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ANALYSIS OF HIGH LONGITUDINAL VIBRATION ON A DIESEL GENERATOR USING MODERN ANALYSIS TOOLS

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Abstract

The tools used for vibration analysis have improved radically over the last few decades. However design for low vibration is still based on the principle of keeping the frequencies of dynamic forcing functions well removed from those of structural resonances. Exploration of this age old issue in a modern vibration analysis context is undertaken, using an example of high longitudinal vibration on diesel generators which power an Australian COLLINS CLASS Submarine. As the diesel and generators are supplied by different manufacturers, the result highlights the requirement to properly integrate machinery combinations from a perspective of design for low vibration.

1. INTRODUCTION

High axial vibration levels were measured on HMAS WALLER'S mid-generator in December 2003, before its full cycle docking (FCD). Specifically, the axial vibration level of a particular running order on the non-drive-end (NDE) bearing was excessively high in level.

During the FCD, inspections of the three diesel engines have revealed that the crank shafts of the mid and starboard diesel engines were each bent approximately 0.8mm from the shaft axis (expected to be caused by hydraulic shock from start-up of the diesel generators when seawater had flooded some cylinders). Bending of the crankshaft creates a coupling between transverse and axial vibrations of the crankshaft, as detailed in [1]. This means that engines that have bent crankshafts will vibrate more in the longitudinal direction than engines without bent crankshafts.

However from the vibration measurements on the NDE bearing of HMAS WALLER'S generators revealed that there were excessively high longitudinal (parallel to the diesel generators' shafts) vibration levels on the mid generator, but not on the port generator.

Therefore an investigation into the longitudinal vibration of HMAS WALLER'S generators was undertaken, to determine the reason that high axial vibrations were found on the mid generator's NDE bearing but not on the port generator's NDE bearing.

2. METHOD

Vibration measurements were undertaken on HMAS COLLINS to aid in determination of the reason for the discrepancy in vibration levels.

2.1 Vibration measurements on HMAS WALLER'S generators whilst under load

Vibration measurements were taken on HMAS WALLER'S generators during the pre-availability condition assessment in 2003 prior to the 18 month long full cycle docking. These measurements were undertaken with a tri-axial piezo-electric accelerometer, and were recorded using Sony DAT cassette recorders. The measurements included calibration of the accelerometer with a vibration exciter (calibrator). The recorded data was post processed using the Bruel & Kjaer Type 3560C "Pulse" analyser. To ensure the accuracy of the post-analysis individual gains were used for each axis of the accelerometer, such that the processing of the recorded calibration measurements resulted in the expected 10 m/s^2 level.

2.2 Vibration measurements on HMAS COLLINS' generators whilst under load

Vibration measurements were undertaken on HMAS COLLINS's three generators whilst the diesel-generators were running at full load. The measurement system was calibrated prior to the measurements. Measurements were undertaken on the NDE bearing in the axial direction. The measurements were undertaken with uni-axial piezo-electric accelerometers mounted to the NDE bearing housing using magnet mounts. The measured vibrations were analysed using a Bruel & Kjaer Type 3560C "Pulse" analyser. The analyser undertook linearly averaged FFT analysis with one hertz per FFT line.

2.3 Operational Modal Analysis of HMAS COLLINS' generators whilst not running

Operational modal analysis was undertaken on the NDE of HMAS COLLINS' three generators. These measurements comprised the following:

- Connect together measurement system
- Create software based representative geometry of generators' NDE including the exciter, NDE bearing, NDE plate, and NDE lifting lugs (see Figure 1 below)
- Calibrate accelerometers with vibration calibrator
- Place reference and roving accelerometers on generator
- Measure vibration whilst impacting generator with 1.5 kg dead blow hammer to excite all modes of interest
- Move roving accelerometer to next location
- Measure vibration whilst impacting generator with 1.5 kg dead blow hammer
- Repeat until all points measured
- Process mode shapes using Operational Modal Analysis software

