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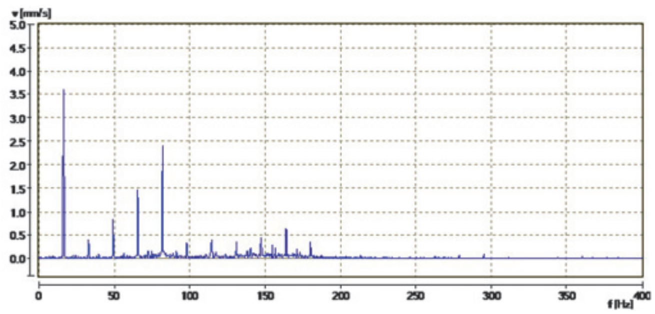
Vibration based outlook to monitor health conditions of dragline machine in opencast coal mine in India

Vibration is a common phenomenon for all rotating machines but when it reaches beyond the limit then becomes vulnerable and poses as matter of concern. This paper focuses on importance of condition monitoring in-terms of vibration analysis for a dragline machine working in an opencast coal mine of one of the major coal producing companies in India. Vibscanner of Pruftechnik is used for gathering vibration related data and plotting its frequency spectrum.



The data are analysed to prepare suitable sample size and also for finding the root cause of machine vibration. From the analysis a number of contributing factors e.g. misalignment, unbalance and looseness are observed as the main factors behind extensive machine vibration. The in-depth analysis on the machine shows that, though the highest amplitudes recorded does not depict a concern but fluctuations in frequency observed through the spectrums and variations of temperature in bearing housings poses a serious concern. Here, in this paper an attempt has been made to investigate on the generic causes of vibration behind the potent vibration of components and suitable recommendations are provided to overcome the faults as a preventive measure.

Keywords: *Dragline, vibration, frequency spectrum, amplitude, misalignment, looseness.*

1. Introduction

Vibration is the oscillating, reciprocating or other periodic motion that disturbs the state of equilibrium of machine by transmitting sound and become unbalanced. Vibration is present in every machine components to some extent but when it reaches the extensive level then it not only symbolizes warning for the machine health but also provides alarm towards the persons working in its vicinity. Rotating masses within machines are periodically prone to misalignment and large amplitudes of vibrations. Heavy stationary machines need proper vibration isolation and noise insulation arrangement to prolong the machine life and to keep the working environment favourable for human intervention. The main reasons behind the machine vibration are: repetitive forces, looseness and resonance. Repetitive force is the result of rotating components working with imbalanced and misaligned part. Looseness of components may cause vibration to intolerable levels if the machine is allowed to be operated for longer periods. Resonance is a phenomenon which should be normally avoided by designing the machine in such a way that the natural frequency of vibration of any part within the machine should not be equal or near to the working frequency for that particular component.

Mining industry depends on a number of heavy duty machines, where the rotating components sometimes results in larger amplitude of vibration. Dragline is one of such machines used in opencast mines with the purpose of handling the large quantity of overburden rocks produced during excavation of coal. This paper describes a case study followed by suitable recommendations on one such dragline machine working with a major coal producing organisation in the east central part of India.

As vibration analysis is a basic aspect in effective condition monitoring of any mechanical equipment, therefore, variety of work is present in this field, some of which are explained herein. Scope of application of modern technologies and instruments for predictive maintenance and proper condition monitoring within the workstation [1] has relevance in condition based monitoring, focusing on vibration of machines in mining fraternity along with the benefits [2]. The early fault detection and requisite maintenance to minimize the failures [3] sometimes proves to be an important issue for machine health up-keeping. An expansive knowledge base to evaluate the current condition of machine along with finding the root cause of the machine status are required to be

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developed irrespective of machine [4]. The need of condition based monitoring of machine for improvement of performance using vibration analysis as an effective tool can be better served [5], application of transducer in the belt to sense the level of vibration and temperature [6], use of fuzzy synthetic decision making system for predictive maintenance [7] can be gainfully utilized for lining the procedures of vibration monitoring to achieve overall condition monitoring of machine [8] importance of properly designed CBM programme in early fault detection to avoid unscheduled outages [9] helps to retain better availability of the equipment.

This paper explains the practices to be followed to improve the overall maintenance of opencast mining equipment in Indian scenario. The maintenance practice should ensure higher availability, better reliability and improved productivity. The cross-section made towards literatures on machine vibration helps finding the steps associated with the vibration analysis. Problems identification associated with the machine components, hurdles to improve the machine availability and reliability including suitable recommendations for overall condition monitoring of the equipment.

2. Selection and description of machine

Opencast coal mines deploy large numbers of heavy earth moving machineries (HEMMs) for different operations such as, drilling, coal preparation, handling and transportation of coal and overburden rocks. Dragline is one of such important and high capital intensive machine commonly used in opencast coal mines throughout the world. Dragline is giant excavation machinery specifically suited for handling of soft unconsolidated material, blasted rock, minerals and coal etc. The basic construction of dragline is depicted through the schematic diagram shown in Fig.1. The main components of a dragline besides driving accessories are boom, bucket, drag cable, boom hoist cable and hoist cable etc. The technical specifications of the dragline under study are shown in Table 1.

