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VIBRATION ANALYSIS AND INFRARED THERMOGRAPHY TECHNIQUE FOR EVALUATING MISALIGNMENT PROBLEM

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ABSTRACT : *Vibration analysis and thermography techniques are both commonly used for proactive and predictive maintenance in industrial plants. Historically, these two technologies have been separate and distinct. The present work aims to perform a comparative study as an attempt to obtain the reliability of a two techniques in analyzing and diagnosing the misalignment problem at a pumping system. Vibration measurements were performed to evaluate the dynamic state of the pumping system under the effect of misalignment. The thermal imaging camera was used to early detect misalignment problem by measuring the temperature of the coupling and bearings for different values of misalignment. Laser alignment process between motor and pump was done to correct the misalignment problem. Comparison between vibration and temperature measurements before and after alignment process was applied. The results had shown that the data acquired by the vibration signal processing and thermal images are all relevant between them. It has been found that the use of vibration analysis was more effective in detecting the misalignment problem than thermography analysis.*

KEYWORDS: vibration analysis**;** misalignment problem**;** thermography analysis**;** centrifugal pump.

INTRODUCTION

The objective of optimized shaft alignment is to increase the operating life span of rotating machinery. To achieve this goal, components that are the most likely to fail must be made to operate within their acceptable design limits. While misalignment has no measurable effect on motor efficiency, correct shaft alignment ensures the smooth, efficient transmission of power from the motor to the driven equipment. Incorrect alignment occurs when the centerlines of the

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motor and the driven equipment shafts are not in line with each other. Misalignment produces excessive vibration, noise, coupling, and bearing temperature increases, and premature bearing, coupling, or shaft failure.

Sanjiv Kumar (2015) performed experimental studies on a 2 rotor dynamic test apparatus to predict the vibration spectrum for rotor misalignment. He used a 4 Jaw flexible coupling in the experiments. The rotor shaft accelerations and frequency spectrum were measured. The experimental results of aligned and misaligned rotors are compared at two different rotor locations. F. Jeffali (2015) has used infrared thermography technique as a predictive tool for the maintenance of electrical installations. He presented a methodology based on thermographic imaging for fault detection in induction motors and the repercussion of these faults along the production chain. He indicated that due to the type of mechanical failure caused by misalignment in infrared technology, there is a heating of rotating machine. S. M. Khot and Pallavi Khaire (2015) presented an experimental study deals with investigation of faults such as parallel misalignment and angular misalignment with the help of FFT analyzer. He obtained frequency spectrums by using experimental set-up developed for rotor system. They performed a simulation study of the misalignment effect on a rotary system using ANSYS. Results are compared to validate simulation study with experimental results and found to be in close agreement. C. Kumar (2015) carried out an experimental investigation on three phase induction motor to detect rotor misalignment. Proximity and current probes are used to monitor the vibration and current signal respectively. Fast Fourier Transform is used for signal processing. A full spectrum analysis is presented for both current signal and vibration signal to reveal the fault-specific whirl signatures. The results clearly indicate the potential and feasibility of the discussed approach to the rotor misalignment diagnosis in a shaft/rotor system coupled with a three phase induction motor. Aditya U. Ganapathy and K. Sainath (2014) identified the causes of vibrations using latest non-destructive testing tools. Corrective measures were implemented. The condition of the pump after the correction was checked and was found within acceptable healthy condition. Shahab Fatima, Amiya R Mohanty and VN Achutha Naikan (2015) have performed an experimental study to detect the early presence of misalignment in systems, by measuring the temperature of the shaft couplings using a thermal imaging camera. The effects of load, speed and misalignment on the types of couplings and their temperature rise have been studied. It has been found that by monitoring the rate of temperature rise within the time constant of a cooling system, a misalignment in a system can be detected. The experimentally measured time constant is found to be in the range of estimated time constant of the system from one-dimensional heat transfer models. It has been found that the measured transient spatial temperature distribution on the couplings also indicates the presence of misalignment in the shafting system. Vincent Leemans, Marie-France Destain (2011) evaluated the possibility of infrared thermography to measure accurately the temperature of the elements of a rotating device, within the scope of condition monitoring. It was shown that an efficient temperature correction should compensate for the variability of the process, and for the ambient temperatures vary, either daily or seasonally. Mann Singh Rathore, R. K. Yadav, and Rajesh Kumar (2016) have focused on the analysis of different conditions of misalignment and recorded data for each fault in controlled conditions. The fault detection is achieved in two stages: image processing followed by image evaluation. Also, an attempt is made to provide a reliable choice between image processing and image evaluation method according to their need to in particular fault detection method. Nikolaos G. Athanasopoulos and Pantelis N. Botsaris (2014) performed a comparative analysis on rolling bearing fault analysis. They used three detecting methods: infrared thermography, vibration analysis and airborne sound. Those methods are applied to a specific rolling bearing and developed on an experimental setup. The conducted experiment depicted that this comparison is feasible as the results of each method are relevant.

RESEARCH METHODOLOGY AND FACILITIES

Case study setup of a closed loop centrifugal pump system was carried out in the hydro mechanical lab. The pump is 15 L/S flow rate, 7.5 m head, 3hp power, and 1485 RPM, connected to an electric motor through coupling. The pumping system consists of motor, pump, suction, and delivery pipelines as shown in Figure 1.

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Figure 1. Pumping system test rig.