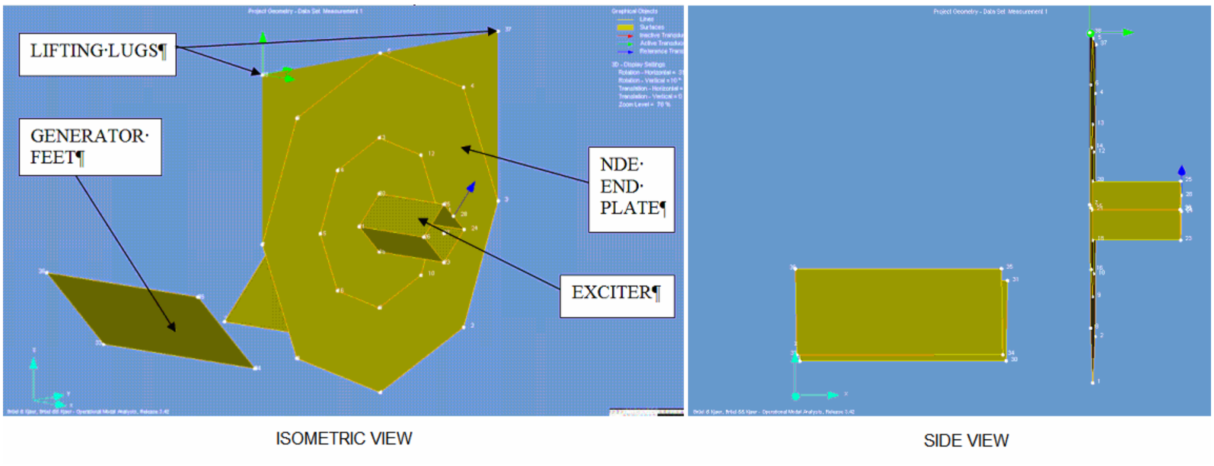

Figure 1: Isometric and side views of geometry used for modal analysis of the generators NDE end plate and exciter

3. RESULTS

3.1 Vibration measurements on HMAS WALLER'S generators whilst under load

Figure 2 below details the longitudinal vibration measured on HMAS WALLER'S generators' NDE bearing and exciters whilst the generators were under full load in December 2003 (frequencies and levels removed):

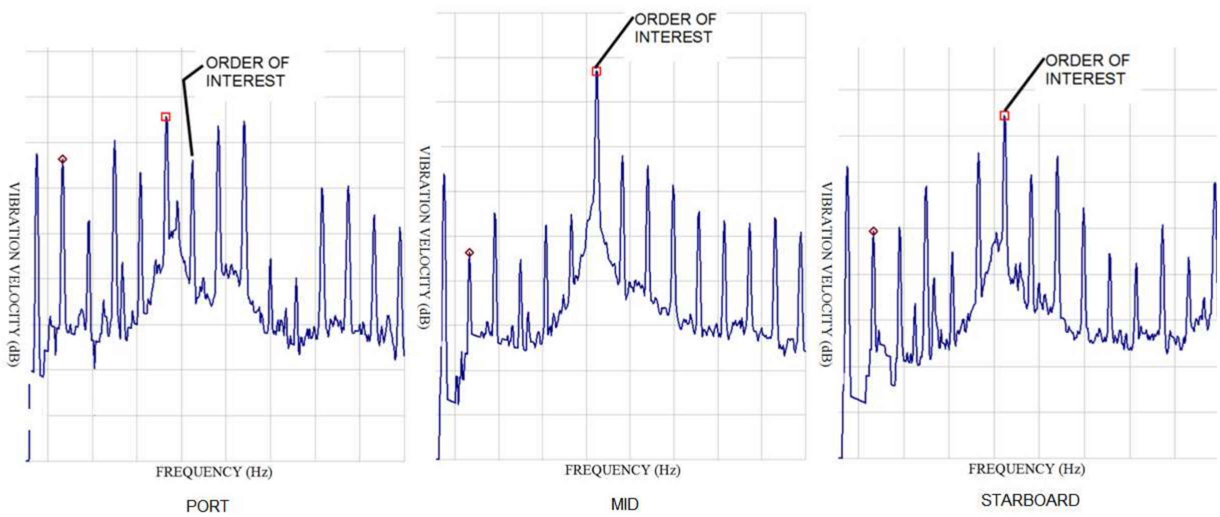

Figure 2: Vibration measurements on HMAS WALLER'S generator's NDE bearings

As the frequencies and levels have been removed, Table 1 below details the relative vibration level at the order of interest:

Table 1: Comparison of Vibration Level on Generators at Order of Interest

Generator	Port	Mid	Starboard
Vibration level at order of interest (dB re level measured on mid generator at order of interest)	-31	0	-13

3.2 Vibration measurements on HMAS COLLINS' generators whilst under load

The generators' NDE bearing axial vibration levels measured on HMAS COLLINS are detailed in Figure 3 below:

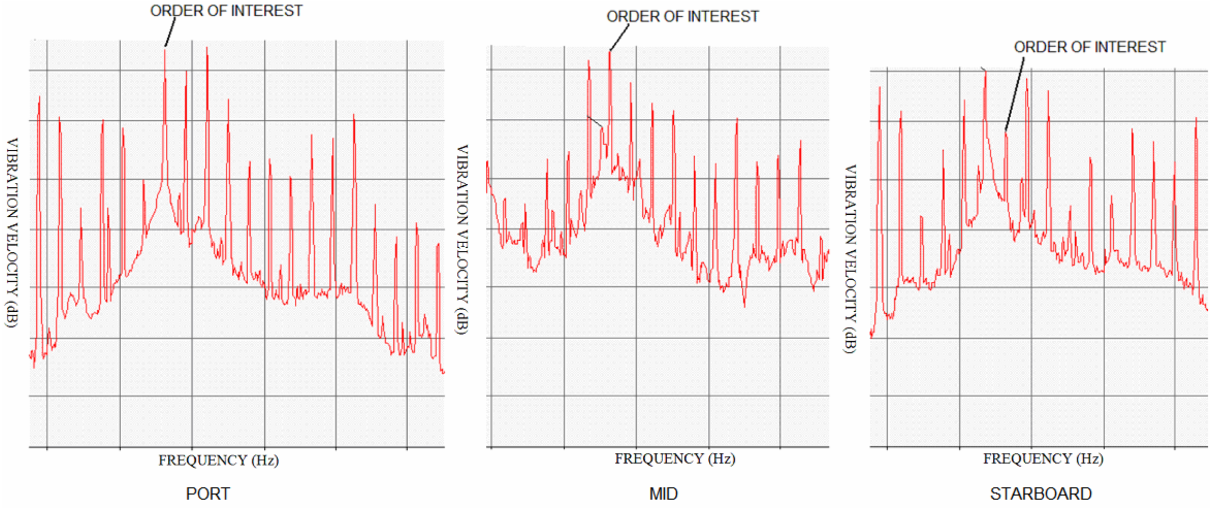

Figure 3: Vibration measurements on HMAS COLLINS' generator's NDE bearings

3.3 Modal analysis of HMAS COLLINS' generators whilst not running

The singular value decomposition lines from the operational modal analysis measurements for HMAS COLLINS' mid generator is detailed below in Figure 4. The frequency of the order of interest is indicated with a vertical black line. The longitudinal blister mode is identified. The mode extracted at a frequency just above the longitudinal blister mode involves lateral bending of the exciter and associated motion of the generator NDE end plate.

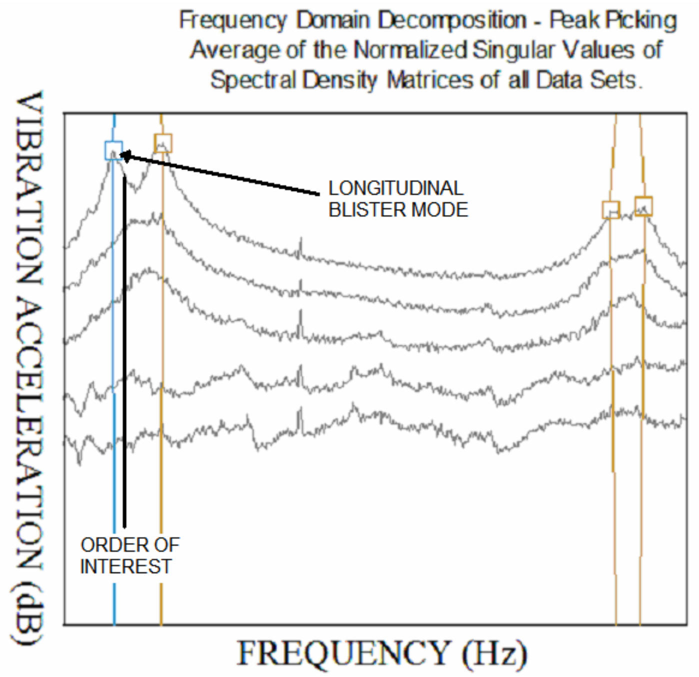

Figure 4: Extraction of Operational Modal Analysis Modes from the Singular Value Decomposition (SVD) lines for HMAS COLLINS' mid generator NDE plate

Figure 5 below details the side view of the longitudinal blister mode of the mid generator’s NDE end plate. The mode shapes of the same mode for the starboard and port generators are very similar to that for the mid generator.

