Resolving High Vibrations of Shipborne AC Plant Using OMA / ODS Analysis

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Recurring issue of high vibrations were observed on AC plant of a ship. As part of the analysis, it was observed that broadband vibration trends of these AC plants of ships of similar class were high. Advanced techniques like Operational Modal Analysis (OMA) and Operation Deflection Shapes (ODS) analysis techniques were used to study the equipment foundation. The study was aimed at identifying the various mode shapes, associated natural frequencies and foundation behavior whilst the equipment was in operation. The same was then utilized to establish and resolve the root cause of high vibrations of these plants. The OMA results indicated that forcing frequencies generated by the equipment were coinciding with the equipment foundation. Besides, improper alignment tolerances and absence of dowel pin / fit bolts arrangements was leading to inception of dynamic misalignment. Based on the study, foundation strengthening followed by alignment was undertaken and equipment performance was found to be satisfactory. Further, Finite Element Analysis was used to corroborate the findings of the OMA / ODS study. In addition, the foundation strengthening results were revalidated by repeat OMA / ODS analysis.

KEYWORDS

Vibration; Warship; Compressor; OMA; ODS; Modal Analysis; Foundation; Natural Frequency; Operational Deflection Shape; Stiffeners; Strengthen; Condition Monitoring; Misalignment; Dynamic Misalignment; SV Mounts; Finite Element Analysis

INTRODUCTION

Recurring issue of high vibrations were observed on Air Conditioning (AC) plant onboard three ships. Operational Modal Analysis (OMA) and Operation Deflection Shapes (ODS) analysis was undertaken to study the equipment foundation / structure. The study was aimed at identifying the various mode shapes, associated natural frequencies and foundation behavior whilst the equipment was in operation. The study established that the root cause for recurrence of high vibrations was inadequate stiffness of the foundation and dynamic misalignment. This resulted in forcing frequencies generated by the equipment to coincide with natural frequencies of the foundation structure. The study paved way towards resolving similar issue on other AC plants of the same class of ship.

PROBLEM DEFINITION

A ship is fitted with three AC plants of capacity 1.44 million BTUs each. These AC plants have been plagued with recurring issue of high vibrations, mechanical seal leakages, reed damage, etc., which has affected the operational availability of these equipment for the respective platform. High vibrations also leads to frequent cracking of gas-lines connecting compressor to the various alarms and cut-outs.

Aim

Aim of the study was to identify the root cause for high vibrations repeatedly observed on AC plants post exploitation for some period of time and arrive at a way ahead to improve reliability of the AC plant.

OBSERVATIONS FROM THE STUDY

Analysis of Broadband Vibration

Under the condition monitoring program, broadband vibration is recorded by the ship's crew on monthly basis and sent to ashore facility for trending / analysis. Analysis of this broadband vibrations indicates that vibrations measured are higher on AC plants of a particular class of ship. Similar AC plants are fitted on other class of ships; however, the vibration levels were within promulgated vibration monitoring limits. This implied that there were no design issues with the plant as such.

Comparison of Defect History

As part of its maintenance programme, the organisation maintains a defect management system which records the details of defect, reasons for occurrence, equipment downtime and how the defect was resolved. Scrutiny of defect history indicates that majority of defects could be attributed to misalignment between motor / compressor or due to high vibration. Analysis indicates following:-

- Repeated failure of refrigerant system pipes could be due to high vibration.
- Repeated failure of compressor mechanical seal could be attributed to misalignment / high vibration.
- Repeated failure of motor / compressor coupling could be attributed to misalignment.
- Misalignment in dynamic condition could be leading to high vibration on the equipment.

Distribution of the defect serials indicates that almost 30% defects correspond to high vibration, misalignment, coupling and foundation related defects. Tree map placed at Fig.1 is relevant in this regard.

