Infrared Thermography Inspection on Potential Failures of Rotating Equipment

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(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

_____

(IR. DR. MOHD SHIRAZ BIN ARIS)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

_____

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ABSTRACT

Maintenance and inspection strategy in industries is very important to ensure the process run smoothly with the low maintenance cost and time consuming. In almost all industry, typically, the reliability of the critical motors is usually taken care by vibration monitoring and trending program. Although vibration is part of important element of rotating equipment, the heat transfer also can be used in order to determine the condition of the motor. This is done by applying the non-destructive testing (NDT) which is Infrared Thermography (IRT). Through the technology, the failure can be detect at the early stages. This avoids machine failure and costly unplanned shutdown. Therefore the aim of the project is to validate the use of IRT in detecting the failure of the motor through control IRT testing. The results from the experiment are very significant in order to establish the application of IRT in inspection strategy. In this experimental study, a laboratory cell was designed and the two common faults which are overload and misalignment were created to stimulate the condition of motor in plant. Factor such as defect's limitation, object distance and emissivity are the parameters that affect the accuracy of the results. Thus, infrared image in parallel with numerical analysis in term of different temperature distribution as time the increased will used to detect the failure during the running process of the motor in plant

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in his will and given strength, the author successfully complete this final year project (FYP) entitle, Infrared Thermography Inspection on Potential Failure of Rotating Equipment.

Utmost appreciation goes to Ir. Dr. Mohd Siraz bin Aris, who has been very supportive and kind to guide throughout the entire FYP I and FYP 2. The author would like to dedicate special thank for his guidance and supervision toward the completion this project. The author also owe a great many thanks to the lab technologist Mr. Zuaraimi, Mr. Azhar and Mrs. Suhaila from Electrical Power laboratory Block 23 and Mr. Ghani from Mechanical laboratory Block 21 for the assistance and help throughout this project.

I dedicate this work to my beloved parents who have been the greatest support in every my success. Last but not least, to Universiti Teknologi PETRONAS for providing the lab facilities to run the experiments.

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ABBREVIATION

IR	-	Infrared
IRT	-	Infrared Thermography
NDT	-	Non-Destructive Testing
UTP	-	Universiti Teknologi PETRONAS

CHAPTER 1: PROJECT BACKGROUND

1.1 Background Study

In the industry, the used of IRT is now widely used in preventive and diagnostic inspection technique. At the early stage of infrared testing came about in non-destructive testing (NDT) after the considerable testing by military system in early 1960's [2]. Infrared thermography (IRT) has become more important method in preventive maintenance due to its high precision and sensitivity imaging characteristics [3]. IRT is used in industry in order to supervise the normal operations and, more importantly, to locate the thermal possible faults, defects or inefficiencies within a system or machine.

IRT is used to detect infrared energy and converts it into thermal image and also perform the temperature calculation. Since, it is non-contact device; it is safe, reliable and inspection can be used without shutdown the equipment [3]. IRT can monitor the condition of the equipment by detecting the emission of the infrared energy which is heat that radiated from the surface of the equipment. Heat is created in number of ways such as by excessive friction, high electrical resistance and problems with current flow in a motor. All the defects will reveal through the IR image capture by the IRT camera. From the result, the analysis can be done and determined the failure mode and condition of the equipment.

This approach is relevance to the basic knowledge that, the life of electrical equipment is drastically reduced as the temperature increased. Due to this support, the temperature can be a parameter for monitoring the performance of the equipment. Through this inspection, the failure and any anomalies can be detected at earlier stage and prevent the failure from happen and then consequences a big loss in term of maintenance cost and time consuming in order to repair and replace the components [3].

Although, the inspection method by using IRT is straight forward, there are several factors that need to be considered to ensure the accuracy of the thermal analysis. There are emissivity, the reflection of light and the ambient temperature.

This project focussed on the fundamental of the relationship between the infrared image and potential failure of rotating equipment by the aid of the experimental investigation using IR. Therefore, the main target for this project is to validate the effectiveness of using IRT to detect potential failure on rotating equipment.

1.2 Problem Statement

In the industries, motors are the main equipment that runs all the process. The motor will affect the process of a system if it getting faulty, that will consequence in term of highly maintenance cost and time consuming. Common practice in inspecting and detecting the failure is by using the vibration approach that only focused on the sound or the wave of the motor. However, the thermal approach also can be used to detect the failure. Therefore, advance and effective monitoring techniques are required to monitor and detect the motor problems at early stages.