TABLE 1 TECHNICAL SPECIFICATION OF THE DRAGLINE UNDER STUDY

Boom Length	95.6m
Bucket capacity	$24m^3$
Boom angle	30^o
Walking speed	0.24Km/Hr
Dump height	38.2m
Digging depth	74.5m
Average bearing pressure of base	$0.95kg/cm^2$
Electrical input	6.6KV
MG sets	2×1750 HP AC synchronous motor
Hoist motors	2×1300 HP at 475V
Drag motors	2×1300 HP at 475V
Swing motors	3×640 HP at 475V
Walk motors	2×640 HP at 475V

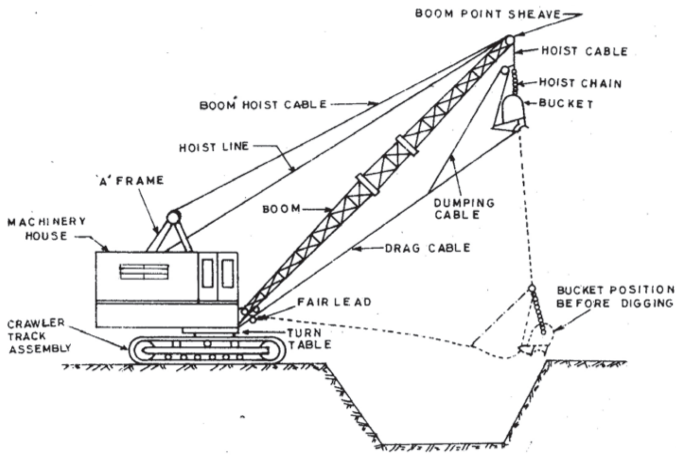


Fig.1 Schematic diagram of a dragline

Fig.2 Dragline machine on working

Different relevant positions within the motor generator sets are found to be in most accurate positions to mount the Vibscanner to fulfil the required purpose.

The outline of basic motor generator configuration is shown in Fig.3.

Where,

SG = Swing generator

TB = Terminal bearing (journal bearing)

DG = Drag generator

HG = Hoist generat

SM = Synchronous motor

⊠ = Coupling

3. Description of the vibration measuring instrument

Machine vibration without few exceptions is undesirable and needs a thorough check-up for the components and their fitment. The condition monitoring of dragline had been accomplished with the help of Vibscanner of Pruftechnik; which is a versatile tool for overall condition monitoring of mechanical equipment. The tool is capable of producing some

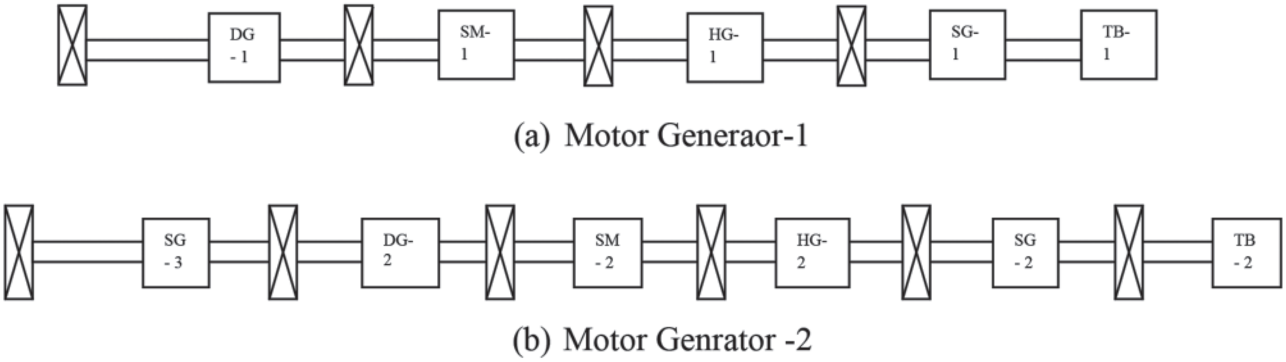


Fig.3 Motor generator configuration; (a) Motor generator 1, (b) Motor generator 2

useful graphical spectrums and different signatures to read and notify the machine health conditions and can depict an indicative trend if monitored regularly. The Vibsacnner integrates a sensor interface, alarm display and an intuitive backlit graphic display which incorporates an on-spot depiction of the measured parameters along with suitable symbols and notations [11].

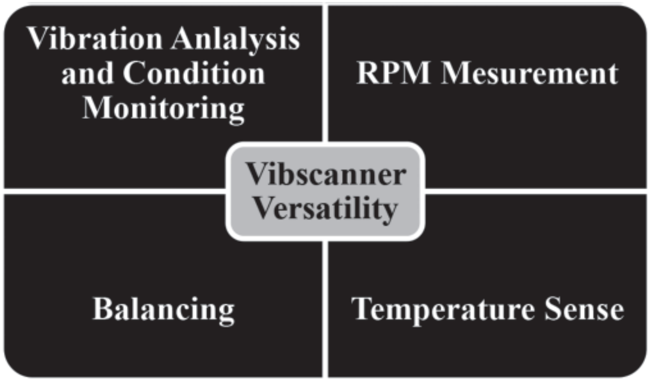


Fig.4

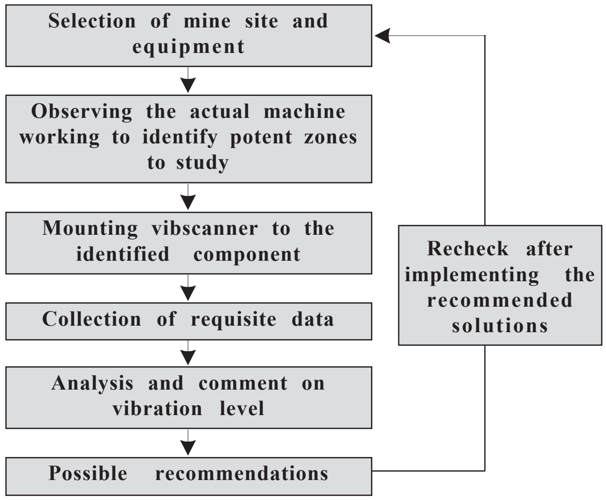
There are a few integral systems already provided to perform various tasks of condition monitoring and depiction of alarming levels. The machine is capable of measuring the rotational speed in RPM without contacting up to 0.5 m distance from the rotating shaft. The Vibscanner is provided with a red pointer beam to measure the number of rotations and aim properly towards the rotating shaft in low light condition. Vibscanner does not even require reflecting tape for the purpose.

