A NOISE CONTROL EXPERIMENT OF A DIESEL ENGINE TURBO COMPRESSOR AND CHARGE AIR COOLER SYSTEM AS A MACHINERY ACOUSTIC PROCESS

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1 INTRODUCTION

Engine noise levels are controlled to ensure a safe working environment for people working in and near engine rooms. Since the noise limits are tightening, it is necessary to implement noise control measures both to the engines and the engine rooms. Wärtsilä's targets for the engine sound power level reductions was 3 dB(A) for existing designs and 5 dB(A) for new designs. These reduction targets apply to a given engine size and power.

To reach these goals, Wärtsilä has had several internal R&D projects, in which both theoretical and practical noise control measures have been studied and tested. These measures have included exploitation of low noise components, application of low noise engine type (gas), and reduction and control of noise generation mechanisms, like gear hammering and improved designs of engine covers and partial enclosures.

Despite the work done over the years, 1…2 dB(A) depending on the engine type was missing from the targets in summer 2008. At that time, the deadline to receive the target was also predated by a year – there was less than half a year to the deadline. Turbo Charger (TC) and Charge Air Cooler (CAC) enclosure was designed and tested to demonstrate, that the missing dBs in the total engine noise reduction is reachable. In this paper we concentrate on the execution of an enclosure design and verification process. This kind of procedure, in general, is described e.g. in [1] and the need for this kind of pragmatic approach is outspoken e.g. in [2].

2 TC AND CAC ENCLOSURE DESIGN AS A PROCESS

2.1 Background

The challenging part in the process was the timetable. Whereas as the earlier noise control measures were developed, designed and verified over the years, since 2003. Only few months were available for TC and CAC enclosure development. It is Wärtsilä's company policy that noise control measures are tested and their attenuation is measured and verified with running engines. In the beginning of this project it was not known when, an engine will be available for the test. To compensate these challenging boundary conditions, it was agreed that an optimistic version of the enclosure is sufficient as demonstration. The enclosure would cover the TC and CAC entirely; this coverage was known to be slightly larger than required.

2.2 Few months to D-day - Calculations

The design process begun with spreadsheet calculations, by which the insertion loss (IL) requirement for the enclosure was determined. The calculations had three levels: The first level was based on the effects of the earlier noise control measures verified on the engines [3]. This gave the earlier mentioned 1…2 dB(A) remaining noise reduction requirement for the whole engine. The second level was based on the same measurements. Now the required reduction was transformed to a 4…5 dB(A) reduction for the TC and CAC sound radiation. The result was based on calculations with various engine configurations, both inline and V-engines, supporting the idea that same enclosure is feasible for all engines.

The third level was the calculation of the maximum insertion loss (IL) of the TC and CAC area excluding TC inlet noise. It was encouraging to notice that the IL potential was 7 dB(A). It was further calculated that a 10 dB(A) attenuation on all the surfaces, except the inlet, would result in 5 dB(A) total IL.

2.3 Few weeks to D-day – Ensuring results

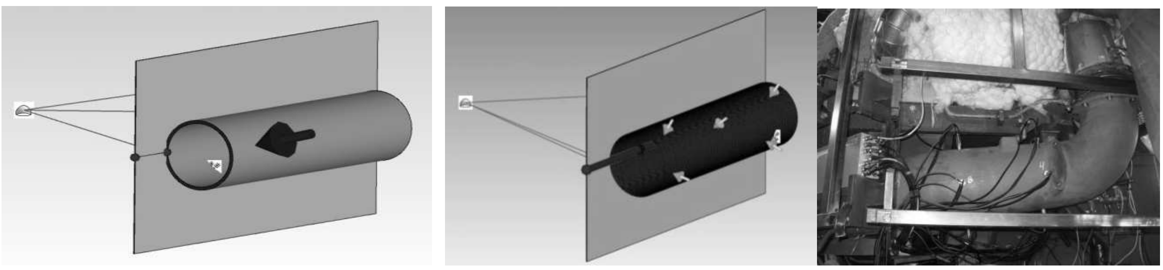
The first ideas of the enclosure were based on minimal structures and constructing, the idea was to use ”duct lagging” or “floating” -type treatment. The duct lagging performance was estimated by simulations in advance for number of reasons. One was to evaluate the materials and enclosure coverage required to meet the target. The second reason was to gain machinery acoustics understanding on the vibroacoustics behavior of TC related noise, i.e. to find out the issues concerning the system behavior and realization of the enclosure. The third reason was to make sure that we have at least some indicative results in case something went terribly wrong in the actual tests...

