Inertial Mass Active Mounts Used in a Marine Application

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Abstract

Different actuators have been developed for active noise cancellation. For volumetric applications, a loudspeaker is usually used. When the noise is induced by engines it may be more efficient to work on the noise source itself, the engine vibration. In this case it is important to have an actuator that can counteract the vibration, not the sound field. In the research project AVIIS (Active Vibration Isolation In Ships), such an actuator has been developed. The actuator is an electrodynamic, inertial mass type shaker, designed and tuned for this project. The boat used in these experiments is a Storebro Royal Cruiser 33, powered by two Volvo Penta TAMD engines. Each engine is mounted to the hull in four points. Prior research, [1] shows that the main transmission paths for the vibrations from the engine and the propeller to the hull, are through these mounting points. Once the hull is excited, a lot of sound and annoying noise is produced in the cabin. The main idea is to isolate these vibrations from the hull by adding a combined active and passive engine mount that will control the vibrations by minimizing the sound field in the cabin using microphones as error sensors, a so-called ASAC (Active Structural Acoustic Control)[2] approach.

1 The Actuator design

The actuator used in the AVIIS project combines active and passive techniques. The passive part consisted of a regular, passive damper, the Novibra RA800EM from Trelleborg Industries AB. When choosing the passive damper there is always a trade off between making it very soft, for good attenuation, and making the actuator stiff enough to prevent “break through” in rough sea.

![Figure 1: Construction for mounting the inertial mass damper.](image-url)
Mobility
Excitation in point 4, response in point 4

Figure 2: Mobility at one of the engine mounts.

The passive damper selected for this project was slightly stiffer than normal since it was intended that the active system should handle the vibrations at low frequencies. The active element was an inertial mass damper designed by Metravib in France, for our requirements in the AVIIS project. The actuator yields a large output force for its volume and utilizes Metravib’s patented multipolar technology. The inertial mass damper is mounted between the engine and the hull with the construction in figure 1, where the passive damper should be mounted on the top.

2 Force Requirements

It is important to predict the right force required to obtain the attenuation needed in this type of active noise control system. The actuator force is limited by the size, selection of magnetic material, cooling etc. It always comes down to a matter of cost and size but this trade-off is most important. An over-sized actuator will therefore cost much more than necessary and of course, an under-sized actuator will result in an active noise controller, which doesn’t work, which is just as bad. One approach for calculating the force, given by the following fundamental equation:

\[
F(f) = \frac{V(f)}{M(f)}
\]  

The mobility should be measured at the point where the actuator is to be attached to the structure and the velocity should be measured during normal operation mode, using, for example, an accelerometer. The mobility measurements were carried out with the engines removed from the boat. A large shaker was mounted together with an impedance head, from PCB Piezotronics at the place of the actuator. The impedance head, model 288, facilitated the measurement of both acceleration and force at the same point.

Measurements were repeated at all eight of the engine mounting points. Figure 2 depicts the mobility in one of the engine mounts. It is very important to check the quality of the measurements. There are at least two different criteria that should be met, when determining if the measurement is correct:
The coherence should be high, preferably above 0.95, within the relevant frequency range. If the coherence is within this range, it is likely that the excitation force used was too small. A high coherence implies that the output signal is related to the input signal in a stationary and linear sense. A low coherence can be caused by many things, but doesn’t necessarily mean that the data is bad.

Another common quality test is the reciprocity measurement. When exciting the boat in one of the engine mounts, the velocity should not be measured at this point only, but also in the other seven engine mounts. If the measurements are of a high quality, the cross mobility should be the same when, for example, exciting engine mount 3 and measuring the velocity at engine mount 2, as when exciting engine mount 2 and measuring the velocity at point 3.

The reciprocity test does require some extra measurements, but if the reciprocity is confirmed, the probability that the point mobility is correct is very high. Therefore, this is time well spent. The crossmobility was about 10-20 dB lower than the point mobility, this indicates that the force can be calculated for each engine mount separate without that the cross terms have to be taken into account.

Once the velocity was measured at all eight engine mounts the force could be calculated using equation 2. The resulting force for one of the engine mounts is presented in figure 3. A narrowband complex Filtered-X LMS controller,[4], will be used in this project. It is therefore of interest to know the total force needed to attenuate the main peaks in the spectrum. Since the peaks in the spectrum are sinusoidal??, the total force required can be obtained by summing the RMS values using equation

\[
Total \text{Force} = \sqrt{\text{peak}_1^2 + \text{peak}_2^2 + \text{peak}_3^2 + \ldots}
\]

Using this expression only the largest force peaks will actually influence the value of the total force needed by the controller, which simplifies the calculation.

3 The Controller

The controller used in this project is a multiple reference, multiple input and multiple output, filtered-X LMS controller. The controller uses microphones as error sensors since
it is the sound field that should be minimized. In this way the actuators will only cancels the vibrations that couples good to the sound field in the cabin. The fact that the engine vibrates itself is not a problem in this application. The engines in a smaller boat is never synchronized, therefore a twin reference algorithm is used. This will give good attenuation even though the engines are driven with a big rpm. difference. Figure 4 depicts the sound pressure level inside the cabin with the controller switched on and off. The peaks in the figure are tonal components the originates from the engines and propellers. Due to amplifier limitations only one tone could be attenuated at a time. The experiments showed though that it was possible to attenuated all the tones. The tonal component attenuated in figure 4 corresponds to the 3th order of the engine while the peak to the right corresponds to 3.5 order. How can it be that the 3.5 order is larger than the 3 order, with a six cylinder engine? One should remember that it is the sound pressure level being depicted not the vibration level, this indicates the importance in using an ASAC approach.

![Sound Pressure Level (SPL) graph](image)

**Figure 4:** Sound pressure level (SPL) at one microphone placed in the cabin of the boat. The dashed line is the original SPL without control while the solid line represents the SPL with the controller on.

## 4 Summary and Conclusions

In many ANVC applications, shakers are used as exciters. In real applications many shakers are often needed. Therefore, it is important to dimension them correctly especially in terms of output force. This paper presents one method of calculating the force needed for a narrowband controller, to be used in a boat application. The method is based on measurements of mobility and velocity. These parameters are then transformed into the frequency domain where the force is calculated. The method is straightforward but there are a lot of practical difficulties to be considered. Results are also presented from experiments, on board the boat, where the actuators have been used together with a complex Filtered-X LMS controller to minimize the sound field in the cabin.
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References