The forced vibration test was done to determine vibration levels and exciting frequencies and evaluating the dynamic running condition of the pump unit. Alignment process was done using a laser alignment system and Alignment program to perform Laser vertical and horizontal alignment between motor and pump. In order to measure the temperature of bearings and coupling, a FLUKE Ti25 thermal imaging camera was used. The pump system was running for one hour to reach a stable condition before any measurements. After running the pump unit for a period of time, the temperature of various parts of the test rig attained steady state. The camera should be in front of the pump unit and there should be no other heat source in the camera view because that may change the temperature scale range of the thermal camera. Misalignment was introduced by using 2.0 mm thickness shims below the MNDE bearing.

RESULTS OF VIBRATION ANALYSIS

Forced vibration analysis was done to specify the sources of vibration and define the excitation operational frequencies at different locations. The measurement locations were chosen for the parts of the pumping unit, including the motor, bearings, and the pump at 9 locations in the axial, vertical, and radial directions as shown in Figure 2.

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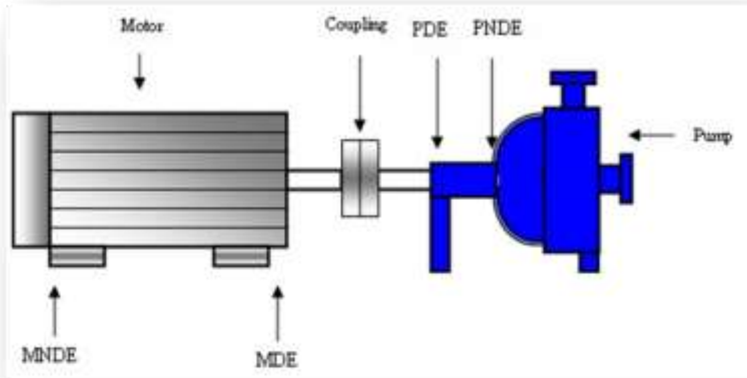

Figure 2. Measurement locations.

The signals from the accelerometers are directly fed into the analyzer which possesses an internal signal conditioning system comprising filters, integrators, amplifiers, etc. The signals are then transferred to the PC via USB connection to the software for signal analysis.

All these measurements were taken according to the ISO 10816 -3 where the root mean square (RMS) was measured for all parameters because it is the most accommodate one for machine diagnosing where it expresses for the energy consumption due to vibration. It also takes the time history of vibrations. ISO 10816 -3 determines the status of machines if they are working in good dynamic conditions in accordance with international measurements. It gives the criteria for the limits of good vibrations and limits the dangerous and not permitted to run through the measured speed level in accordance with the rules and the power and foundations installed by the machine.

Overall vibration velocities measured at the measurement locations of the test rig are shown in Figure 3. Measurements at the motor non drive end (MNDE) showed that the maximum vibration velocity reached 3.89 mm/s and 2.95 mm/s in the axial and vertical directions respectively. These levels exceed the permissible levels by 38% and 5%. On the other hand, the measurements on the motor drive end (MDE) showed that the maximum maximum vibration velocity reached reached 4.11 mm/s and 3.00 mm/s in the axial and vertical directions respectively. These levels exceed the permissible levels by 46% and 7%. Maximum vibration velocity reached 2.88 mm/s on the pump drive end (PDE) in the axial direction. The overall vibration level of the motor drive and non drive ends is falling within the unacceptable range.

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Figure 3. Overall vibration level velocity measured at different locations.

The FFT spectrum analysis that has been recorded indicates that, there are vibration peaks founded at motor running speed (1RPM, 25Hz) in the axial and vertical directions of the motor drive and non drive ends. Vibration amplitude reached 3.52 mm/s, and 2.72 mm/s at the motor drive no drive end in the axial and vertical direction respectively as shown in Figure 4. On the other hand, vibration amplitude measured at the motor drive end reached 4.06 mm/s and 2.23mm/s in the axial and vertical direction as shown in Figure 5. These high levels of vibration are unacceptable. The results indicated that the amplitude changed with directions. Also the amplitude in the axial direction is about 50 percent of the highest radial amplitude. Depending on all these remarks, it is obvious that there is a misalignment problem. Misalignment causes an overload on bearings and results in shortening bearing life. This reduction depends on the degree of misalignment. Bearing defect factor is a value that gives proof on the bearing statues if it operates within good conditions or not. The bearing defect factor level is within the alarm range at the motor drive end and pump drive end sides. Maximum overall bearing defect factor reached 8.61 on the motor drive end in the vertical direction, and 7.67 on motor drive end in the vertical direction.

