DESIGN AND FINITE ELEMENT ANALYSIS TO IMPROVE MTBF OF VARIABLE SPEED CENTRIFUGAL PUMP

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ABSTRACT

Vibration analysis is a technique for analyzing vibration spectrum of individual machine components and identifying its causes and extends of failures. The method of vibration analysis is not only minimizes the need for extensive, but makes it possible to detect developing problems which are out of the range of human sense of touch and hearing. The Objective of this work is to study the problems results in the failure of pump and suggest some better maintenance strategies to improve MTBF (Mean Time between Failures) of the pump and the motor and to reduce maintenance cost by finite element analysis using ANSYS R14.5 software. Results have been discussed and found that parallel misalignment of pump-motor coupling and defects in pump foundation lead to excess vibration. Required actions were performed andthe vibration at the drive end and non-drive end of the motor has been reduced by 30.5 % and 29.4 % respectively.

KEYWORDS: Condition Monitoring, Finite Element Analysis, Mean Time between Failures (MTBF), Roller Bearings, Vibration Control.

1. INTRODUCTION

Among all the parameters, the vibration signature has most of the information regarding the machinery health. When a machine fails or breaks, the consequences can range from annoyance to financial distortion, personal injuries. To avoid this, three crucial steps includes, early detection, identification and correction of machine problems are followed in every industry to ensure continuous and safe productive operation. The scholars in the field of vibration concentrated on understanding the natural phenomena and developing mathematical theories to describe the vibration of physical systems. In recent studies [1, 2, 3] the investigationshave been motivated by the engineering applications of vibration, such as the design of machine components, foundations, and control systems. Thus one of the important purposes of vibration study is to reduce vibration through proper design of machines and their mountings. Condition monitoring is the process monitoring the condition of the internals of any running equipment without disrupting the operation. According to the data analysis techniques[4] the principal cause of excessive vibration is due to resonance, i.e. the excitation frequencies match with the system's natural frequencies.The primary method of prevention against excessive vibration is the detuning of the system, i.e. such a modification of natural frequencies of the structure to differ from the excitation frequency [4]. The automated statistical analysis of vibration characteristics [5] can be effectively used for the condition monitoring of hydraulic systems. The FFT vibration data analysis using a micromechanical accelerometer can be applied to any fluid system. The result [5] shows that, studied fault scenarios can be particularly detected (internal pump leakage) and even quantified concerning the grade of severity in case of valve switching degradation, accumulator gas leakage.Determination of natural frequencies is important while designing any equipment. The condition-based maintenance can be applied in four main phases includes, the feasibility phase, the analysis phase, the implementation phase, the evaluation phase [6].The reactive approach [6] proves the sufficiency, when reliability and availability are easy to reach. This study has successfully suggested a suitable bearing and pump foundation design to reduce the maintenance cost and to improve the mean time between failures (MTBF).

2. METHODOLOGY

This study was then conceptualized by looking in to the problems existing in the pump used, design ofpump foundation and the service methodologies available. The relevant data's were collected and then experimental analysis was performed. Then designed a foundation and subjected to finite element analysis.

Table 1: Conceptual framework of study

INPUT ↓	**Relevant information gathered on:** • Type of pump used. • Service of the pump. • Techniques available for condition
PROCESS ↓	• On-site data collection and Tabulation of data. • Experimental and Numerical analysis of data. • Root Cause Analysis.
OUTPUT →	• Design and Analysis of foundation with Grout. • Proposal of suitable bearing for the pump.

3. SPECIFICATIONS OF PUMP AND PUMP FOUNDATION

The choice of materials used for making various parts of the pump depends on the properties of the fluid pumped and the pressure difference required at the discharge.The pump used was a variable speed (1496-2960) rpm, high head, and high power (5hp) centrifugal pump with 223 m^3/hr flow rate. The bearing used at the initial setup was 6316 C3 deep groove ball bearing.

