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Innovative solutions to reduce the transfer of structure borne noise in couplings

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ABSTRACT

Modern couplings for ships and especially for mega yachts have to fulfill various tasks. Located between gearbox and propeller shaft, they have to minimize the transfer of structure borne noise while transmitting high torque levels. In addition, they have to resist high misalignments due to very softly mounted frames of ship engine and gearbox. Couplings also have to deal with sometimes difficult torsional vibration situations of the drivetrains, they have to be lightweight and in case of electric motors they often need electric insulation properties. To fulfill all these partly contradictory demands, innovative approaches are essential. In this paper, the development of a lightweight coupling made of a combination of glass and carbon fibers, elastomer layers and steel will be presented. After the design phase, the couplings have been tested at an acoustic test bed. In the next step they have been tested together with an Advanced Electric Drive (4 MW-range). And finally, the new Geislinger Silenco®-coupling has been validated during sea trials. Thus, the coupling helps significantly to reduce the noise radiation. This includes the noise reduction in the ship cabins as well as the noise reduction into the environment.

Keywords: Structure borne noise, Insulation, Transmission, Coupling, Hybrid propulsion, Electric drive

1. INTRODUCTION

The acoustic requirements for ships and especially for mega yachts are continuously increasing. On Mega yachts like (e.g. figure 1), noise and vibration must be almost imperceptible in the owner's areas while the engine is running at cruising speed. And due to rising environmental requirements, the noise transmitted into the water via the hull must be minimized more and more.

Figure 1 – A modern 100m-class Mega yacht at the pier of a shipyard.

Looking at the paths of the structure borne noise from the engine into the surrounding, the engine mounts used to be the most critical components. The sound pressure waves going from the engine via the mounts of the elastic or even double elastic mounted engine frame into the ships structure, and then further on as airborne noise into the cabins and as under water noise into the environment. (primary path in figure 2 shown in red). But the full potential of a resilient mounting system is achieved only if all other transmission paths are considered. The secondary path goes along the powertrain via coupling, gearbox, gearbox mounts, into the ship's hull, as shown by the blue lines in figure 2. Thus, together with the engine mount, the misalignment coupling is the most important component in the powertrain, where structure borne noise can be reduced significantly (1).

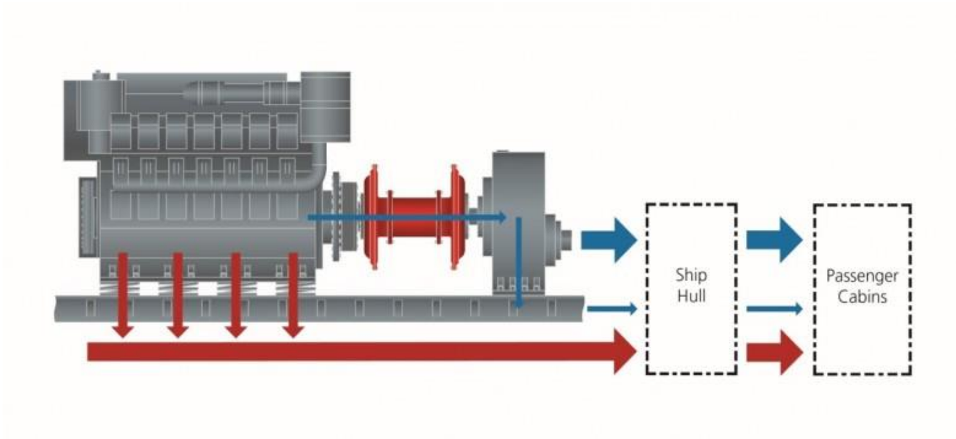

Figure 2 – The path of structure borne noise on a ship. Red: primary path, blue: secondary path.

2. Couplings in the powertrain of yachts

As an example, figure 3 shows a typical powertrain in a high-performance, hybrid Mega yacht. Usually the engine is built on a double elastic mount and coupled to a gearbox which is mounted either elastic or hard elastic. In hybrid applications, the gearbox is also connected to an electric generator or engine on a separate elastic mount. Most critical for the transfer of structure borne noise is the misalignment coupling between the gearbox and the propeller shaft (pos. 3, fig. 3). From the shaft bearings, the noise may be transferred into the whole ships structure and into the environment.

In many cases, the powertrain includes lightweight composite couplings (no. 1-3 in figure 3) as well as individually adapted streel spring couplings and dampers (no. 4 in figure 3).