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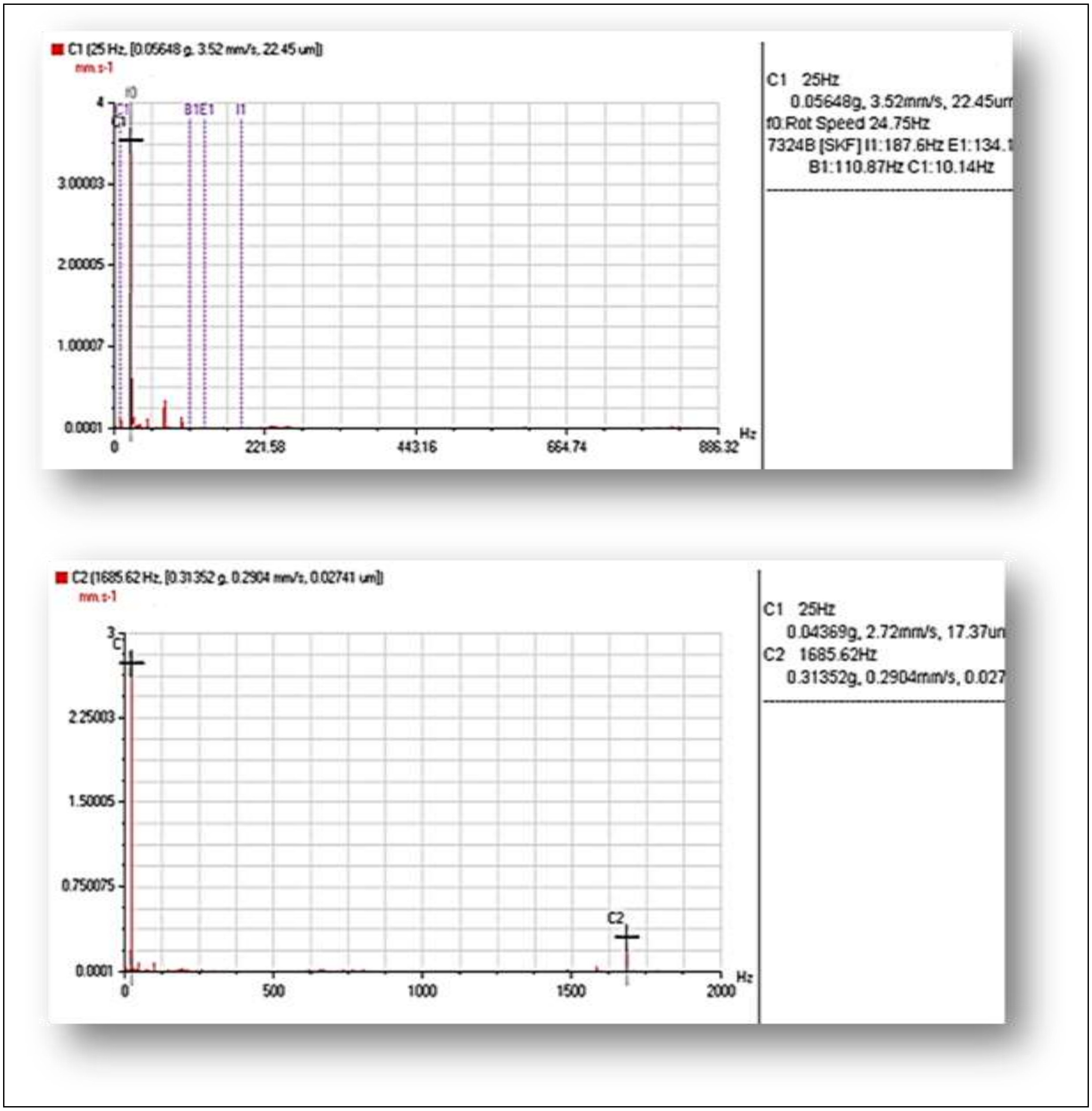

Figure 4. Vibration spectrum measured at motor non drive end in axial & vertical directions.

