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AVIIS, ACTIVE VIBRATION ISOLATION IN SHIPS: SOURCE IDENTIFICATION AND ANVC APPROACH

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ABSTRACT

Engine induced sound and vibration levels in boats for professional and leisure use is in many cases unacceptably high in term of comfort and the environment. Classical methods for passive treatment are normally less effective due to the low frequency content and often leads to an increase in weight. This contradicts the requirements for lower weight for increased speed. More efficient vibration damping methods must therefore be found. With active engine mounts, it is possible to achieve a decrease in the vibrations even when the hull is not very stiff. This is especially important in marine applications since the engines are mounted on weak and light structures. The AVIIS project aims at investigating the effects of a combined passive/active engine mount for use in boats. A Storebro 36 Royal Cruiser with two Volvo Penta engines has been used in the project. Four different approaches have been appraised, the results of which are presented here: 1. passive engine mounts, with and without thrust bearings, 2. optimized passive engine mounts, 3. passive engine mounts, rigidly mounted, 4. A combined active/passive engine mount. This paper reports the key data from the measurements and how the different primary sources have been estimated from the analysis. This analysis has then been used to select the ANVC approach.

1. INTRODUCTION

For the AVIIS project, a 1985 Storebro Royal Cruiser 36 Baltic boat powered by two Volvo Penta Diesel engines, TAMD 63P, has been used. It is a luxury cruiser built by the Storebro shipyard in Västervik, Sweden. Despite stringent requirements on noise and vibration the boat could benefit from a lower noise level, enabling a relaxed conversion in the saloon. This is difficult to achieve with a classical solution [1][2]. The new engines give 265 kW each at 2800 rpm and are turbo charged. The propellers are RADICE S8 and the top speed of the boat is approximately 23 knot. **Figure 1** gives a view of the boat during a cruise outside the Gothenburg coast.

For the first series of measurements the factory-installed engine mounts, Metalastic 65 Sh, were used. In **Figure 2** below the Metalastic engine mount is illustrated as well as the other mounts used in the tests. The Metalastic 65 Sh engine mounts are quite rigid since no thrust bearing was originally used. A softer engine mount could have been used when a thrust bearing is mounted.

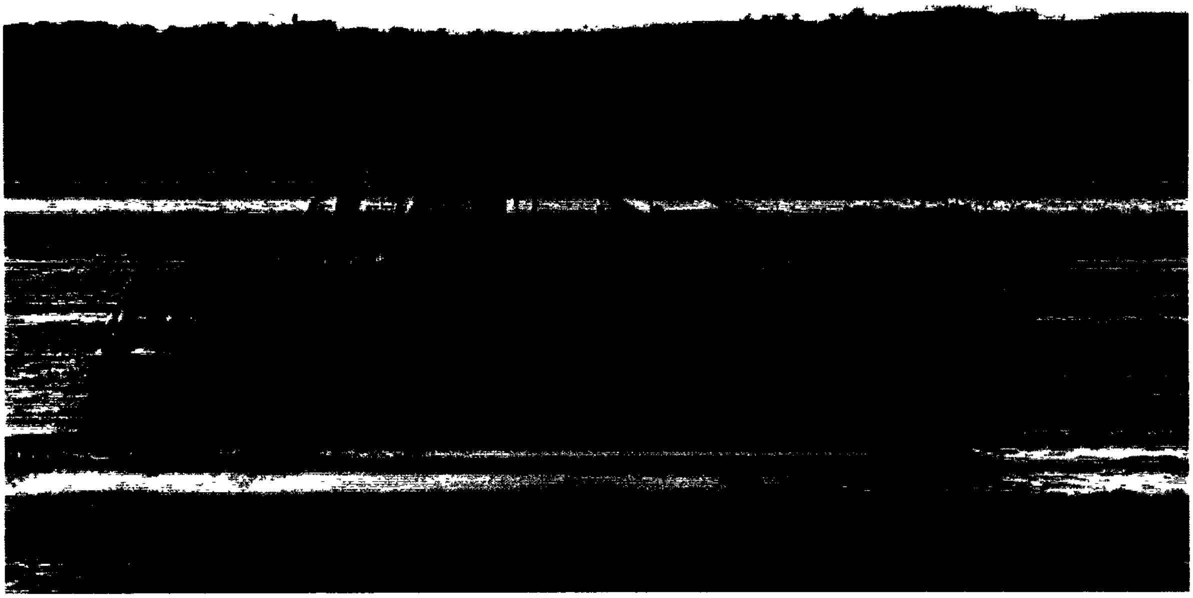

Figure 1. A view of the 1985 Storebro Royal Cruiser, a 36 foot boat equipped with two Volvo Penta TAMD 63P Diesel engines with 265 kW @ 2800 rpm.

