Operational Vibration Analysis of Naval Platforms for System Integration

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ABSTRACT

In this study, the operational vibration analysis and evaluation of the pedestal mounted missile system, BORA, which was developed for air defense of naval platforms, are performed. The main mission of BORA is the low level air defense of naval platforms such as frigates and fast attack boats. The gyro stabilized turret of BORA enables automatic target tracking and firing capabilities without being effected from the disturbances due to the waves and maneuvers of the ship.

The location of the systems depends on many operational conditions in the platforms and is generally fixed. Therefore it is meaningless to perform operational modal analysis and obtain mode shapes; resonance frequencies etc. of the boat itself and locate system to the suitable regions. Solving vibration problems with signal analysis that is the process of analyzing the response of a system, due to some generally unknown excitation, are carried out in this work.

1.0 INTRODUCTION

ASELSAN Pedestal Mounted Stinger (PMS) System is a highly capable very short range low level air defense system. It is equipped with several sensors for target detection and tracking and all the functions are controlled by the fire control computer. At night and bad weather conditions fire control functions enable target detection, tracking and identification. The system is armed with four/eight ready to fire Stinger missiles and one 12.7 mm automatic machine gun.

While integrating PMS BORA System to attack boats, measurement of rotational velocity and linear acceleration reactions which will affect the system was aimed. Being able to determine the mechanical vibration magnitudes and frequencies during the lifetime of the system is of great importance in checking the stabilization with respect to the inputs from the boat and the strength of mechanical pedestal structure. In this study, data acquisition from the accelerometers and the frequency responses are reported.

The BORA system incorporating electronics and electro-optical subsystems can be tested in the laboratory after obtaining the operational vibration tests data of the boat. For this purpose integrated circuit piezoelectric (ICP) accelerometers are located at points of interest for testing vibration on the system. Power Spectrum Density (PSD) analysis is performed to define the vibration profile that the electronic equipments should withstand. It is also intended to obtain required stabilization during operation of the platform.

The aim of the environmental tests is to ensure that the production equipment meets the specified requirements over the full range of the specified environmental conditions. Mechanical shock and vibration are the most complicated type of the environments because of the importance of their spectral characteristics, but it must still be dealt with simple terms. Many vibration and shock specifications related to the conditions at the locations of the usage so that they provide design and development incentives for

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survival and operation of the product in such conditions. Usually these specifications attempt to require the environmental tests to simulate such conditions. The specifications lead to developmental tests guiding the designers in revealing features which might require redesign [1, 2].

Figure 1: PMS Bora system on an attack boat.

For many electronic systems, shock and vibration are a part of the qualification test requirements. Military Standards proposes limited approximate (empirical) values for various military platforms. These values can be used when there is no opportunity of measurement. The PSD graph for shipboards is given in vibration section of MIL STD 810F [3] (Figure 2). The standard particularly stresses the requirement of performing test at the installation region of the systems.

In naval platforms structural effects of the platform to the equipments are more critical than the effects of the equipments to the platforms, as expected. Products which are analyzed experimentally and/or numerically will have less production time and costs, also higher quality and reliability.

There are several solutions the vibration problem during design stage.

1) Decreasing the power of the vibration source (removing unbalance and misalignment, maintenance etc.),

2) Manipulating frequency band by geometric modifications (modal design) in the system,

3) Isolating regions that might fall in resonance by the source,

4) Increasing energy absorption ability of the regions that are possibly in excessive vibration.