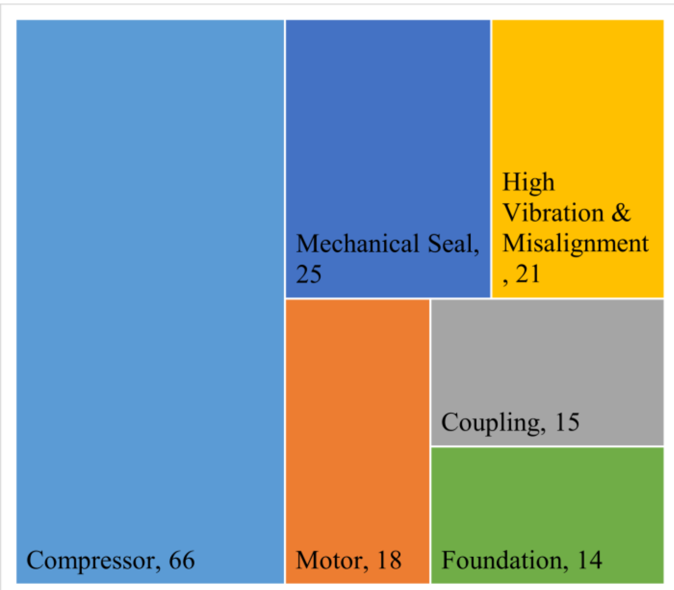

Fig. 1: Comparative Study of Defects – AC Plants

Misalignment

Misalignment indications such as dominant 2X and 'M' and 'W' shaped time waveforms were omnipresent in the vibration spectrum of these AC plants, the amplitude of which differed from plant to plant. It was observed that in most of the cases the vibration amplitude post defect rectification and alignment reduced drastically in terms of vibration amplitudes. But the amplitude increased gradually with time with misalignment symptoms, causing similar defects. Based on these facts it was summarized that dynamic misalignment was likely to be present in the system.

In the absence of Original Equipment Manufacturer (OEM) prescribed alignment tolerances, alignment was being undertaken whilst adhering to limits laid down in technical documentation (RTDL) for similar equipment. The shaft diameter and other parameters considered by the RTDL are similar to the AC plant under consideration. The alignment was undertaken by axial and radial movements of the driver (motor) and vertical movements of the stator (compressor). The movement of the compressor would have been causing unwarranted strains on piping and stresses in the crankshaft of compressor. Additionally, height of the motor was adjusted by putting shims which may compress in course of time and will cause angular misalignment.

Foundation Design

The AC plant is mounted on a raised platform of 120 cm height as indicated in Fig 2. The foundation was suspected to be weak and thus contributing towards increase in vibration levels.

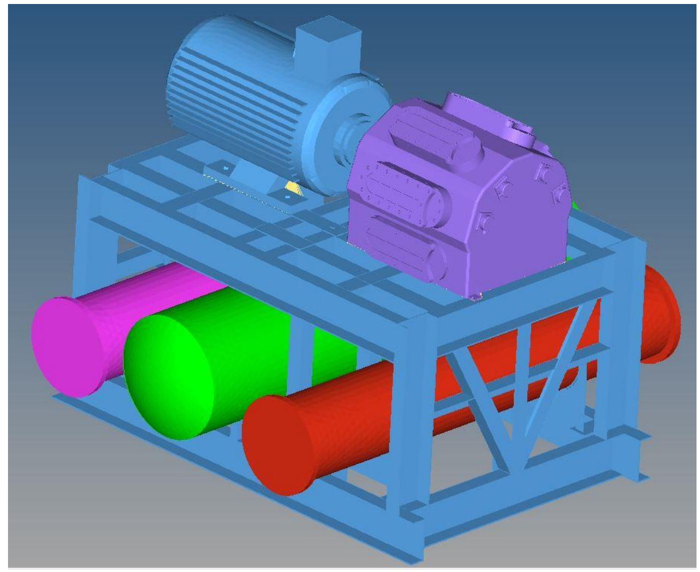

Fig 2: AC Plant Setup with Foundation

SV Mounts

The compressor / motor setup is rigidly mounted on the foundation whereas the foundation in turn is supported on 12 Shock and Vibration (SV) mounts. Further, the compressor and motor on the top of foundation do not have fit bolts or dowel pin arrangement for securing the compressor/ motor in place post alignment.

Inferences Post Comparison

The raised foundation (120 cm height) coupled with mounts located below the frame and not below compressor/ motor posed a unique problem. This high foundation made of C-section frames was considered to be weak for such an equipment setup. Further, absence of proper securing arrangement can lead to compressor/ motor getting misaligned during exploitation. Repeated failure of tyre coupling and high vibrations indicated that misalignment in dynamic condition could have been the other reason leading to repetitive failures onboard.

OMA/ ODS ANALYSIS

In order to localise the core issues with foundation design, it was decided to undertake Operational Modal Analysis (OMA) and Operational Deflection Shape (ODS) analysis. These advanced vibration techniques help in identifying mode shapes of the foundation structure and associated frequencies thereby providing a direct comparison with the forcing frequencies generated by the equipment setup. Further, the ODS analysis can be utilized to visualize the deflection pattern/ shapes of the foundations structure with the equipment in operation. The same can be utilised to identify areas on the foundation which require additional stiffening.

Comparison of AC foundations onboard indicated that though the basic foundation layout of these AC was similar, but the stiffeners erected on all 09 AC plants were at varying locations.

OMA was undertaken on one AC plant using 6-Channel LANXI with PULSE software. The structure geometry used for the analysis included 28 points for the equipment foundation and 06 points each for the motor / compressor. Results from OMA indicated that 2nd natural frequency of foundation was coinciding with 1X of compressor RPM. In addition, the 3rd natural frequency of foundation was coinciding with 2X of compressor RPM. A result of OMA from the Pulse software used for OMA/ ODS analysis is as indicated in Fig. 3.

