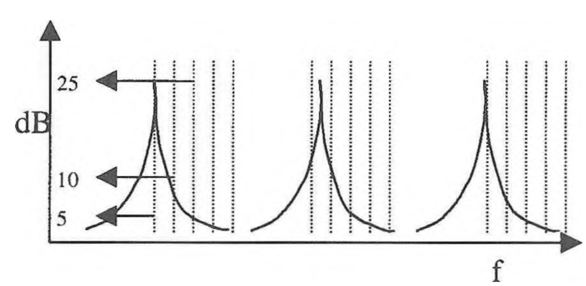


Figure 3 : transmission loss of a resonator

Note that the resonator acts not only at a single frequency but in a certain band. The graph presented figure 4 allows a quick determination of the tube length for the frequency to be cut. Each set of curves in the figure 4 represent the 5 dot line showed in figure 3. The centred curve in the figure 4 being the highest point of attenuation zone and the 4 others curves showing the different range of attenuation. By example, a the efficiency of a 300 mm tube will more than be 5 dB between 250 and 400 Hz, and more than 10 dB between 275 and 310 Hz.

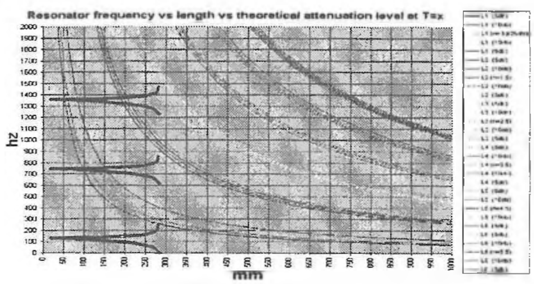
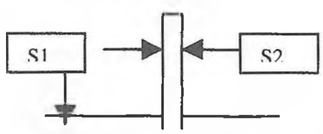


Figure 4: Efficiency of a resonator

The resonator efficiency is related to the expansion ratio m=S2/S1 (S1, S2 being area) [1]. Higher is the ratio, better is the transmission lost.



The figure 5 shows the measured exhaust noise with resonators. Note that the low frequencies peaks are removed from the spectra.

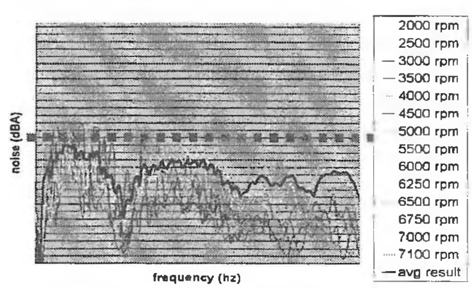


Figure 5: Exhaust noise with resonators

4. PREDICTIVE TOOL

We have seen how to design resonators tubes and their effect in an exhaust line.

If one wants to predict perfectly the sound attenuation along the exhaust line, there are a lot of parameter that need to be known; the speed of sound vary with temperature, the exhaust flow vary with the speed of the engine, the engine power vary with the load line, the exhaust noise vary with the load line, etc.... Because most of the parameters vary with the load line, the software uses an experimental database containing information related at each engine RPM.

First, we calculate the transfer function of the exhaust line corresponding to each rpm and then we sum up to predict the results. The software will calculate the attenuation that the resonator produce along the load line. The inputs are basically the tubes length and the noise spectra before adding the resonator:

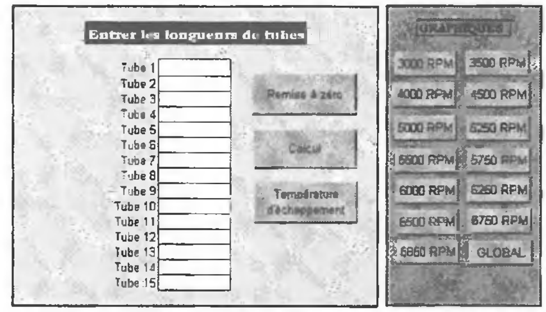


Figure 6: input panel of the software

With this tool we can vary manually the tube length in a way to optimise the attenuation with the target fixed earlier. The result can be printed at each rpm of the load line or only on the average result.

5. CONCLUSION

Both the experimental and the analytical approach allows to design very efficient exhaust system.

The use of side branch resonators, in conjunction with classical expansion chamber, give a very good attenuation of the exhaust noise in all the spectra, without compromise on the packaging of the system and on the back pressure of the exhaust. The use of these resonators in a PWC was patented in 1999.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] HARRIS. (1957) *Handbook of noise control*, McGRAW-HILL. Chapter 21.

[2] Lecours & al. US patent 6.019.648, noise reducing system.