Table 2: List of Specifications

Pump Specifications	
Operating Temperature	80°C
Design Temperature	110°C
Pump discharge size	0.15m
Pump suction size	0.15m
Power	5hp
Pump Foundation Specifications	
Length, L	1545 mm
Breadth, B	730 mm
Thickness, t	275 mm
Length of frame, a	1393 mm
Width of frame, b	530 mm
Material used	Concrete

4. EXPERIMENTAL ANALYSIS

The given centrifugal pump with the above specifications subjected experimental processes using the equipment's such as; CSI 2130 machinery health analyzer and Triax accelerometer is used as the transducer.Machine vibration is measured with a small piezo-electric accelerometer.

This transducer is normally attached with a magnetic base to a bearing housing or another suitable measuring point. The transducer can be pressed by hand against a non-magnetic material, or can be fitted with a 100 mm long probe tip. Vibration transducers are sensitive only along three main axes; axial, horizontal and vertical. The accelerometer was connected to the health analyzer using multi-conductor 3-pin half breakaway shielded cable.

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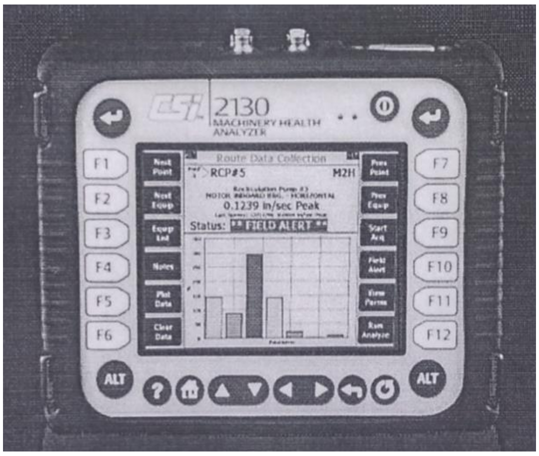


Fig 1: CSI 2130 Machinery

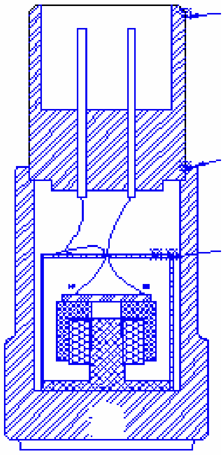


Fig 2: Triax Accelerometer

The experiment was performed in three stages. First, accelerometer probe is mounted on the bearing housing along axial direction and in second and third stages it is mounted along horizontal and vertical directions respectively. It was repeated at both the drive end and non-drive end of pump and motor.

The readings were decoded from the system and stored. These reading are then compared with equipment severity comparison chart- ISO 10861-3, and it was observed that the motor is running with excess vibration at both drive end and non-drive end along axial and horizontal directions respectively. The drive end vibration is about 12 mm/s and non-drive end vibration is about 6 mm/s, both values are RMS velocities.