The test series has compared the boat with and without thrust bearing, standard Metalastic 65 Sh engine mounts, completely rigid mounting and a set of Novibra RA800EM engine mounts. Vibration levels on the engine mounts, selected hull points, reference microphones in the saloon and two tacho signals were recorded for the vibration phase. In order to be able to find the main noise sources, run-ups, run-downs and steady cruise at several common RPMs were measured. One of the reasons for testing several passive solutions is to enable a good comparison between the active/passive and different classical passive solutions. It is important to know what difference in performance that can be expected by using an active/passive solution instead of a classical approach. Many active projects compare active on/off, but this is not a fair comparison since the best passive should be compared with the combined active/passive. It has been an important goal in the AVIIS project to handle this comparison.

2. ENGINE MOUNTS AND THRUST BEARING

In order to give a fair comparison between the active/passive system and classical standard solutions, tests with different engine mounts have been performed. The hull has only been modified to fit the new VP TAMD 63P engines and it has a stiffness that is comparable to a standard installation. There has not been any intention to reinforce the hull to make it more rigid. **Figure 2** illustrates the three different engine mounts used in the tests.

The blade passage frequency, BPF, of the propeller generates some large pressure variations that will be transmitted through the hull but also via the propeller shaft. If this sound should be handled by the active system, it is of outmost importance that the main sound from the propeller is transmitted via the propeller shaft and engine through the engine mounts to the hull, and not directly to the hull via the water.

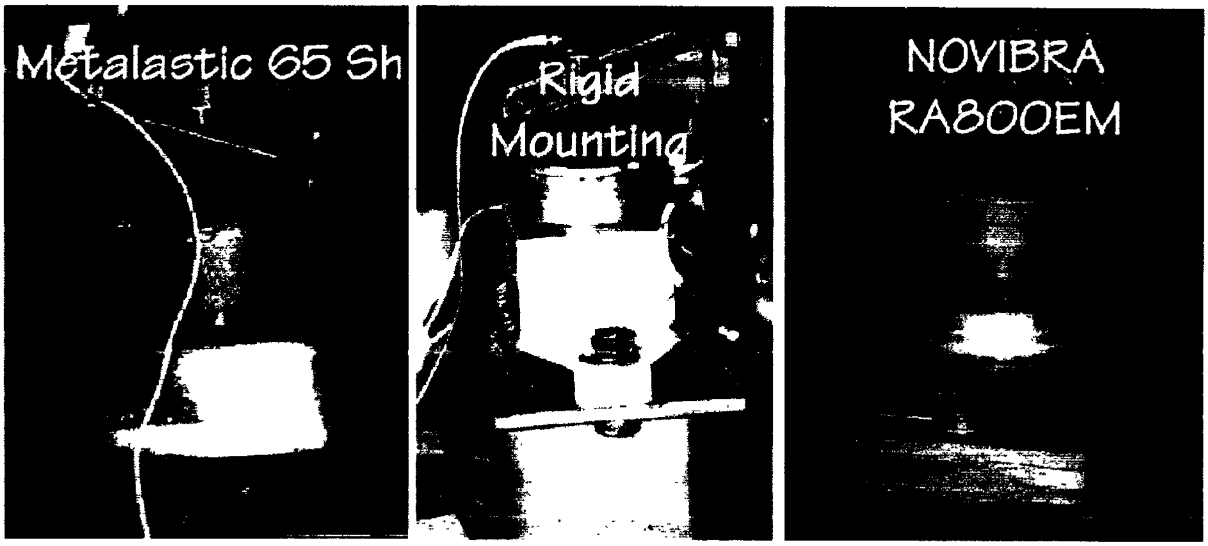

Figure 2. Views of the different engine mounts used in the tests. On the left, a standard installation using Metalastic 65 Sh. In the middle, a completely rigid mounting using a large aluminum block mounted in place of the normal passive damper. On the right, a NOVIBRA RA800EM engine mount. The engines has been lifted a little to make room for the combined active/passive engine mount to be mounted later.