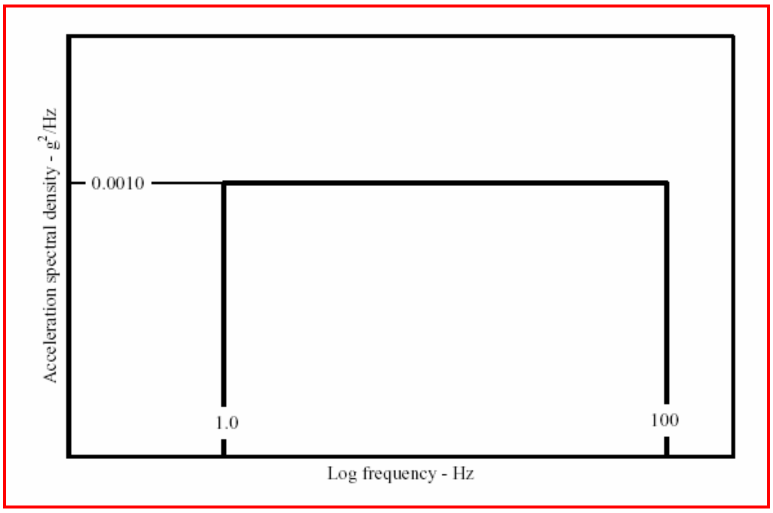

Figure 2: MIL-STD-810F, Ship vibration PSD profile.

Ruggedization of the systems are handled with reinforcement of the components that are located inside the structure and/or external protection of the systems by isolators for minimizing disturbing force and/or modal design of the equipments and their mounting points. Initially, shock and vibration are caused by some types of sources such as tracks and engine of the vehicle, firing of a projectile etc., which are unavoidable during the operation. In this case, the path of the energy which is transmitted to the target system should include isolators and/or should be modified according to the target sensitivities by optimizing the stiffness and the mass of the structure [4, 5, and 6].

2.0 SIGNAL AND SYSTEM ANALYSIS IN MECHANICAL STRUCTURES

Signal Analysis is the vibration analysis for determining the response of a system due to generally unknown excitation and presenting it in a manner which is easy to interpret [7]. In the analysis under operational conditions the loads which are input to the system are unknown. But the data obtained from the test results give the behavior (operational deflection shapes) of the system under operational conditions.

In Signal Analysis time signal does not give too much information. Converting signal to frequency domain forms acceleration spectrum information. This spectrum can show the energy intensity concentrated around one or more of the frequencies. By the knowledge and experience of the system mechanics, relation between these frequencies and special mechanic components are defined so that the source of the vibration can be determined.

As an example the magnitude of frequency in one spectrum might coincide with a specific rotational speed of a particular shaft in the transmission system. This analysis is a strong evidence to identify the source of the vibration. As the source is identified new questions arising should be examined like; does the source has enough dynamic energy to vibrate the structure, or is the response of the structure extremely high when the structure is weak and insufficient?

Determining the vibration properties of the path between source and sink shows dynamic structural characteristic of the whole system. All the peak points in the graph can not be termed as resonance points. Since the excitation function is unknown and modal analysis must be done to understand whether the reason is structural or excitation.

System (Modal) Analysis is the vibration analysis that deals with techniques for determining the inherent properties (modes, resonances, damping etc.) of a system and constructing mathematical model of the system. This can be done by stimulating the system with measurable forces and studying the response/force ratio (receptance). For linear systems this ratio is independent, inherent property which remains same whether the system is excited or at rest. Modal analysis is performed by numerical and experimental techniques.

Structure's vibration modes and frequencies give structure's dynamic properties. When obtained results and excitation frequencies coincide then some precautions must be taken. After the outputs are evaluated adding stiffness to the system might be a solution. Much of the effort is expended for making mounting supports rigid and less is spent for damping them. This stiffness shifts the natural frequencies to higher values. Structure could be taken out from excitation range by modifying the structural design. The amount of this modification is based on proper mathematical models and iterations in modal analysis software's [8] or engineering background. The modifications will be easier after the numerical model confirmed with the experimental results [9].

In some cases isolating the structure (free-free) from external forces or applying enough vibration forces to excite the system (tank, bridge etc.) is not possible when performing the modal analysis. Then operational modal analysis should be applied and only response function might be necessary to analyze the system [10]. It is an important approach in vibration analysis since the modal analysis method could be applicable to both the equipments and the platforms.

In this study operational vibration analysis is performed by using signal analysis on naval platform for system integration. Modal analysis is applied to BORA structure to analyze possible effects coming from the platform to the PMS system before the integration. And also environmental qualification tests could be performed to the electronic equipments by using PSD vibration profile obtained from operational tests.

3.0 OPERATIONAL MEASUREMENTS OF THE BOAT STRUCTURE

The three dimensional rotation and translational movement inputs are collected during design stage of the PMS system that will be mounted on the battleship (Figure 3).

