CASE STUDIES OF HIGH-PERFORMANCE INDUSTRIAL SCALE SILENCER AND FLUE GAS SYSTEM DESIGNS

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Abstract

We present three cases of verified high-performance industrial scale silencer and flue gas system design.

First is an exhaust silencer system for reciprocating engine test run, where low frequency noise was a nuisance at nearby dwellings. Measurements identified a low frequency tonal component. Complete exhaust system was redesigned to implement a distributed silencer system, including two reactive silencers and a broadband resistive unit. Measurements after installation at dwellings indicated the tonal component attenuation by 20 dB.

Second case is a pulp mill recovery boiler with induced draft fan noise audible at nearby residential area, during favourable wind conditions. Current silencers had modest noise attenuation and flow performance, probably exacerbating the fan noise generation. Measurements indicated a ca. 400 Hz tonal component. The exhaust system was remodeled to improve the fan performance and a low-loss baffle silencer was designed. Design target was 25 dB at 400 Hz and 20 dB A-weighted noise reduction. Commissioning test verified a 25 dB(A) reduction of stack top noise and pressure loss of under 200 Pa.

Third is a large passenger ship where low frequency tonal noise was identified in passenger areas. Engine source measurements revealed the engine periodic excitation. Classical Helmholtz-resonators were designed and installed in the exhaust ducts considering system performance. Commissioning measurements indicated attenuation of 15 dB in passenger areas at design frequencies.

Keywords: reactive silencer, resonator, finite element method, tonality

1. Introduction

Low frequency noise can sometimes be a nuisance, even when the A-weighted level of noise is not high or compliant to regulations. Situation can be emphasized by the total ambient A-weighted noise level being low, combined with typical lightweight house exterior wall having relatively high sound insulation at high frequencies, but sound insulation in the order of 10 dB at low frequencies. Hence indoors a low frequency tonal noise is further elevated in relation to other noise. [1], [2].

Retrofitting silencers is always more challenging compared to if the silencer(s) or the whole exhaust system would be designed initially to mitigate the noise sufficiently. In most design cases, available space is a constraint. This can lead to smaller silencers than what would be ideal, which can be a major challenge for reactive silencer design. The position due to available space, of the added silencer in the duct can also be non-ideal in terms of the whole exhaust system impedance design. [3], [4], [5]

In some cases, the installation of an additional silencer is very difficult, as the exhaust ducting has been covered or surrounded by other equipment, and there is no extra room. Such can be the case in, for example, a passenger ship.

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Successful silencer retrofitting and ultimately solving the noise problem requires field measurements with good skills in problem solving and acoustics. Sound pressure measurements performed with probe microphone from inside an exhaust duct ("in-duct") are crucial in establishing the noise source properties. Narrowband analysis is often needed to pinpoint the specific noise source and the exact frequency. Balanced design of the silencer is required so that the added component does not excessively disturb the existing exhaust system, where an additional silencer was not initially designed to be added. [3]

Finite element method has proven to be an efficient and accurate tool for designing and dimensioning reactive silencers for exhaust gas applications. In the presented cases, Ansys harmonic acoustics module was utilized as practical approach to design. Accumulated experience in silencer design ensures successful outcome, along with long-lasting co-operation with a well-known silencer supplier. Both the designers and the manufacturer need to have good idea of what can and what cannot be manufactured and installed in each specific case. [6],[7]

2. Methods

Critical to retrofit success is the successful definition of the problem. What are the relevant engine firing order and the fan blade bypass, what is the typical plant operating point and load.

2.1 Measurement method

Often sufficient information is obtained by relatively simple frequency space analysis, defining the sound pressure inside the duct by a single probe microphone. It is preferred to sample a sufficient physical length of ducting to capture a possible standing wave in the duct. See [4], [8].

In some applications with suitable system dimensions and acoustic wavelengths, it is possible to revert to wave decomposition [4], [8]. Application of wave field decomposition makes it possible to extract scattering or transfer matrix of the device under test (e.g. exhaust silencer, duct system section). The theoretical background is presented in [4] and also [9].

It is important to perform measurements at the right operating point of the plant. Exhaust or flue gas temperature, static pressure, acoustic pressure among others are largely governed by the engine or fan load.

For a reciprocating engine, the exhaust gas temperature largely varies as a function of load, differences can in the range of 200 °C. Reactive silencers are always tuned to a defined operating point, and while they do work sufficiently well around the specified temperature, the acoustic wavelength starts to differ significantly with large change in gas temperature. Hence the tuning of reactive element is not at the correct frequency anymore.