For temperature measurement there is a retractable and flexible temperature probe [11]; which is capable of taking quick and accurate readings even in liquid. There is also a provision to mount external probe specified for the purpose.

Vibscanner is mounted with a unique accelerometer patented and specified for the purpose of sensing high frequency shocks produced by antifriction bearing and during cavitation of pumps.

4. Methodology for the analysis

The identification of the mine site and equipment was firstly



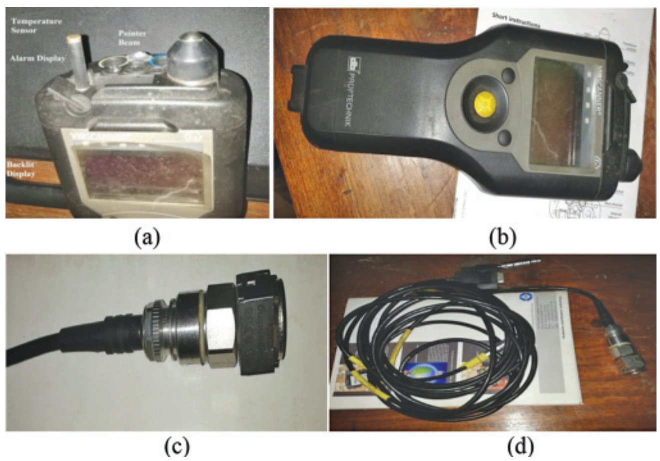


Fig.5 (a) Vibsacnner integrated sensors, (b). Vibscanner, (c) Magnetic probe for vibration measurement, (d) connecting wires

pointed out by the managing authority of the concerned mine. The competent authority then took further steps to control the menace and arranged for suitable solution on the matter.

During the course of study the first task was to observe the machine while working and identifying the zones where the root cause of the problem may lie. The Vibscanner was then mounted to the identified components to check the level of vibration and to collect requisite data such as; temperature, vibration amplitudes and spectrum etc. Finally the analysis and recommendations were made for considerable performance improvement of the machine.

5. Results of observations and recommendations

The study was conducted in a dragline operated opencast mine and visits were made to the mine site several times for a considerable period. Firstly, the machine was observed for identifying the potent zones having the root cause of abnormal level of vibration. The vibration frequency spectrum and amplitude values observed during basic inspection through Vibscanner with its suitable mountings identified the motor generators as highly potent vibrating zones. The generated frequency spectrum and amplitude values of different components of two motor generator sets of the dragline were then considered for further analysis. Few of such vibration amplitudes of different components are graphically presented below which is accompanied by their short significances:

a. Components of motor Generator 1

The amplitudes of vibration of each components of the dragline were compared to a standard value obtained from the equipment manufacturer's guidebook provided for the purpose by the competent authority of the concerned mining company. These standard values are considered as the pre-alarming level amplitude values.

From the above graphs (Fig.6), depicting the measured vibration amplitude against the maximum standard value for Motor Generator -1, describes no such alarming instance in respect of continuous vibration amplitude.

b. Components of motor generator 2

Similar graphical representation is accomplished for components of Motor Generator-2. The graphs and their significances are depicted in Fig.7.

From the above graphs similar inferences to that of Motor Generator 1 can be drawn as there is no alarming consequence observed. Therefore, the amplitude does not signify any level of ambiguity in high level of vibration. Consequently, the analysis of frequency spectrums becomes necessary to find conclusions to any ambiguous condition.

c. Frequency spectrums recorded by vibscanner

The frequency spectrums of components of Motor Generator-1 and Motor Generator-2; depicted considerable improvement after implementation of the recommendations mentioned as under:

i. Drag Generator – 1(PCC end coupling)

Fig.8.(a) depicts repetitive peaks and its harmonics, this symbolizes looseness of the foundation of the coupling. This may be due to its inadequate foundation on movable machine body.

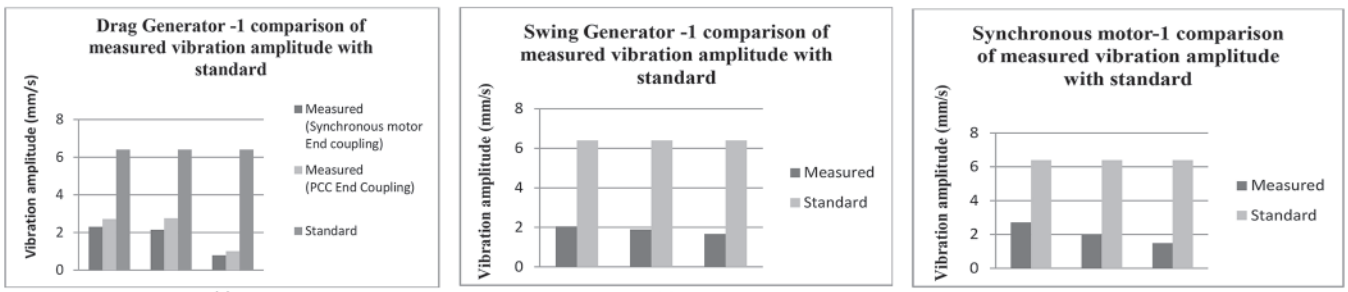
Recommendations

i. A formal physical inspection to find the source of looseness was recommended.
ii. Complete stability analysis of the system is recommended.