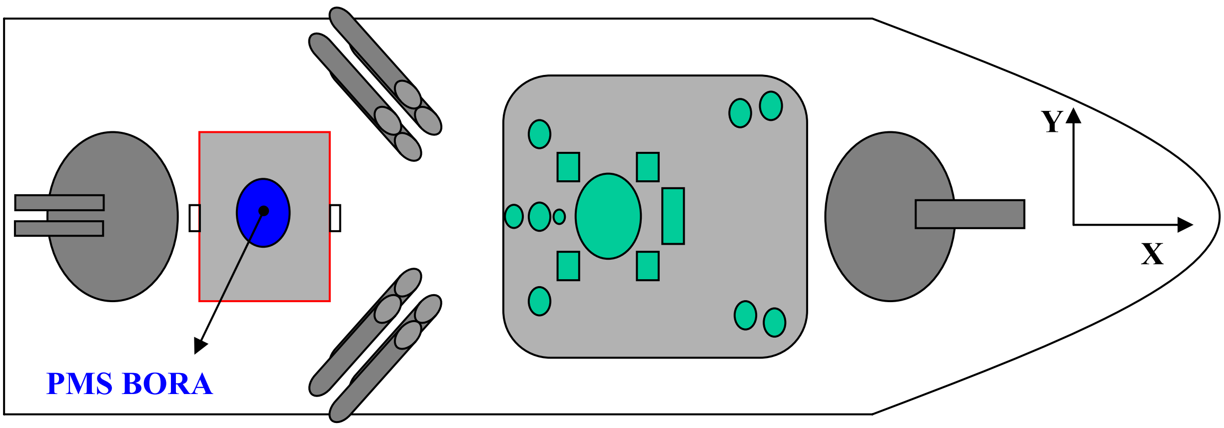

Figure 3: Bora system installation region on the ship.

In the operational tests, mobile Traveller Plus [11] data acquisition system with 32 channels is used. Traveller Plus has the capability of pointing out the events which are probable to occur in the experiments. The test set up which is compact is capable of using strain gages, accelerometers, pressure and force sensors and also thermocouples. It can be used efficiently for all kinds of stationary systems and mobile vehicles with 24-36 VDC power source. The test set up that had been inspected is placed on the ship and data acquisition is performed.

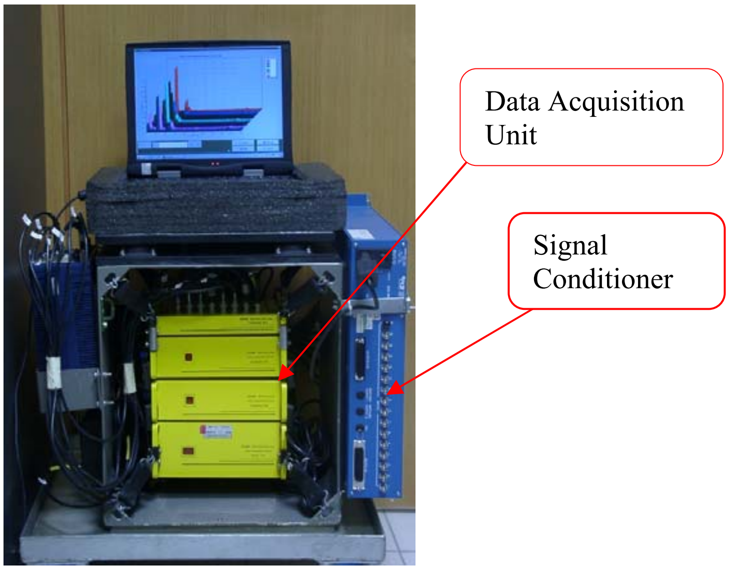

Figure 4: Traveller Plus dynamic data acquisition and processing system.

