Analysis for Structural Robustness of Induction Motor under Shock Load Using Finite Element Method

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Abstract— **Shock analysis for structural robustness of induction motor is one of the important criteria for the qualification of any design for its application. High Shock can severely damage the functioning of the machine and even in medium range of shock cases can destroy the machine. Submarines & naval machines are expected to encounter such situation of high impact & shock load condition. Under such working condition, the induction motor structural robustness of naval machines plays a vital role. In this presented research work it is attempted to analyse structural robustness of naval machine part i.e Induction motor. The performance and reliability of induction machine under high shock load falls down drastically. The shock, which is an impulsive wave front under goes an initial dynamic acceleration followed by deceleration at different time periods induces severe stresses and deflections on different location of electrical machine such as static structure of stator and its foundation feet, DE (Drive end) and NDE (Non Drive End) end shield, shaft rotor system, and stator and rotor interface, can generate operational damage. The proposed work involves design investigation using finite element method on UG NX Model followed by ANYSIS *Mechanical APDL* and the result of this work gives the allowable stresses condition.**

Keypoints: Shock loads, Induction motor, Submarine, Finite element analysis and ANSYS

I. INTRODUCTION

The present work consist the characteristics and use of Navy High-Impact class shock machines. In addition the report will present recent views relating to shock tests and test procedures. One of shipboard equipment i.e. Motor (Induction Motor) has been analyzed (structural analysis) for the underwater shock or when shock occurs due to any reason and passes to the equipment.

Shock loads [2]: Shock, is generally understood as a sudden and violent blow or impact. It is characterized as a dynamic disturbance with a short duration compared to the natural frequency of the affected equipment. Equipment subjected to shock beyond its fragility level can fail structurally and functionally.

Naval vessels [1] and the equipment on board such vessels, generators, frequency convertor, propulsion motor (Induction Motor), etc. are generally required to withstand and survive shocks. The most severe shocks that a naval vessel needs to withstand are usually those related to an underwater explosion, where explosives are detonated in the waters surrounding the vessel.

Under water explosion [6] [7] generate shock waves that strike the hull of the naval vessel. The shock energy that is transmitted via the ship structure to the various locations on board the ship has the potential to damage equipment installed at these locations. Equipment damage usually occurs when the transmitted shock exceeds its design specifications. Forms of damage include malfunction of electronic components within the equipment, mechanical deformation or collapse of the affected equipment and general interference between equipment due to misalignment or breakage from its mountings. As such, the adequacy of the equipment design against shock is an important consideration during the acquisition of equipment to be installed and operated on board naval vessels. This is an aspect of equipment acquisition must be managed for shock.

II. SPECIFICATION OF SHOCK REQUIREMENTS [2]

1. SHOCK FACTOR:

Shipboards are generally designed to survive and remain operational after exposure to UNDEX, the level or magnitude of UNDEX that a vessel is expected to be subjected to depend on ship type and its mission role. The magnitude of UNDEX that a shipboard is designed to withstand may be estimated by an explosion energy parameter (shock factor) that relates the explosive quantity and position from the ship. Hull Shock Factor (HSF) is a representation of available energy that a shock wave contains which may damage the hull plating on the ship. Keel Shock Factor (KSF) is relevant when the relative position of the explosive charge and the angle of incidence of the shock wave with respect to the ship are taken into account. A vessel designed to a higher shock factor is able to withstand larger and hence more damaging UNDEX.

2. SHOCK TRANSMISSION IN THE SHIPBOARD:

Except for equipment such as sonar arrays that are installed externally below the waterline, the majority of shipboard equipment are located within the vessel or on the super structure above the waterline and are not directly exposed to the shock energy from UNDEX. Instead, the shipboard equipment experience shock energy transmitted via the ship structure. And since shock energy dissipates as it travels through the ship structure, the shock experienced by equipment mounted on the higher decks or the superstructure would be lower than that experienced by those mounted inside the hull or on the lower decks. As such, in larger ships where the shock energy is transmitted over relatively longer distances, shock levels can vary significantly between the lower decks and the upper decks. On such larger ships, the ship is frequently divided into zones and equipment installed within each zone will need to withstand different level of shock. Equipment in the zone closest to the bottom of the ship is expected to experience the highest levels of shock. Shock level reduces from each zone to the next, moving up the ship structure. For a smaller ship where the attenuation by the ship structure is less pronounced, the entire ship may fall into a single zone for the purpose of managing equipment design against shock.

