Vibro-Acoustic Analysis for Muffler Design

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Actran vibro-acoustic modeling software was used to solve a community noise problem involving the testing of large diesel engines. Redesign of the muffler resulted in an acceptable solution to the problem.

A night-time noise complaint was issued from the residential area near one of Wärtsilä's main large four-stroke, medium-speed engine factories located in downtown Vaasa, Finland. For example, the Wärtsilä 32 ship engine produced at the plant brings higher unit power, enhanced fuel consumption, significantly reduced componentry and integral computer control to a fiercely competitive sector of the engine business. The facility produces about 500 engines per year, and every engine is subjected to a test run. An investigation found that the likely source was exhaust noise from a W6L32E engine 1000-hour endurance test that was running continuously at 750 rpm and full load.

Challenge

An environmental noise study was conducted in the middle of the night when the test engine was running, with measurements taken at three locations between the test facility and the nearby residential area. Sound pressure level measurements indicated a peak in the sound spectrum at the 100-Hz. 1/3-octave band at approximately 94 Hz in a narrow band, which corresponds to the crankshaft rotation frequency (CRF) order of 7.5.

Typically the exhaust noise of the W6L32E engine should have the highest peaks at CRF orders 3 and 4.5. The measured noise was found to be well under the night-time environmental noise limit. The annoyance levels were presumed to be high because of the dominant, half-order, modulated, low-frequency noise components.

The exact cause of the 100-Hz, 1/3-octave-band noise was investigated with additional measurements taken near the engine exhaust system, located on the factory roof. High noise levels were noted near the first-stage silencer (Figure 1), which is a double-expansion-chamber, reactive silencer.

Measurements were taken at several points 1 m from the silencer surface. It was discovered the noise peak in the 100-Hz, 1/3-octave band dropped more than 10 dB when the engine load went from 100% to 75%, while the total noise level dropped by nearly 8 db. Speed sweeps were performed under varying loads to determine the resonances of the entire exhaust system. The primary peak in the measured sound pressure curves occurred at 94 Hz for 100% engine load and 90 Hz for 75-80% load.

Solution/Validation

"Wärtsilä requested that we use Actran to address this problem, because they wanted to evaluate the software's effectiveness in solving vibro-acoustic problems," said Erin Komi, a research scientist for VTT Technical Research Center of Finland, who performed the simulation.* Actran software was used to create a vibro-acoustic model of the silencer (Figure 2), including both internal and external air volumes as well as infinite elements for sound radiation computations. The mesh had 23.4 k nodes.

Either unit velocity or realistic pressure excitation was applied at the silencer inlet and a nonreflecting infinite-duct boundary condition was applied at the silencer outlet. A zero-admittance boundary, which characterizes the surface as a rigid wall, was applied at the laboratory roof. Field points were positioned in and around the silencer for comparison with physical measurements.

Initial simulation results indicated the occurrence of a longitudinal standing-wave mode in the first chamber at 75 Hz and a cross-channel mode in both chambers at 106 Hz. The primary acoustic resonances predicted by the model matched theory extremely well but failed to explain the source of the 94-Hz noise (Figure 3). However, a curved duct leading to the silencer inlet was of a length that could potentially have a first axial resonant frequency near 94 Hz. The finite-element model was then expanded to include both

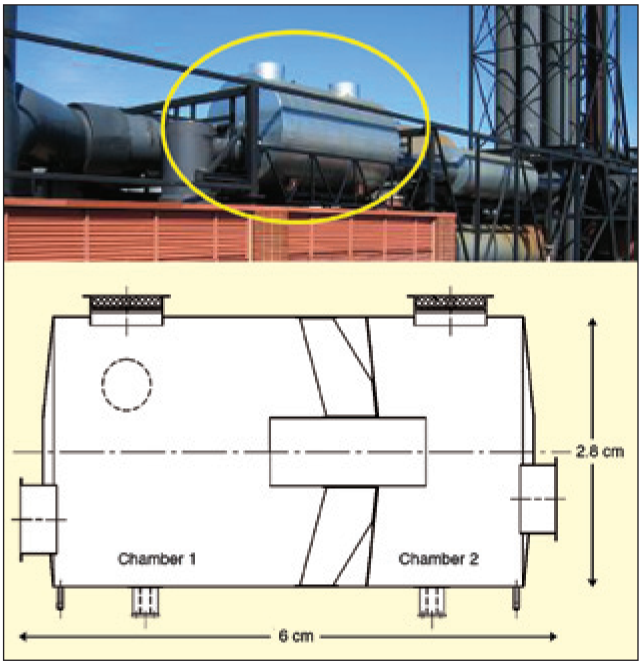

Figure 1. First-stage exhaust silencer.