Fig.8.(b) depicts the vibration spectrum at the same location after implementation of previous recommendation and necessary correction within the system.

Same recommendations were meant to be continued for this particular phase of observation.

After particular period of working in the same condition



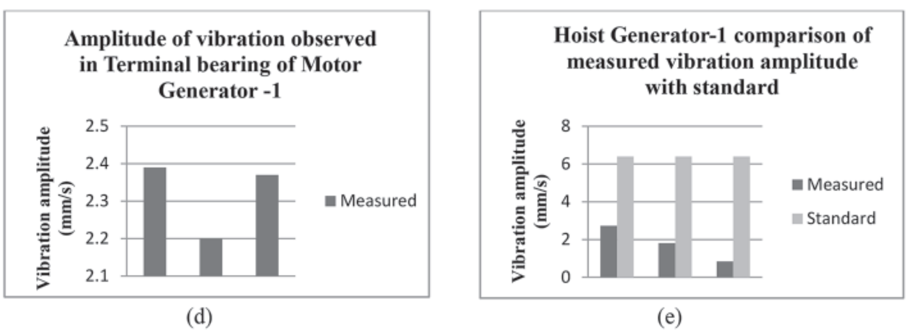


Fig.6 Vibration amplitude comparison with standard for the following components of Motor generator Set-1 (a) Drag generator, (b) Swing generator, (c) Synchronous motor, (d) Terminal bearing, (e) Hoist generator.

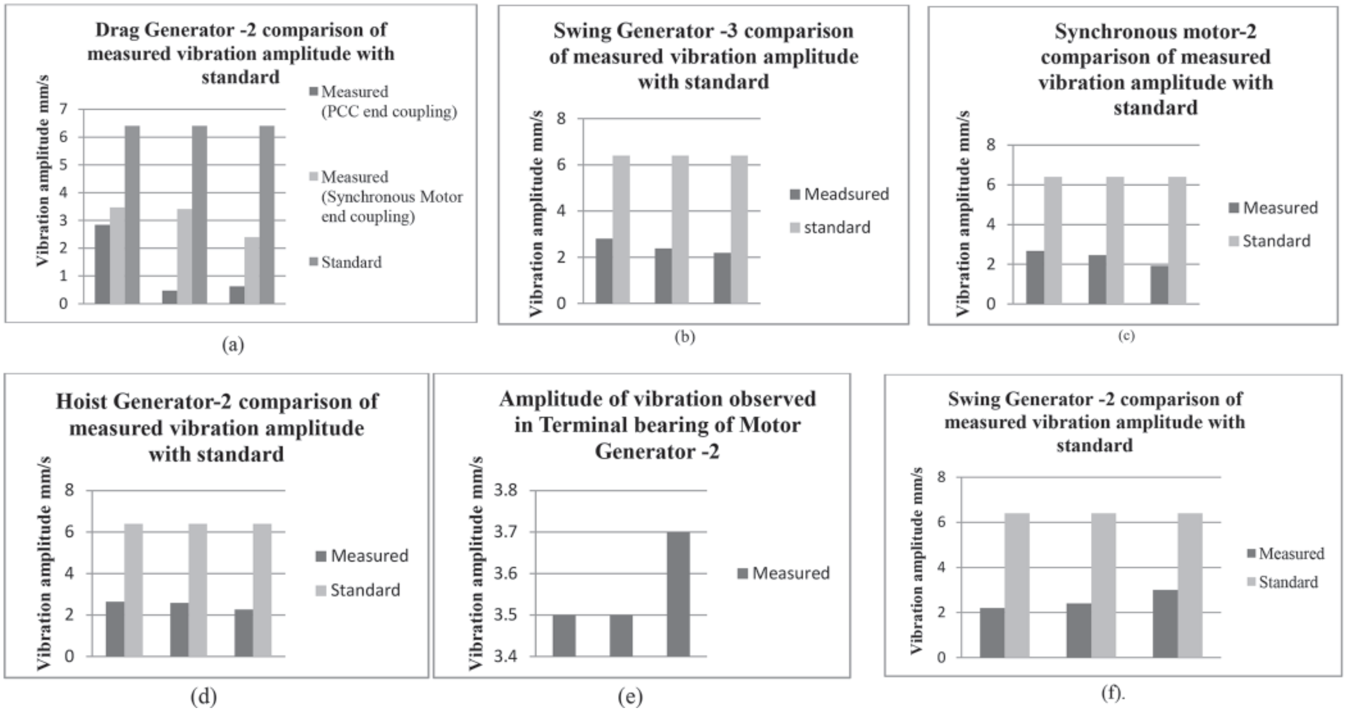


Fig.7 Vibration amplitude comparison with standard for the following components of motor generator set 2 (a) Drag generator, (b) Swing generator 3 (c) Synchronous motor, (d) Hoist generator, (e) Terminal bearing, (f) Swing generator

the third observation depicted few repetitive peaks in Fig.8(c), which again substantiates the looseness requiring close watch to the system and demands permanent cure to the root cause of the trouble.

Recommendations

i. A formal physical inspection to find the source of looseness was recommended.

ii. Complete stability analysis of the system was recommended.

iii. Thrust analysis and sliding investigation was also recommended.

ii. Hoist generator 1 (HVC end coupling)

Fig.9(a). depicts repetitive peaks at 1X and 3X which indicates looseness.