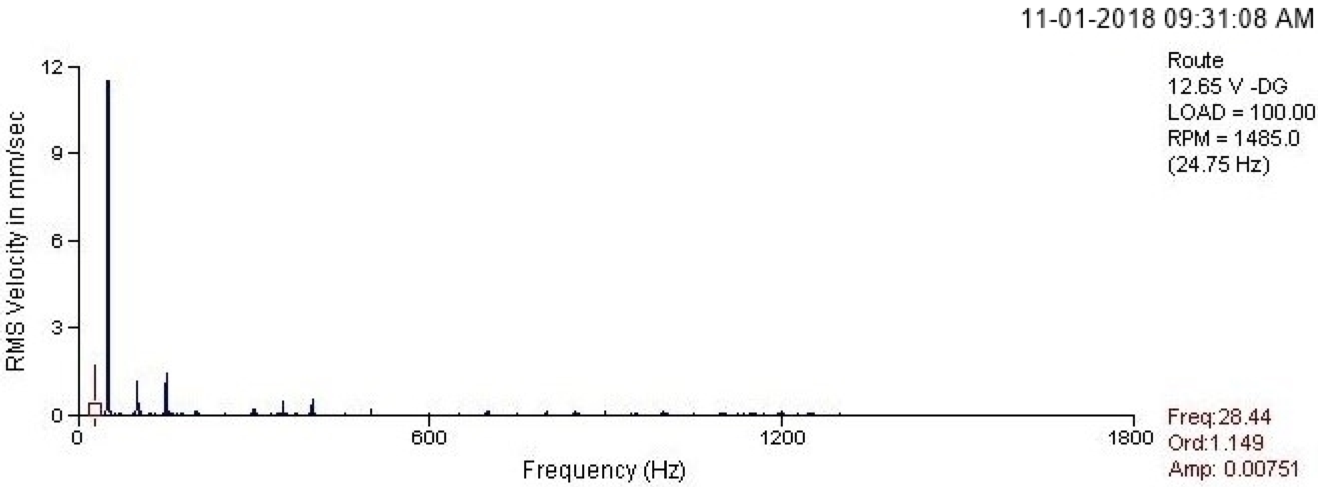


Fig 3: Vibration of motor at non-drive end along horizontal direction

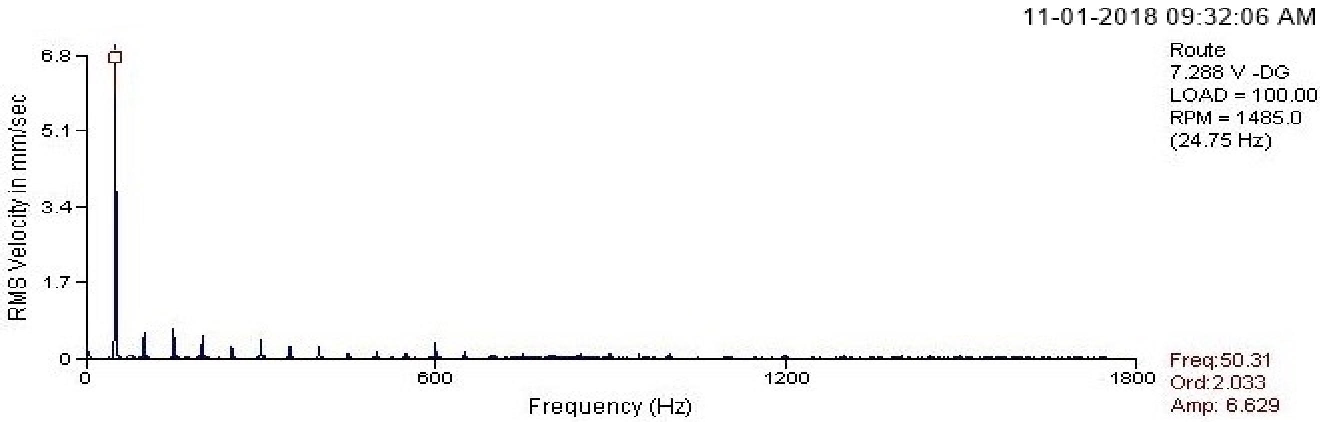


Fig 4: Vibration of motor at drive end along axial direction.

After the root cause analysis it was found that, the pump foundation was weak and noted the presence of cracks and the bearing were completely worn out and acted by an excess radial force resulted in wearing of bearing housing. Then it was decided to modify the foundation and to design a suitable bearing. And the experiment was repeated after the implementation of the findings.

5. PROPOSED MODEL OF FOUNDATION WITH GROUT

After the completion of proper study, it is decided to keep an additional layer called epoxy grout, above the foundation with suitable dimension. Epoxy grout is particulate reinforced polymer matrix composite made of amid resin and blended aggregate of quartz or silica. The exotic behavior of grout includes; high physical strength, high vibration damping capacity, approximately 2 to 3 times stronger than concrete. The grout will absorb the vibration and equally distribute the force over the entire area of foundation. One of the advantages of using the epoxy grout is; it will absorb the transferred vibration from the neighboring machines. Suitable drawings were prepared and pump foundation was modeled using Autodesk Inventor 2016. The dimensions are specified in Table 3.