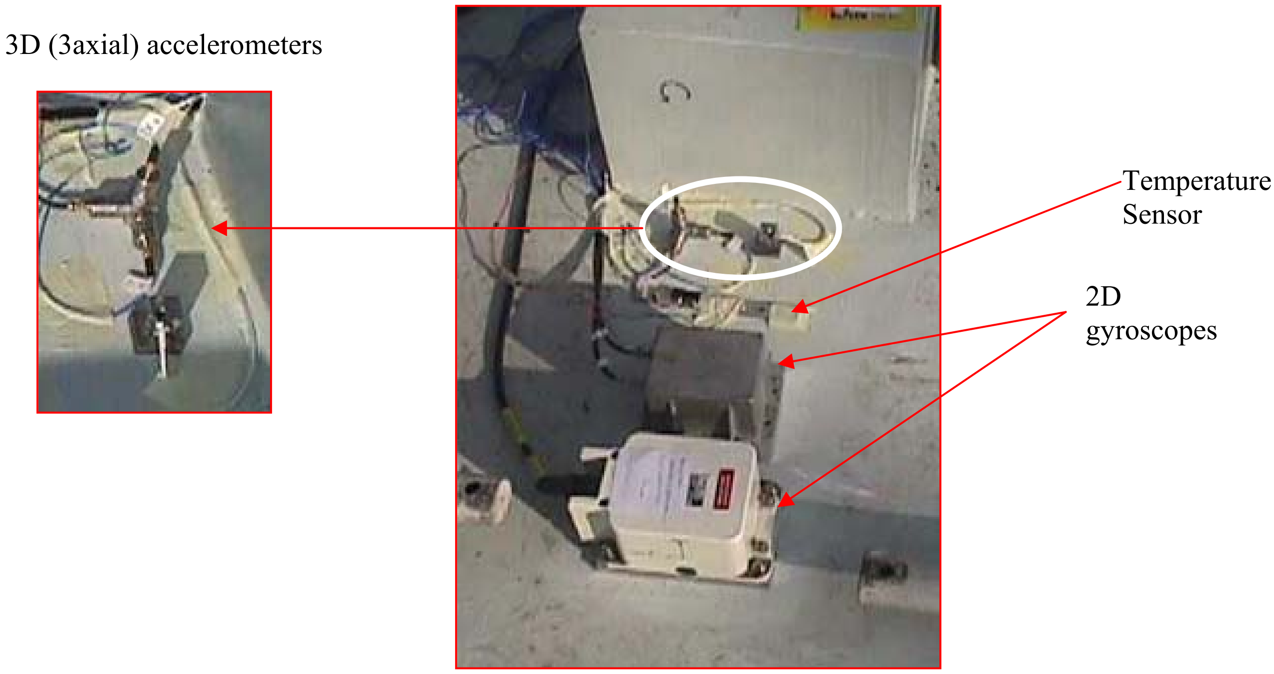

Figure 5: The sensors used in corresponding location of PMS.

The ship test was performed in operational conditions as follows; leaving the harbor, accelerating up to maximum speed (knot) by sinusoidal maneuvers. The ship experienced high speeds so that vibration amplitudes increased considerably. Further pitch and roll motion were also experienced.

The ship is cruised at 18-20 knots and the nominal test speeds were planned to be between 20 and 22 knots.

The weather was clear and wave length was recorded as 3 feet. The maximum vibration amplitudes aroused when the ship was making turns by the port and starboard (to the left and right) and also during approaches to the harbor.

The strength of the wind was recorded as 2 knots blowing from southern to northern at 180 degrees. The barometric pressure (air pressure) and relative humidity was 1020 mmHg and 82% respectively.

After the data is collected with the data acquisition system, test results are processed with the software of the system ESAM [11]. First of all, the acceleration versus time data is passed through appropriate filters then PSD and the other relevant plots are obtained. The modal response of the accelerometer measurements of a point under test might be different for the x, y and z axes. Therefore there will be discrepancies between the results obtained from different axes accelerometer readings for the same point.

As a result of the signal analysis, natural frequencies of the platform and also the excitation frequencies (motor, transmission etc.) including their amplitudes are obtained. Consequently, the effects of all vibration signal contributions exposed to the structure and the passengers are evaluated in order to obtain optimum performance of the system.

4.0 EVALUATION OF THE MEASUREMENTS

The Ship's rotor, motor and other repetitive signals are estimated by the harmonic analysis of acceleration signal. In the ship, there are four diesel motors and four in-line propellers each with three wings at the ship rear part. While the motor is rotating the connected propeller rotates at 900 rpm going forward and rotates at 560 rpm while moving rear. The outer propellers rotate outwards and inner propellers rotate inwards. According to cruising condition of the ship only outer ones, only inner ones or all might work together.

