Exhaust Gas Silencers for Diesel and Gas Power Plants

MAN Diesel & Turbo SE / PPPET Process Application Engineering
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Abstract

MAN power plants from 10 to over 200 MW are equipped with Diesel and gas medium-speed engines with mechanical powers between 10 and 20 MW each.

Through the acoustical design of the plant, several silencer types types are specified considering environmental and customers' requirements. In this article the attention is focused on exhaust gas silencers.

Nowadays, a direct or indirect control of the net sound emissions is to be expected in practically any application. An important challenge is the engineering of the silencer(s) in the context of the exhaust gas system requiring, besides an adequate interpretation of the boundary conditions and legal requirements, a proper design. Mistakes in such design can have serious technical (as too high emissions) and economical impacts on the project, as the need for replacing/installing additional silencers under strong feasibility and penalty constrains. Preventive measures, as simulation of the silencers and of the exhaust gas system as well as realization of factory acceptance tests help to reduce such risks. For this, strategic partnerships with specialized consultants and manufacturers, confident with the technics of their services and products, are a must.

1 MAN Diesel and Gas Power Plants - An Overview

MAN Diesel and gas power plants, covering a wide generating range from 10 to over 200 MW, are equipped with Diesel and gas medium-speed engines with mechanical powers typically between 10 and 20 MW each. Examples of these are the engines 20V 35/44 GTS (gas engine, two-stage turbocharging, 20 cylinders, 350 mm piston diameter, 440 mm stroke) or the 18V 48/60 TS.

From an acoustical point of view, the engine behaves as a multiple sound source as a result of its working principle (reciprocating engine) and of the combustion process. *Structure-borne noise* is transmitted through the foundation to the civil works, *air-borne noise* is radiated on its side directly to the surrounding air in the engine room, *intake air noise* is emitted from the compressor side of the turbocharger through the intake air unit directly to the outdoor environment, and finally, *exhaust gas noise* from the turbocharger outlet and an exhaust gas system as far as the stack outlet. In this article the focus is centered on this last sound source and the silencers required in the exhaust gas system to ensure that the allowable sound emissions are not exceeded. Fig. 1 and Fig. 2 show a typical engine room and the exhaust gas systems of a group of six generator sets of a power plant.

Fig. 1: Typical engine room

Fig. 2: 200 MW Diesel power plant

The exhaust gases are led from the engine through a first silencer, a SCR catalyst, a heat recovery boiler, a second silencer, and finally through the stack to the outer environment.

2 Unsilenced Exhaust Gas Emissions

The sound power emitted by reciprocating engines can reach overall levels between 130 and 140 dB(A), being the low frequency range from 20 to 80 Hz of particular importance.

Fig. 3 shows a typical narrow band spectrum of the unsilenced sound power level of an engine at the turbocharger outlet in the low frequency range.

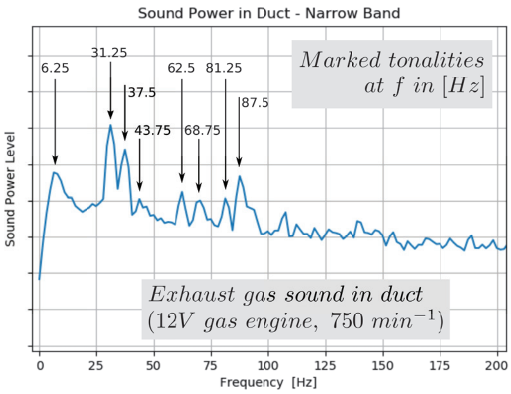

Fig. 3: Typical exhaust gas sound spectrum

Characteristic for the reciprocating engine are the tonalities with significant amplitudes in the low frequency range at few critical frequencies, something that manifests itself in the form of pressure pulsations in the exhaust gas flow. Such a behaviour depends strongly on the characteristics of the engine, among others the number of cylinders, the rotating speed, the firing sequence, the combustion process itself (pressure gradients), the pressure differences during the opening at the exhaust gas valves and the configuration of the exhaust gas ducting to the turbocharger.