Recommendations

i. Physical checking for excessive gap between meshing components causing unwanted vibration within the Hoist Generator 1.

ii. Check-up for both rotating type and non-rotating type looseness.

Fig.9(b) depicts the frequency spectrum of Hoist Generator-1 at the same location of the previous study. Here, some improvement can be noted as the amplitudes have been lower as compared to the spectrum of Fig.9(a).

Recommendations

i. Further physical check for excessive gap between components was recommended.

Fig.9(c) depicts the frequency spectrum at the same location, which shows further improvement to the previous spectrum depicted in Fig.9(b).

Recommendations

i. Physical check up was further recommended to omit the unwanted level of vibration caused by rotating and non-rotating type looseness.

iii. Terminal bearing-1 (HVC end coupling)

The first spectrum depicted in Fig.10(a) does not depict any severe alarming condition of the component. Therefore that was allowed to run till further inspection.

The spectrum shown in Fig.10(b) is produced by mounting the Vibscanner in the same location that shows few higher peaks symbolizing the probability of bearing problem.

The third spectrum as shown in Fig.10(c). also depicts bearing problem as it shows peaks with high frequency. These three spectrums symbolize the probability of bearing damage or requirement of proper lubrication.

From the above spectrum, in depth analysis of the health condition of the machine becomes necessary. Temperature of the bearing reached 54^{o}C which is high as compared to the standard level. The above spectrums and higher temperature range signifies bearing problem.

Recommendations

In order to get significant idea on the extent of bearing

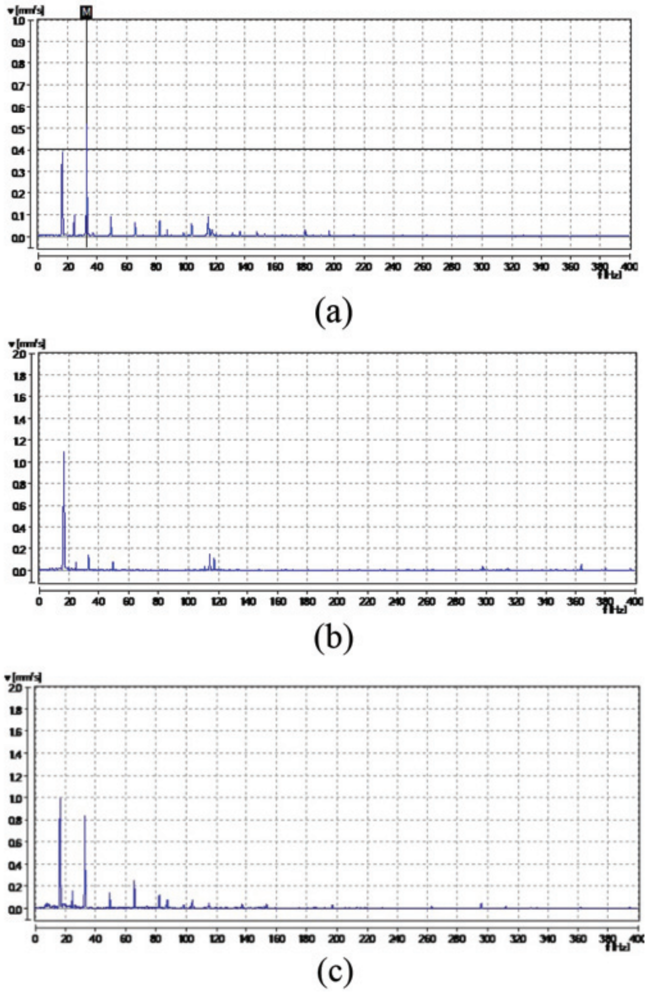


Fig.8 (a) Drag generator 1 spectrum initially, (b) Drag generator -1 spectrum during second inspection, (c) Drag generator -1 spectrum on third inspection

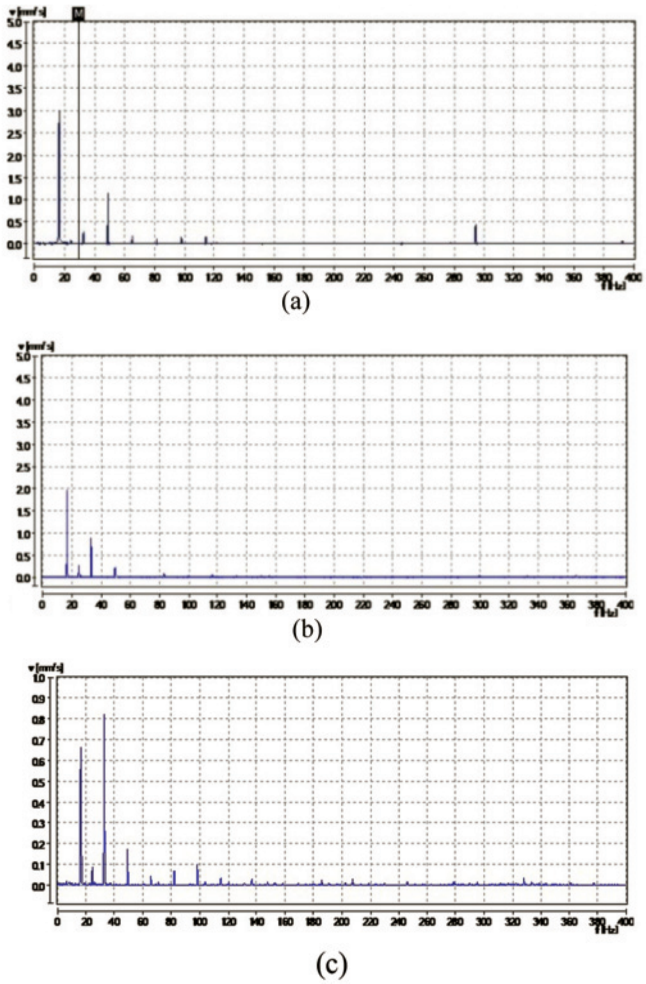


Fig.9 (a) Hoist generator 1 spectrum initially, (b) Hoist generator 1 spectrum during second inspection, (c) Hoist generator 1 spectrum on third inspection

related troubles following parameters are to be investigated and should be kept within the permissible limit:

i. Excessive load if any

ii. Over heating reasons

iii. Bearing capacity

iv. Contamination,

v. Corrosion, and

vi. Bearing lubrication condition.