The graphs are arranged according to test intervals. Looking at energy content of the excitation (by PSD) at all frequencies conclusion is derived. When the ship is considered as a complete system or the local region of BORA test point might come out to be a node point or a peak point or a point between these two under dynamic loads according to fundamental mode shapes. In addition to this the excitations coming from the sources like motor, rotor, bearing etc. affect the system similarly. By the measurements all of the effects on the system are investigated. High frequencies correspond to motor and propeller rotor's harmonics, and other frequencies correspond to bearings, gear's frequencies, etc. The PSD behavior of the ship's test location without BORA system is given in Figure 6.

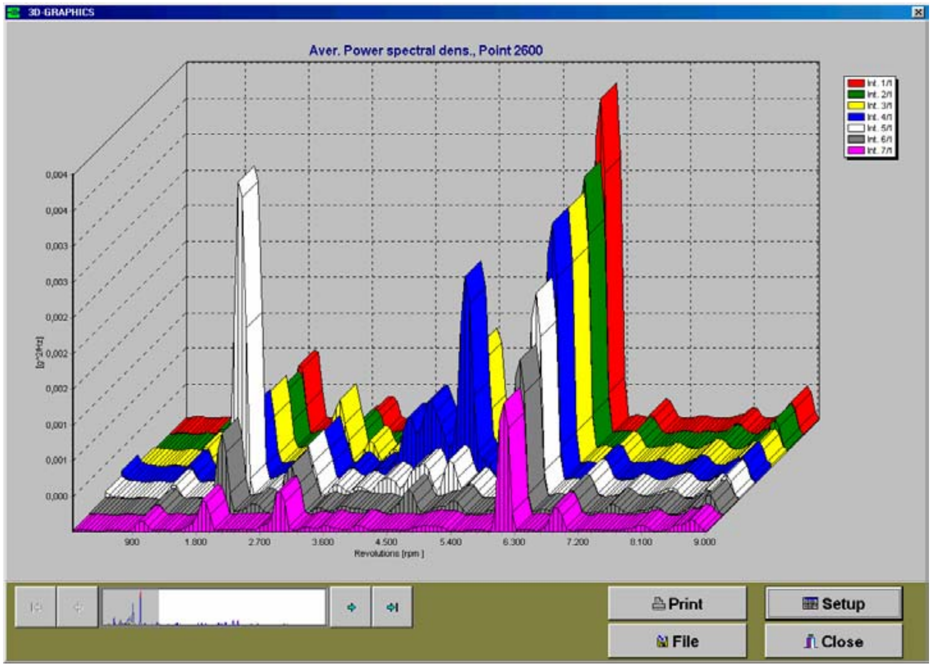

Figure 6: The structure perpendicular (Z) axis PSD graph (all intervals).

Vibration increased during the tests especially at high speeds of first interval and these are specifically marked on Figure 7. The corresponding frequencies that cause these vibrations are determined in Figure 8.