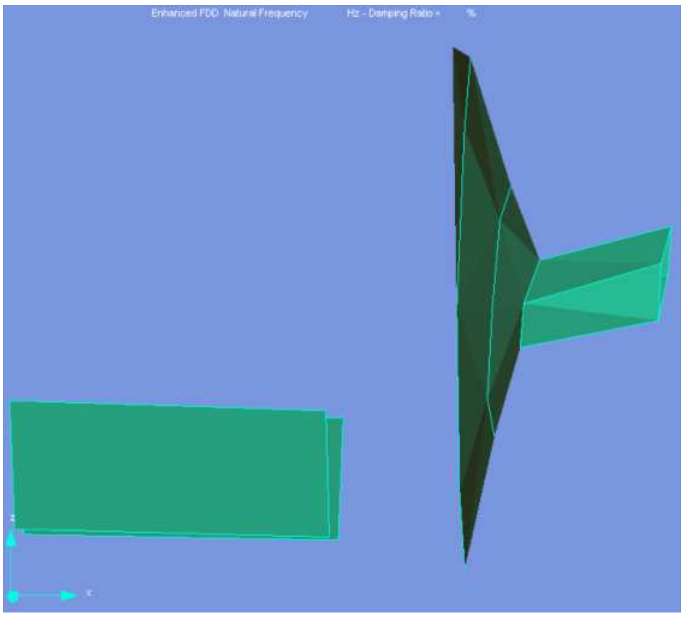

Figure 5: Mode shape of mid generator: side view of longitudinal blister mode of generator NDE end plate

Table 2 below details the natural frequencies associated with longitudinal blister mode of vibration of HMAS COLLINS’ generators NDE’s extracted from the modal analyses:

Table 2: Natural frequencies of the longitudinal blister modes of vibration of HMAS COLLINS' generators' NDE bearings

Modes of vibration contributing to longitudinal vibration of HMAS COLLINS' generators' NDE bearing	Natural Frequency (% frequency with respect to frequency of order of interest)		
	Port	Mid	Starboard
Longitudinal blister mode of NDE end plate	90%	96%	100%

From Table 2 above it is seen that the generators NDE end plates have longitudinal modes of vibration near in frequency to the order of interest. The frequency of this mode varies for each generator within a frequency range of approximately 10%.

3.4 Comparison of forced and natural vibration frequencies of HMAS COLLINS' generators NDE bearings

Figure 6 below compares HMAS COLLINS' generators' NDE bearings' forced vibrations with the natural frequencies extracted during the modal analyses. The black curves drawn beneath each red forced vibration plot highlight that the shape of the resonances can be seen in the "background" vibration at frequencies between the orders. These curves were drawn by eye using the vibration levels between running orders as a guide.