A fan appears to be a more sensitive fluid machine than reciprocating engine. Even a large industrial radial fan with output typically of ~30...50 m^3/s of exhaust flue gas at ca 150 °C is fairly sensitive to system outlet pressure losses, emphasizing the need for careful flow design.

A good basic quantity to observe in fan noise control is the specific sound power level or german Spezifischer Schallleistungspegel which combines the fan pressure increase and volumetric output to noise emission.

The fan operating point governs the rotation speed of the fan. In most cases, the fan blade pass frequency is visible in measured narrow band spectrum and the noise at blade pass frequency can be a source of noise annoyance. Therefore, proper selection and measurement at selected operating point is important, to be able to tune the silencer to give maximum attenuation at the blade pass frequency, or sufficiently low pressure loss over the silencer. [2], [9]

Further, using the robust single probe microphone measurement it is difficult to separate the propagating acoustic wavefield from turbulent pressure, especially near the fan outlet. To exclude this pseudo-noise of source result, it is often beneficial to measure >10 channels diameters downstream of fan.

2.2 Simulation method

Ansys Harmonic Acoustics module was used for finite element calculation of the silencers. Modelling approach for the presented cases was relatively straightforward and simple. The silencer geometries were modelled roughly to 5 cm accuracy using Ansys Spaceclaim. Meshing was performed inside Ansys, mostly with standard settings. The mesh size was selected to achieve at least 10 elements for the wavelength of highest frequency of interest, for example in engine test run exhaust resonators frequency being 200 Hz, corresponding to element size 25 cm. [7]

2.3 Target definition

When solving an already existing noise problem, it is necessary to target the design to reduce noise at least by 10 dB to make a meaningful audible reduction of noise. This is because of the old Weber-Fechner relation or Stevens' power law: 10 dB reduction equals the halving of perceived loudness of sound. [10] This is experienced as clear and relieving reduction of noise.

3. Reciprocating engine test run low frequency silencer

A nearby resident at approximately 300 m distance from the heavy-duty off-road engine factory test run had complained about disturbing low frequency noise in his apartment, particularly in the bedroom.

To assess the situation at the apartment, measurements were performed both outdoors at apartment vicinity and inside the bedroom, close to where the head of a sleeping person would be. Measurements were also performed in the apartment office room. Figure 1 presents the third octave band results of measurements, compared to national decree on housing health low frequency nighttime limit values. The limits were exceeded in both bedroom and office room. [11]

Based on the measurement results, and on the information of when the disturbance occurred, it was possible to identify the source of the noise to be a certain engine, in a certain test run.

In-duct sound pressure measurements were then performed in the factory test run #9, #10 and #11 exhaust ducts using probe microphone while six-cylinder engine and four-cylinder engine were running. Standard sound pressure measurements were also performed at 1 m distance from the exhaust stack top. Together these two measurements allowed identification of the noise source and on the other hand the noise attenuation properties of the current exhaust gas ducting and components.

Measurement results indicated that the source of low frequency environmental noise was the exhaust noise of a six-cylinder engine type, in test runs #9 and #10, frequency being 64 Hz. It was estimated that on low frequencies the sound insulation of the lightweight wooden exterior wall in the house of nearby resident is in the order of 10 dB. [2]

The current exhaust silencer unit was rather old and replacement was soon due to happen anyway. Noise attenuation performance of the silencer had perhaps deteriorated over time, therefore noise impact at nearby resident could have also been elevated due to silencer aging.

To attenuate the low frequency noise, a two-unit reactive and single absorptive silencer system was designed using Ansys finite element method to replace the current system where a single silencer unit was placed just before the stack pipe. In the new system, three silencers were installed, and the current silencer was removed.

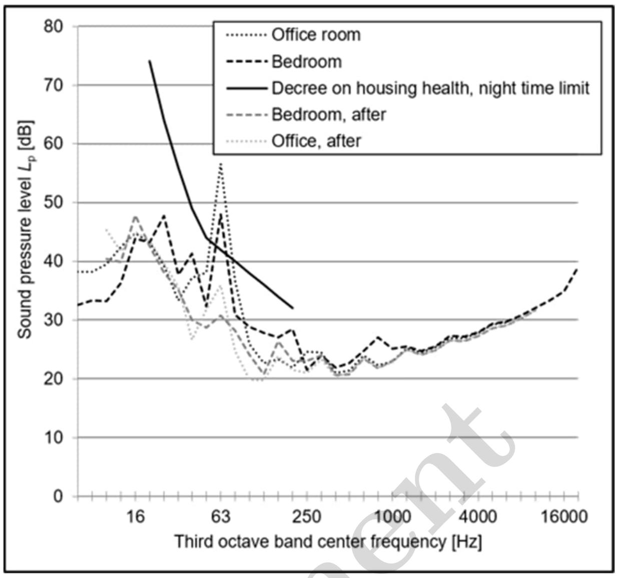

Figure 1. Measurement results before and after the silencer system installed.