1.3 Objectives

The objective of the project is **to validate the use of infrared thermography (IRT) testing to identify the potentials failure** in motor and **to establish calibration process** in order to develop the database.

1.4 Scope of Study

The scope of the project is to investigate the ability of IR camera to detect the fault of motor. There are three main focuses;

1. The **concept of heat transfer** in detecting the failure
2. The **external and parameter** that have to establish for the experiment.
3. The **potential failure** of a specifics rotating equipment.

1.5 Relevancy of the Project

This study has a significant value in which it can help the company to measure the effectiveness of applying IRT to detect the failure mode of the rotating equipment such as pump that is the critical equipment in a company. Therefore, the successful of the project will help the industry to practice and apply the use of Infrared technology in inspection strategy.

1.6 Feasibility of the Project within Scope and Time Frame

For the whole 8 months period of final year project (FYP) given, the project must be completed and experimentally proved the good result within the time frame. The references related to the scope of study are basically referred to some industry papers and journals following the codes and standard of inspection.

1.7 Dissertation Structure

The author will first described the introduction of the project which includes the background study, objective, problem statement, scope, the relevancy and feasibility. Next, in the second chapter, the author will explained the theory relating to infrared thermography and type of fault of motor based on some papers and journals. In chapter 3, all the planning like Gantt chart, milestone of the project activities are stated and also the methodology approach such as experimental set-up, apparatus list and procedures. The results recorded are presented in form of table and figure and some discussion to justify the result are included in Chapter 4. Lastly, in chapter 5, the project will be summarizing in conclusion and some recommendation for the future of the project.

CHAPTER 2: LITERATURE REVIEW

2.1 Infrared Thermography (IRT)

The principle of IRT is based on the thermal radiation laws. The objects with the temperature above the 0K or -273^{o}C emit electromagnetic radiation in the infrared region of electromagnetic spectrum [3]. The camera will capture the information from the emission of the equipment to determine the surface temperature. The temperature will determine the quantity of the radiation and also the color displayed on the camera. There are several factors that influence the emissivity of the infrared radiation emitted by an object. They are temperature, emission angle, and wavelength [4]. The figure 1 shows, the principle of the Infrared Thermography.