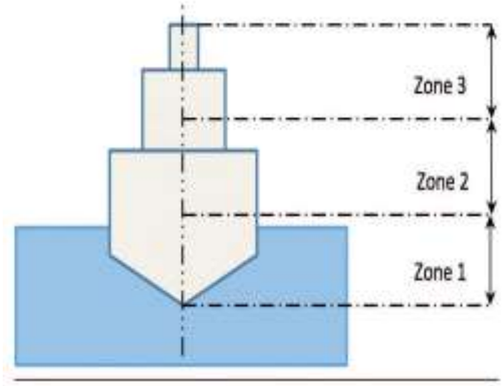


Figure 1- Example of Ship Shock Zone Variations across Ship Structure

III. DESIGN AGAINST SHOCK [2] [6] [7]:

For critical shipboard equipment, there are typically two approaches with regard to equipment protection against shock. One is to install resilient mounts (Shock-mounts) between the equipment and its foundation to attenuate the shock entering the system where feasible. The other is to harden the equipment that needs to be rigidly mounted due to performance considerations.

Shock Qualification [2]: Besides requirements definition, qualification is another important aspect of shock management. Shock qualification provides the technical evidence that the equipment design has fulfilled the requirements for design against shock. The qualification can be achieved through testing, analysis or similarity. The decision hinges on the availability of qualification data, cost and, to a lesser extent, the project schedule. Analysis and testing can be synthesized; where testing cannot be carried out, analysis is used for inference. For developmental equipment, both approaches of qualification by testing and analysis have been applied.
Qualification is done to ensure that the equipment is able to withstand the effects of a predetermined shock input from handling, transportation and service environments while maintaining its functional performance as well as to ensure that the equipment remains attached to the shock mounts.

IV. SHOCK ANALYSIS

Induction Motor has associated shock requirements that it must withstand. The shock requirement for Motor is related to severe ship motions like pitch and roll. Motor shall be specifically designed to endure some defined lifetime of shock loading and are required to endure harsh environment, vibration and shock environments.

Concept of Shock

- A 'SHOCK', whether it is Electrical, Mental or Mechanical is dangerous things, and in spite of all the precautions adopted, it may not possible to prevent it to take place. Therefore, it is necessary to minimize its damaging effects.
- To avoid any damaging effect on equipment (Electrical motor) under such shock, the equipment must be shock proof.
- The 'SHOCK' an impulsive force, cause an equipment to undergo initial dynamic acceleration followed by deceleration, the period of which are different.
- An impulsive force is force acting on an object over a short span of time, which is caused by change in moment of object.
- Shock is some time fun loving activities like Trampoline and Roller coasters of theme amusement park.

The acceleration and time period acceptable for fun loving:

Table 1: Acceleration & Corresponding Acceptable Time Period

Sl no.	Acceleration	Time period
1	-2g to +6.0 g	0.2 sec.
2	-1.5g to +5.0 g	1.5 sec
3	-1.5g to +2.5 g	>12 sec.

- Shock of longer time duration is more dangerous than shorter time duration for same value of 'g'.
- Rapid changes in acceleration of a cutting tool can lead to premature tool wear and result in uneven cuts..
- The shock associated with ships, caused by underwater explosion, gun blast and gun shots generate high stress on the hull structure and finally equipment attached to it.
- MOAB (Mother of All Bomb), FOAB (Father of All BOMB) are also an examples of shock Pulse.
- The basic concept of checking the design capability for withstanding shock without damaging the equipment is to calculate the maximum stress generated due to shock for and compare these calculated stress to allowable stress of material.