Reactive silencers were of quarter wave resonator type, tuned to 65 Hz and 100 Hz frequencies, presented in Figure 2. The new silencers were positioned relatively early in the duct, effectively reducing the noise radiated by the exhaust duct downstream.

Figure 2. Two units of the three-unit silencer system visible in two adjacent exhaust ducts.

As shown in previous Figure 1, it can be concluded that the silencers work well and as intended. Both the overall low frequency noise level and the tonal noise peak at 64 Hz are effectively reduced, tonal peak by approximately 20 dB. The result can be considered a success, especially considering retrofit installation.

4. Recovery boiler induced draft fan noise silencer

The neighbouring residents of a pulp mill recovery boiler located in Central Europe had filed a complaint of noise. The noise situation was assessed on mill site.

Both in-duct measurements to define the fan source sensitivity to flow conditions and boiler load, and the flue gas stack top noise emission at different operating conditions were carried out. The flue gas system had two separate fans, both with their own moderately sized absorptive baffle silencers situated directly after the fan outlets. Both in-duct and flue gas stack top noise measurements at site revealed that there was a tonal component of approximately 400 Hz at blade pass frequency, in-duct measurement narrowband result in Figure 3. The stack top measurement tonality was rather slight, but audible at resident, Figure 4.

According to earlier design phase and measurements, the current silencers had A-weighted sound reduction performance of approximately 7 dB. The fans also struggled apparently with poor flow conditions, likely due to silencer placement very close to fan outlet, combined with abrupt flow direction change after the mufflers. There was a need to both reduce the flue gas stack top noise and to create better flow conditions for the flue gas fans.

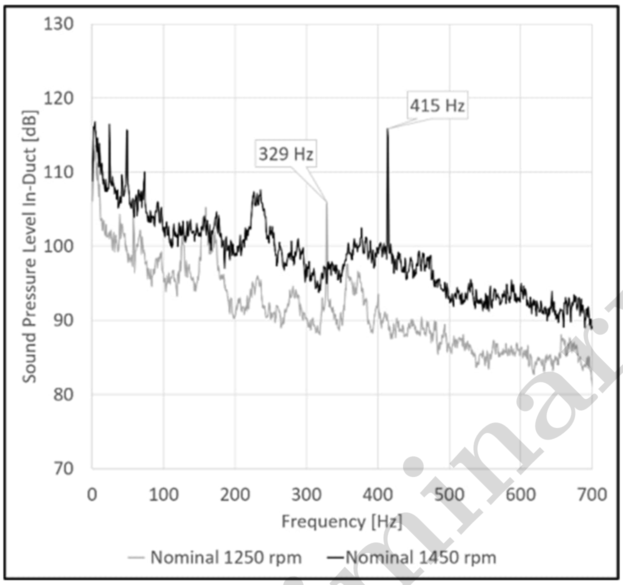

Figure 3. In-duct measurement of induced draft fan noise, measurement position after silencer.

Design target for replacement silencers was 25 dB noise reduction at 400 Hz frequency and 20 dB overall A-weighted noise reduction.

This can be considered overkill in hindsight, but oftentimes the practical installation is complicated and can be compromised. In any case, to achieve a successful noise reduction, it is necessary to reduce existing noise by 10 dB to induce a perception of loudness of half as loud, as referred to earlier. [10]

In addition, to provide better flow conditions for the fans, the flue gas ducting was redesigned, and the silencers were positioned further away from the fans in the new layout. Cladding of the new ducting was also dimensioned from noise radiation point of view to not radiate noise into the environment.

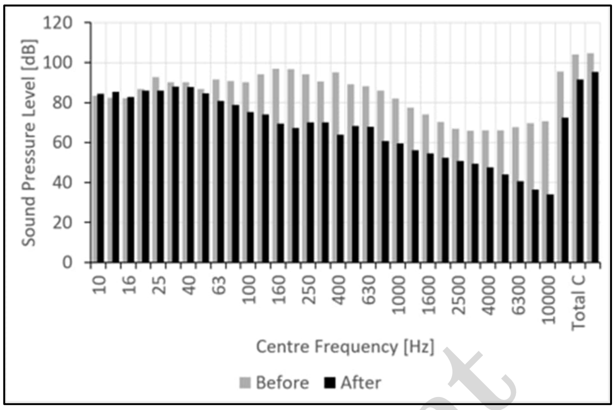

Figure 4. Impact of installed silencer and new duct system on stack top emission sound pressure level.