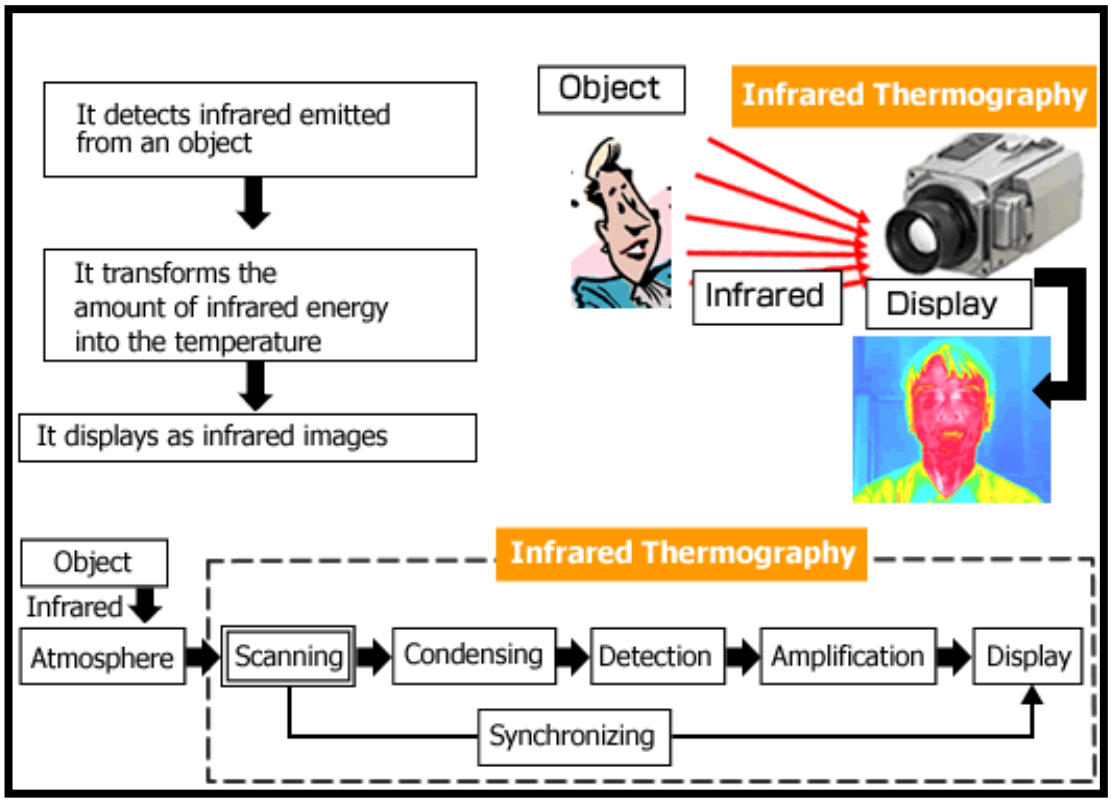


Figure 1: Principle of Infrared Thermography

2.2 Types of Thermography Testing

Thermography camera consists of large numbers of sensor which is sensitive to infrared radiation that can detect and measure small temperature differences. There are two basic types of thermagraphy, which are active and passive.

Active thermography is defined as applying a stimulus to a target to cause the target to heat or cool in such a way as to allow characteristic of the target to be observed when viewed by thermal imagery. It is based on the evaluation of a previously excited heat flow in the tested component and its disturbance by hidden defect [4]. Active thermography required adequate external heat stimulation like ultrasonic, optical and heat wave. There are five modes of active thermography which are pulsed, lock-in, pulse phase, step-heating and vibro-thermography. The active thermography can be used in defect detection, characterization and coating thickness.

Passive thermography is defined as the investigation of the temperature without any external heat simulation as the object itself at as a source of the heat [5]. This approach is simply pointed at the target area and from the thermal image, a temperature map is constructed. The passive thermography is used in condition monitoring of equipment, medical applications and surveillance.

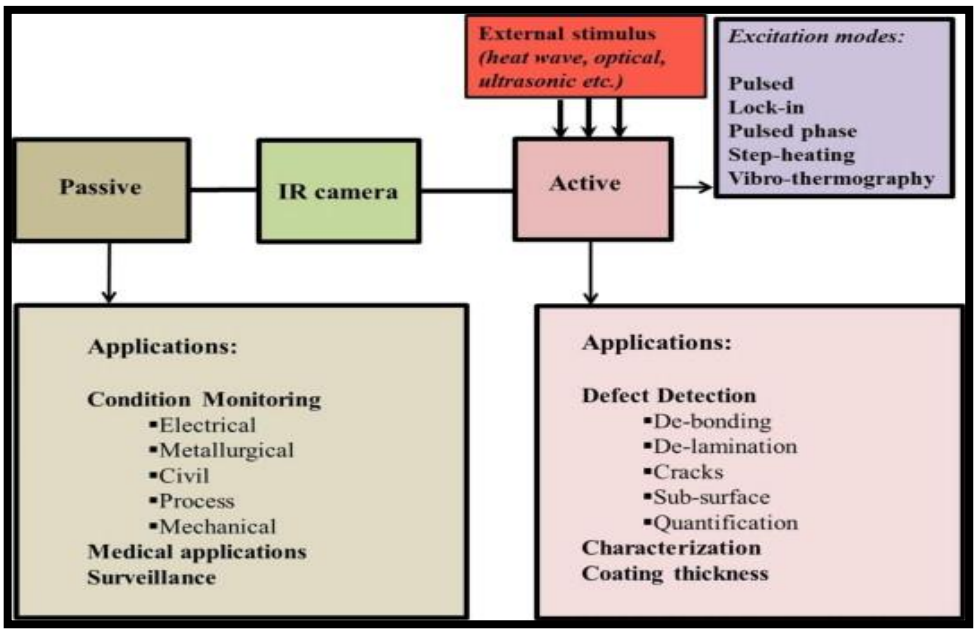


Figure 2: The Schematic Representation of Passive and Active Thermography

2.3 Method of Measurement and Analysis

There are two types of the thermal condition of the equipments which are quantitative and qualitative.

Quantitative is simple as take the exact temperature of the equipment [3]. This method is used to evaluate the condition of the equipment by comparing the temperatures between identical items and baselines [7].

Qualitative approach is taking the relative temperature value of hotspot with respect to the other parts of equipment under the similar condition [8]. This method is suitable for collecting a large number of data and manages it to be interpreted easily. The interpretation of the method is through comparing the thermal pattern and the intensity variation between two similar object will determined the condition of the equipments. In qualitative approach, a ΔT criteria is determined in order to validate the fault of the electrical equipment. A ΔT criteria is the difference of maximum value between the hotspot and the reference temperature [9]. The table 1 shows the standard of the IRT based inspection of electrical equipment [3] [6]. These standards can be used as the reference for validation of the ΔT.

