CYLINDER PRESSURE GENERATED NOISE OF MEDIUM SPEED DIESEL ENGINE

Lasse Lamula

VTT Technical Research Centre of Finland
P.O. Box 1300, FI-33101 Tampere, Finland
lasse.lamula@vtt.fi

Kari Saine

Wärtsilä Finland Oy
P.O. Box 244, FI-65101 Vaasa, Finland
kari.saine@wartsila.com

Kari Saarinen

VTT Technical Research Centre of Finland
P.O. Box 1300, FI-33101 Tampere, Finland
kari.p.saarinen@vtt.fi

Johannes Hyrynen

VTT Technical Research Centre of Finland
P.O. Box 1300, FI-33101 Tampere, Finland
johannes.hyrynen@vtt.fi

ABSTRACT

Ranking of noise generation mechanisms is essential for designing low noise diesel engines. Engine noise is caused by several excitations or sources of noise, such as combustion, turbo charger, piston slap, valve mechanism, fuel pumps, gears and inertia forces.

Noise generated by the cylinder pressure was studied using multipoint coherent power analysis. Cylinder pressure probes were mounted in all cylinders. Partial coherence functions were used to analyze the contribution of the cylinder pressures to the measured engine surface velocities.

The effect of different fuels, diesel and gas, was studied comparing cylinder pressures and measured vibrations and sound power levels. It is already known that a gas engine is more silent than a similar diesel engine. The reasons for the disparity are differences in combustion processes and absence of the fuel pumps in gas engines. The fuel pump causes impulsive excitations via the cam shaft to the driving gear. The importance of these phenomena was studied using a dual fuel engine.

1. INTRODUCTION

The noise level in engine rooms on ships must be controlled to ensure a safe working environment for crew working in and near the engine room. As the noise limits are becoming stricter, it will be necessary to implement extensive modifications to the engine and the engine room [1] itself to fulfil these limits. The A-weighted total sound pressure level in typical merchant ship engine rooms are usually 110…115 dB. Such high noise levels cause hearing damage even for a short exposure time.

Wärtsilä has several internal R&D projects where possible measures to reduce the noise from the engine are studied: use of low-noise components, use of low-noise engine types (gas), reduction of internal noise mechanisms, like gear hammering, improved design of engine covers and engine top part enclosure. Wärtsilä has set a target for the reduction of the A-weighted sound power of the engine by 3 dB for existing engine designs and by 5 dB for new designs.

2. MEASUREMENTS

A large diesel engine is a complex noise source. There are several excitation mechanisms and the sound radiation of the different parts of the engine varies widely. The sound power of the engine depends on several factors, such as the size of the engine, number of cylinders, engine load and speed, type and load of turbocharger and type of fuel. Therefore finding effective noise reduction measures requires various measurements.

2.1. Coherent power analysis

A diesel engine has various structure borne noise excitation mechanisms. The most obvious excitation is the combustion process. An easily measurable quantity which is proportional to the combustion process is the cylinder pressure. There was however no evidence that the cylinder pressure would have a remarkable contribution to the engine block vibration and thereby the noise. This contribution was examined by multi channel coherent power measurements.

Coherence functions are measures of linear dependence. They represent the correlations between spectral components of random processes. Multiple coherence [1] represents the linear dependence (correlation) between spectral components of for example the vibration of a crank case cover and those of a set of random processes such as the cylinder pressures. The product of the coherence function and the auto power spectrum of the output signal are referred to as the coherent output power. The coherent output power represents only the auto power spectrum caused by the input under measurement out of the auto power spectrum of the output. Hence the multiple coherent output power is used to estimate the amount of vibration energy at a response point correlated with the cylinder pressures.

The vibration responses were measured from 16 positions covering the W7L32 engine block, gear housing covers, crank case covers, cam housing, engine top etc. The measurements were made at the nominal speed with full power and with idling. A typical result is shown in Figure 1. When the ordinary auto spectrum of the vibration is compared to the coherent output power it is quite clear that at certain frequencies the vibration is highly correlated with the cylinder pressures.