To investigate which transmission path is the most dominant, an Aqua Drive thrust bearing was mounted in the rear of the boat, as shown in **Figure 3**. Also shown is a large mounting block, installed to handle the forces from the propeller BPF through the thrust bearing.

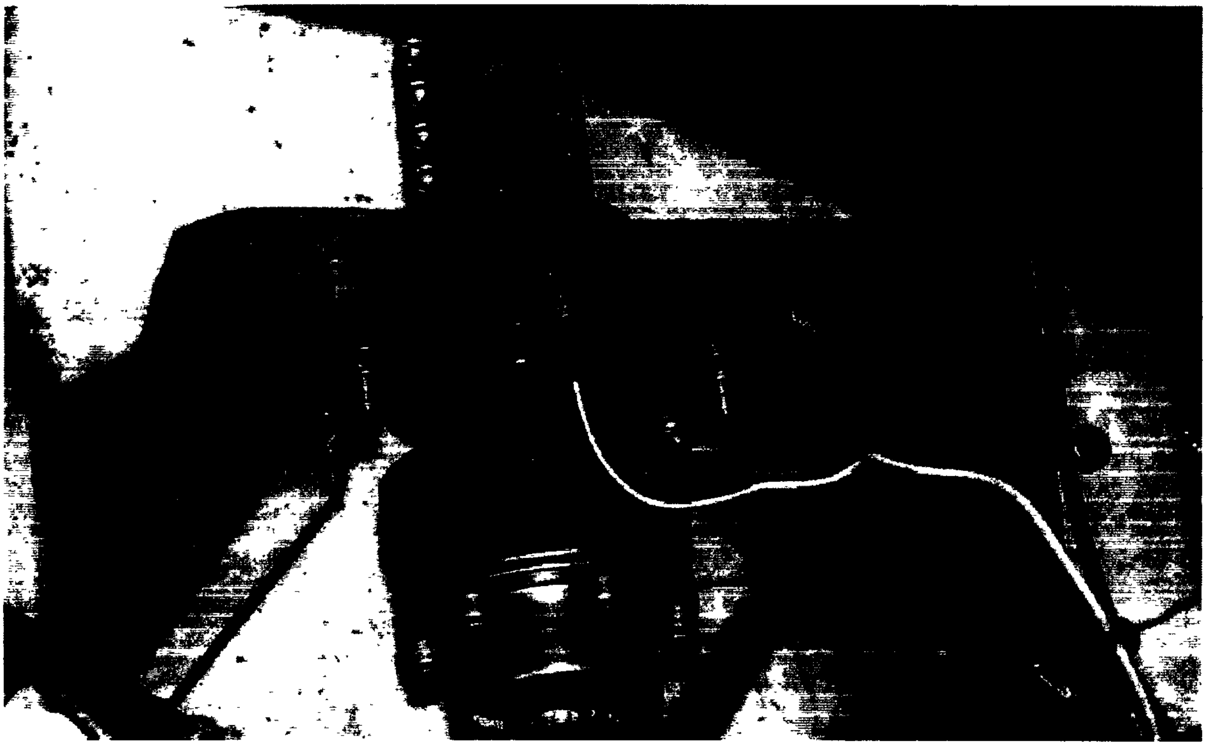

Figure 3. A view of the Aqua Drive thrust bearing. An accelerometer has been placed on the engine side of the bearing mount to measure the quantity of vibrations passing the thrust bearing. The BPF from the propeller is usually one of the main vibration components.