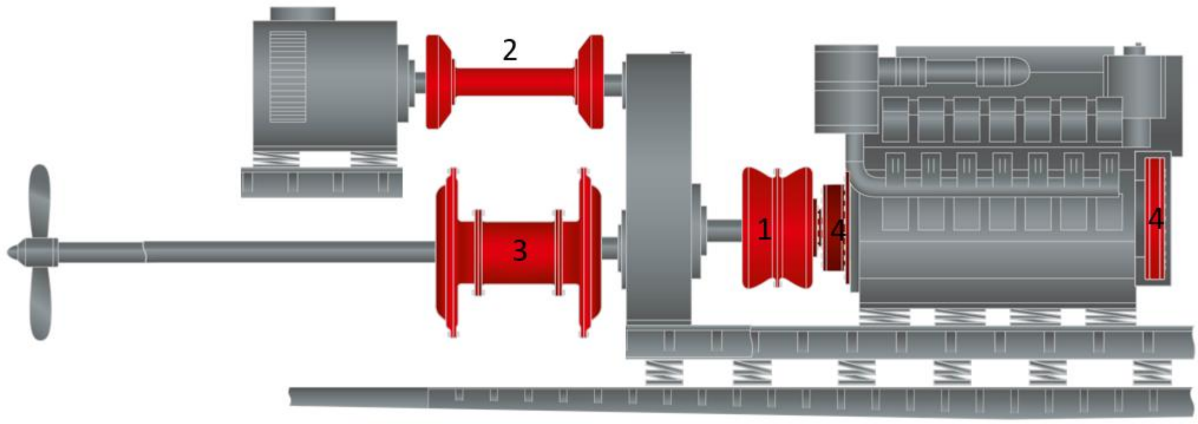

Figure 3 – An example of a powertrain in a mega yacht with different couplings (2).

The lightweight composite misalignment coupling no. 1 in figure 3 reduces the engine noise.

Figure 4 shows measured noise levels of such a Silenco®-coupling on the Geislinger test bed. The black curve shows the FFT of the acceleration sensor in front of the coupling (engine side), the red curve shows the FFT of the acceleration sensor in the rear (gearbox side). The coupling was excited with two electrodynamic shakers generating real engine noise. Typically, the highest noise levels will be between 32 and 160 Hz. It was possible to reduce the structure borne noise of the most critical engine orders by 27 dB.

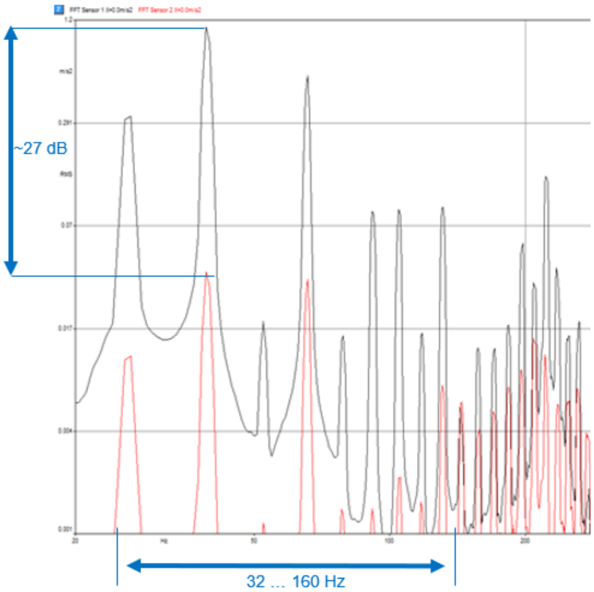

Figure 4 – The acceleration caused by engine noise measured in the front (black) and in the rear (red) of a coupling on the Geislinger test bed.

Often, the misalignment couplings are combined with steel spring couplings and dampers, see no. 4, figure 3. They mainly reduce the torsional vibrations, but also decrease the low frequency noise. Below 200 Hz, they can reduce the structure borne noise (torsional excitation) by up to 10 dB. Figure 5 shows the design of such a steel spring coupling, in this case under 50% load.

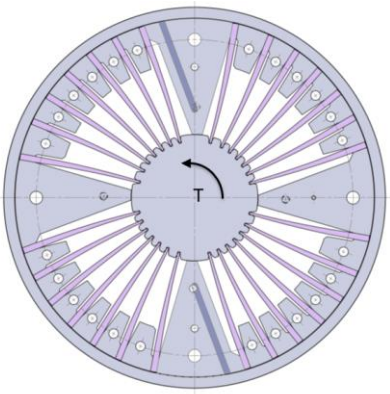

Figure 5 – The Geislinger NCA coupling.