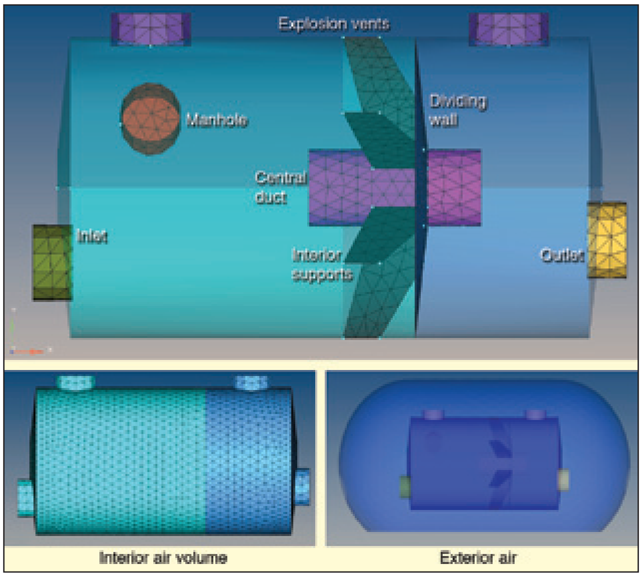

Figure 2. Original Actran vibro-acoustic model.

*VTT Technical Research Center of Finland is the largest applied research organization in Northern Europe. VTT employs and combines a wide range of world-class technologies and creates innovations in delivering applied research services that improve its clients' competitiveness and competence. VTT is a part of the Finnish innovation system under the domain of the Ministry of Employment and the Economy.

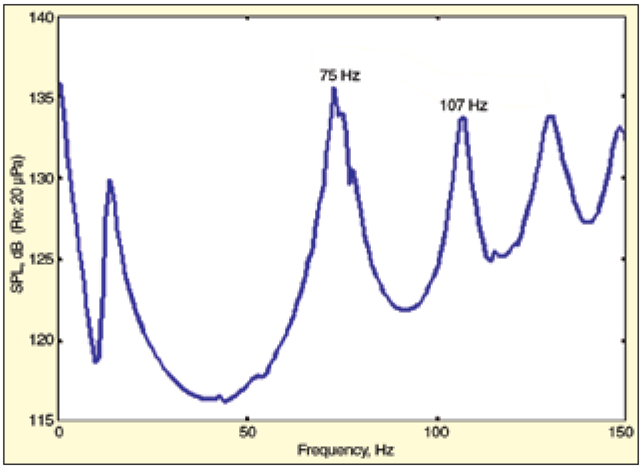

Figure 3. Mean-square sound pressure in Chamber 1.

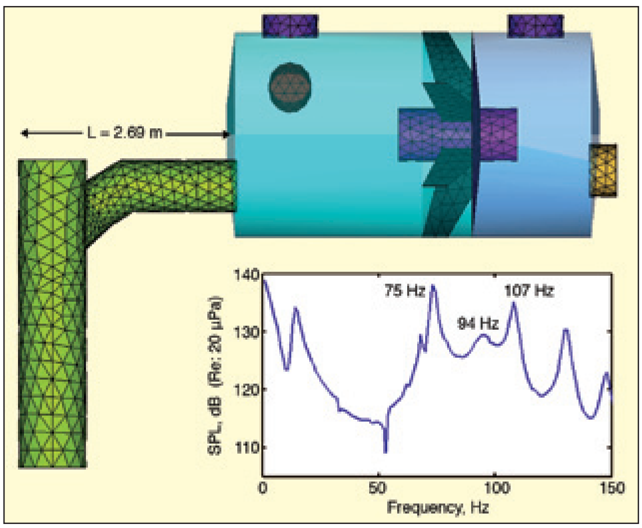

Figure 4. Modified Actran model and mean-square sound pressure in Chamber 1.