3. SPECTRAL MEASUREMENTS

In order to verify the distribution of the sound field and global effects in the saloon, a series of sound measurements was performed in 72 positions in three layers giving a total of 216 measurement points. These measurements were also performed using slow run-ups and steady cruise at several RPMs. This data is invaluable in explaining the effects of different noise solutions. The sound measurements inside the saloon were performed using an array of 3X4 PCB microphones, model TMS130A10 with TMS 130P10 preamplifiers. **Figure 5** illustrates how this matrix was used in one area of the boat at a time. Two microphones in the front of the saloon were used all the time as a reference. The data was collected in three layers: standing ear height, mid level and sitting ear height. This gigantic data set (Gigabytes of data) was compiled and 3D sound maps could be extracted using Matlab and in-house developed complex interpolation algorithms. A Hewlett-Packard VXI system was used for the data collection and a small power generator was placed in the front of the boat to supply the data acquisition system with the 220V power needed. Accelerometers, microphones and impedance head came from PCB Piezotronics. The 3D plots are very illustrative when analyzing the effects of different solutions for decreasing noise. In **Figure 4** below, the change in sound field between the different situations is presented. The pilot is standing in the upper left side. With the Novibra RA800EM 55 Sh the sound field is much lower and also more evenly distributed. In the rigid mounting measurement one microphone connection had a problem when collecting one data set. That is why there is a white spot, and this is an error. The data is plotted using SPL (dB) with linear weighting.