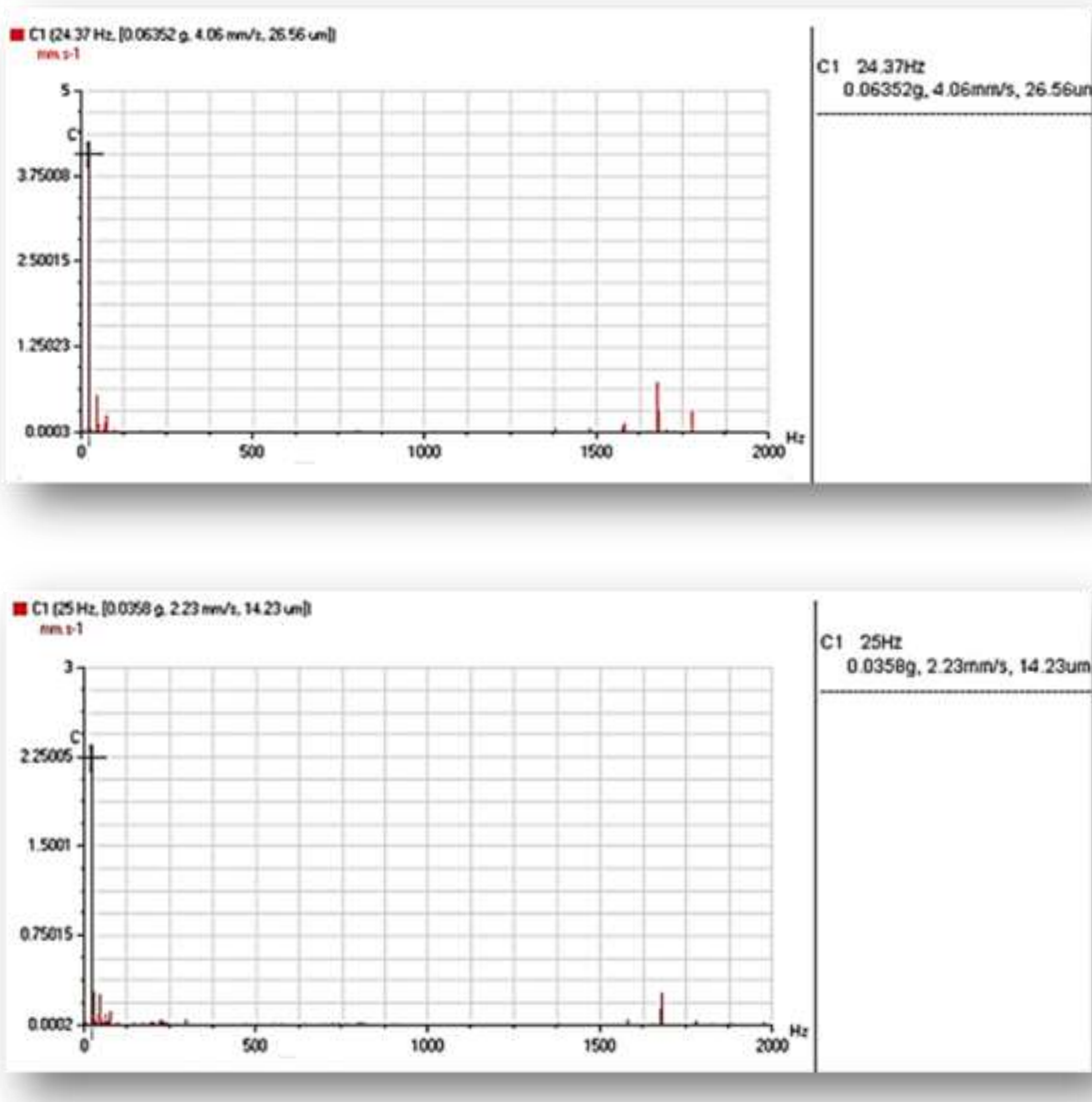

Figure 5. Vibration spectrum measured on motor drive end in axial & vertical directions.

Alignment Procedure

Alignment is the process to bring the shafts center line of movable machine to be in-line with stationary machine, or Adjustment of the relative position of two coupled machines, so that the center line of the axis will be concentric when the machines are running during normal operation. In practice, proper alignment is difficult to achieve without using alignment equipment such as dial indicators or laser alignment tools. The proper shaft alignment procedure is to secure the driven equipment first because of pump moving. Angular misalignment occurs when the axes of

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a motor and pump are not parallel. When the axes are parallel but not exactly aligned, that's parallel misalignment.

The laser system can calculate from the shaft movement how much each foot has raised as shown in Figure 6. Correct machine dimensions must be input into a laser alignment system for correct calculations. Once foot movements have been established, the results need to be interpreted and translated into shim thicknesses needed to correct any soft foot situation. In this case the offset alignment reached 0.310 mm while the angular alignment value reached 0.366 mm. These values are dangerous, so it must be but shims under the motor and move it to be within acceptable tolerance. After applying alignment procedure, the offset alignment decreased to 0.035mm while the angular alignment decreased to 0.013mm and these values are within the acceptable range according to device limit.

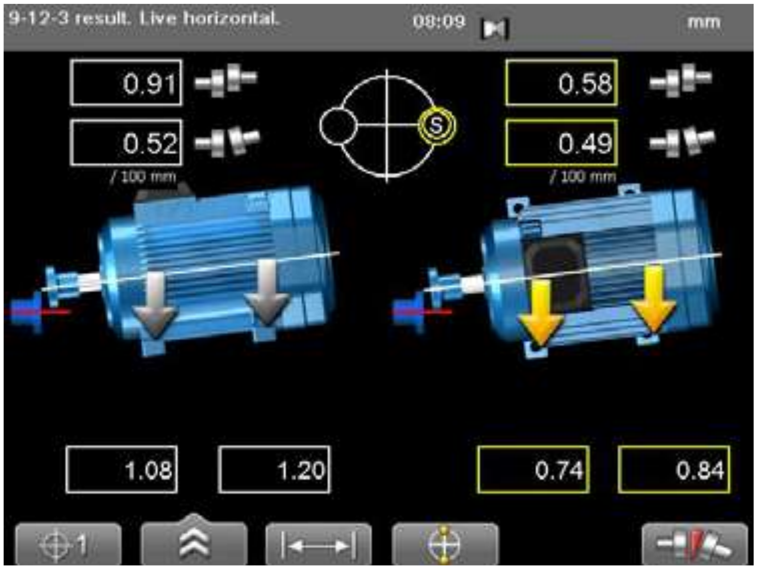

Figure 6. The laser system calculation for how much each foot has been raised.

Results of Vibration Measurement after Applying Alignment Process

After applying alignment process between motor and pump, the results indicated that vibration Levels are within the acceptable range according to ISO 10816 -3. The measurements showed that the maximum overall vibration level measured reached 1.6 mm/s and 1.51 mm/s on the motor non drive end. Vibration levels decreased to 57% and 48% in the axial and vertical direction respectively. On the other hand measurements showed that the maximum overall

vibration level measured reached 1.82 mm/s and 1.24 mm/s at the motor drive end. Vibration levels decreased to 41% and 29% in the axial and vertical direction respectively. Comparison between vibration levels before and after applying the alignment procedure is shown in Figure 7.
The FFT spectrum analysis indicates that he maximum vibration amplitude reached 0.4083 mm/s, and 0.9067 mm/s at the motor drive non drive end respectively in the axial and vertical direction as shown in Figure 8. Maximum vibration amplitude measured at the motor drive end reached 0.8729 mm/s and 1.22 mm/s in the axial and vertical direction as shown in Figure 9. The analysis result confirmed that the vibration level became within acceptable healthy condition after correcting misalignment problem. Therefor this will help to prolong machine life through the application of proactive maintenance strategies.
The bearing defect factor level is within the acceptable range at the motor drive end and pump drive end sides. Maximum overall bearing defect factor reached 2.20 on the motor drive end in the vertical direction, and 2.23 on pump drive end in the vertical direction. Bearing defect factor decreased by 74% and 71% at the motor drive and non drive ends respectively.