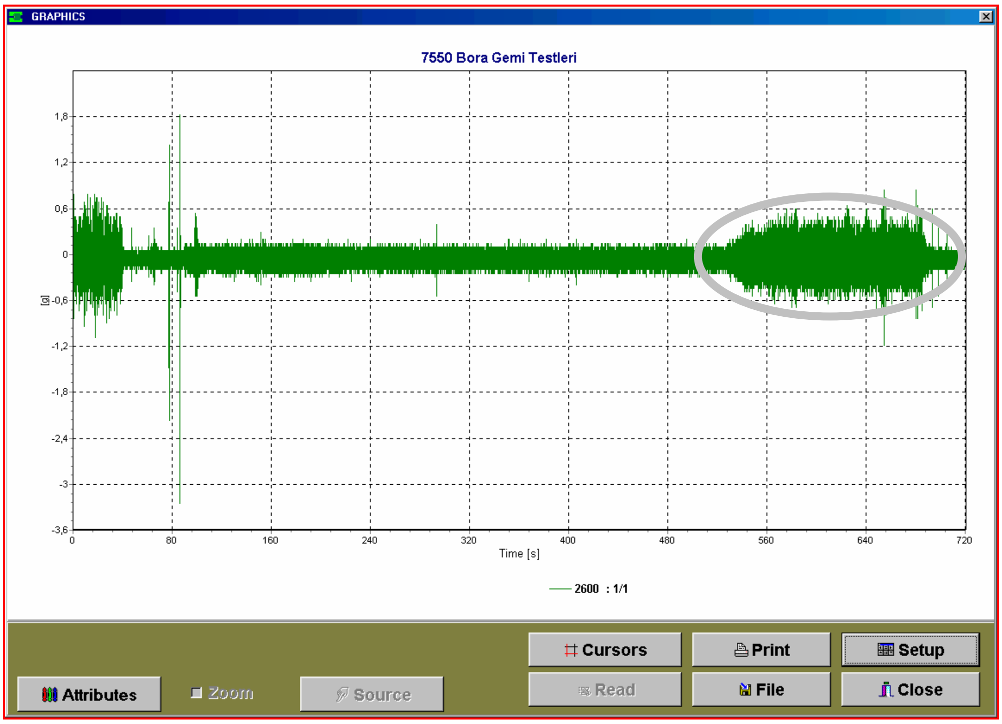

Figure 7: The interval where vibration arises, (1st interval raw signal) Z axis.

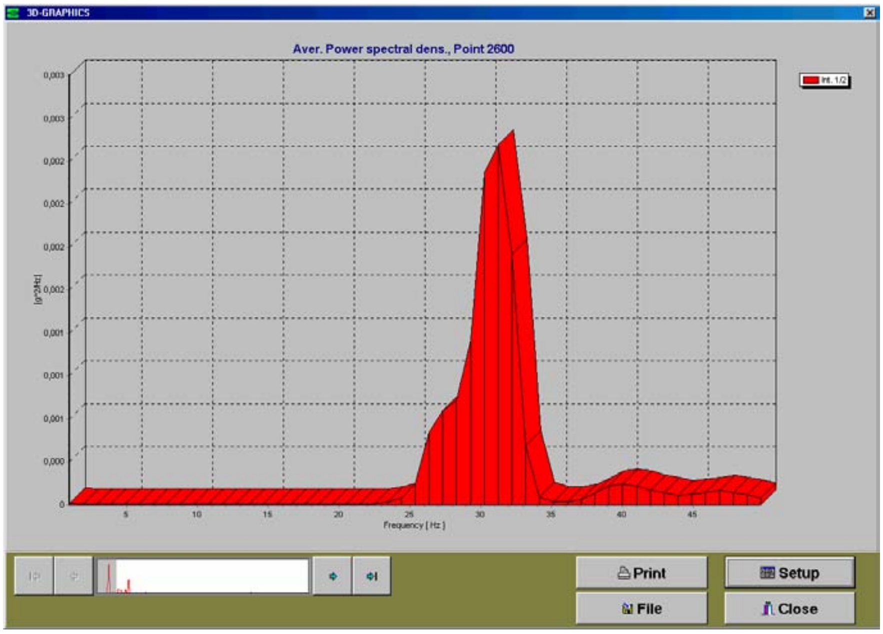

Figure 8: PSD graph of the vibration frequency, (selected region of 1st interval) Z axis.

Under normal operating conditions, some instrument reading problems are experienced on the bridge of ship. The cause of the problem is excessive vibrations at the bridge. An analysis of the operational vibration signal indicates that the response increases exponentially with propeller speed. The vibration spectrum shows a concentration of energy at the propeller blade-passing frequency, which identifies the propeller as the primary source of the vibration.