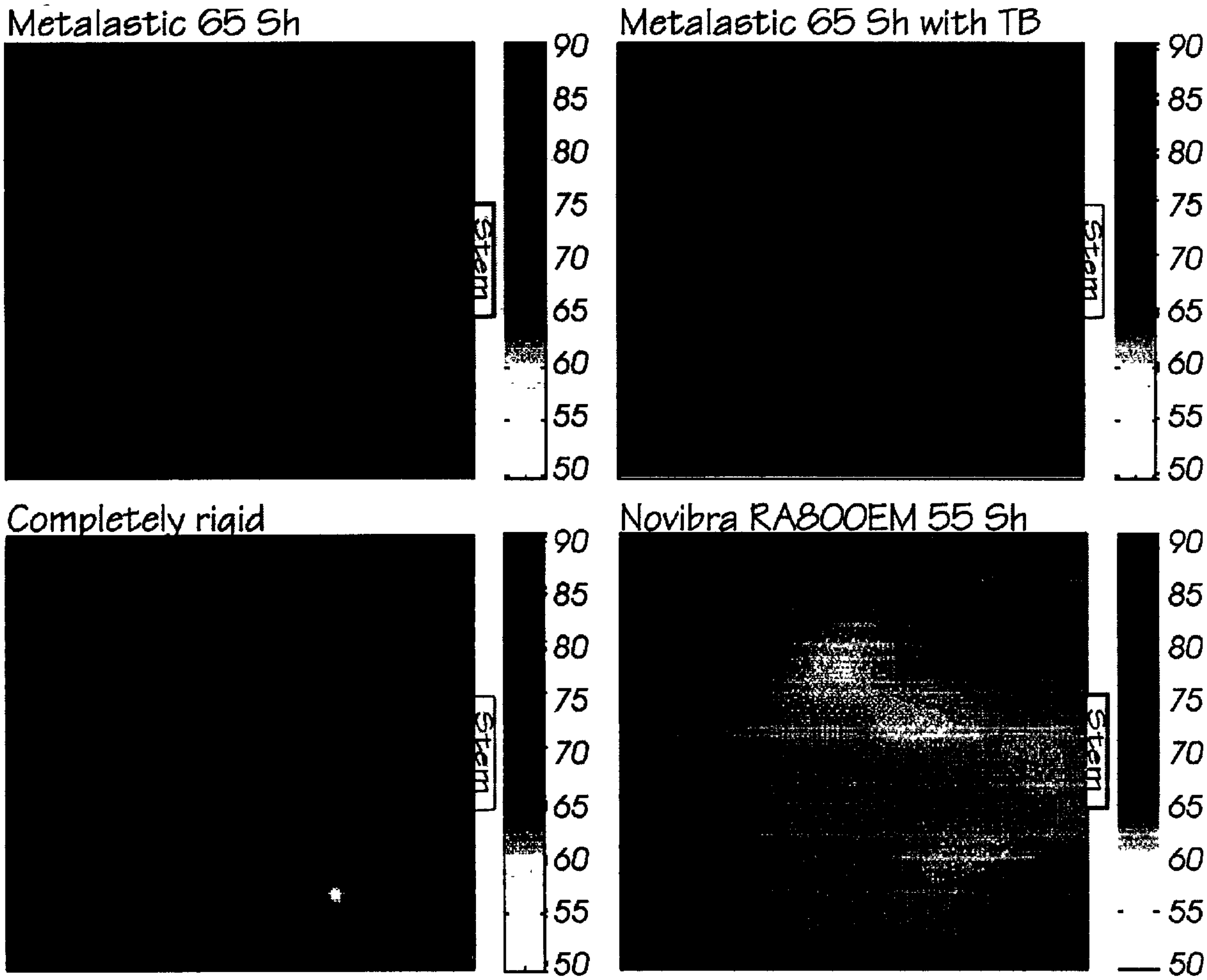

Figure 4. A 3D plot of the SPL (dB) in the saloon using different engine mounts.