3 Allowable Exhaust Gas Emissions

Exhaust gas sound emissions are, due to their considerable higher levels, to be attenuated, such that the impact on the surrounding environment does not exceed the legally established immission limits. In a strict formal way, the determination of the allowable emission is one of the results of the iterative process of the acoustical design of the power plant, for instance according to ISO 9613-2 under consideration of the legal and Clients' requirements as well as of the particular boundary conditions. Such a specification can be found in different forms, for example:

- Unprecise ("unsharp") formulations as a silencer with an attenuation of 35 dB(A)
- Still not precise formulations as a maximum A-weighted sound power level and in accordance to the legal requirements for the low frequency range, as the TA-Lärm in Germany
- Precise ("sharp") formulations specifying concrete limits for both the A- and C-weighted overall levels.

The difficulty to specify the allowable emissions in the low frequency range lies in the fact that requlations specify the allowable impact at the sensitive receptors. This can be explained with the help of the German regulation TA-Lärm in its current edition of 1998, section 7.3 and of Fig. 4.

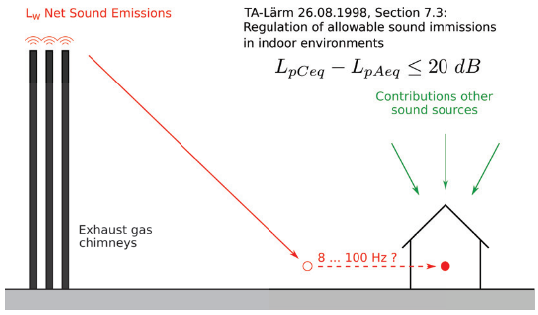

Fig. 4: TA-Lärm requirements in the low frequency range

Roughly speaking, TA-Lärm specifies through the German standard DIN 45680 a maximum difference of the C- and A- weighted sound pressure levels $L_{pCeq} - L_{pAeq} \leq 20dB$ in the indoor environment of sensitive receptors (as inside of residences) located in the neighborhood.

Since the (exhaust gas) emissions of a power plant will not be the only sound sources in its surroundings, a determination of the allowable contribution of the plant to the impact at the sensitive receptor is a non-trivial task, in particular when the existing noise impact (background noise) at the sensitive receptors is unknown. However, a verification can be carried out through determination of the noise impact at the outside of the sensitive receptor and estimation of a minimum damping characteristic of the building components.

Although the previous example was taken from the German regulations, equivalent requirements can be found in other countries as for instance the specification of a maximum A-weigthed overall sound power level level together with a limitation of the unweighted sound pressure levels in the 1/3 octave band resolution.

As a result, Fig. 5 shows exemplary both unsilenced (blue curves) and allowable (green curves) exhaust gas sound emissions.

For each of the two sets of curves the diagram show the Z-, the C- and the A-weighted unsilenced and allowable emissions. The difference between pairs of these curves

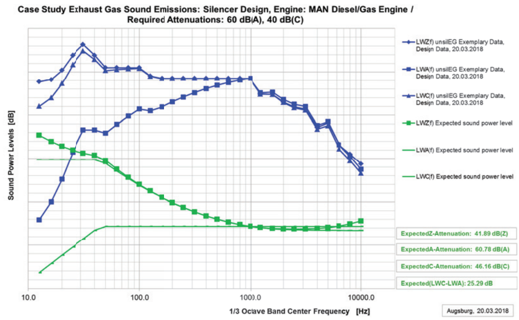

Fig. 5: Raw and allowable net sound emissions

does correspond to the required attenuation spectrum of the exhaust gas system:

$$\Delta L_{IL}(f) = L_{W,unsilncd}(f) - L_{W,silcd}(f)$$

with ΔL_{IL} as *insertion loss*.