Both SEA and SEA hybrid methods were utilized for simulations. They were also considered as the only possible methods within the timeframe. All simulations were performed by Jukka Tanttari (VTT). Considering the boundary conditions, a simplified, but yet a realistic structure was chosen for the geometry.

2.3.1 The model

The air duct was modeled as a straight duct with a uniform diameter of 20 cm and uniform thickness of 12 mm. The length of the duct was 100 cm. The duct material was GRS. The cover plate (heat cover) was steel, with a uniform, 3 mm thickness. The plate (1,35 m x 0,676 m) was divided into two subplates and connected to the duct with three point connection of 15 mm in diameter and with a line connection to each other. The model is shown in Figures 1.

The duct had simply supported (or Pinned in VAOne) boundary condition in both ends. Both diffuse acoustics field (DAF, inside the duct, 1 Pa per third octave band) and randomized and normalized forces (to 1 Nrms) on the duct were used as a source. The randomizing meant 5 forces on the surface. The simulations were performed on 1/24 octaves. NTP conditions were used. Simulations were performed both as SEA model and FE-SEA model.



Figures 1. A VAOne models used to estimate the enclosure performance. On the right the real duct without the cover plate.

In the model, the duct lagging (enclosure) was modeled as a noise control treatment. The treatment was applied on the duct (air duct) and plate (heat cover) surfaces. The surfaces were covered with a 50 mm and 60 kg/m^3 wool (wool “guess” at the time) with or without a 50 mm air space between the wool and 1mm the steel plate. The treatment model did not include the wave propagation in the wool fibers or the wool loading effects on the cover plates [4].

The simulations, combined with the earlier experience, showed that 90…95% coverage of the TC and CAC (excluding the inlet parts) area and 50 mm absorption thickness combined with 1 mm steel plates was enough for the IL target, if the structureborne noise could be avoided. Obviously, almost any other surface material with the same surface mass would do.

2.4 Week to D-day - setbacks

It was only a week before measurements, and after discussions with both the mechanics and the engine test personnel that a frame was decided to be built for the enclosure. From vibroacoustics point of view, a frame meant the risk of structureborne noise, which could ruin the enclosure performance.

At the same time, it was realized that only one day will be available for the measurements and two days for building the enclosure. It was decided that the enclosed TC and CAC will be measured first and the unenclosed case after that – if time was to remain.

The meeting also confirmed that two different kinds absorption material will be necessary to meet temperature requirements. Luckily both materials were available from Wärtsilä subsupplier for silencers JTK Power Oy.

2.4 Days of ad hoc decisions and hard labor

2.4.1 Monday – D-day minus 2

Monday morning, the first building day, begun with decisions on how large the frame was to be. The choice was given to the builders, who were guided by saying that the consult will remain within 0,5 m from the enclosure during the measurements with running engine. Obviously excessive strength verification testing was performed to the frame before covering it, i.e. we spent an hour trying to tear it down.