Table 3: List of Specifications

Proposed Foundation Dimensions	
Foundation length, L	1545 mm
Foundation width, B	730 mm
Motor foundation thickness, t_1	310 mm
Pump foundation thickness, t_2	150 mm
Proposed Grout Dimensions	
Motor grout length, x_1	616 mm
Motor grout width, y_1	510 mm
Motor grout thickness, z_1	120 mm
Pump grout length, x_2	584 mm
Pump grout width, y_2	410 mm
Pump grout thickness, z_2	120 mm

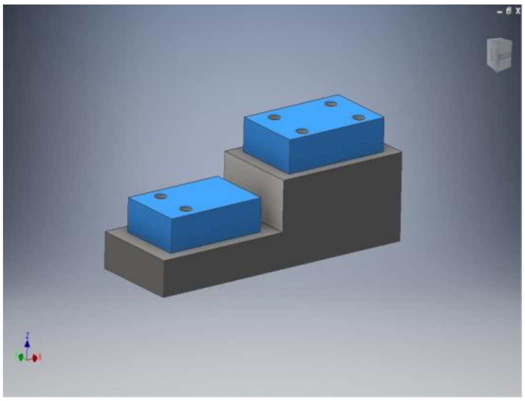


Fig 5: Proposed model of foundation with grout.

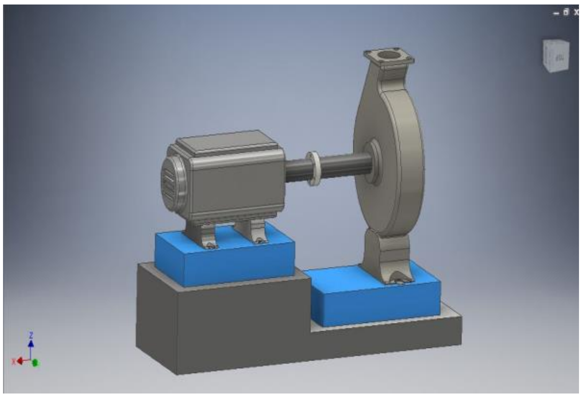


Fig 6: Assembled model of the proposed design.