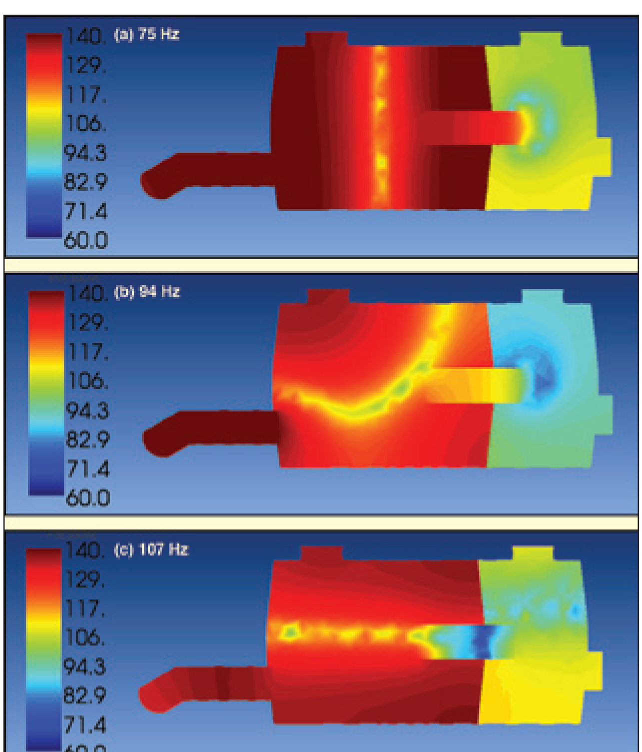

Figure 5. Sound pressure color maps (dB) showing pressure distribution inside the silencer at three frequencies.

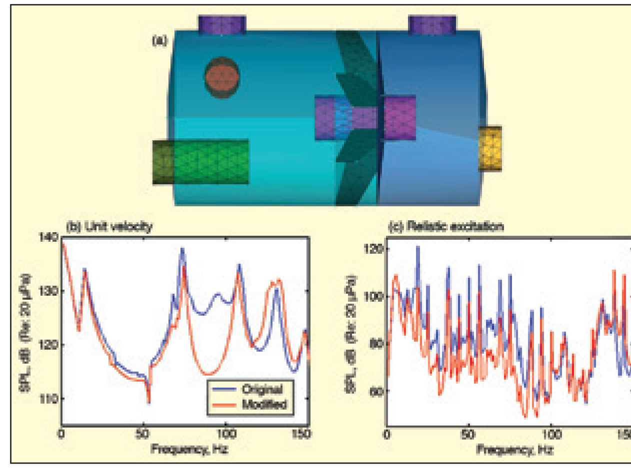

Figure 6. Simple suggested silencer modification and simulated mean-square sound pressure in first chamber for original and suggested design for applied unit velocity and realistic pressure excitations.

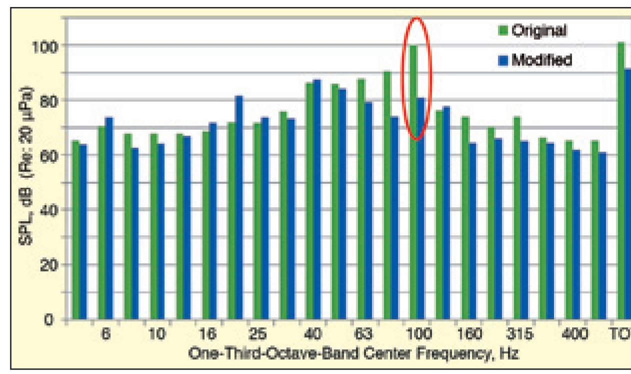

Figure 7. Sound pressure measurements for original versus modified design.

a 4.2-m vertical duct and the bent-inlet side duct (Figure 4). Sharp peaks were still seen at 75 and 107 Hz, but now a peak at 94 Hz was also clearly visible (Figure 4). The peak at 94 Hz was not as sharp as those associated with the actual silencer resonance, most likely because the associated standing wave is strongly coupled to the vertical duct, causing higher apparent damping.

"While physical measurements only provide sound levels at a finite number of points, Actran provides detailed predictions throughout the simulation domain (Figure 5)," Komi said. "Actran also allows us to easily modify the model and re-run the analysis to determine the impact of a change. In this case, when the original model did not shed light on the problem, we expanded the model to include the duct and quickly identified the root cause."

Extending the silencer inlet by 1.4 m to the centerline of the first chamber was proposed as a solution to the noise problem (Figure 6). Lengthening the horizontal duct leading to the silencer changes the resonant frequency so it no longer matches the engine order at 94 Hz.

Second, the extended inlet lies at approximately the nodal line of the first longitudinal and cross-channel modes of the first chamber, substantially reducing the effects of both modes. The simulation predicted that this change would reduce the sound level at 94 Hz by 7 dB and that significant reductions would also be made at frequencies near 75 and 106 Hz (Figure 6).

Results

The physical silencer was modified to match the changes made to the Actran model and sound pressure level measurements were repeated. The final measurement results showed that the modified silencer reduced noise in the problematic 100-Hz, 1/3-octave band by 20 dB, and total noise was reduced by 10 dB (Figure 7). With the help of Actran, it was possible to understand this particular noise problem, which resulted in a simple solution. SV

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