iv. Swing Generator 3 (PCC end coupling)

First spectrum shown in Fig.10(a) depicts single peak and symbolizes unbalance.

Recommendations

i. Evaluation and correction of balancing of rotating masses

ii. Regular monitoring of the component was recommended.

The second spectrum depicted in Fig.11(b) also indicates single peak but with lesser value, this though indicate unbalance but with lesser frequency, again similar recommendations were advised for monitoring and maintenance as the unwanted frequency of vibration could not be avoided.

Third spectrum depicted in Fig.11(c) describes better trend of maintenance. However, unbalance is present but in a smaller extent.

Recommendations

i. Proper balancing of rotating masses

ii. Regular monitoring of the component.

iii. Investigation of lubrication of rotating masses.

v. Drag generator -2 (PCC end coupling)

The initial spectrum depicted in Fig.12(a) shows a dominant peak indicating unbalance of the machine.

Recommendations

i. Check for balancing of rotating masses

ii. Investigation of lubrication condition of rotating masses.

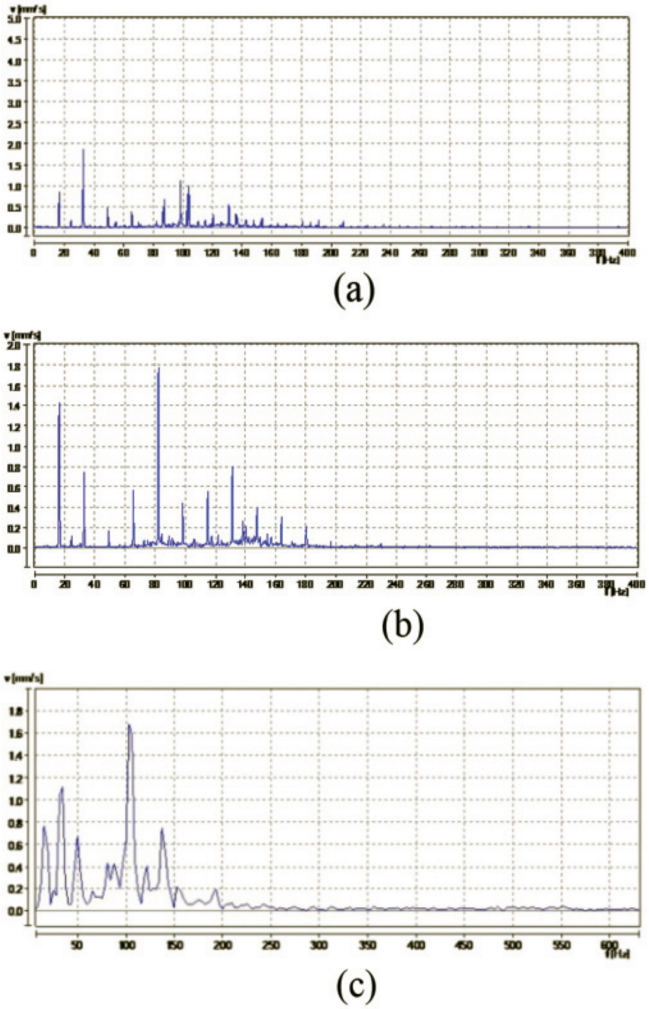


Fig.10 (a) Terminal bearing-1 spectrum initially, (b) Terminal beraing-1 spectrum during second inspection (c) terminal bearing-1 spectrum on third inspection