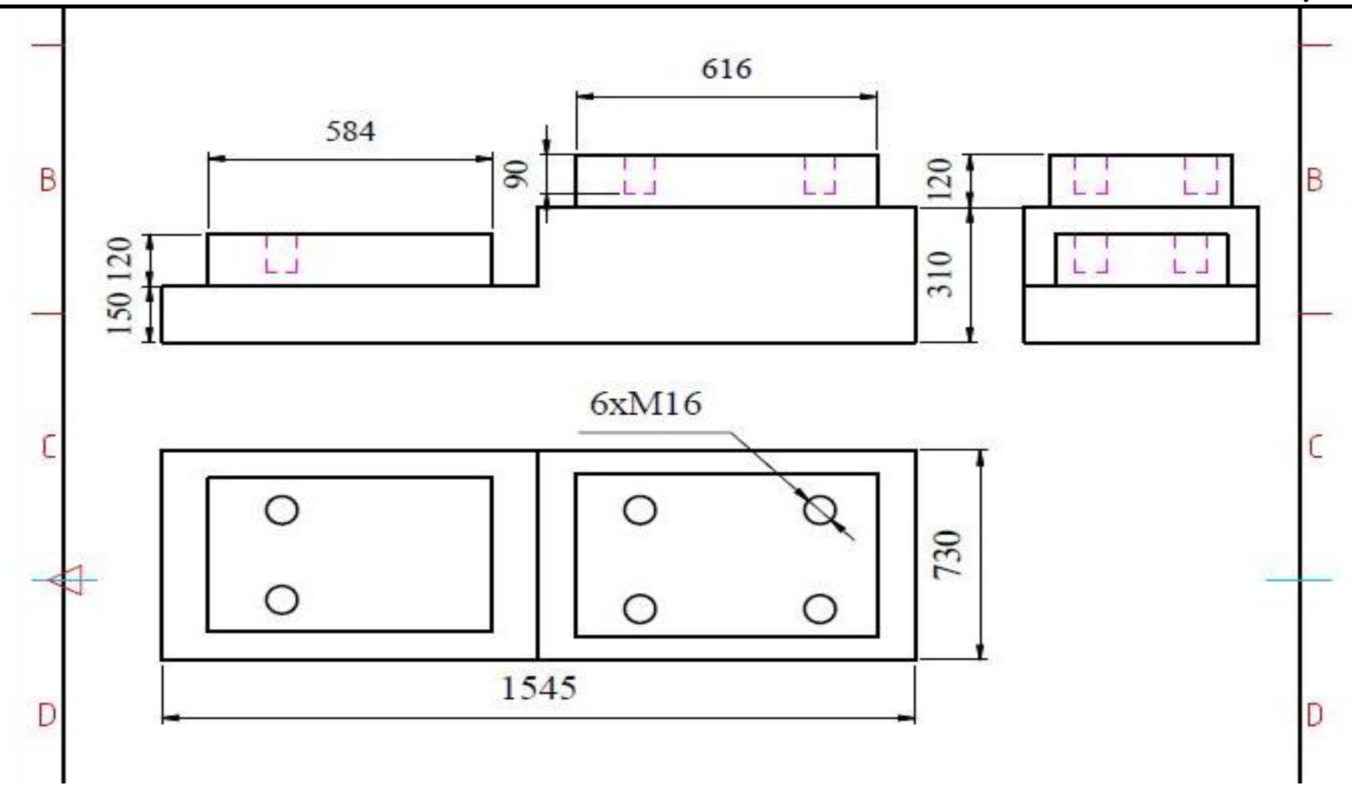


Fig 7: Drawing of the proposed design.

NUMERICAL ANALYSIS OF FOUNDATION WITH GROUT

Finite element analysis of the designed pump foundation with grout was performed in two modules; Modal analysis and Response Spectrum analysis. The model was initially imported to the ANSYS Workbench 14.5. After a detailed optimization the mesh size was chosen and then meshed with triangular and quadrilateral elements. Required boundary conditions were applied and a dynamic load of 762 N/m was applied as a UDL over the entire surface. Using Lanczos solver, modal analysis was performed and natural frequency and mode shapes of the system was obtained.

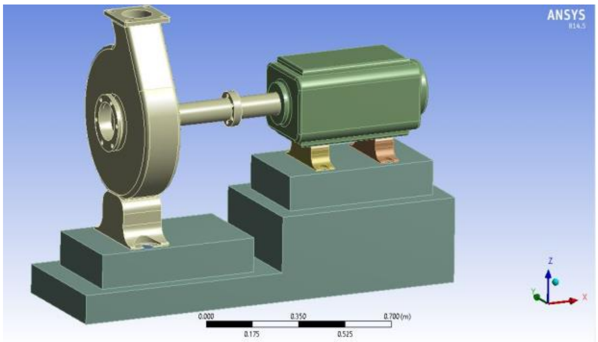


Fig 8: Model imported to ANSYS workbench.

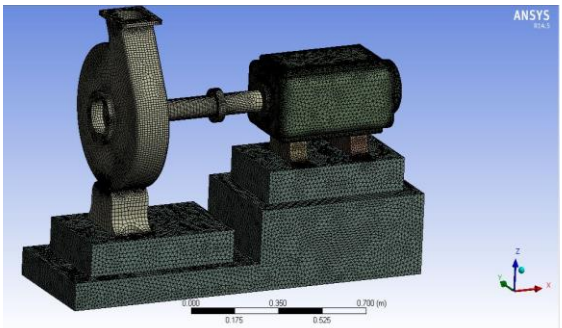


Fig 9: Meshed model.