After the new ducting system and silencers were installed, commissioning tests verified a reduction of 25 dB A-weighted total level, and pressure loss of less than 200 Pa over the silencers. The slight narrowband characteristic of the environmental noise at 400 Hz band emitted by the plant completely disappeared. Ducting and silencer replacement was considered a success.

5. Large ship low frequency silencer

Low frequency "rumble" was identified on a large passenger ship during load testing at outfitting pier and sea tests in passenger lounge areas. Sound pressure measurements at the lounge revealed the noise to be a narrowband tonal component of 40 Hz. It was quickly determined that the source of the low frequency noise was engine exhaust ducting, which were situated relatively close to the lounge area. The ship had two types of engines, differing in the number of cylinders. Field tests including exhaust channel in-duct measurements for both engine types were performed to verify the cause and source of the noise.

Measurements indicated the source of the low frequency noise to be the exhaust gas noise of the 12-cylinder engine. The exhaust ducts had a main silencer positioned as last component of the exhaust line.

Additional 40 Hz Helmholtz (classical "mushroom" layout) were designed for installation into the exhaust duct. A significant challenge for the design and installation was that the ship was already built and being tested, so there was very little space for the additional resonators. The designed units had to be relatively small, and they had to be manufactured in pieces, to be hauled into ship and finally welded together inside the ship funnel shafts. The positions of the resonators were also governed by space constraints, so they could not be installed in acoustically optimal locations. On-site assembly and welding is challenging from dimensional tolerance point of view, and a volumetrically small Helmholtz resonator is sensitive to tuning shift when dimensions vary. Time was also of essence, timetable from measurements to design and installation was measured in days, instead of months as in a typical case.

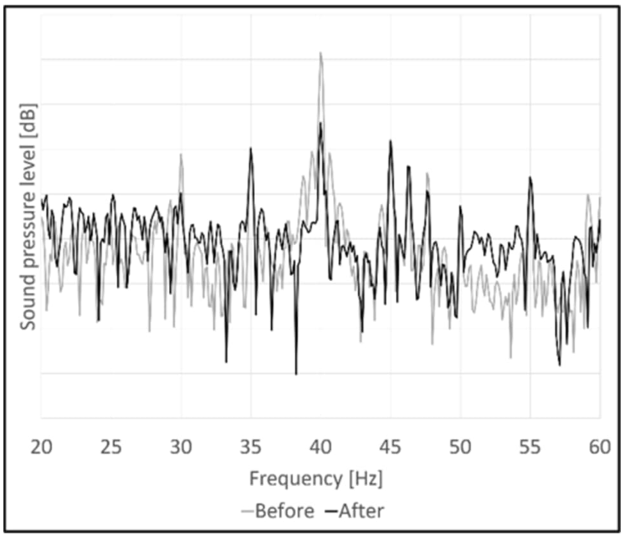

Figure 5. Reduction of 40 Hz engine harmonic in ship public space.

Measurement during subsequent sea test indicated narrowband sound pressure reduction of 15 dB at 40 Hz frequency at the lounge area, see Figure 5, effectively reducing the level of low frequency tonal noise or "rumble".

6. Conclusions

Three different high performance verified retrofit silencer and duct system design studies are presented. Problem solving started with field measurements, followed by design of silencer(s). In all three cases the situation was verified after installation by commissioning test measurements. In all cases the silencers worked as designed and noise level was reduced sufficiently, tonal noise was reduced by 15...25 dB, which can be considered a significant improvement.

Retrofit silencer design is always more difficult than when the silencer(s) is designed initially as part of the exhaust system. Most often there are space constraints, or silencer cannot be placed where the acoustical optimal position would be. Sometimes the limiting factor is the specified system performance, that does not tolerate the added pressure loss of the silencer, though pressure loss in typical reactive silencers is relatively low (typically less than 100 Pa).

Ansys harmonic acoustics module using finite element method has proven to be an efficient, user friendly and accurate tool for exhaust system silencer design. Long lasting co-operation with silencer supplier ensures efficient design phase and manufacturing, ultimately with good outcome at the plant or ship, solving the customer noise problem.

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