Modern yachts are often built with a hybrid propulsion including a power take in (PTI) or a power take off (PTO). These electric generators or engines can easily be integrated using e.g. Membrane-Misalignment- Couplings made out of composite material with a composite shaft in between (see figure3, no. 2). The length of the shaft can be varied over a wide range. In this case, the transfer of the higher frequency noise, mainly caused by the inverters, needs to be minimized.

In most applications, the coupling between the gearbox and the propeller shaft is the most critical connection concerning the acoustics (see figure3, no. 3). The Geislinger Silenco® coupling was originally designed for this application as it can do both: transmit the high torque and reduce the structure borne noise to non-critical values.

3. Development of the Geislinger Silenco® Coupling

To achieve the noise reduction, as shown in chapter 2, a specially adapted misalignment coupling has been developed. The general equation of machine acoustics can be used to describe the transfer path of the noise through the coupling (3)(4):

$$P_i(f) = \tilde{F}_i^2(f) \cdot \frac{1}{Z_{E,i}^2(f)} \cdot T_{v,i}^2(f) \cdot S \cdot \sigma(f) \cdot (\rho \cdot c) \tag{1}$$

The equation includes the following parameters:

- P = acoustic power
- F = excitation force
- Z_E = input impedance
- T_V = transfer function of the structure-borne sound
- σ = radiation factor
- (ρ·c) = impedance of the surrounding media (usually air)
- S = radiating surface

An important factor for the design of the coupling is the transfer function of the structure-borne sound, which can be influenced by the material. Steel, composite materials and elastomer layers have different impedances. When the pressure wave of the structure borne noise passes the different materials, it will be partly reflected and damped.

Thus, the Silenco® coupling is made from carbon and glass fiber combined with elastomer layers. The segments are connected by steel bolts. Figure 6 shows a picture of the coupling. The outer sides, usually connected to steel, are the acoustically optimized flanges. They are designed with elastomer layers inside the power flow. Thus, the structure borne noise will be reduced as the sound pressure wave passes the materials with different impedances and damping factors. In between these acoustic flanges, the membranes of the couplings are located. They permit the necessary misalignment between input- and output shaft. To avoid noise caused by the movement of the membranes, they are built as a “sandwich structure” with elastomer layers in between the composite materials. In the middle, the membranes are connected to a lightweight composite shaft. The length can vary depending to the necessary misalignment and the customers needs.

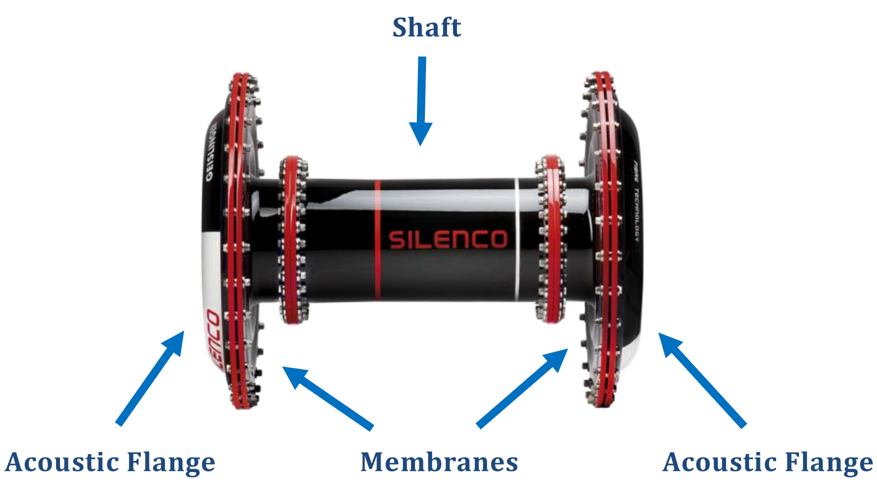

Figure 6 – The Geislinger Silenco® coupling.

Due to this design, the coupling is a modular system and easy adaptable in length. Further components will be available in the future. Due to the different sizes, it can be used for a wide torque range. With a diameter of 630mm (SC63), the coupling can transmit a nominal torque of 20 kNm with a weight of just 42 kg. Therefore, this coupling is not only highly efficient in terms of noise reduction but also extremely lightweight. This offers additional value to the shipbuilder.

4. Tests of the acoustic performance

For the development of the couplings and to confirm the predicted transmission loss, Geislinger has built two acoustic test beds in their Salzburg R&D headquarters. One is designed for the smaller couplings with up to 630mm diameter, (figure 7). The larger test bed can handle couplings with up to two meter diameter.