Followed by modal analysis, the response spectrum analysis was performed.A response-spectrum analysis calculates the maximum responseof a structure to a transient loading. It is performed as a fast alternative of approximating a full transient solution. The maximum response is computed as scale factor times the mode shape. Using single point response spectrum method these maximum responses are combined to give a total response of the structure.

6. DESIGN OF ROLLER BEARING

After performing Root Cause Analysis it was understood that, the existing bearing (deep groove ball bearing - 6316 C3) in the motor is not capable to withstand the excess radial force acts during its operating condition. The bearing was then designed to withstand the very high radial force being generated during the up time of the pump. The design calculations as follows;

Design conditions,

d = 80 mm, D = 170 mm, N = 5000 rpm, C = 22000 kgf, C_o = 19000 kgf.

Operating conditions,

Diameter of shaft, d = 80mm
Speed in rpm, N = 2960 rpm
Required life of bearing is 7 years running 24 hours per day.

Where,

d – Inner diameter of bearing, mm, D – Outer diameter of bearing, mm,
N – Maximum Permissible speed, rpm, C – Maximum Dynamic load capacity, kgf,
C_o – Maximum Static load capacity, kgf.
Required life of bearing, L = 8951.04*10^6 rev.
L_{10} = 1*10^6 rev [7].
k = 10/3, for roller bearings.
= 1/3, for ball bearings.

Load equations [7];

Equivalent load, $P = \frac{C}{C / P \text{ ratio}}$, Newton (1)

Dynamic load, $C = \left[\frac{L}{L_{10}}\right]^{(1/k)} * P$, kgf (2)