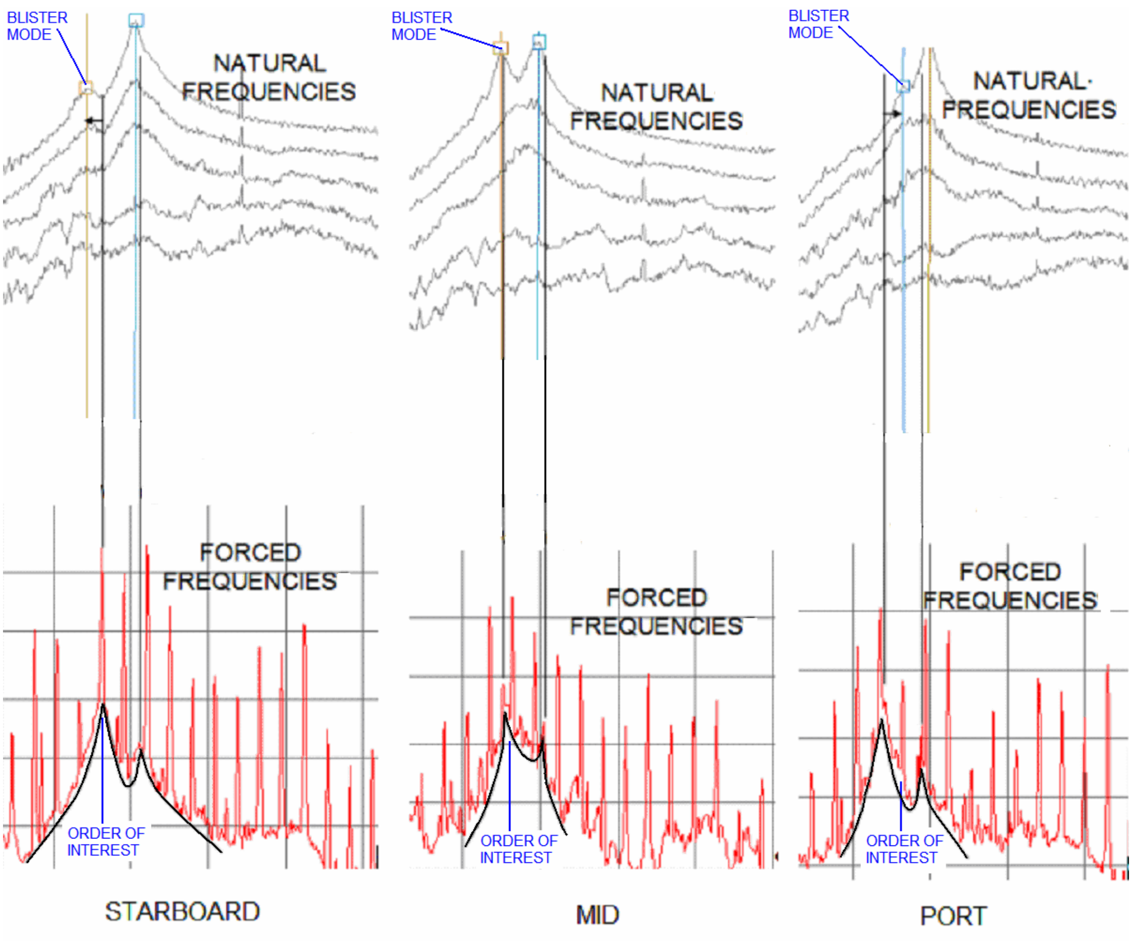

Figure 6: Comparison of natural and forced frequencies for HMAS COLLINS' generators' NDE plates

Table 3 below compares the frequency of the longitudinal blister mode of HMAS COLLINS' NDE plates for the generator running case and the generator not running case. The frequencies of this mode for the generator running case have been taken from the left hand peak of the lower black curves in Figure 6.

Table 3: Comparison of frequency of longitudinal blister mode of HMAS COLLINS' generators' NDE plates for generator running case and generator not running case

Generator	Natural frequency of longitudinal blister mode from forced vibration measurements (% frequency with respect to frequency of order of interest)	Natural frequency of longitudinal blister mode from operational modal analysis (% frequency with respect to frequency of order of interest)	Change of natural frequency of longitudinal blister mode from generator running to generator not running (% frequency with respect to frequency of order of interest)
Starboard	90%	100%	10%
Mid	96%	96%	0%
Port	100%	90%	-10%

Table 3 above shows that the natural frequency of the longitudinal blister mode of vibration of the generators' NDE end plates changes by up to 10% depending on whether the generator is operating or not. It is seen from Table 3 that when the generators are run, the frequency of this mode can increase or decrease.