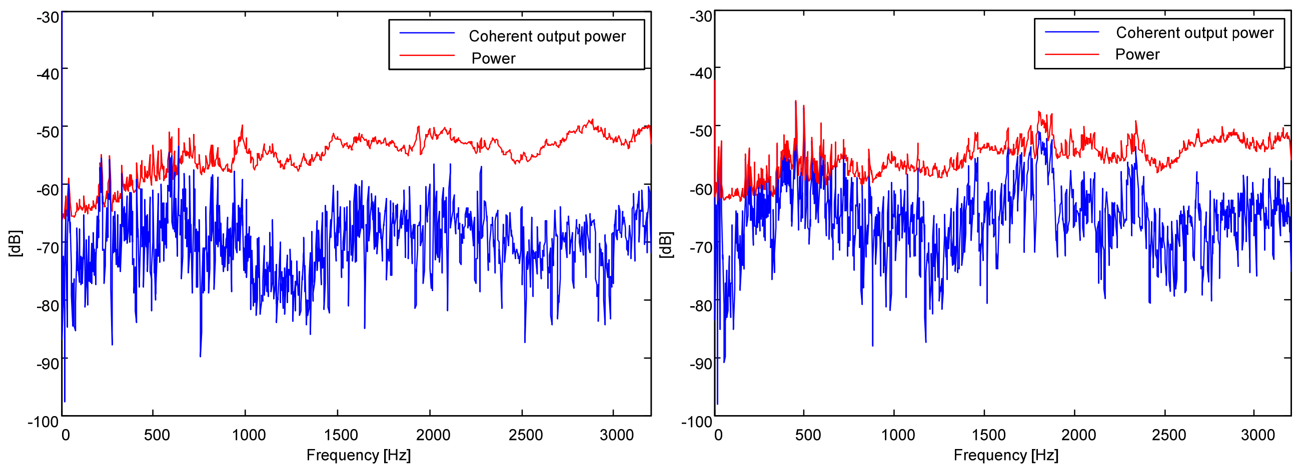

Figure 1. *Coherent power analysis of the point on the engine block of W7L32 diesel engine. Maximum load on the left side and idling on the right.*

2.2. Sound power measurements of a dual fuel engine

The studied engine is a 12V32DF (Dual Fuel) which means that the same engine can be run with both diesel and gas fuels. This is a V12 engine with cylinder diameter of 320 mm, nominal speed 720 rpm and the full load 4020 kW (335 kW/cylinder). Sound power level of the maneuvering side of the engine was measured using sound intensity method. The engine side was divided into 14 measurement surfaces (Figure 2). Sound power level estimates with diesel fuel and gas were measured at full load. Total sound power levels and corresponding 1/3-octave spectra are presented in Figure 3. Total sound power level difference is 4.5 dB.