7. RESULTS AND DISCUSSIONS

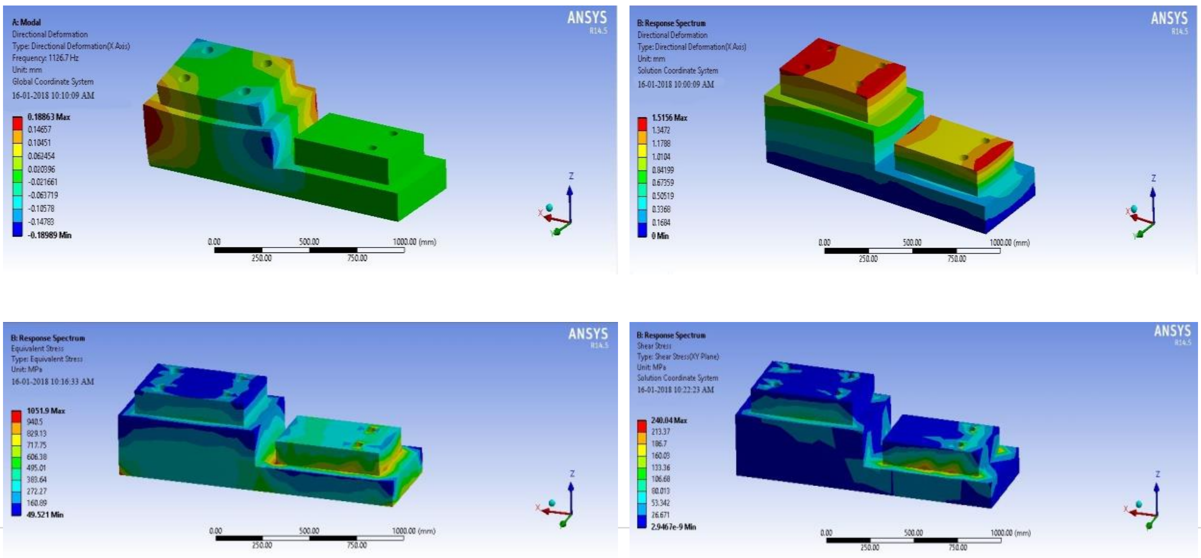
7.1.RESULTS OF NUMERICAL ANALYSIS

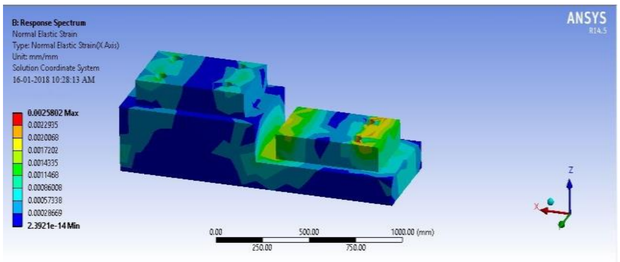
The first six natural frequencies obtained from the modal analysis are shown in table 4;

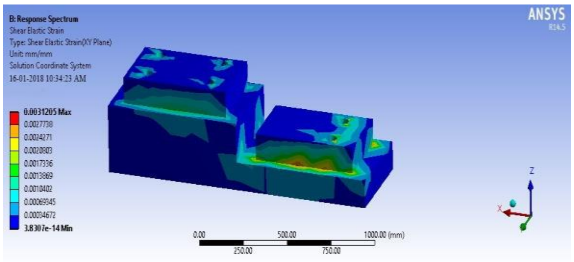
Table 4: List of Natural frequencies

Mode no.	Frequency (Hz)
1.	1126.7
2.	1463.8
3.	1568.3
4.	1768.7
5.	2014.9
6.	2511.5

The results of response spectrum analysis and the 1st mode shape (Fig.10) corresponding to the fundamental frequency are discussed below;







7.1.1. Directional deformation (Fig.11)

Response Spectrum displacement (RS displacement) is maximum in the grout of both the pump and motor. And the base of foundation is completely fixed with zero deflection. Maximum value of deformation is 1.5156 mm. And minimum value is 0 mm. The epoxy grout has absorbed the vibration and the pump foundation is found to be safe.

7.1.2. Equivalent stress (Fig.12)

The stress induced in the foundation due to dynamic forces is reduced to a great extent. The addition of grout to the foundation has equally distributed the stress over the entire area. Overall stress induced is about 272.27 MPa.

7.1.3. Shear stress (Fig.13)

The shear stress due to the dynamic force acting on the foundation is reduced by the addition of grout. The overall shear stress is about 240.04 MPa.

7.1.4. Normal elastic strain (Fig.14)

The normal strain induced in the foundation is reduced to a great extent due to presence of grout. The maximum normal strain is about 0.00282 mm/mm. And the minimum normal strain is about 0.00096 mm/mm.

7.1.5. Shear elastic strain (Fig.15)

The shear strain induced is minimized by the addition of grout. The stain induced on the foundation in very less about 0.0006945 mm/mm. And the maximum strain is about 0.00312 mm/mm.

7.2.RESULTS OF BEARING DESIGN

A detailed number of trails were performed to choose a suitable bearing. The result is as follows;

Table 5: Results of trails performed

Trail	Bearing Type	C, kgf	C_{max}, kgf
1.	6216deep groove ball bearing	5736.74	5700
2.	2216 K Self-Aligning ball bearing	3824.33	3800
3.	7216 B Single Row Angular contact ball bearing	6340	6300
4.	3316 Double Row Angular contact ball bearing	16405.05	16300
5.	NU 2316 Cylindrical Roller bearing	21759.7	22000

The result of the first four trails shows that, the calculated dynamic load, C is higher that the permissible dynamic load capacity, C_{max}. But the fifth trail shows an acceptable value which is less than the permissible load capacity. And it was selected to replace the existing bearing.