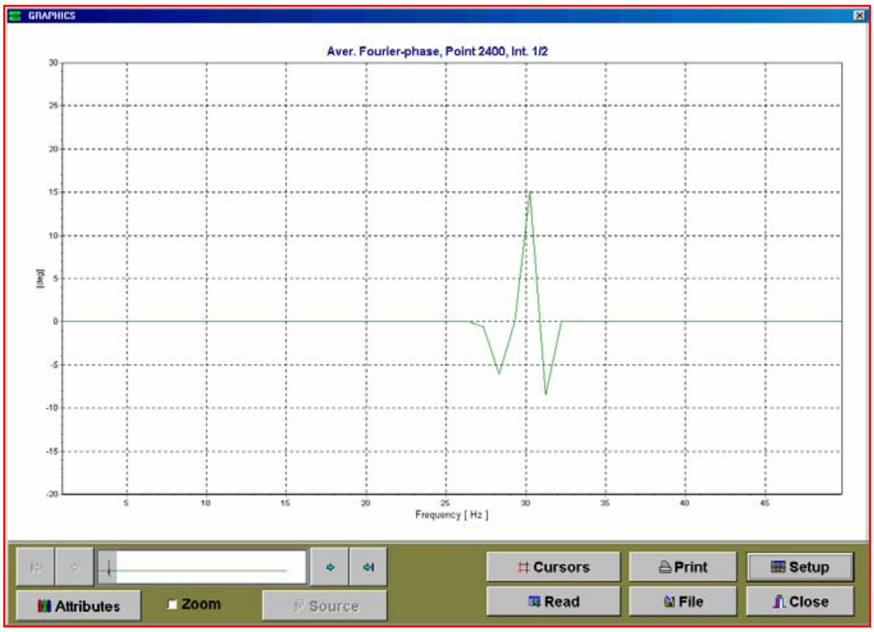

Figure 9: The interval Fourier phase graph, (selected region) Z axis.

The problem then is to determine where the energy is entering into the structure. It is identified when the signal analysis PSD and phase difference (Figure 9) are found to exhibit a peak about 30Hz (1800 rpm). Although reason for this level is suggested to be propeller's second harmonic (2*900 rpm), important point here is the structure's first fundamental frequency and its magnitude. It can be also understood that lower excitation frequencies (<15Hz) do not appear in the system. A stiffening modification to the base structure reduces vibration levels. Subsequent measurements demonstrate that the operational vibration level is reduced by the same level.

5.0 MODAL ANALYSIS OF THE BORA SYSTEM

Furthermore, these excitations are evaluated with respect to PMS turret's experimental modal analysis (done on PMS system) results [12].

In PMS turret experimental modal analysis, one of the mode natural frequencies comes out to be 28.9 Hz and % 0.56 damping. In addition to this, excitation frequency which effects the results obtained in ship test comes out to be 30.1 Hz. Coincidence of excitation and natural frequency (although higher modes effect is small) may cause resonance. For this reason at the ship deck, support pieces are designed such that stiffness of these pieces increased which increased natural frequencies to high levels. Furthermore connection pieces of PMS system to the ship are designed stiff enough to get rid of the excitation frequencies.