4 Exhaust Gas Silencers

The *insertion loss* introduced in the section before will have to be provided by the exhaust gas system as a whole, but mainly by the silencer (set) itself. In a first approach, the eventual attenuation provided by all other components of the exhaust gas line (as ducts, bends, catalysts, boilers) is neglected due to the fact that their contributions are rather low or unknown.

Silencers for the power plants mentioned here are commonly of two types: *reactive* and *absorptive* silencers. To the first group belong typically so called *pass tube* silencers, *duct resonators* and *plate absorbers*, all of them sufficiently known in the literature. An overview is given in Fig. 6.

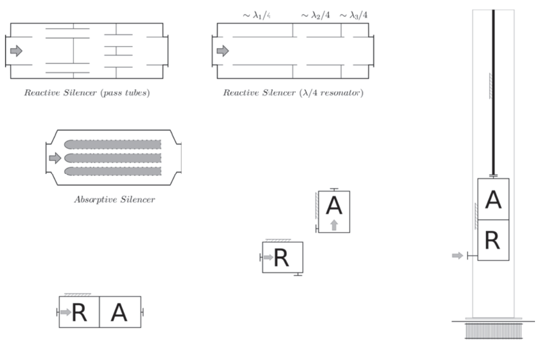

Fig. 6: Common silencer types

In general, the silencer design will be a compromise between the attenuation, the pressure losses and the dimensions, these last constrained directly by the overall space restrictions (feasibility) and the total mass (costs).

While absorptive type silencers are adequate to attenuate the sound emissions on a broadband in the middle and higher frequency range, reactive type silencers are to be designed to attenuate the sound emissions at very specific critical frequencies. In this sense, knowledge about the spectral distribution of the unsilenced exhaust gas sound in the lower frequency range is of particular importance. Contrary to *pass tube* silencers, *duct resonators* ensure lowest pressure losses. These are mostly foreseen with several concentric chambers, each with a different characteristic length and acting as a $\lambda/4$ resonator on a relatively narrow frequency range.

This has a direct impact on the dimensions of the silencer. Fig. 7 shows qualitatively the typical application range of $\lambda/4$ resonators and absorptive silencers as well as the relationship between the wave length and the dimensions of such silencers.

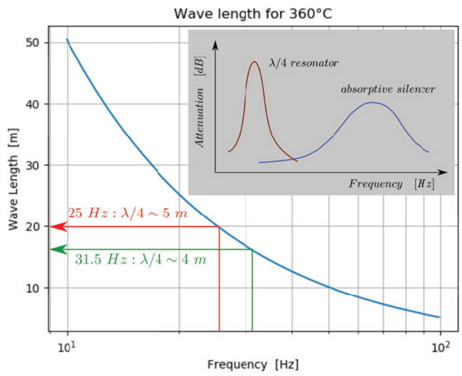

Fig. 7: $\lambda/4$ resonators, wave length and silencer dimensions

Should the low frequent emissions be characterized by higher levels on a broadband range, then the silencer will have to be provided with several $\lambda/4$ chambers requiring at the end a considerable length.

5 Validation through Simulation and Acceptance Tests

The sound propagation in restricted environments as inside of the exhaust gas system is characterized by standing waves, reflections and additional attenuations of minor or major significance. Since the main goal will be to ensure a maximum net sound emission at the chimney outlet, the necessary attenuation will have to be ensured by the whole system, even if it will be provided mainly by silencer (set) itself. Numerical simulations of the exhaust gas system allow to carry out a preliminary evaluation, and consequently, an optimization.

Condition for this is the knowledge of the geometrical data of all components and of the operating modes of interest. Contrary to series production, for instance in the automotive industry, the design of a power plant, including its exhaust gas systems, can be unique due to its very particular boundary conditions, such that the required data will not necessarily be available at the beginning of a project. When necessary, corresponding assumptions will have to be made.