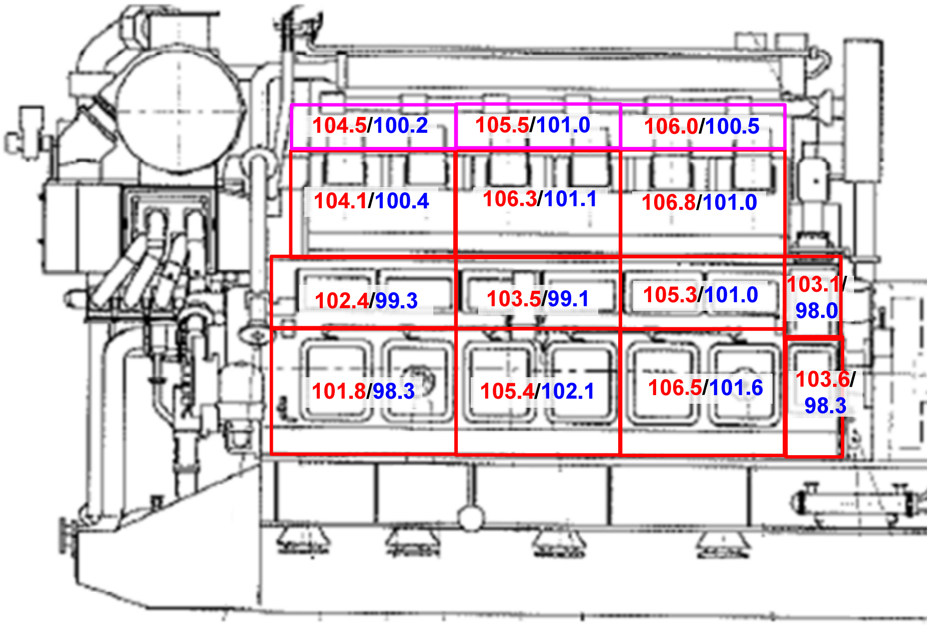

Figure 2. *A-weighted sound power levels of the maneuvering side of a 12V32DF engine driven with diesel (red values) and gas fuels (blue values).*

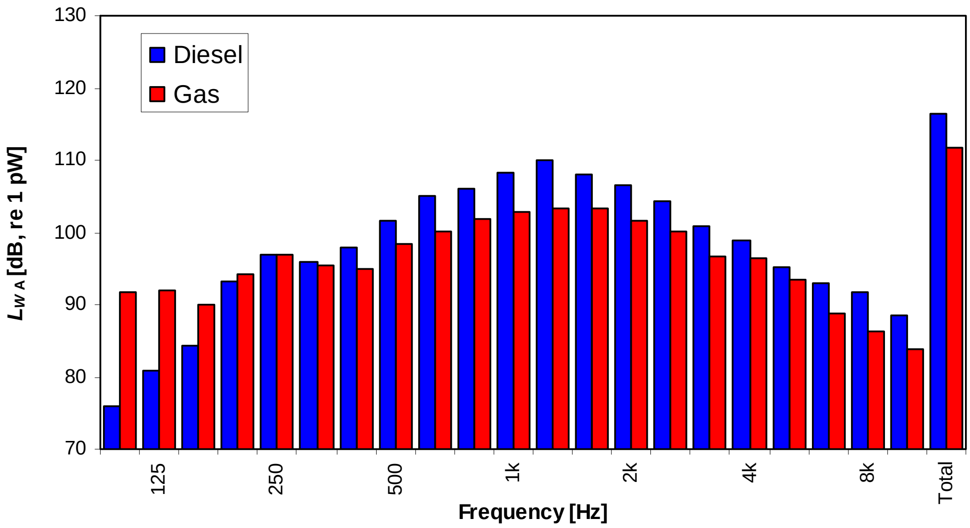

Figure 3. *A-weighted sound power level spectra.*

2.3. Torsional vibration of the camshaft

One of the most important mechanical differences between a diesel and a gas engine is the fuel injection pump which delivers the required fuel pressure of diesel engine at the correct time. A gas engine does not have an injection pump but the fuel is sucked in mixed with the air. The fuel injection pump generates impulsive excitation on the camshaft. This is one of the main noise excitations for a typical diesel engine.

In a diesel fuel engine the camshaft drives the injection pump by a cam. The load from the injection pump gives the camshaft a torque that intends to resist the camshaft rotation during fuel pumping period. Therefore a torque fluctuation is generated on the camshaft and the camshaft vibrates torsionally, as well as the cam gear.

Besides, the diesel camshaft torque increases significantly with engine load increase while the load variation has no influence on the gas engine camshaft torque. According to earlier measurements (Figure 4) the diesel camshaft torque is tripled at 100 % load compared to idle load.