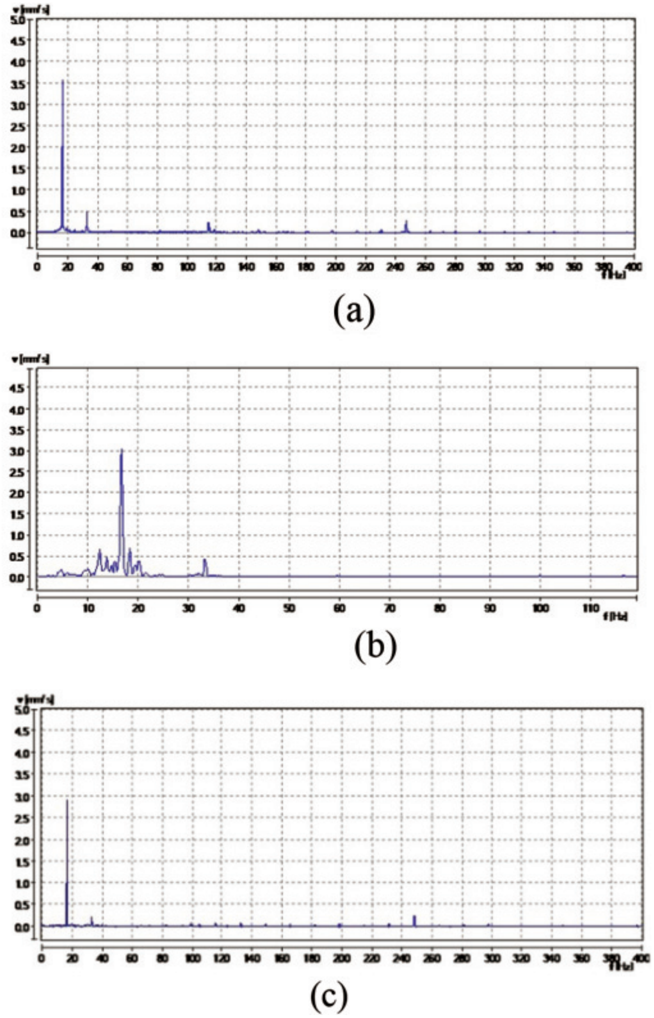


Fig.11 (a) Swing generator 3 spectrum initially, (b) swing generator 3 spectrum during second inspection, (c) Swing generator 3 spectrum on third inspection

The second spectrum in Fig.12(b) shows dominant peak but the frequency is almost 1/4th therefore there is no indication of fault.

The third spectrum depicted in Fig.12(c) shows a dominant peak and tendency of fault was detected. An in depth inspection to pinpoint the root cause of the unbalance and unnecessary vibration was recommended.

Recommendations

i. Close watch and general maintenance of the component in regular interval.

ii. Inspecting and balancing of the unbalanced mass.

vi. Drag Generator 2 (synchronous motor end coupling)

Initial spectrum, as shown in Fig.13(a) depicts dominants peak, which is an indication of unbalance.

Recommendations

i. There is a need of maintenance.

ii. Balancing of rotating mass is required.

The second spectrum in Fig.13(b) also depicts unbalance and inspection is required to find out the cause of unbalance along with proper maintenance was recommended.

Third spectrum in Fig.13(c) depicts a dominant peak but with diminished amplitude and indicates better maintenance work as compared to the previous inspection.

The same inspection and maintenance plan was recommended to be followed as it seemed compatible for the system, to reduce the level of unbalance of rotating masses.

vii. Terminal bearing 2 (HVC end coupling):

The initial spectrum depicted in Fig.14(a) indicates multiple higher peaks with considerably higher values. This indicates the probability of looseness and unbalance.

Recommendations:

i. Investigation of balancing of rotating masses

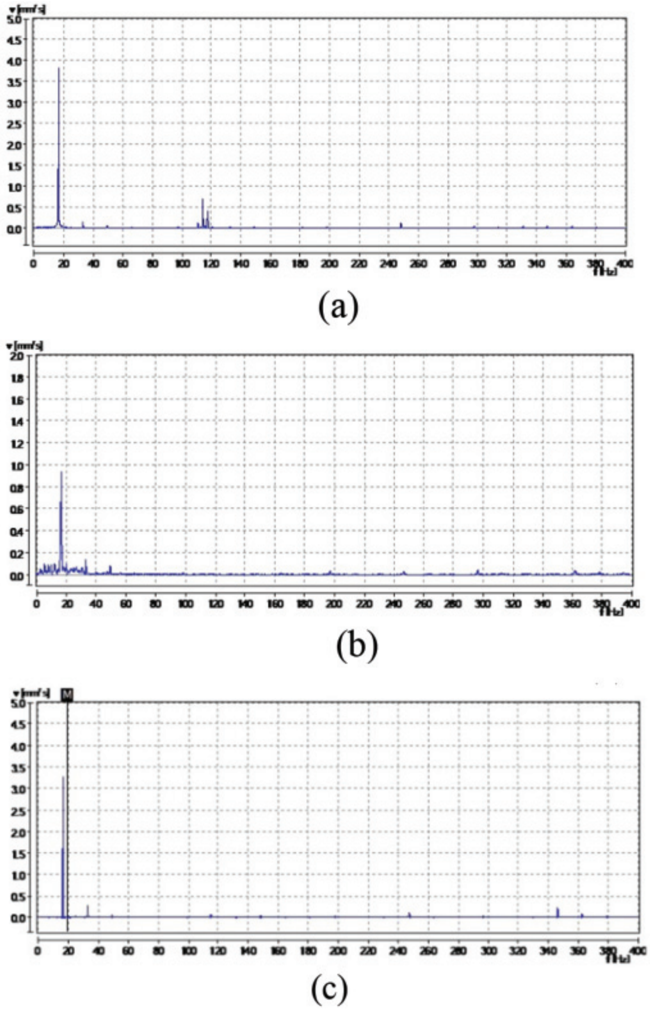


Fig.12 (a) Drag generator 2 spectrum initially, (b) Drag generator 2 spectrum during second inspection, (c) Drag generator 2 spectrum on third inspection