Basic Design Principle for Modelling [5] [8]

- Stress concentration should be avoided.
- All parts should be as light as possible and compatible with adequate strength.
- Assembly of parts requiring a fixed relation should be positively located to prevent serious displacement.
- Adequate clearances should be allowed between fixed and moving parts, and between all semi-rigid parts to prevent distortion due to shock causing collision, thus increasing the risk of failure.
- Brittle material should be avoided. All material shall be capable of yielding appreciable without fracture.
- Over hang components should be avoided.
- Assembly parts requiring a fixed relation should be positively located to prevent serious displacement.
- Adequately clearance should be allowed between stationary and moving parts, causing collision between them, thus increasing the risk of failure.

Finite Element Analysis [8]

FE analysis has been carried for qualification of motor against Shock load. FE model of components of assembly have been developed as per the proposed CAD models and following analysis have been carried out:

1. Equivalent Static load Analysis

In this approach a peak load is constantly made acting on Rotor and combined assembly of motor in all X, Y & z direction, i.e Lateral, Axial and Vertical direction respectively.

2. Transient dynamic load Analysis:-

The Motor has been subjected to full sine wave shock pulse of specified value for appropriate time range.

Rotor and Stator Assembly Overview

A well Electrically designed motor is considered, meeting all parameters to be tested for shock analysis to fulfil the shock parameter

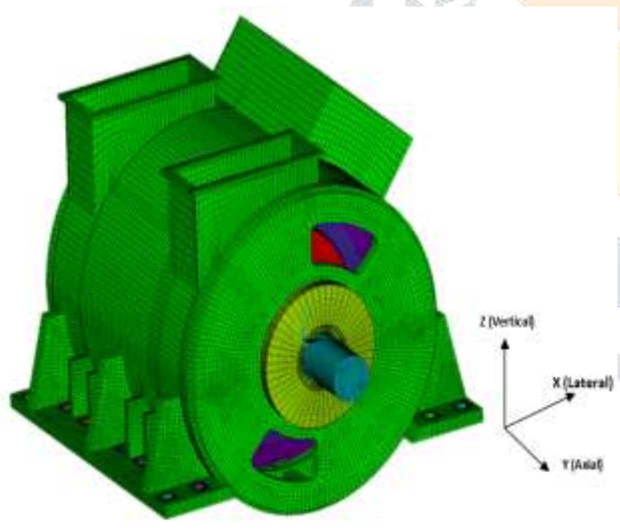


Figure 2 - Solid Hex Elements Have Been Used to Model the Components of Rotor and Stator Assembly

Assembly Cut Section

Following assembly represents the cut section of proposed model which has been analysed under shock loads.

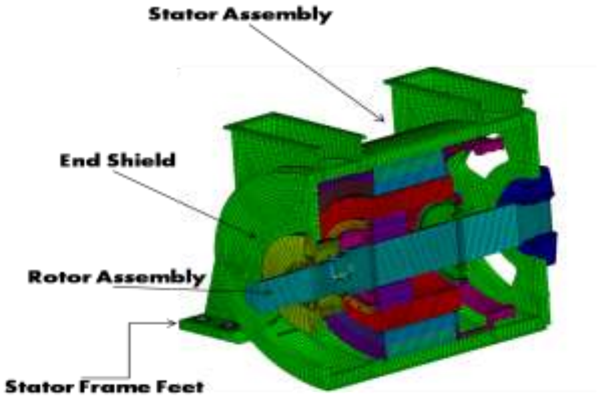


Figure 3 - Cut Section of Stator-Rotor Assembly

FE Model has been investigated for Rotor and Stator Assembly of proposed CAD Model. Solid Hex elements have been used to model the components of Rotor and Stator Assembly. Model analysis has been carried out to estimate the natural frequencies for the Assembly. Transient Shock Analyses and Vibration Resistance analysis have been carried out. Based on the analysis, Material of End Shield and Base plate has been selected to meet the Shock Requirements.

Considering this approach, the whole work has been carried out to develop the results and conclusions of objective.

Research Gap

As we see that the equipment mounted on shipboard must meet the criteria of fulfilling its shock requirements, so it is very much necessary to ensure that the design criteria are full proof for those equipment. Those all three methodology are used for actual component testing, Ansys helps to simulate those results with the help of FE model structural analysis. . It was seen in the literature review that not so much work has done in the direction of using Computer Aided Engineering (CAE) to carry out the same investigations.