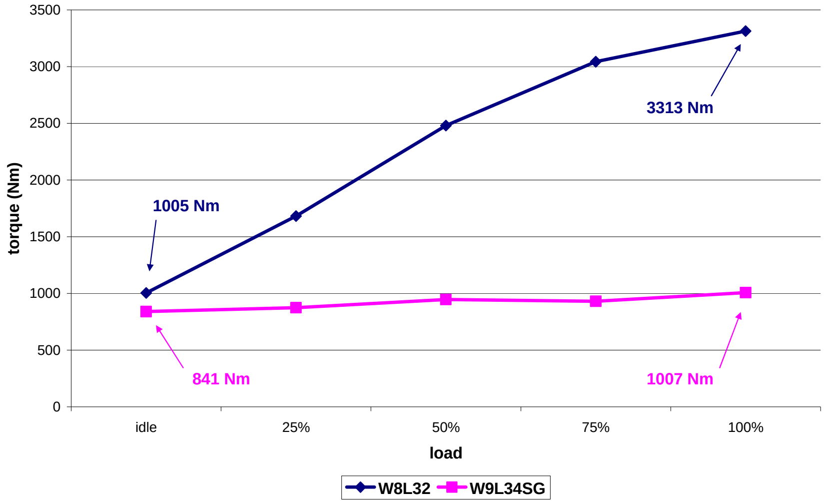

Figure 4. *Camshaft overall torque of a diesel (W8L32) and a gas engine (W9L34SG).*

Torsional tension vibration of the camshaft was measured with telemetric strain gauge setup. The results are presented in Figure 5. The harmonics of the firing frequency (36 Hz) are seen to be clearly distinct and the level with diesel fuel is generally 2…10 dB higher. It is assumed that this excitation creates gear hammering, which is typically detected as a stronger sound radiation in the vicinity of the gear. In this case however the sound power on gear area was not significantly pronounced.

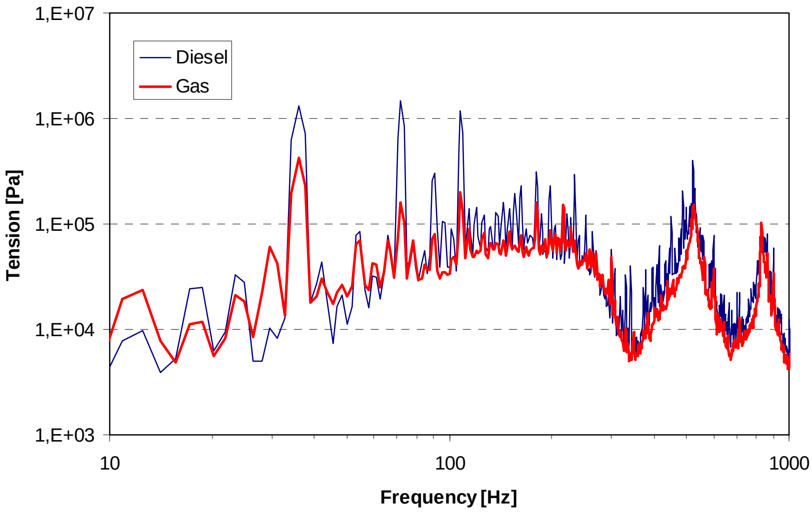

Figure 5. *Measured camshaft torsional tension spectra with different fuels.*

2.4. Cylinder pressure

Unlike the diesel combustion based on compression ignition that makes the cylinder pressure high, normal gas combustion is based on sparkle. With a DF engine a very small amount of diesel fuel is injected to ignite the gas which is taken in with the air. Therefore much less high frequency vibration and noise is believed to be generated on a DF as well as gas engine. It is well known that burning process of diesel fuel produces very similar cylinder pressure each time. When gas is used the cylinder pressure varies a lot more (Figure 6). Spectral differences were studied using cylinder pressure curves presented in Figure 7. Wavelet analysis was used to get an idea of the spectral variation over the time of combustion.