Figure 7 below highlights the presence and frequencies of the longitudinal blister modes of the generators NDE end plates for HMAS WALLER, taken directly from the original vibration measurements (originally detailed in Figure 2) taken when the generators were running:

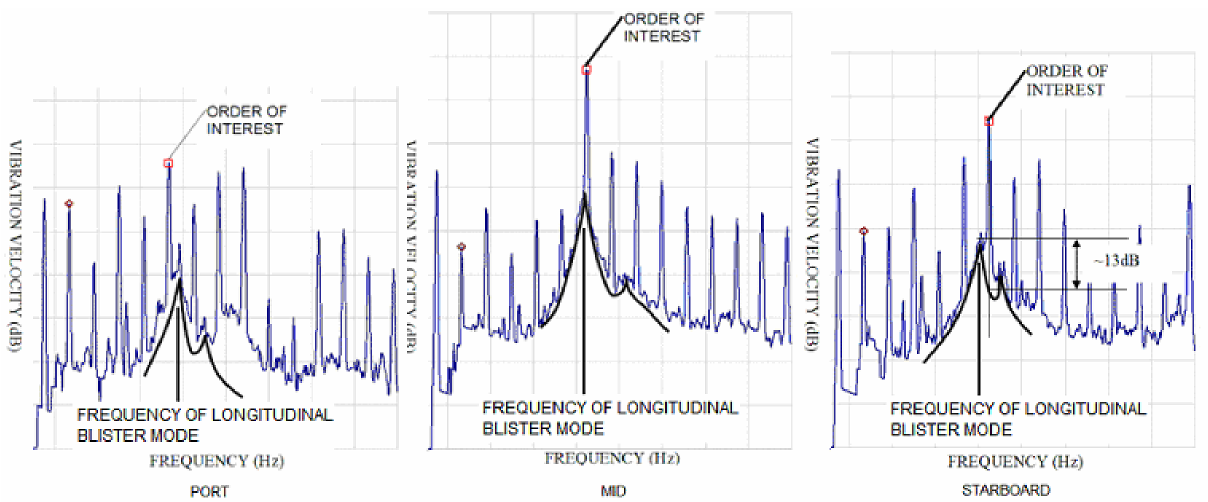

Figure 7: Vibration measurements on HMAS WALLER'S generator's NDE bearings, with structural resonances indicated with black curves

Table 4 below details the frequencies (taken from Figure 7 above) of the longitudinal blister mode of the generators' NDE end plates for HMAS WALLER when the generators are running:

Table 4: Summary of the frequencies of HMAS WALLER'S generators' NDE end plates' longitudinal blister modes when the generators are running

Generator	**Port**	**Mid**	**Starboard**
Frequency of longitudinal blister mode when generators running (% frequency with respect to frequency of order of interest)	95%	100%	105%

From Figure 7 and Table 4 above, it is clear that the longitudinal blister mode of the generators NDE end plates aligns in frequency with the order of interest for the mid generator, but does not for the port or starboard generators.

The plot of the vibration of the starboard generator in Figure 7 includes a black curve representing the longitudinal resonances of the generator's NDE end plate. It is seen that the amplitude of this black curve is approximately 13 dB lower at the order of interest when compared to the maximum amplitude (at a frequency slightly lower than the order of interest).

Therefore, if the longitudinal blister resonance of the generator NDE end plate aligned with the order of interest, it is expected by linear superposition that the vibration at the order of interest would increase by approximately 13dB. It is noted that this is the approximate difference in vibration level at the order of interest between the mid and starboard generators (as detailed in Table 1).

Both the starboard and mid crankshafts were bent equivalently (crankshaft bending was subsequently fixed during the Full Cycle Docking). Therefore the coupling provided between lateral and longitudinal forcing is expected to be the same for both diesel-generators. Therefore this 13dB difference is concluded to be due to the alignment of the longitudinal resonance, not due to differences in the level of forcing.

4. CONCLUSIONS

The results demonstrate that when the frequency of the longitudinal blister mode of the generator NDE aligns with the frequency of the order of interest, it produces an increase in level (of 13 dB in this case) when compared to the case when they do not align.

The diesel engines and generators used on the COLLINS CLASS Submarines are manufactured by different companies. Each company has designed their equipment for low vibration operation, however when connected together, new and changed system modes of vibration can occur. The problem detailed in this paper therefore highlights the need for integration of such equipment from a perspective of vibration, to ensure that system resonances do not align with significant forcing frequencies.

When inspecting forced vibration measurements of rotating machinery, the influence of vibration modes can be seen as increases in the vibration levels between orders.

REFERENCES

[1] *"Measuring Vibration"*, Bruel and Kjaer, Naerum, Denmark, 1982, pp 36.