V. FLOW-CHART OF ANALYSIS PROCEDURE

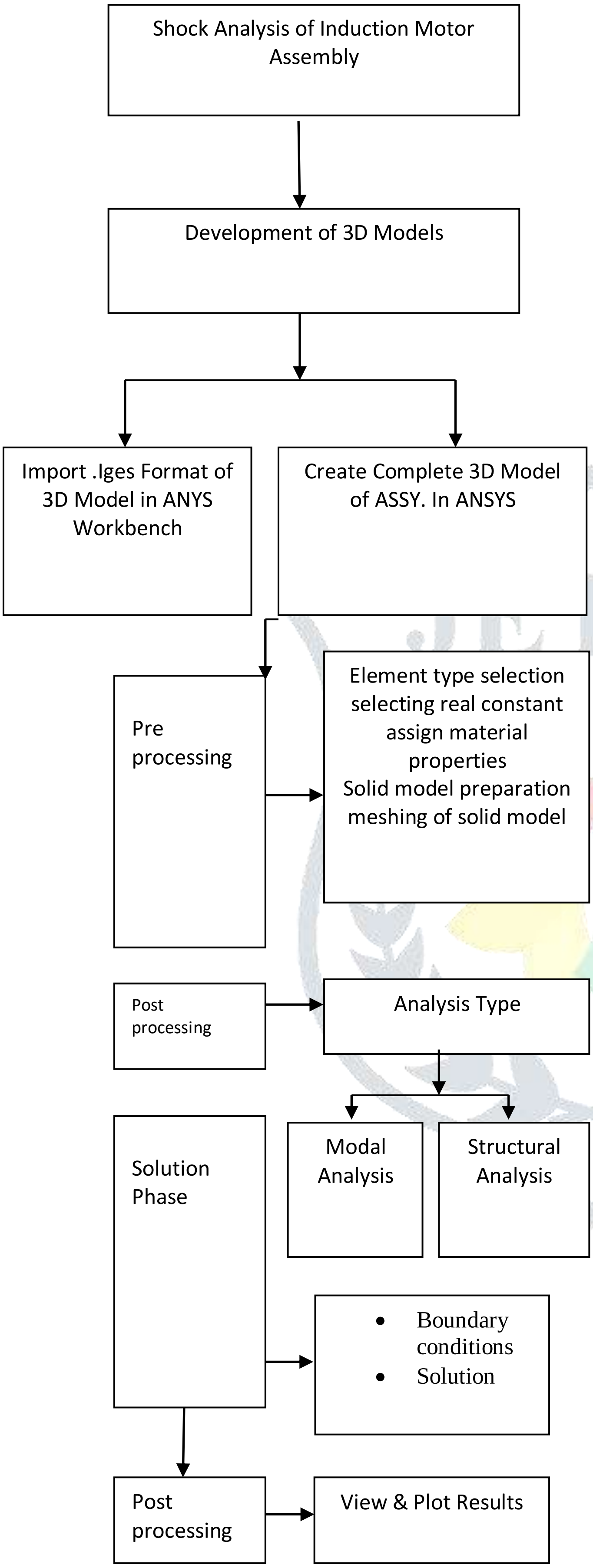


Figure 4- Flow chart of analysis procedure

VI. ANALYSIS

FE analysis was performed for qualification of the INDUCTION MOTOR Assembly against shock loads. FE Models of the components of the assembly have been developed as per the CAD Models and the following analysis has been carried out.

1. Modal analysis to identify the natural frequencies of the INDUCTION MOTOR Assembly.
2. Transient Dynamic analysis for 3 cases.
   a. Lateral shock along X-direction.
   b. Vertical shock in Z-direction.
   c. Axial shock in Y-direction.

INPUTS

Shock loads:
Transient dynamic analysis has been carried out for the following shock pulse as specified.

1. Full sine wave shock pulse of 39 g for 48 milliseconds.
2. Analysis has been carried out upto 100 milliseconds

An electrical motor has been selected for analysis under high shock & vibration condition.