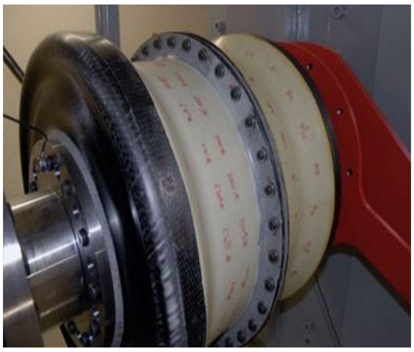

Figure 7 – A Composite Coupling on the Geislinger test bed.

During the test, electrodynamic shakers generate the vibrations, measured with acceleration sensors in front and in the back of the coupling to measure the transmission loss over the whole frequency range.

However, due to the different impedances compared to real systems, the transmission loss on the test bed may be different to the transmission loss in the real powertrain. Thus, in the last stage of the product development, measurements on the real systems are essential for validation. Figure 8 shows a measurement of a Silenco® SC140 coupling connected to the ~4MW Renk Advanced Electric Drive (AED), before the system was installed in a ~110m Mega yacht. The measured structure borne noise levels for narrow band and 3rd octave band are shown in figure 9. These measurements confirmed the predicted noise reduction of the coupling.

Figure 8 – A Silenco® coupling tested with the Renk AED.

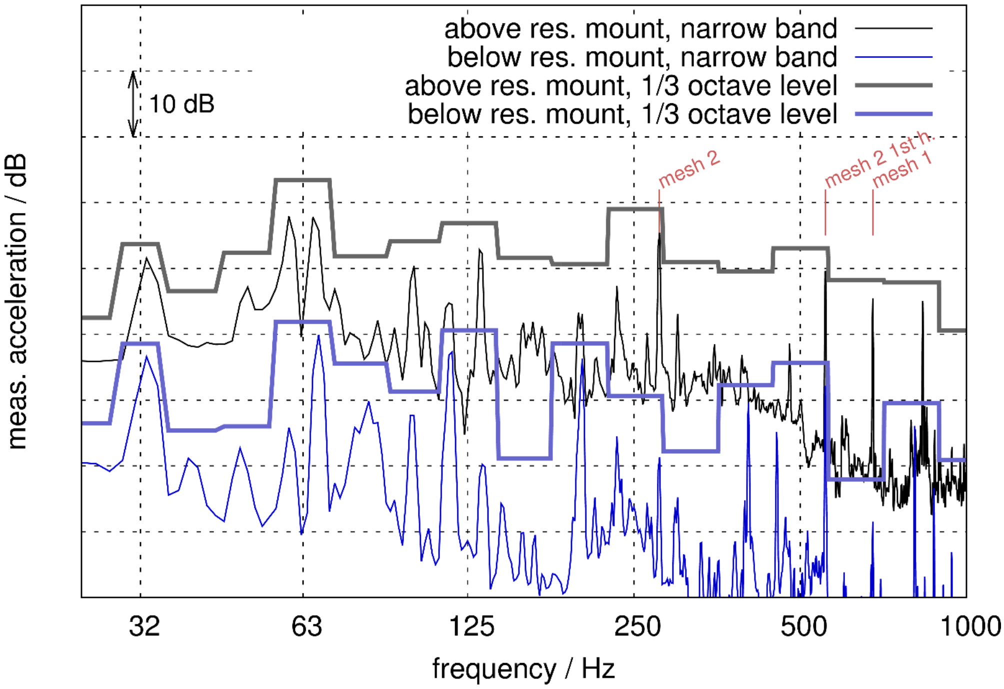

Figure 9 – Measured structure borne noise levels for the AED (1).

In addition, there is always a dynamic interaction between the shipside machinery foundation with limited stiffness, the resilient mounting system and the machinery itself (4). This makes an on-board validation essential. Figure 10 shows a vibration measurement of a coupling on board a ship during a sea trial by laser vibrometry. In the background, the (already low) vibration of the soft mounted frame with the engine and the gearbox can be seen in yellow and red with measured surface velocities below 300 µm/s. On the right-hand side is a Geislinger coupling between the gearbox and the propeller shaft. As the green colour shows, the vibrations are reduced to below 50 µm/s in this case (1).

Figure 10 – Validation of the transmission loss of a Geislinger coupling during a sea trial (1)

5. CONCLUSION

To minimize the transfer of structure borne noise on ships from the engines into the ships structure, ships cabins and into the environment, the secondary path from the engine via the gearbox and the propeller shaft has become more and more important. In such a drivetrain, the couplings do not only handle the misalignment. They can also be used to minimize the structure borne noise. Due to the material impedances and damping factors, lightweight couplings made out of composite material and elastomer layers are an efficient and lightweight option to minimize the noise transfer. Measurements on test benches as well as during sea trials of ships proved that they are able fulfill the requirements for ultra-silent propulsion.

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