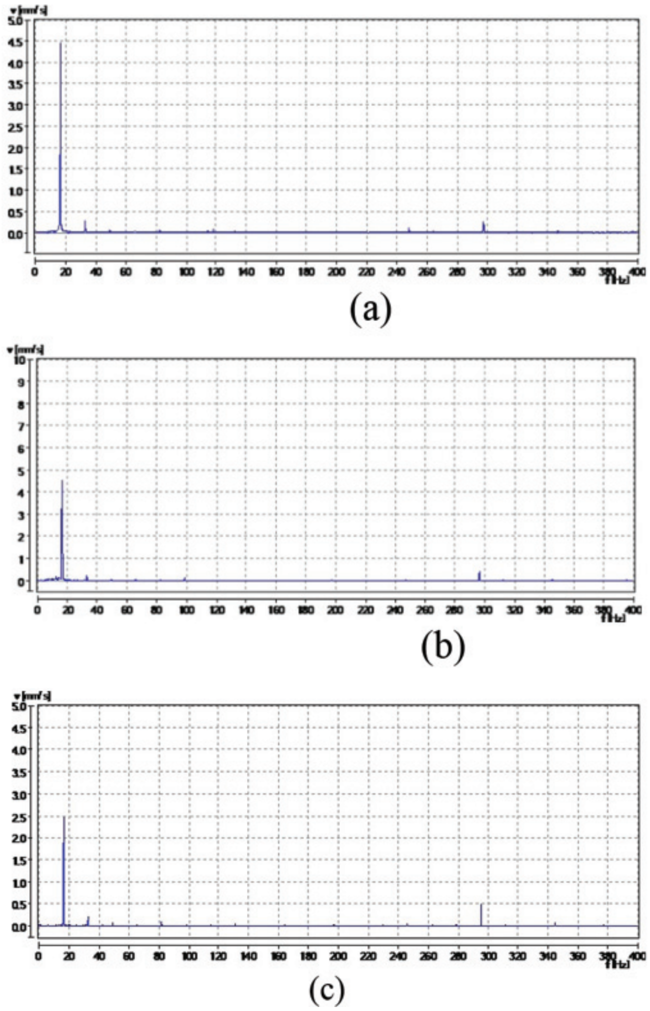


Fig.13 (a) Drag generator 2 spectrum initially, (b) Drag generator 2 spectrum during second inspection, (c) Drag generator 2 spectrum on third inspection

ii. Investigation of lubrication of rotating masses.
iii. Physical checking for excessive gap between components causing unwanted vibration.
iv. Check-up for both rotating type and not rotating type looseness.

The spectrum Fig.14(b) from the second observation depicted that there is similar higher amplitude which signifies the same as above. All recommendations are similar to the previous but this time the evaluation and investigation requires considerable attention.

The third spectrum Fig.14(c) depicts the similar higher amplitude with multiple peaks and this necessitates further in depth study such as thermal analysis.

During initial inspection the temperature of the bearing was found to be 58°C, which signifies mild to severe bearing problem.

Recommendations:

The followings are the areas that require in depth analysis and investigation for the performance improvement of the component:

i. Bearing capacity and its load
ii. Contamination and corrosion possibility,
iii. Bearing lubrication condition.

6. Conclusions

This paper presents a case specific intervention of vibration analysis for the components of dragline through Vibscanner. From the overall study it is seen that besides few exceptions, the overall condition of the machine is good. From observations it was seen that looseness, misalignment and unbalanced rotating masses were the main factors plying key role in amplification of amplitudes and temperature. This necessitates the improvement in the design and implementation of a proper maintenance plan, to plan and monitor the condition of meshing components, bearings and foundation or feet of the walking dragline. Overall it can be concluded that integrating condition monitoring into

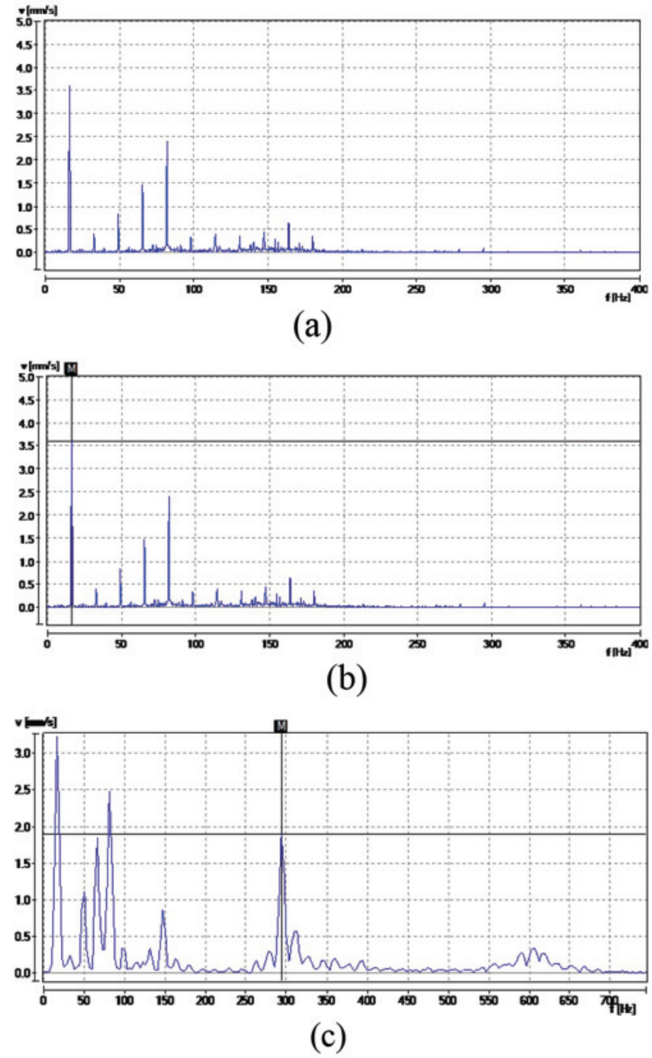


Fig.14 (a) Terminal bearing 2 spectrum initially, (b) Terminal beraing 2 spectrum during second inspection (c) Terminal bearing 2 spectrum on third inspection

Comprehensive Maintenance Management Programme (CMPP) will be highly beneficial in terms of economics and availability of the equipment. This may in future lead to a better practice of equipment handling and maintenance to increase the productivity and life expectancy of not only this dragline but of any other similar HEMM's.

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