Details of motors for analysis are given below:
Diameter of motor stator frame – 1150 mm
Effective length of motor between bearing – 1080 mm

- Air gap between stator & rotor – 4.00mm
- Weight of Motor – 4.5 ton
- Weight of stator – 3 ton
- Weight of Rotor – 1.5 ton
- Allowable stress for material taken – 400 MPa
- Operating frequency – 50Hz

Table 2: Mass of Components in Induction Motor

Component/Assembly	Mass (Kg)
Stator Frame Assembly	3440
Rotor Assembly	1250
TOTAL MASS OF INDUCTION	4690

MATERIALS

The following are the materials considered for the analysis.

Table 3: Material Properties

Material Grade	UTS (MPa)	Yield Strength (MPa)	% Elongation	Allowable (MPa)
Alloy Steel	720	430	17	430

FE Modal

FE model has been developed from the CAD Model. All components of the INDUCTION MOTOR Assembly are modeled with Solid HEX elements. Figures 4 & 5 show the FE Model for the analysis.

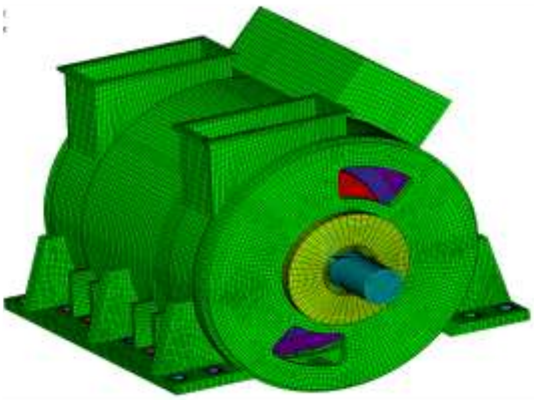


Figure 5 - FE Model of Induction Motor Assembly

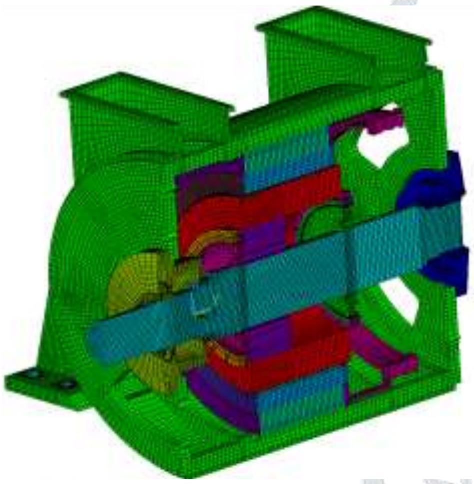


Figure 6 - FE Model of Induction Motor Assembly

Boundary Conditions

The INDUCTION MOTOR Assembly is fixed at the base plate. The Rotor is connected to the stator by coupling at the bearing locations. The INDUCTION MOTOR assembly is fixed at the base plate at its bolt locations.

VII. RESULT ANALYSIS

Modal analysis has been carried out to identify the natural frequencies and Mode shapes of the INDUCTION MOTOR Assembly. Following table lists the first five natural frequencies of the INDUCTION MOTOR Assembly.