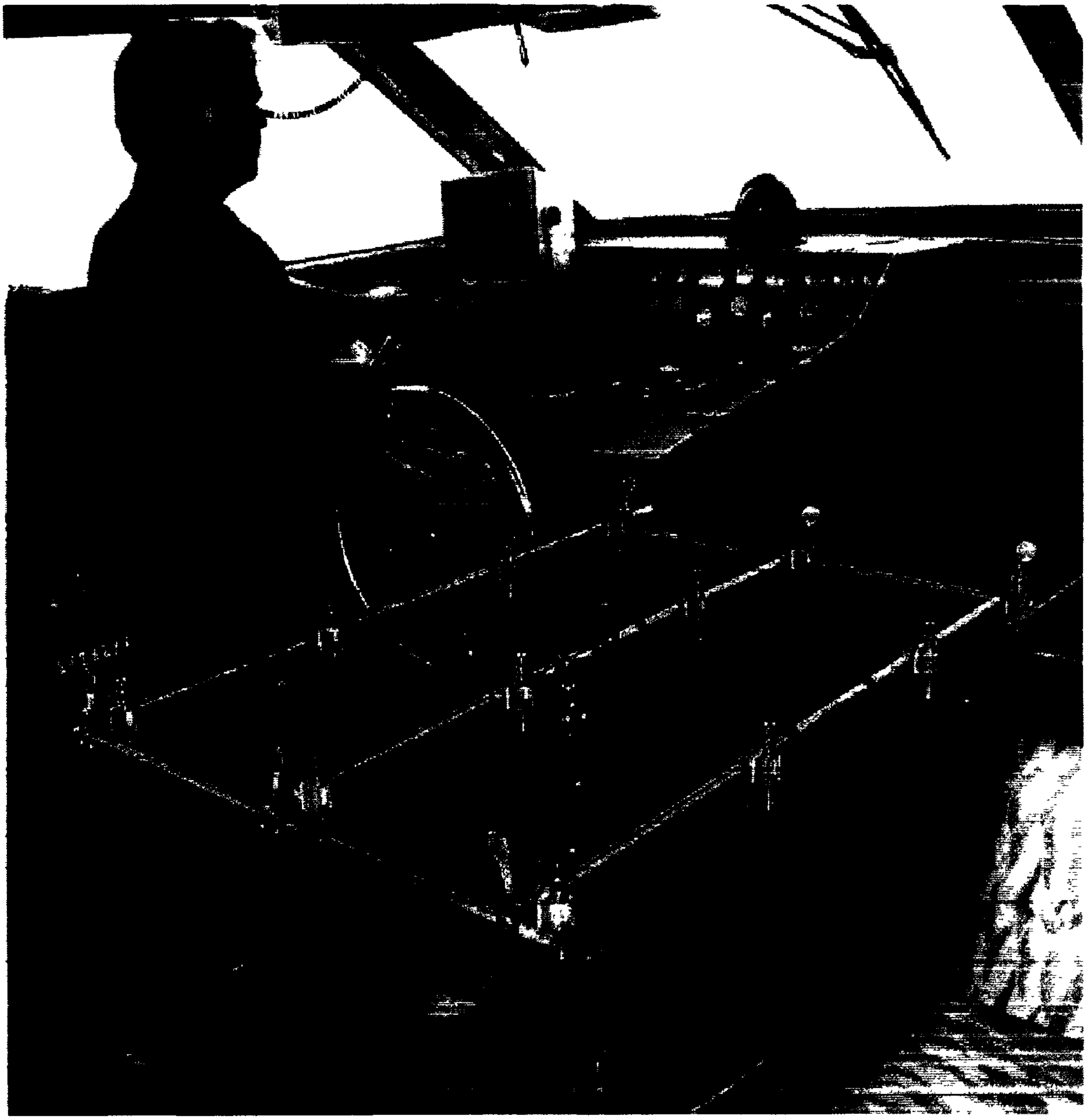

Figure 5. A view of the matrix containing 12 PCB microphones, TMS130A10. This matrix was moved to different locations in the boat enabling a total of 216 points to be measured.

4. ANVC APPROACH

The ANVC approach is to use a combined passive/active actuator as engine mount for all four mounting points at each engine. A combined active/passive engine mount is currently under development. The passive part is developed by Trelleborg Industri AB and the electrodynamic actuator has been built by Metravib RDS in France under a separate contract. The first approach will be using a narrowband multiple reference filtered-X LMS algorithm with the two engine RPMs as the reference and the minimization criterion will be sound, that is an Active Structural Acoustic Control (ASAC) approach, [3][4][5][6]. For simulations of the ANVC performance, feed forward transfer functions are needed between each engine mount and all possible microphone positions. For this reason, data has been collected in the boat using a shaker at each of the engine mounts and several possible microphone positions collected simultaneously. An in-house optimization software will be used to select a set of microphone positions from the measured set. Later, the predictions from this selection will be compared with the results from the real installation. In **Figure 6** below, this measurement is illustrated.