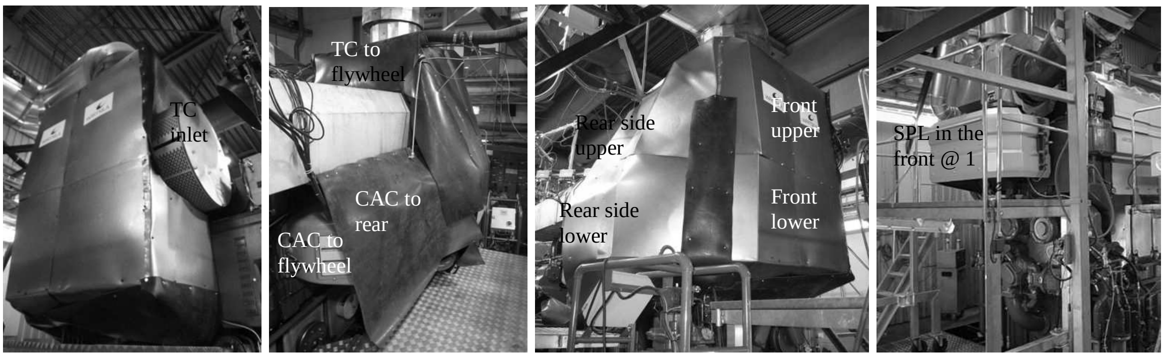
The risk of structureborne noise was evaluated qualitatively in the evening. It was done by hammering the rackets with the cover plates installed. In practice the judgments were made by ears. Two kinds of “vibration isolations” were chosen. For most of the structure, the more efficient (less risky) one was chosen. It was implemented by adding absorption material between the frame and the cover plates. On two surfaces, the wire net of the absorption material (with or without rubber sealant) was used to separate the frame and the cover plate. Based on the results (Figure 6), the latter kind of structure might have been just enough for the target.

2.4.2 Tuesday - D-day minus 1

Tuesday was the day to cover the frame with the “vibration isolated” plates – or with nitrile rubber (6 mm) to keep the timetable. The enclosure included two different wools. “White wool” (by Isover) was used for thermal insulation of the “hot spots”. Paroc Wired Mat 80 was the basic absorption and vibration isolation material. The wool also provided loading and damping to the cover plates.

The enclosure covered most of the TC and CAC subsurface, see Figures 2. The only subsurface totally without noise control treatment was CAC towards flywheel end. Also the TC inlet surfaces were partially enclosed and CAC to rear side was covered by nitrile rubber only. The open area of the enclosure could not be uniquely defined, but it was app. 5…10 %.

At the end of the day, while the consult was in the antenatal training, the engine was finally started and the short term durability of the enclosure tested. This was the first time everything actually looked promising – until that, we had been fighting for our life.



Figures 2. The enclosure and the engine (with cover plate) without the enclosure.

2.5 Wednesday – D-day

Wednesday morning began with the enclosure measurements. The enclosure performance was verified by intensity and SPL measurements. Scanning sound intensity, with 12 mm spacer, method was applied. The measurement surfaces covered the whole enclosure (all TC and CAC subsurfaces). SPL measurement points covered the whole engine.

The methods were applied to get maximum information for evaluation and comparison of IL results and to meet the in-house test code. The intensity results are considered to give a better estimate of the material (and structural).

2.6 Weeks after D-day - results and discussion

According to measurements the IL was 7,5 dB(A), when measured with the intensity method at full load. The first estimate, from third calculation level, from Novia's measurement estimated that enclosure max IL is 7,1 dB(A). These results are shown in Figure 3. The main differences between the spectra above 4 kHz are most probably caused by noise actually coming from other surface than TC inlet filter (which was unchanged in Novia estimate). Low frequency differences are probably due to measurement quality problems (noise from unenclosed areas).