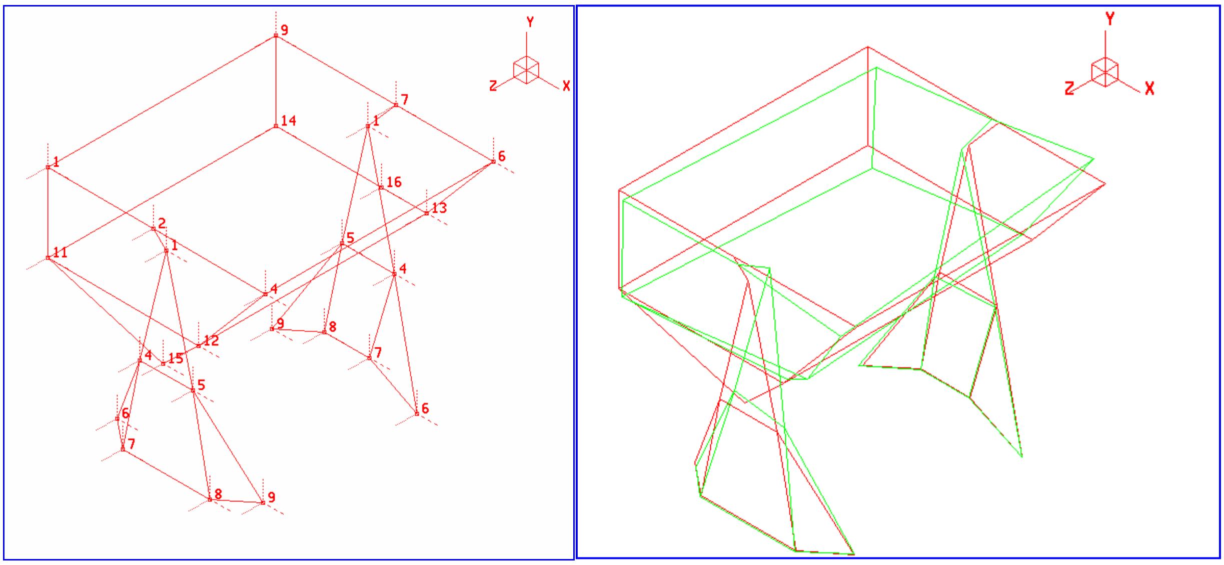

Figure 9: PMS system's mode shape at 28.9 Hz.

After analysis has been finished integration of BORA system to the ship is done and measurements show that system performs its operational functions properly.

6.0 CONCLUSIONS

Shock and vibration are the most destructive agents in the industrial society. They erode the life of mechanical and electronic equipment, driving it from service long before its time. Sometimes this premature deterioration stems from repeated overstress loadings, sometimes from fatigue failures of vital parts. To control the behavior of dynamic structures it is necessary for the engineers to investigate system's excitations, structure transfer functions and behaviors by experimental analysis.

During design of structures used in military platforms, coincidence of excitation frequency with system's natural frequency is not desired, or if there is a coincidence, excitations of the structures should not go beyond certain levels. Furthermore, in case of systems composed of hundreds of pieces and modeling these pieces one by one is not feasible, it is inevitable to have coincidences between excitation frequencies and system natural frequencies. If many coinciding frequency magnitudes are too low, it will be possible to use the system without any changes. Because, when the inputs are not exciting the systems enough, there won't be serious problems in the structures regarding vibration.

Excitation functions that systems are exposed to are not always known that's why advanced analysis (signal, modal, etc.) are necessary to understand whether the obtained responses are structural or excitation oriented. Modal analysis is used in order to find the reason of the responses clearly. The approach included in this study to establish a solution between environments; identification of design risks; evaluation of field data to quantify the relationship between predicted and operating reliability.

After these outputs are evaluated, if necessary, problem can be solved by modal design. It can be possible to take the structure out of excitation range by design iteration. If changing excitation frequency or system's natural frequency seems to be difficult, then vibration could be isolated by using vibration isolators. The excitation frequencies for the ships are lower compared to land and air platforms (<150Hz). This is advantageous for the systems that will be used in naval platforms.

ASELSAN PMS BORA System has been indigenously developed to meet naval platform requirements and it is ready to be tailored for the requirements of the other users in NATO, Partnership for Peace (PfP) and Allied Countries.

7.0 REFERENCES

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Detailed Analysis or Short Description of the AVT-110 contributions and Question/Reply

The Questions/Answers listed in the next paragraphs (table) are limited to the written discussion forms received by the Technical Evaluator. The answers were normally given by the first mentioned author-speaker.

P21 M. Celik, M.F Akbostanci 'Operational Vibration Analysis of Naval Platforms for System Integration' (MSTSMKKS-MTM Aselsan Inc, TR)

Based on the MIL-STD 810F, various electronic components have been submitted to vibrations induced by several kinds of naval platforms. Traditional methods (LMS Int products) were used and tests in operational conditions (operational vibration analysis of large structures) confirmed the results obtained on two coupled shakers.

Discussor's name: J. Blankenship
Q. Did you do PSD averaging? And what windowing did you use?
R. Yes, PSD was analysed by averaging and Hanning windowing was used

Discussor's name: J. Vantomme
Q. Modal analysis (experimental MA) is not easy, especially on such big structures. Is it wise to use operational vibration analysis techniques, with exploitation of response signals only?
R. Yes. The tested system was not so heavy, and it was easy to perform classical modal analysis methods.

Discussor's name: R. Peterson
Q. Did you investigate the longitudinal swhipping motion of the ship in waves?
R. Yes, in case of signal analysis. However we do not need to consider ship's modal analysis itself. The vertical vibrations are much more important than the longitudinal ones.