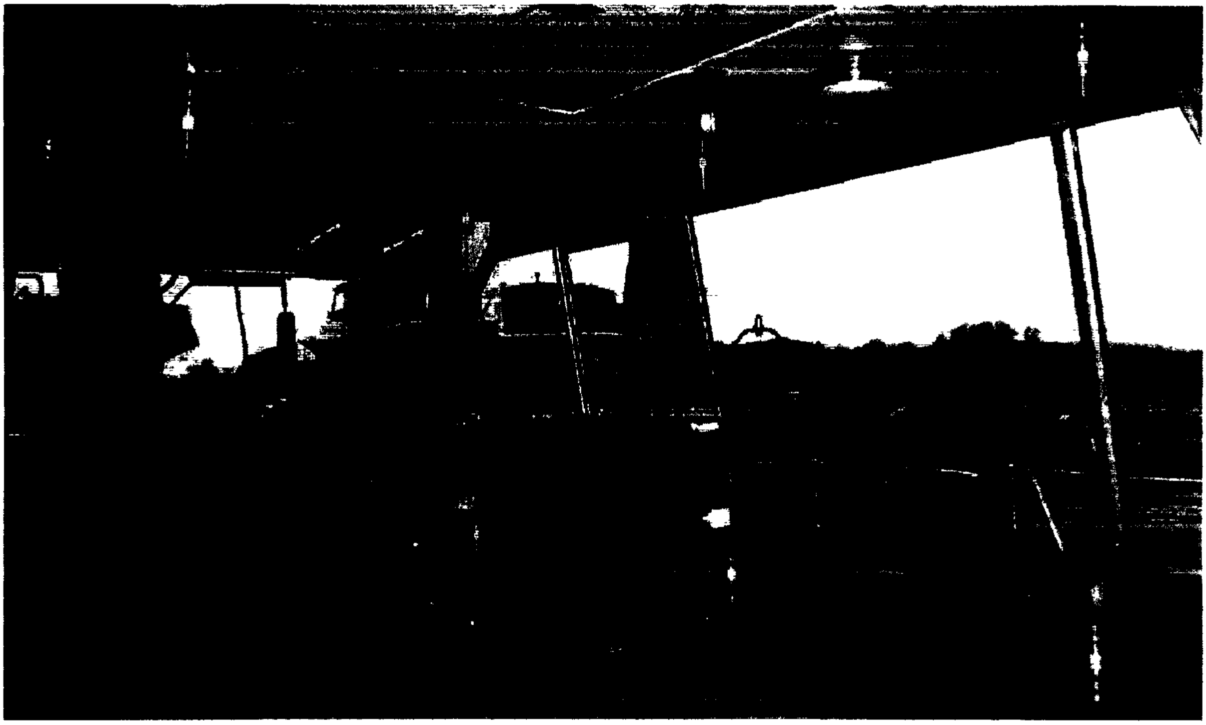

Figure 6. A view of the measurement of the feed forward transfer functions for the ANVC system prediction and optimization of error sensor locations.

5. MEASUREMENT RESULTS

The main noise sources are expected to be the BPF of the propeller and the third order of the engine, given that the TAMD 63P is a 6-cylinder engine. However, when analyzing the sound spectra the second engine order is sometimes larger than the third. The BPF of the propeller is always high. The pressure variations from the propeller can be transmitted through the hull as well as through the propeller shafts and then transmission via the engine mounts. When studying the data before and after mounting of the thrust bearing, it seems like most of the propeller BPF sound is coming through the hull, since there is a negligible decrease in sound level. However, when using a rigid engine mount the propeller BPF level drops by approximately 5 dB and when using NOVIBRA RA800EM a total of 14 dB. This indicates that in fact a lot of the propeller BPF noise is transmitted via the engine mounts. A more detailed investigation of this situation must be performed using ODS (Operational Deflection mode Shape) analysis and correlation analysis. The data indicates that the behavior of the noise transmission is quite complex, but given that there is a large reduction when using the NOVIBRA RA800EM it is likely that an active-passive engine mount could handle the propeller BPF vibration. Further work will be carried out in the end of 1997 to investigate this in more detail.

Figure 7 below illustrates sound spectra from a microphone in front of the driver, close to the ceiling. The left column represents 2500 RPM and the right column 2800 RPM which correspond to full speed. When running at 2800 RPM the propeller BPF and the third order from the engine are increasing. These are the main changes in the sound spectra. Some other components also increase but these are the most significant. This tells us that only a few components in the spectra cause problems. This is a good situation for a feedforward tachometer-based ANVC system.

One effect of the NOVIBRA RA800EM engine mount is that the sound field is more evenly distributed in the cabin. With rigidly mounted engines the sound field consists of some dominant acoustic modes. Some key frequencies at 2800 rpm are: BPF propeller=124 Hz, first engine order=47 Hz, second engine order=95 Hz, third engine order=140 Hz and the propeller shaft rpm=31 Hz. The dominant frequency in most cases is the propeller BPF.