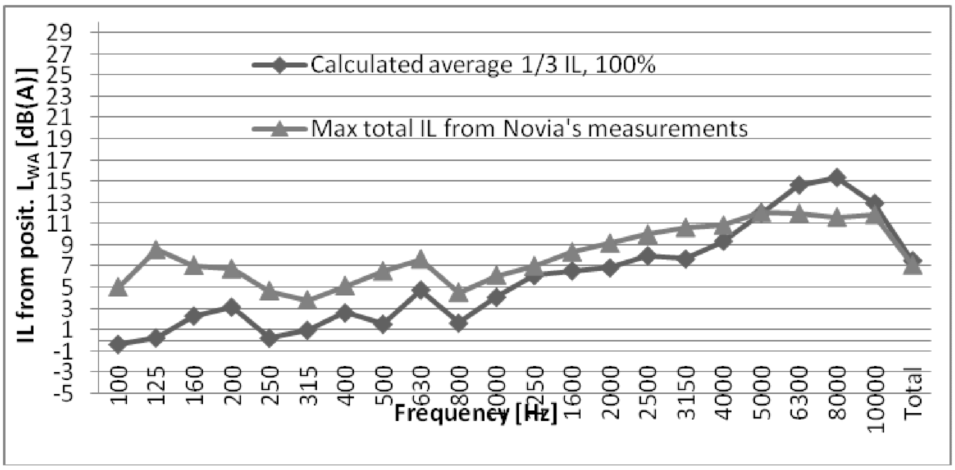
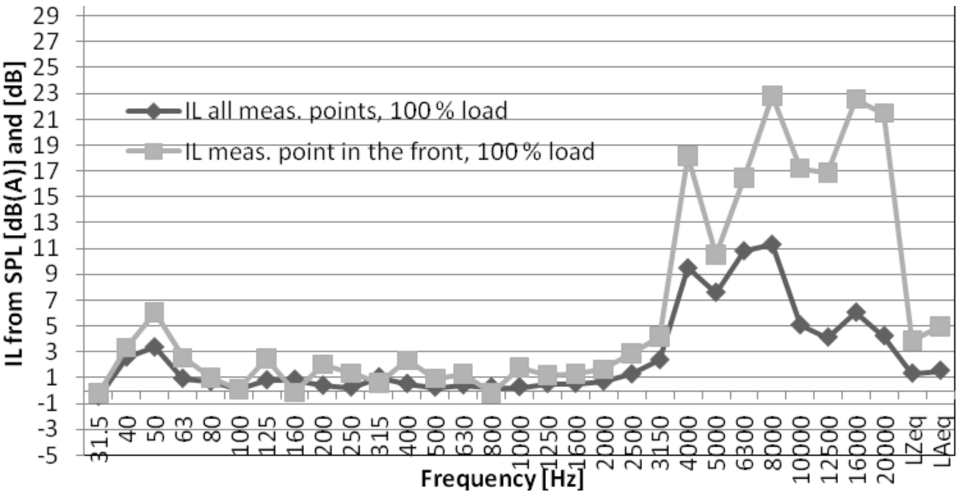


Figure 3. Calculated IL spectra from our measurements and Novia's measurements.

The SPL results are presented in Figure 4. IL in the front was 4,9 dB(A) on total level and 18 dB(A) on 4 kHz (third octave band of TC BPF). The average Il around the engine was 1,6 dB(A) and on 4 kHz band 9,5 dB(A).



Figures 4.   Measured SPL with and w/o enclosure at full load.

Figure 5 shows third octave band comparisons of simulated cases and four measured surfaces. The surfaces are the best from the measurement point of view and had 100% enclosure/treatment coverage. The simulated results are limited to 13 dB by the open area of 5 % (or coverage of 95 %).

The comparison to simulated SEA results suggests that the measured ILs under 4 kHz third octave band, are underestimated. There also appears to be a remarkable difference between the rear side and the front results. Structurally the difference is that Rear side lower panel did not have mineral wool between the plate and frame. The results show also a plausible difference between Rear side lower and upper panels (the upper ones have the “isolation, but are screwed to lower plates). Obviously, one need to keep in mind that incident sound power between the enclosed and “normal” case might be different.