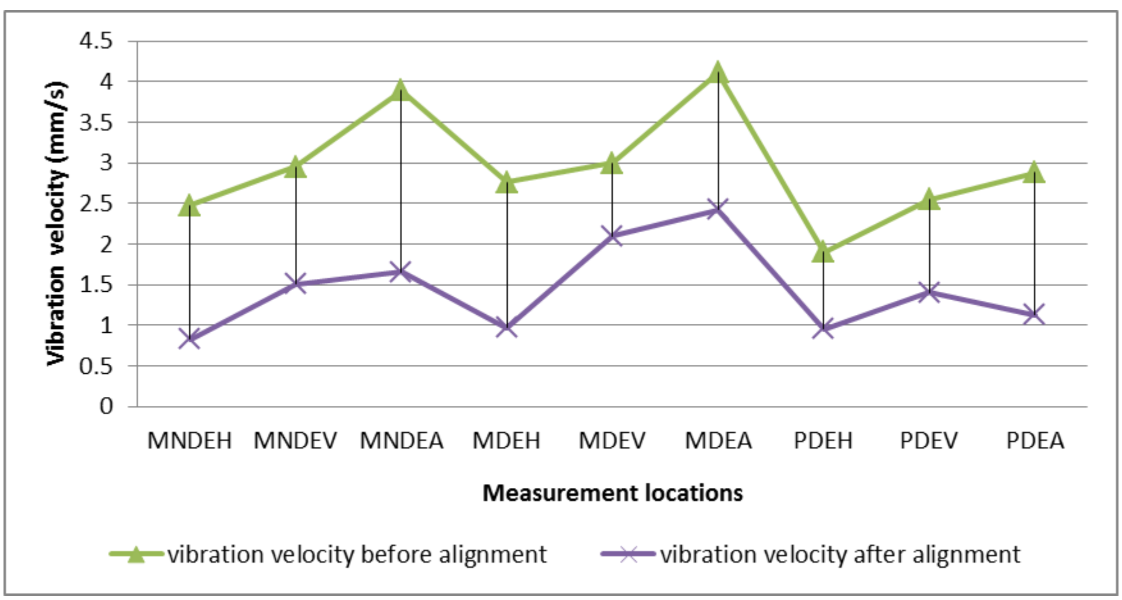

Figure 7. Comparison between vibration levels before and after applying alignment procedure.

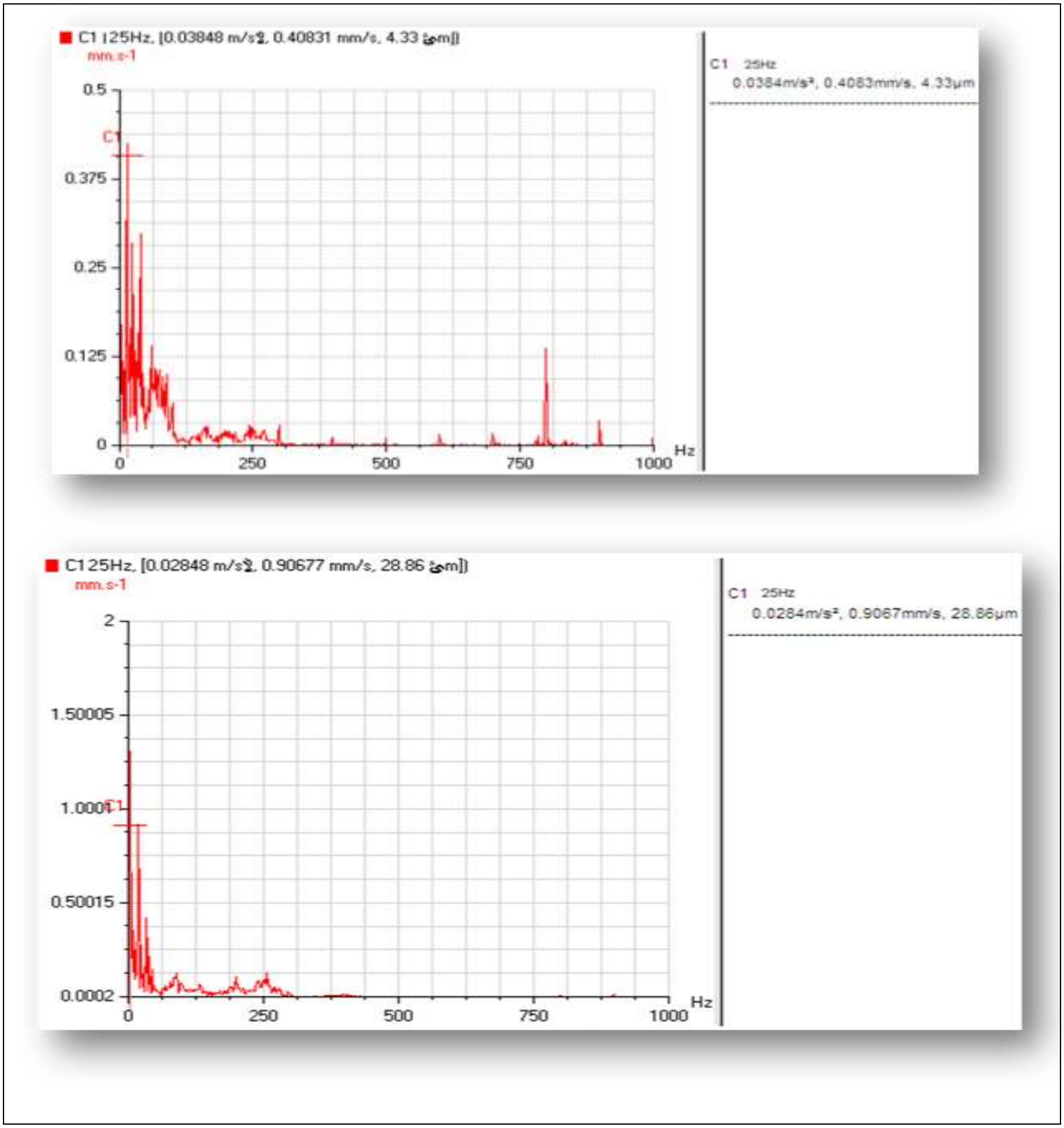

Figure 8. Vibration spectrum measured at motor non drive end in axial & vertical directions.