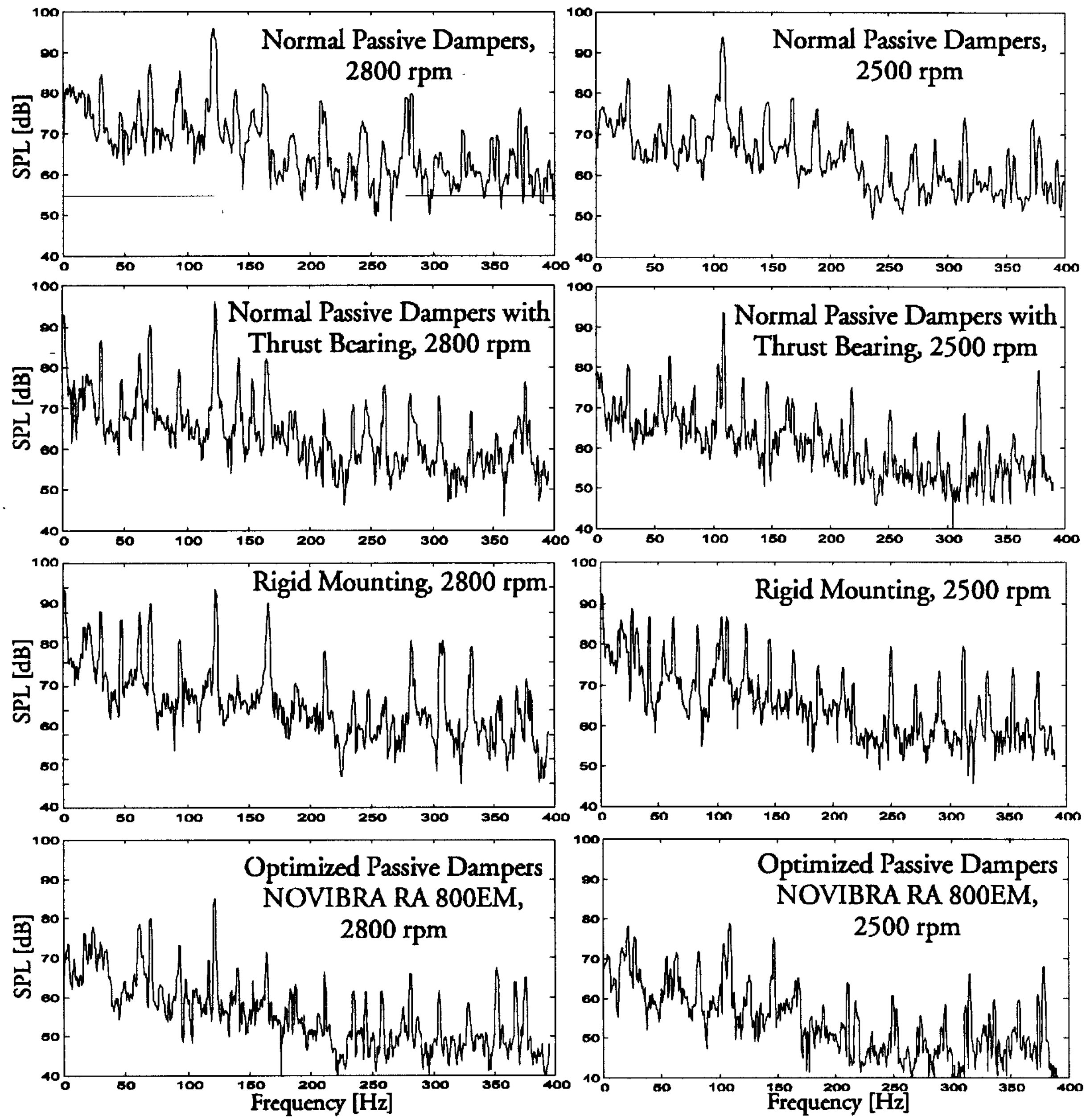

Figure 7. A view of the 1985 Storebro Royal Cruiser, a 36 foot boat powered with two Volvo Penta TAMD 63P Diesel engines giving 265 kW each @ 2800 RPM.

ACKNOWLEDGMENTS

We would like to thank Volvo Penta for all their help in piloting the boat during all the measurements and lifting the engines in and out over and over again for different tests. The project is sponsored by NUTEK (Swedish National Board for Industrial and Technical Development) and KKS (The Foundation for Knowledge and Competence Development).

SUMMARY

The main noise sources in the Storebro Royal Cruiser are the propeller BPF and the engine orders. The propeller BPF can be reduced by using an NOVIBRA RA800EM engine mount, without changing anything else. This implies that the main transmission path for the propeller BPF should be via the engine. However, when installing the thrust bearing, only a small decrease was found on the propeller BPF. This implies that the transmission should be via the hull. However, given that the NOVIBRA RA800EM gave a significant decrease of the propeller BPF, about 14 dB, it is likely that the main transmission is the engine after all. The main engine orders can be handled by an active system.

The noise level in the boat is reduced by about 15 dB using a thrust bearing and NOVIBRA RA800EM engine mounts. In addition, the sound field is more evenly distributed in the saloon, which is good. The goal for the ANVC system is to be able to reach as good performance as with the NOVIBRA RA800EM engine mount but without the thrust bearing. The ANVC system requires a multiple reference controller to be able to handle the large RPM variations between the engines [4][5]. An ASAC control strategy is foreseen to be used thus enabling the sound levels to be minimized, but not the vibration levels [6][7].

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