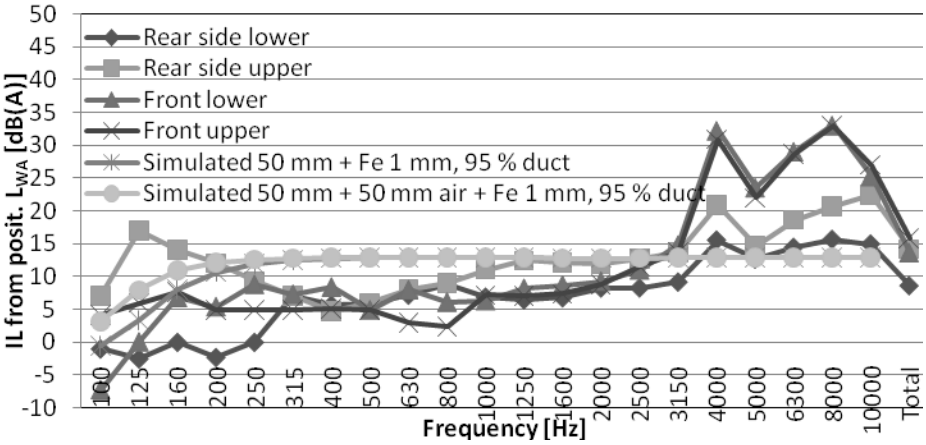
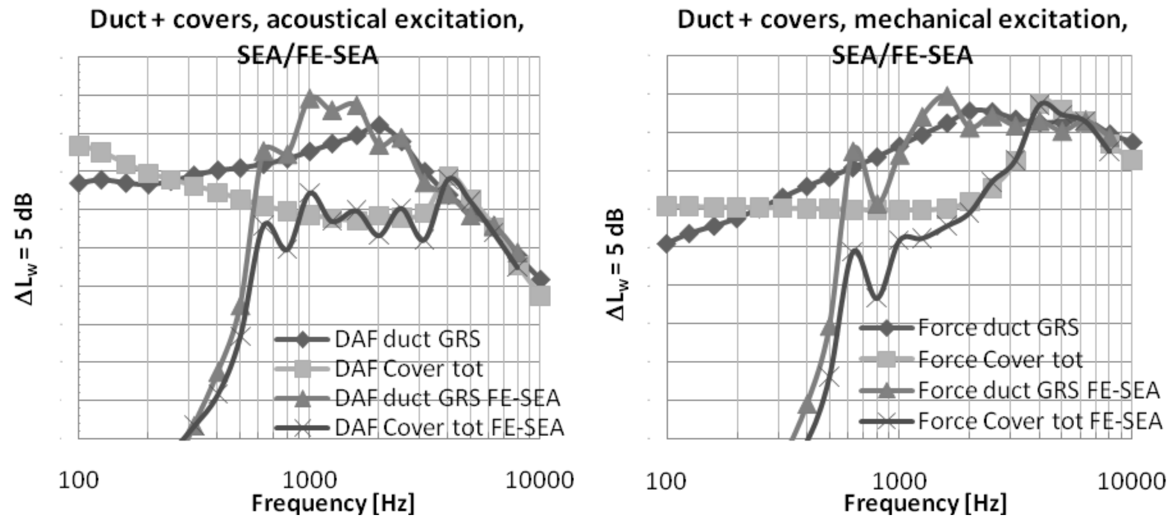


Figure 5.   Comparison of simulated and measured results.

Figures 6 show comparisons between SEA and Hybrid FE-SEA results. The differences are remarkable at and below the lowest natural modes of the components. On the other hand, the agreement is good above 2 kHz, where number of modes and modal overlap are high enough.



Figures 6. Comparison example of SEA and FE-SEA results with DAF and force excitations.

3 MONTHS AFTER D-DAY - LESSONS LEARNED

The bottom line of the test was clearly seen already during the measurements. The results presented here shows that the enclosure, in IL respect, even exceeded the requirements! Later evaluations have further shown that to increase IL, excitation reduction and/or further noise control is required. Noise control has to concentrate on TC suction and CAC areas, which contribute up to 70 % of the enclosed noise emission.

More realistic ways to build the enclosure for production purposes have to be developed and verified. Component based enclosures are preferred in present casing solutions. Still the same principles (materials, coverage and structureborne sound isolation or damping) have to be applied if good acoustic performance is wanted. Special care must also be taken to ensure sufficient cooling of enclosed components; it must be kept in mind that an acoustic enclosure should be as air tight as possible which naturally reduces the cooling by air flow.

Even though the simulations were “quick and dirty”, the results provided vital knowledge for a successful enclosure design within the tight schedule. In the design phase rough estimates for, and influences of, surface material mass, enclosure open area, absorption material properties and structureborne noise risk evaluations were obtained from the simulations. They also guided the decision making during the enclosure building; cover plate structureborne sound isolation, enclosure coverage and usage of rubber for faster the building process were evaluated against the results.

Furthermore, more detailed vibroacoustics simulations and measurements have a solid base on the lessons learned in the process.

4 REFERENCES

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2. Tanttari J., Karjalainen A., Koneakustinen manifesti. *Akustiikkapäivät 2001*, 8.-9.10.2001, Espoo, 75-80.
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4. Tanttari J., Kanavaverhousten vaimentavuus. AutoSEA2-mallinnus. VTT raportti TUR A002, 2000.