Table 4: Natural Frequencies of the Induction Motor Assembly

S. No.	Natural Frequency (Hz)
1	92
2	149
3	152

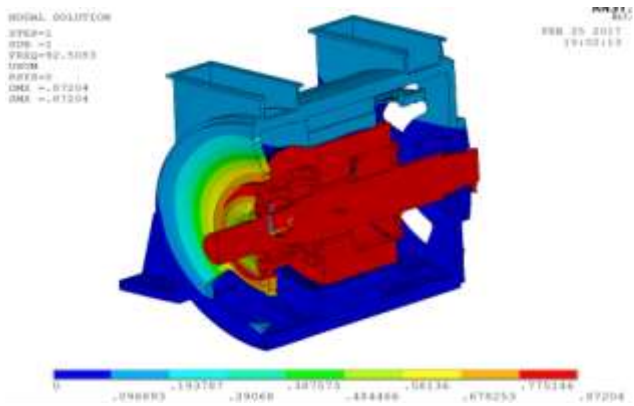


Figure 7 – 1st Natural Frequency Mode at 92 Hz

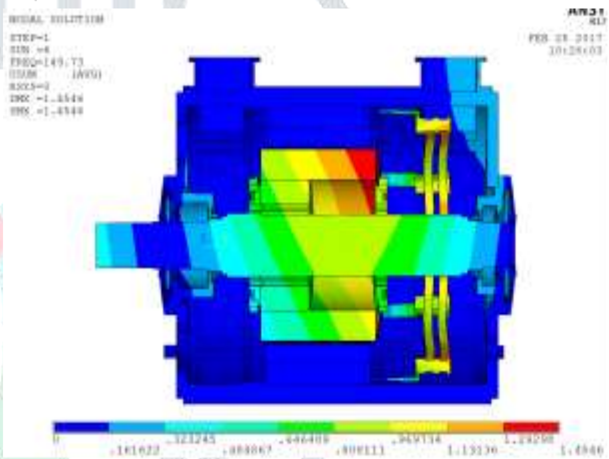


Figure 8 - 2nd Natural Frequency Mode at 150 Hz

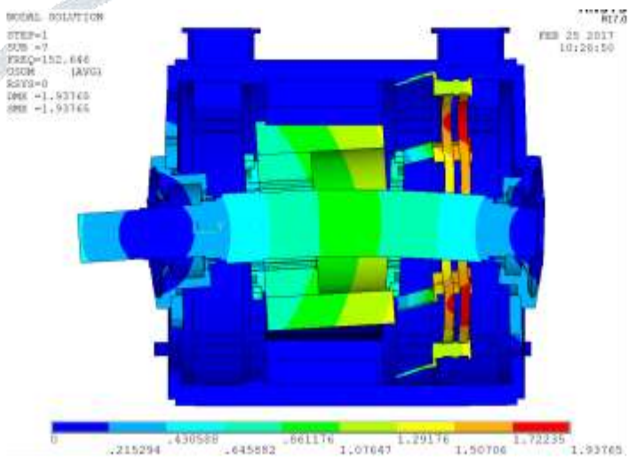
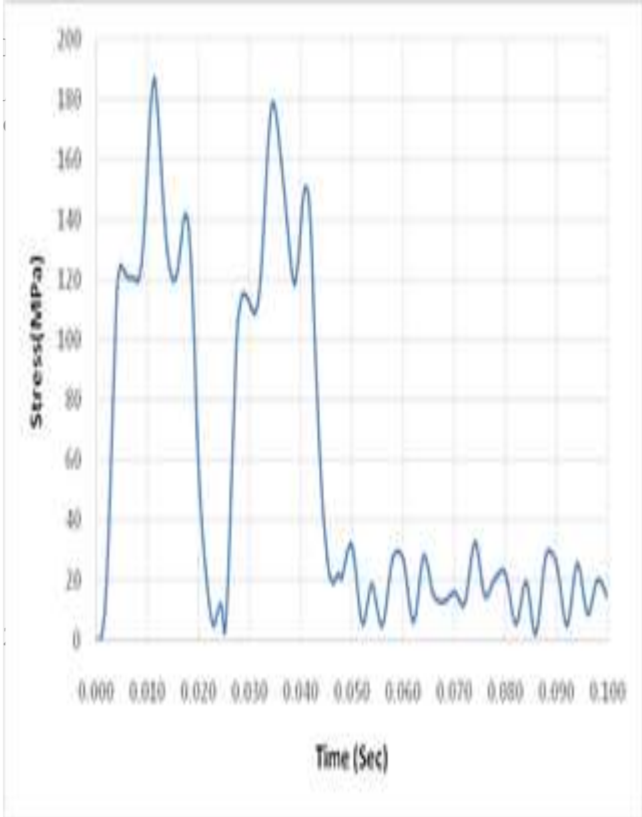