In a first stage, and as part of the silencer design, a determination of the *transmission loss* of the silencer(s) and other relevant components is made. An example is represented in Fig. 8.

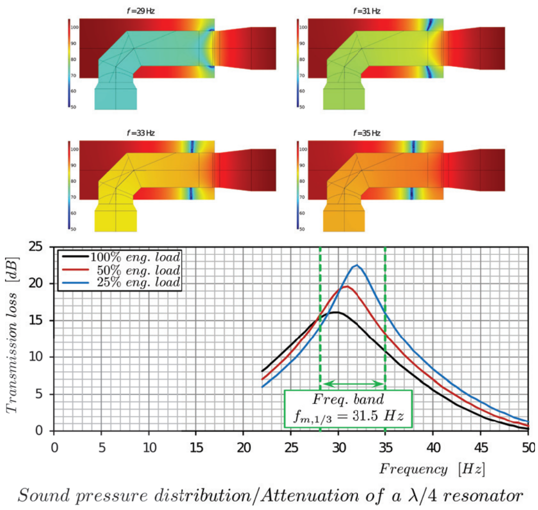

Fig. 8: Transmission loss of a $\lambda/4$ resonator

The diagrams represent first the quite different silencing effect of the resonator at different frequencies between 29 and 35 Hz. The diagram below shows on its side the effect of the different engine loads (consequently different exhaust gas temperatures) and the risk of displacing the effectiveness of the silencer to uncritical frequencies.

On the following, the sound propagation through all components of the system in the relevant operating conditions is simulated.

Complementary to the numerical simulation *factory acceptance tests* (FAT tests) are made. Due to the particularities of exhaust gas silencers (as the unusual forms, dimensions and masses), is not always feasible to test them in laboratories for standarized applications. Instead of that, special tests in the manufacturer's facilities (FAT's) might become obligatory. Fig. 9 shows exemplary some details of a measurement acc. to ISO 7235. Thanks to this arrangement, the *transmission loss* (TL) of the silencer can be determined.

A disadvantage of this type of tests is the fact that the measurements are made under conditions totally different from those of the real application: surrounding air temperatures, no engine noise, no flow, no exhaust gas system. Consequently, the results of the determined transmission loss will have to be "extrapolated" to the later operating conditions by appropriate shifting of the measured attenuation spectrum.

A determination of the net sound emission will be only

Fig. 9: FAT: Measurements at an exhaust gas silencer acc. ISO 7235

possible under real operating conditions at site (*site acceptance* tests (SAT tests, Fig. 10)) for instance acc. to standards as DIN 45635-47 or ISO 10494.

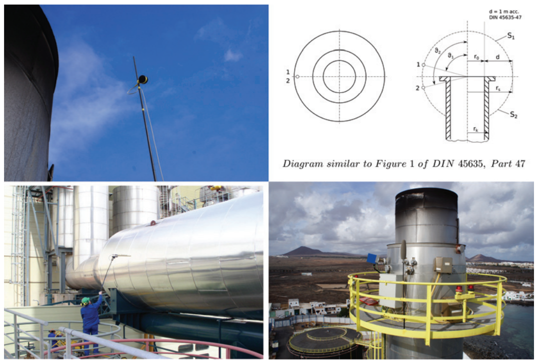

Fig. 10: SAT: Net sound emissions at chimney outlet, background and air-borne noise measurements

These standards assume that the indicated measuring points are representative mean values for the upper and lower semisphrerical enveloping surfaces over and below the horizontal plane at the chimney outlet. There are practical reasons for this. In a strict sense, the sound power determination at the chimney outlet should be made by measuring the sound pressure (better the sound intensity) levels at a series of points uniformly distributed over the whole spherical enveloping surface. However, in real applications this is not feasible in particular due to the too high exhaust gas temperatures over 300 °C.

Another issue is the background noise, in particular during the determination of the emissions of very low sound power levels, when the background noise at the chimney outlet can be even higher than the impact caused by the exhaust gas sound.