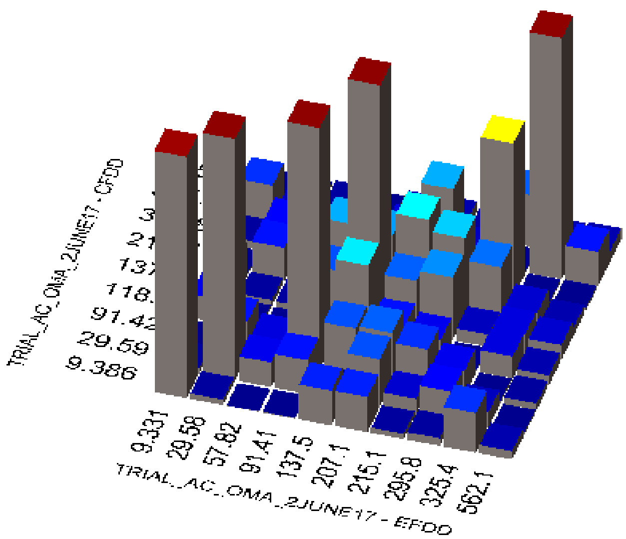

Fig. 3: Before Foundation Strengthening

The above results clearly indicated that the structure required additional stiffeners which would ensure that the foundation natural frequencies moved away from the forcing frequencies. In addition, the ODS analysis indicated the approximate locations on the foundation frame where additional strengthening was required. However, the same had to be finalized based on maintenance envelope available onboard. Accordingly, detailed feasibility study was undertaken onboard each ship. Post strengthening of the foundation; alignment was undertaken whilst adhering to stringent tolerance limits using Laser Alignment Tool.

On completion of additional strengthening, followed by alignment within stringent limits / tolerances, repeat vibration trials were undertaken and vibration levels found to be normal. The trials were repeated post 900 hours of exploitation and the overall vibration levels were found to be comparable to past trend. Repeat OMA was also undertaken to identify the new modal frequencies of the structure and therefore validate the work undertaken. Repeat OMA indicated that the structural modal frequencies have moved away upto 6X of motor rpm and thus unlikely to conflict with forcing frequencies present in the equipment and its foundation setup. Congruence plot from PULSE software for identifying the dominating modes by using Enhanced Frequency Domain Decomposition (EFDD) vs Curve Fit Domain Decomposition (CFDD) is as depicted in Fig. 4.

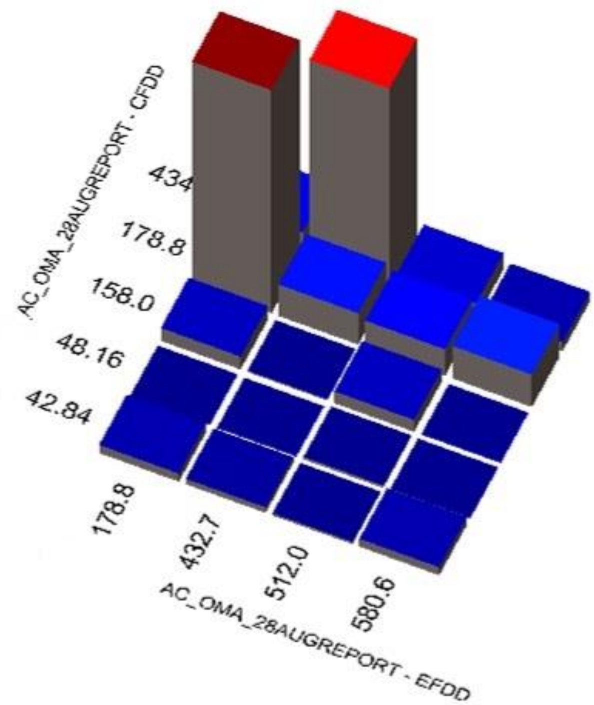

Fig.4: After Foundation Strengthening

Similar exercise was completed for 04 ACs across two ships of the same class and post exploitation the vibration levels have been observed to be normal. The exercise validates the findings of the study and highlights the need for strengthening of foundation and adherence to strict alignment tolerances.

FINITE ELEMENT ANALYSIS

The structure geometry used for OMA is elementary in nature and does not reflect the actual foundation and equipment setup. In addition, the varying maintenance envelope available on each AC plant mandates different foundation design or strengthening requirements. Therefore, Finite Element Analysis was undertaken to validate the findings.