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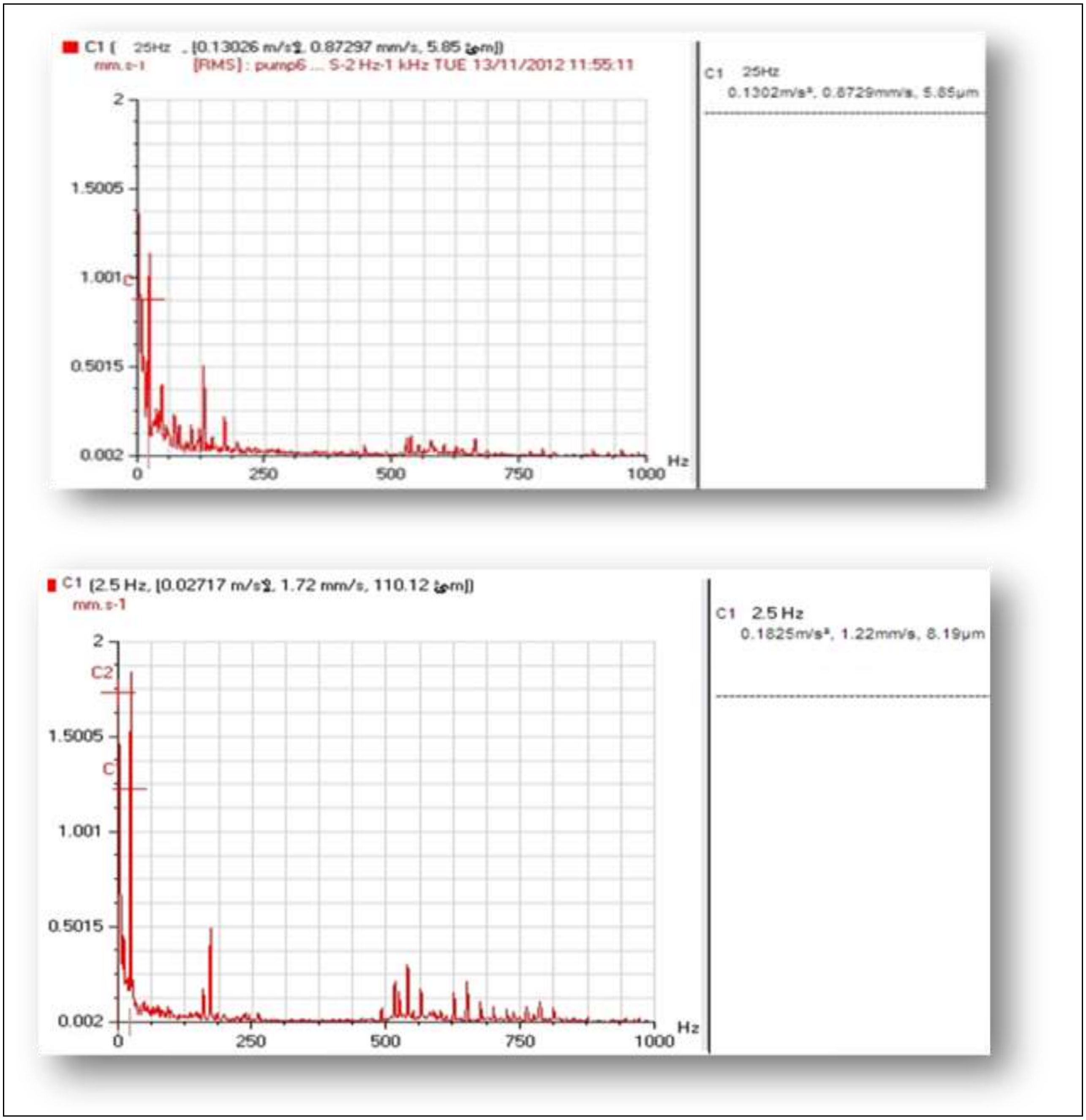

Figure 9. Vibration spectrum measured at the motor drive end in axial & vertical directions.

Results of infrared Thermography analysis

Infrared thermography is another method of detecting misalignment. This technique involves measuring the infrared emissions from machine surfaces allowing surface temperatures to serve as a useful analytical tool when high, localized heat is present.

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Infrared thermography is based on measuring the distribution of radiant thermal energy (heat) emitted from a target surface and converting this to a surface temperature map or thermogram. Thermal energy is present with the operation of all machines. It can be in the form of friction losses or energy losses within machines. As a result, temperature can be a key parameter for monitoring the performance of machines, the condition of machines and the diagnostics of machine problems.

The measured temperature was acquired by a fixed thermo graphic camera. The test rig worked continuously for 16 hour to indicate the effect of the misalignment problem with increasing temperature. Temperature measurements were processed and recorded every two hours. Shaft misalignment evaluation at a region of interest is selected to determine the maximum component temperature. Varying misalignment conditions were achieved by using different thickness stainless steel shims which were placed under machine foot. Infrared thermography analysis was achieved before and after applying alignment process. Figure 10 shows the variation of maximum temperature during different operating hours at bearings and coupling. The variation of maximum temperature with different misalignment values at bearings and coupling is shown in Figure 11. It could be noticed that as the misalignment value increased the equivalent temperature of the part increased. This could be due to friction losses or energy losses.