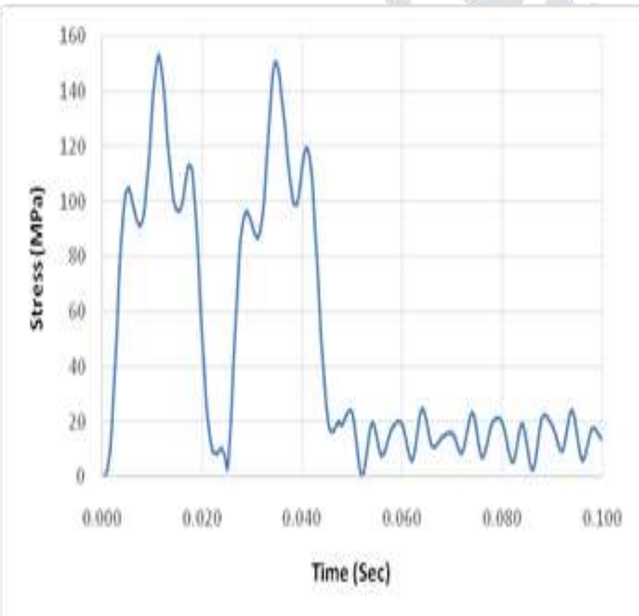
Figure 9 – 3rd Natural Frequency Mode at 152 Hz

SHOCK ANALYSIS

Shock analysis has been carried out for the shock pulse specified in all the three directions. Shock pulse has been applied at the bolt locations of the base plate. Three independent analysis has been carried out for three directions(X, Y and Z direction).



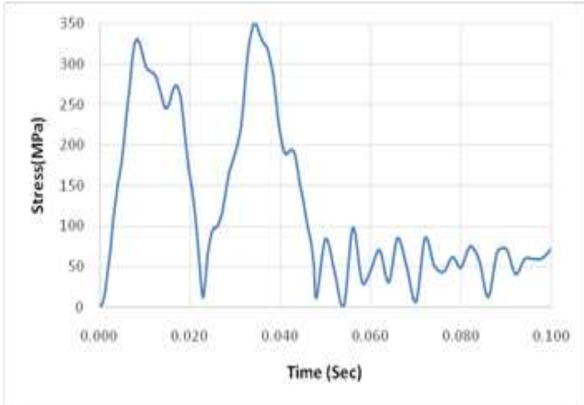
Graph 1 – Stress Variation Max Stress Location in Stator frame for shock in X-Direction



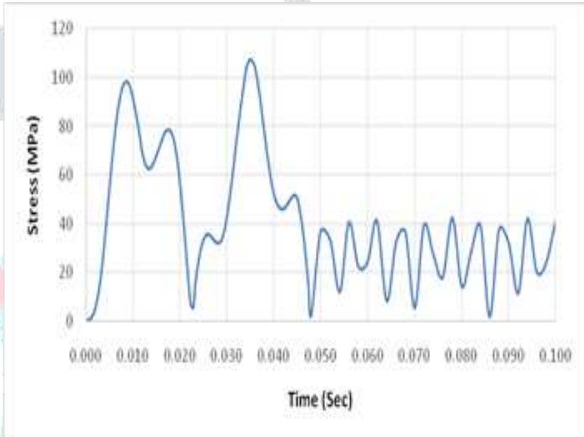
Graph 2 – Stress Variation Max Stress Location In Rotor For Shock In X-Direction

AXIAL SHOCK (Y-DIRECTION)

A peak stress of 350 Mpa is observed for shock at 34.2 milliseconds in axial direction.



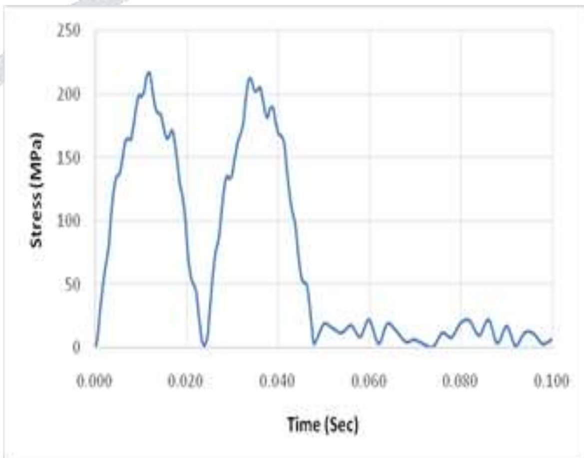
Graph 3 - Stress Variation Max Stress Location In Stator Frame For Shock In Y-Direction