3D model was constructed using Solidworks 3D modeling software and was verified by visiting onboard for its accuracy/correctness. Necessary corrections were incorporated based on onsite measurements. The 3D model was constructed and mesh was generated after de-featuring to suit FE environment using Hypermesh. Thereafter the meshed model was imported to MSC Nastran for modal analysis. The transient analysis output was imported into LMS vibration suite for FFT analysis to identify displacement to the corresponding frequency. The FEA based modal analysis was undertaken including transient analysis and the output was compared with the onboard measured vibration values to identify source of vibration and to draw inference. The 3D Mesh models used for FE analysis, with and without stiffeners are as displayed in Fig. 5.

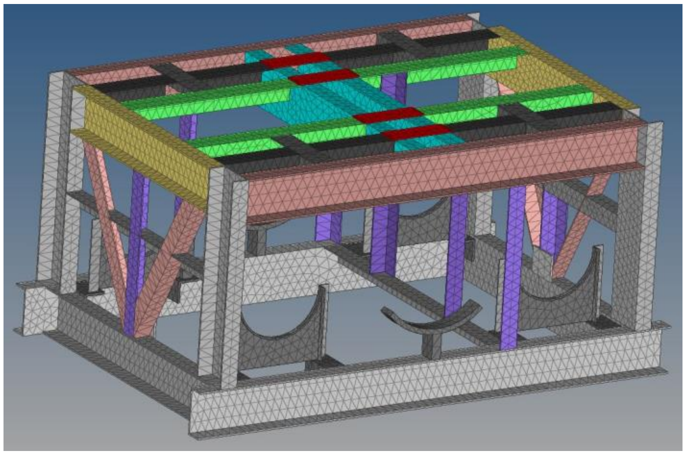

Fig. 5: Equipment Skid with Mesh

Findings from Finite Element Analysis

The natural frequencies obtained post modal analysis using Finite Element Method and FFT analysis are tabulated in Table 1 below which validates the results of OMA. In addition, the 178 Hz frequency, which was the 23rd mode was the most dominating frequency as per Finite Element analysis and coinciding with the forcing frequency (6X harmonic of compressor rpm) generated by the equipment. Mode shape depicted at Fig. 6.

Table 1: Natural Frequencies - OMA vs FE Analysis

Frequency from FFT (Hz)	Simulation Frequencies (Hz)
29.75	30.17
59.6	56.74
89.25	83.32
119	117.24
159.13	164.76
178.38	180.39
224.63	225.26

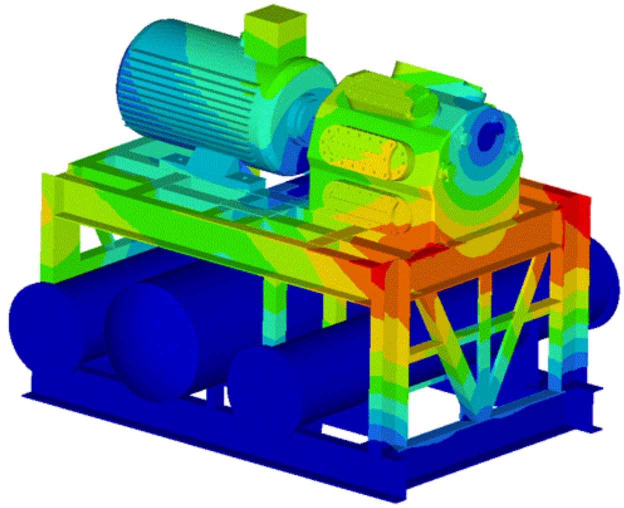

Fig 6: 23rd Mode Shape at 178 Hz – FE Analysis

Validation Post Foundation Strengthening

In order to validate the foundation strengthening undertaken on the AC plants OMA / ODS analysis was repeated post erection of additional stiffeners. The results clearly indicated that the natural frequency of the equipment setup has moved away from the forcing frequencies generated by the equipment. Details are as tabulated at Table 2. The overall vibration levels also have been trended for more than 1000 hrs of exploitation and found to be satisfactory.

Table 2: Comparison for natural frequencies (estimated using OMA / ODS) before / after foundation strengthening

Frequency Before Strengthening (Hz)	Frequency After Strengthening (Hz)
10.65	29.11
178.7	110.4
--	186.9

CONCLUSION

Based on the above study the following was implemented for all three ships of the class to resolve recurring defects and high vibration problems onboard.

Foundation

Foundation strengthening is being undertaken for all 09 AC plants post completion of OMA/ ODS for each plant. This will help in arriving at the desired location of stiffeners and the amount of strengthening required.

Alignment Tolerances and Methodology

The alignment tolerances being followed for AC plants onboard have been changed which would bring down innumerable defects being encountered on these AC plants. The present alignment method being followed is rustic and needs to be improved to achieve stringent alignment tolerances which are only feasible if Laser alignment tools are used. Other aspects such as number of shims being used and trueness of foundation wrt soft foot which have direct bearing on the alignment should be borne in mind.

New Construction Ships

Installation arrangement of machinery should facilitate adherence to maintenance envelope while using as less height of foundation as possible.