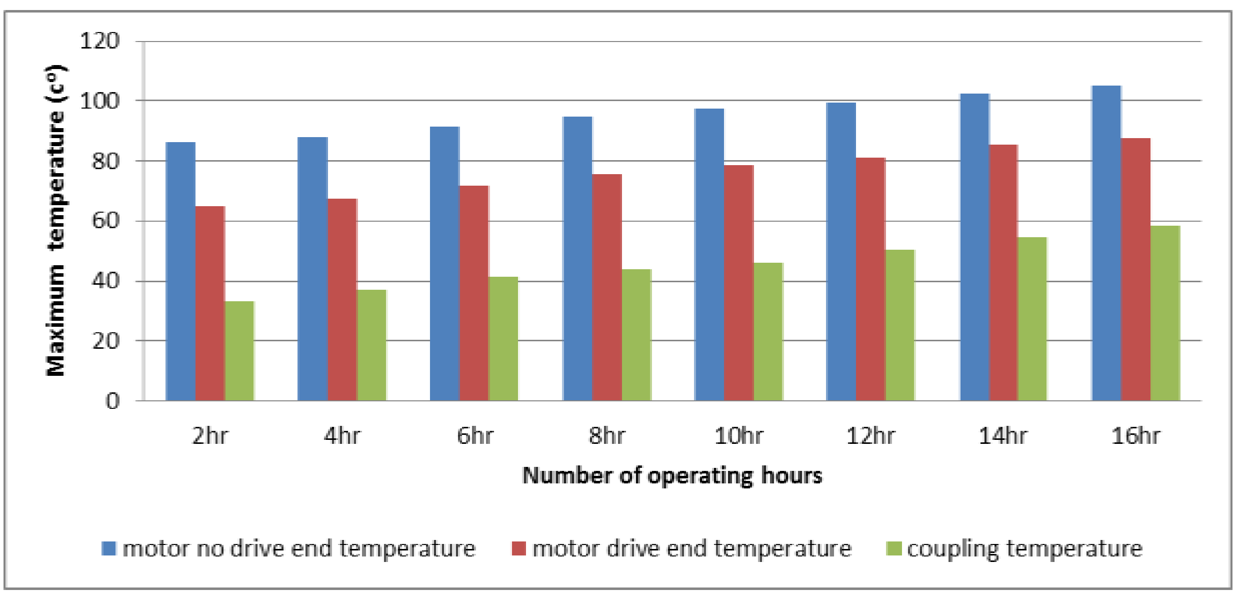

Fig. 10 Variations of maximum temperature during different operating hours.

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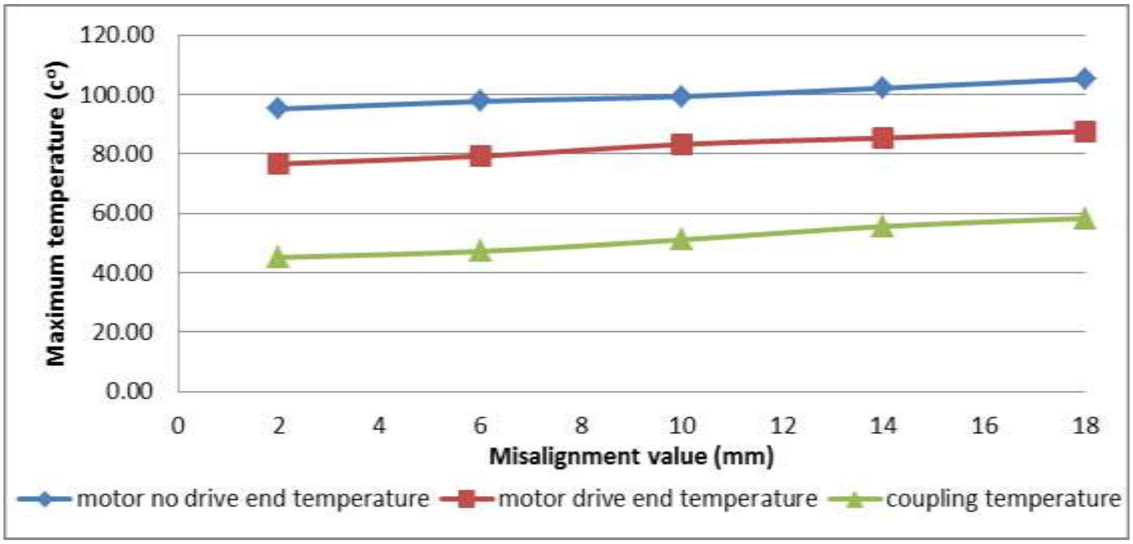

Fig. 11 Variations of maximum temperature value for different misalignment values.

Due to coupling helps in connecting driving shaft with driving shaft, so any deviation in the centerline of shafts can result in increasing in temperature of coupling. It could be noticed that the effect of the misalignment rise at the non-drive end bearing is more than its effect on drive end bearing and coupling.

The thermal images shown in Figure 12 indicated that, as the misalignment develops, the temperature increases due to increasing friction. The first image (A) demonstrates the distribution of heat at the beginning of the operation. This image shows that the temperature of the bearing has started to increase. The entire end cover of the motor is also starting to increase in temperature. The second image (B) indicates that the temperatures changed to be higher as the load increased. The bearing housing is also affected by the heat energy generated from misalignment and even the shaft coupling is affected. The temperature of the entire end casing of the motor has increased to 101C°. The third image (C) clearly shows that the energy wasted in overcoming the forces produced by misalignment is significant. The temperature increased to be 190 C°.

