A New Spiral Muffler: acoustical equivalent model and performances estimation.

A new type of exhaust gas muffler is proposed which is characterized by a spiral shape. A theoretical investigation was carried out to determine the spiral muffler acoustical performances. A muffler electrical equivalent model (EEM) was introduced, insertion loss and transfer function could be found for each value of the muffler geometrical and acoustical parameter. By means of a measurement campaign, lead on a laboratory prototype, the equivalent electrical model was validated by proving that model results are very close to measured ones. The investigation showed that a smaller volume spiral muffler introduces the same insertion loss than a traditional one; furthermore the exhaust gas temperature inside the spiral muffler is more uniform and higher than in a traditional one; thus gases condensation is inhibited and corrosion risk is strongly decreased. The investigation will prosecute to estimate the gases velocity and temperature field inside the spiral muffler in order to improve and optimize its acoustical and fluid-dynamic performances.

The spiral muffler

The proposed muffler is constituted by several spiral steel coils which are contained inside a cylindrical volume. The muffler inlet section is placed at the spiral center coil; gases are exhausted through some holes made on the upper side of the external spiral coils (see fig.1); holes outlets are collected by a pipe which drives away exhausted gases. At muffler bottom a resonant cavity is installed. The principle which roles the muffler acoustical performances is "Reaction". Each outlet hole is separated by the next closest one by a single coil path; thus acoustical waves coming out from each hole are one another delayed by the time the noise takes to go allover a single coil path. Coils path lengths and outlet holes positions are designed to introduce a 180° phase shift between the main acoustical engine noise components. Reaction between such a components hangs out along the pipe which collects the holes outlets. No absorber element or material is installed inside the muffler; so higher temperature is admitted.

The muffler model

An acoustical model is introduced to describe muffler behavior; thus any muffler parts is associated to a single acoustical element once the following hypothesis are achieved: **1)** acoustical pressure distribution inside muffler may be considered one-dimension dependent; **2)** the spiral muffler walls are perfectly rigid. Hypothesis **1)** and **2)** are true because of the following states: noise wave length is much higher than transversal muffler duct dimension, muffler spiral walls have been realized with a 2mm thickness steel. Each element of the spiral muffler is associated to an acoustical model as follows (See Fig.2): **a)** inlet section is modeled by a small circular-section duct, **b)** spiral muffler duct is modeled by a rectangular section linear duct; **c)** each outlet hole is modeled by small circular duct; **d)** outlet collector pipe is modeled by a cylindrical duct; **e)** Resonant cavity is modeled by a parallelepiped volume. Element **a)** EEM is an inductance paralleled with a capacity which is introduced because inlet central spiral section area is greater than the inlet pipe duct thus a cavity effect occurs. Elements **b)** and **d)** EEM is an inductance the value of which depends on each element geometrical dimensions. Resonant cavity **e)** EEM is a capacity the value of which is proportional to the cavity volume. Outlet holes **c)** EEM is an inductance in series with a resistor [1]. Muffler global EEM is shown in Fig.3. Engine exhaust noise is modeled by a square wave signal while airborne irradiation impedance is modeled by a load resistor.

Measurements and model validation

A spiral muffler prototype has been installed to a 6 cylinder, 300KW diesel automotive engine in order to test its acoustical performances. Tests have been lead with 1K-6K r.p.m. engine angular velocity range to which a 50-300Hz noise range corresponds. Noise levels have been measured according to ISO standard [XX] constraints. Prototype measurement results are shown in Fig.4. Model performances have been evaluating supplying EEM by a square wave signal to which a 20kPa amplitude noise signal corresponds [XXX]. Furthermore EEM output has been properly attenuated to keep into account the propagation media which separates the spiral muffler outlet to the measurement point [XX]; thus a coherent comparison between EEM response and measurement results was achievable. Prototype measurement results and EEM response are shown in Fig.4; the maximum difference between model and measurements results is 2dB; EEM performances are very close to real spiral muffler ones.

Optimization and conclusions

Validation of EEM allows to optimize and to match spiral muffler performances to any different application. For example, spiral muffler prototype acoustical performances may be improved by carrying out the following adjustments: **1)** increase of inlet and outlet pipe length, **2)** decrease of inlet and outlet section area, **3)** decrease of spiral muffler total section area, **4)** increase of resonant cavity volume.

Adjustments **1)**, **2)**, **3)** are not suitable because higher pressure drop are introduced; adjustment **4)** is not anyway suitable because of muffler weight increase. Thus a variable spiral step muffler is proposed which is characterized by the same pressure drop and the same weight; such an adjustment introduces more than 5dB reduction on noise components higher than 130 Hz.