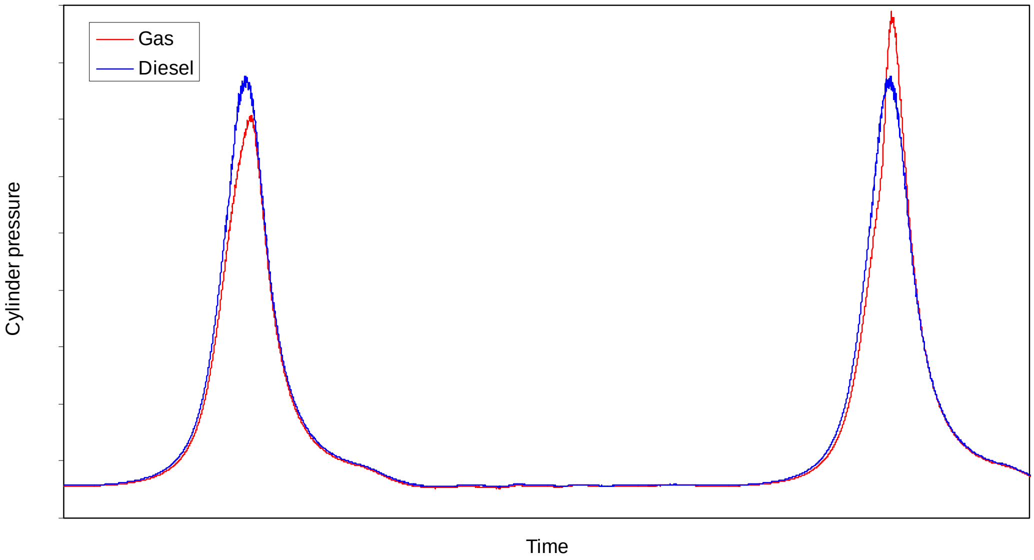

Figure 6. *Cylinder pressure variation of the gas combustion compared to the diesel.*