All of this heat energy passes into the bearing and subsequently into the lubricant. The resulting head and forces accelerate wear of bearing. Left unchecked, this problem will first cause the bearing to wear, followed by the seal and finally the coupling. The fourth image (D) was taken

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with the machine correctly aligned. The heat distribution after applying misalignment indicates that the temperature decreased to be 58.4 C°.

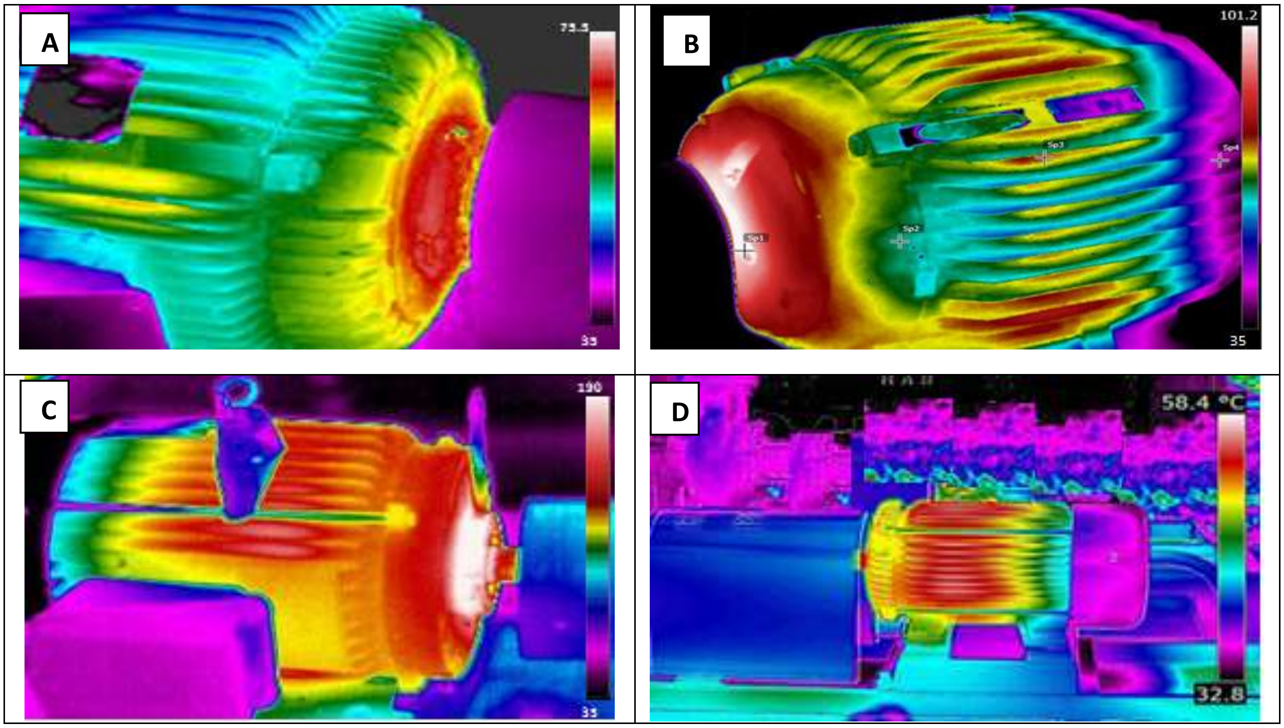

Fig. 12 Distribution of heat change on the test rig before & after alignment process.

DISCUSSION

This research introduced a comparative study as an attempt to obtain the reliability of two techniques in analyzing and diagnosing misalignment. Vibration analysis and thermography analysis are applied experimentally to a pumping system set up. Detecting and evaluation of the misalignment problem using two techniques is performed. The conducted results of vibration analysis indicated that, the overall vibration level of is falling within the unacceptable range during the presence of misalignment. Measurements showed that these levels exceed the permissible levels by 38% and 5% at the motor non drive end in the axial and radial directions. Moreover, these levels exceed the permissible levels by 46% and 7% at the motor drive end in the axial and radial directions. After applying alignment procedure vibration levels decreased to 57% and 48% in the axial and vertical direction at motor non drive end respectively. Vibration levels decreased to 41% and 29% in the axial and vertical direction at the motor drive end

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respectively. On the other hand, thermography analysis indicated that, as the misalignment develops, the temperature increases due to increasing friction. Furthermore, it was observed that the NDE bearing temperature had been always higher than the DE bearing; this is for the fact that the forces at the NDE bearing are higher. Misalignment increases forces and moments at non drive end bearings, so the frictional heat amount increases. Heat energy generated due to misalignment decreases by 43% on the test rig after the machine correctly aligned. A misaligned shaft will result in unequal loading and cause heating at the point of highest mechanical resistance either at the bearing and coupling. The use of vibration analysis was faster in detecting the misalignment problem than thermography analysis. Thermography analysis was accompanied by overheating as the temperature rises gradually and this may need time. At the same time, the use of thermography analysis was more distinct in determining the temperature of places where the vibration sensor can not reach it such as coupling. Thermal camera measured the surface temperature of the body directly without contact.

CONCLUSIONS

Vibration and infrared analysis can both provide a significant amount of benefit to monitoring equipments. The most suitable condition monitoring technique for a particular operation can only be decided by taking in consideration the factors like equipment under test, its loading, defect type and ambient conditions, etc. Depending on all the previous results it concluded that, vibration analysis is more effective than thermographic analysis for detecting misalignment problem. For rotating equipments, vibration analysis is the most precise way, whereas for non rotating equipments infrared analysis considers the ideal way. Moreover the results are revealed that even if the vibration analysis is the most common method of detecting machine faults, it still can be replaced by the use of other methods less accurate but less difficult to operate.

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