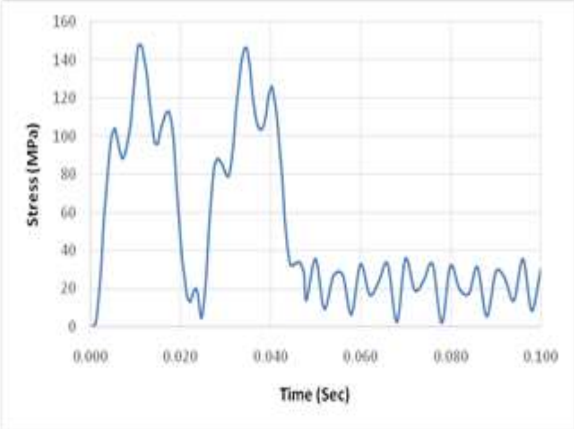
Graph 4 - Stress Variation Max Stress Location In Rotor For Shock In Y-Direction

VERTICAL SHOCK (Z- DIRECTION):

A peak stress of 216 MPa is observed for shock at 12 milliseconds in vertical direction.



Graph 5 - Stress Variation Max Stress Location In Stator Frame For Shock In Z-Direction



Graph 6 - Stress Variation Max Stress Location In Rotor For Shock In Z-Direction

VIII. SUMMARY OF STRESS RESULTS FOR SHOCK LOAD:

Table 5 - Summary of Stress Results for Shock Load

Component	Loading Direction	Stresses (MPa)	Allowable Stress (MPa)
Stator Frame	X-Dir	**187**	430
	Y-Dir	**350**	430
	Z-Dir	**216**	430
Rotor	X-Dir	**153**	Xx
	Y-Dir	**103**	Xx
	Z-Dir	**141**	Xx

Table 5 lists the maximum stress observed at critical locations of the INDUCTION MOTOR Assembly for the shock loads. It can be seen from the table that the maximum stresses are less than the allowable stresses. Hence the design is acceptable from the shock considerations.

XI. CONCLUSION

Shock analysis has been carried out for the shock pulse specified in all the three directions. Shock pulse has been applied at the bolt locations of the base plate. Three independent analysis has been carried out for three directions(X, Y and Z direction). The maximum stress observed at critical locations of the INDUCTION MOTOR Assembly for the shock loads. It can be seen from the table that the maximum stresses are less than the allowable stresses.

REFERENCES

[1] I. Vigness (1961) “NAVY HIGH-IMPACT SHOCK MACHINES FOR LIGHTWEIGHT AND MEDIUM WEIGHT EQUIPMENT”, “U. S. NAVAL RESEARCH LABORATORY, Washington. D.C “ (NRL Report 5618).

[2] ANG Boon Hwee (2013-14), “MANAGING SHOCK REQUIREMENTS OF SHIPBOARD EQUIPMENT”, HAN Mingguang Jeremy.

[3] H. A. Gaberson, Ph D and R. A. Eubanks, Ph D (1982) “SIMPLIFIED SHOCK DESIGN, FOR INSTALLATION OF EQUIPMENT”, “NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME, CALIFORNIA 93043” (PROGRAM NO: YF53.534.006.O1.017).

[4] Ming C. Leu, Amir Ghazanfari & Krishna Kolan, “NX 10 for Engineering Design”, “Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology”.

[5] MingYao Ding, Applications Engineer (2011), “Shock Analysis”, “ANSYS Inc., Mingyao.ding@ansys.com”.

[6] Nicholas Ian Charles Bradbeer (2013), “Implications for Underwater Shock Response of Adopting Simplified Structural Styles in Warships”, “Department of Mechanical Engineering, UCL”.

[7] JASON (2007), “Navy Ship Underwater Shock Prediction and Testing Capability Study”, “The MITRE Corporation 7515 Colshire Drive, McLean, Virginia 22102-7508, (703) 983-6997”, JSR-07-200..

[8] “ANSYS Structural FEA” (2011), ANSYS Inc.

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