7.3.EXPERIMENTAL VALIDATION OF RESULTS

The required actions were performed including the addition of epoxy grout over the foundation and the replacement of existing bearing with a most suitable bearing. Then the experiment was repeated on the modified arrangement. The result is as follows;

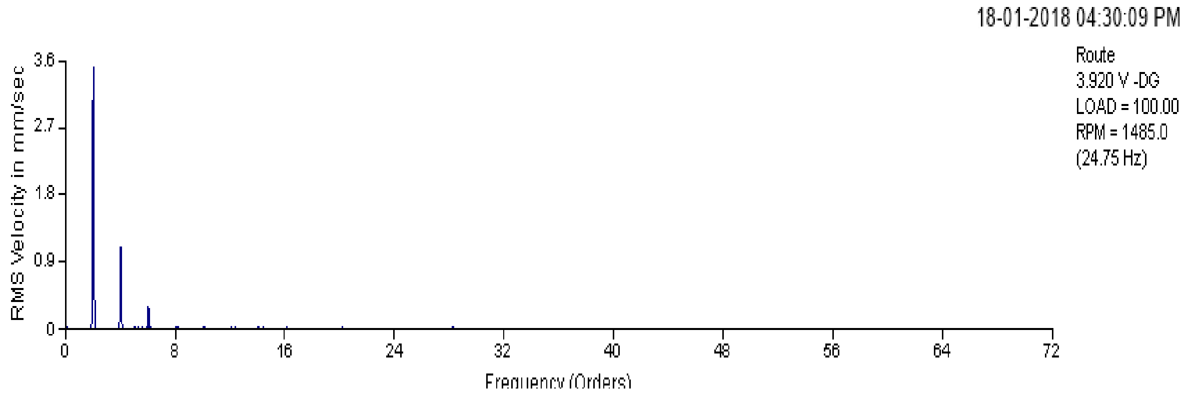


Fig 16: Vibration of motor at non-drive end along horizontal direction.

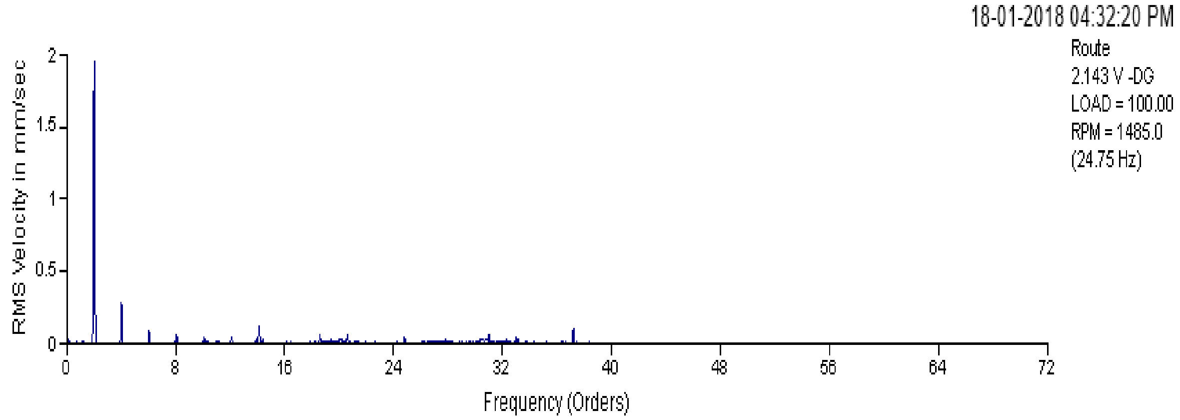


Fig 17: Vibration of motor at drive end along axial

It is evident from the results that the vibration at the drive end and non-drive end of the motor has reduced by 30.5 % and 29.4 % respectively.

8. SUMMARY AND CONCLUSION

The frequent condition monitoring is vital to make sure the smooth running of any equipment within design conditions and to reduce chance of running in off-design conditions. Online condition monitoring is one of the best techniques to identify the faults in the machines; this prevents the possibility of shutdown leading to great losses. Initially the problem was studied and the supporting information's were collected through a detailed literature survey. By on-site inspection the real root cause were understood. Then the required actions were made as mentioned and numerical analysis were performed and validated the results by a detailed experimental analysis.

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