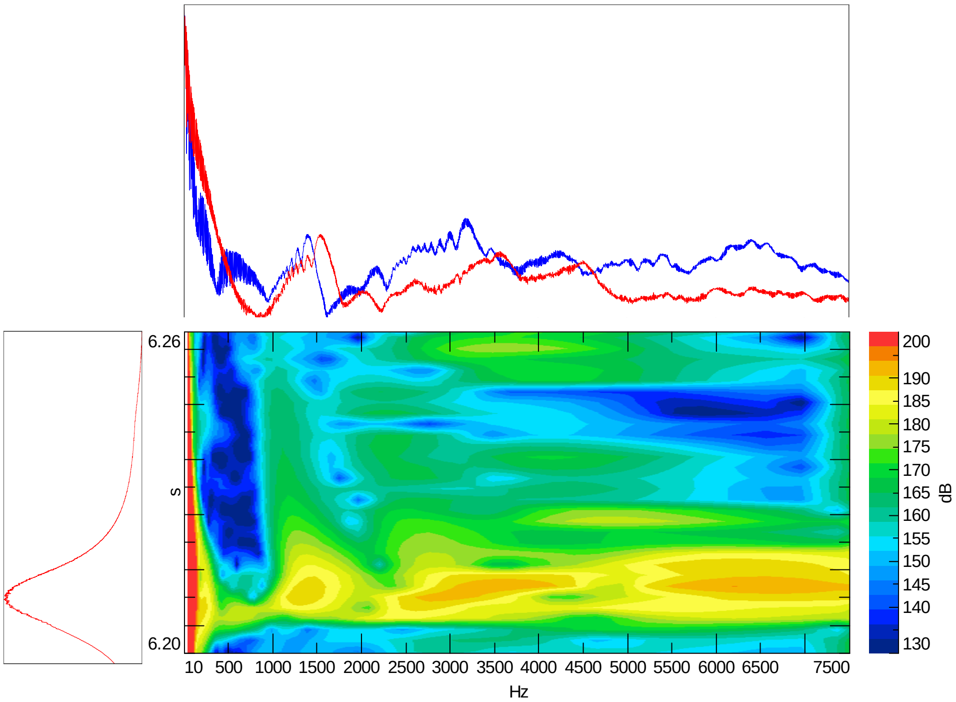

Figure 7. *Measured cylinder pressure. On top the average spectra with diesel (blue) and gas (red), below the pressure wave form and the wavelet spectrogram of diesel combustion.*

It seems that the high frequency content with diesel fuel combustion is due to the ripple of the cylinder pressure at combustion time. To verify this, the diesel cylinder pressure spectrum was calculated for a signal that was smoothed at the combustion peaks. A five point running average was used for the smoothing. The results are shown in Figure 8. The smoothing clearly changes the high frequency content of the diesel combustion spectrum to resemble the gas one.

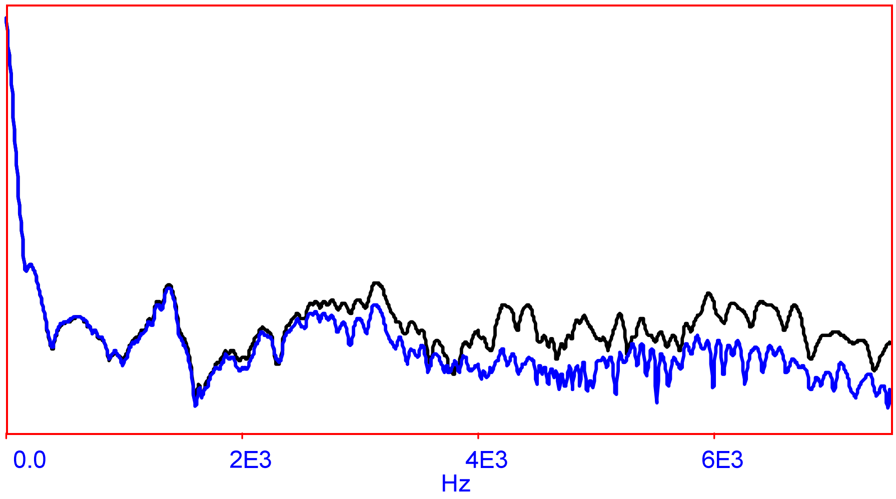

Figure 8. *The effect of the diesel combustion ripple to the cylinder pressure spectrum. Black = original diesel, blue = diesel combustion peak smoothed.*

3. CONCLUSIONS

Significant improvement was achieved by the acoustical optimization of the various covers [3]. Wärtsilä has a reached the mid point in our 5 dB reduction target for engine noise, and pretty much has been done without significant additional expenses. The measurements show clearly that the noise level of gas engines is much lower. It is obvious that the combustion process is one reason and another is the fuel pumps which cause torque variation to the gear. The cylinder pressure ripple of the diesel combustion seems to be the origin for the higher frequency content above 3 kHz. Finding the reason for this ripple is one of the next phases in designing a low noise diesel engine.

4. REFERENCES

[1] Bendat, J.,S., and Piersol, A.,G., "Engineering applications of correlation and spectral analysis". New York: John Wiley and Sons, 1993, ISBN 0-471-57055-9.

[2] Wollstrom, M., and Saine, K. "Reduction of diesel engine in machinery rooms," *Marine Engineering Forum/The Noise and Vibration Conference,* London 17 – 18 September 2007. Lloyd's List events.

[3] Aura, M., Lamula, L., Saarinen, K., and Saine, K. "Ranking of Partial Noise Sources and Noise Control Measures" in *14th International Congress on Sound and Vibration Proceedings,* Cairns Australia 9-12 July 2007, International Institute of Acoustics and Vibration, 2007.