Table 1: Standard Available for IRT based Inspection of Electric Equipment

Standards	Temperature Difference (ΔT) (^{o}C)		Recommendation Action
	Between Similar Components under Identical Loading	Between Components and Ambient air Temperature	
NETA	1-3	1-10	Possible deficiency, warrants investigation (priority:4)
	4-15	11-20	Indicates probable deficiency, repair as time permits (priority:3)
	-	22-40	Monitory continuously until corrective measures can be accomplished (priority:2)
	>15	>40	Major discrepancy, repair immediately (priority:1)
MIL-STD 2914	10-20		Component failure unlikely but corrective measures required at next scheduled routine maintenance period.
	24-40		Component failure probable unless corrected.
	40-70		Component failure almost certain unless corrected
	>70		Component failure imminent
Infraspection Institute Standard for Electrical / mechanical components	>10-20		Corrective measures required as scheduling permits
	>20-40		Corrective measure required ASAP
	>40		Corrective measures required immediately

2.4 Limitation of IRT Inspection

Although, the IRT inspections is quite straight-forward, there are several parameters that have to be considered for the analysis of the IR image. The parameters are emissivity, reflection temperature, wind speed and relative humidity [3].

2.4.1 Emissivity

Emissivity is very important in determine the correct temperature of the equipments. Difference materials have different emissivity due to the different wavelengths. Thus the selection of the accurate emissivity is very essential. Below are the standard procedures in determining the emissivity [10].

1. Place the IRT camera at the desired location.
2. Measure and compensate for the target's reflected temperature
3. Focus the IRT camera on the target
4. Use the camera measurement function such as spot temperature to define the measurement point.
5. Use the contact thermometer as the reference temperature.
6. Without moving the camera, adjust the emissivity until the value is same as the reference temperature.
7. Key –in the value of emissivity in the camera system

2.4.2 Reflected Temperature

The background of the equipment may affect the reading of surface temperature due to the difference emissivity of the background and the equipment [11]. Thus, to reduce the effect of reflected temperature, the equipment set up is needed before the testing is started. Below are the standard procedures for the reflected temperature [10].

1. Set the IRT camera's emissivity control to 1.00.
2. Place the IRT camera at the desired location and distance from the target. Estimate the angle of reflection, α, and the angle of incidence, β, when viewing the target with the camera from this location (refer Figure 3).
3. Position the IRT camera so that it is at the angle of reflection from the target, α, and view the sources reflected by the target (refer Figure 4).
4. Measure the average apparent temperature of these sources with the camera. Use any camera features available (such as area averaging) that average these reflected apparent temperatures. Note this temperature, which is the reflected apparent temperature, Trefl, of the target.

5. For greater accuracy, repeat procedures b) to d) a minimum of three times and average the temperatures.

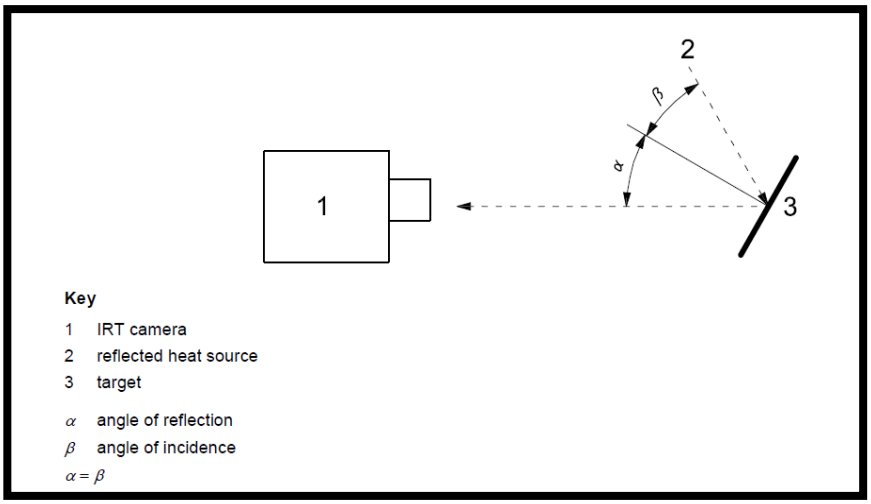


Figure 3: Position of the Camera and the Equipment

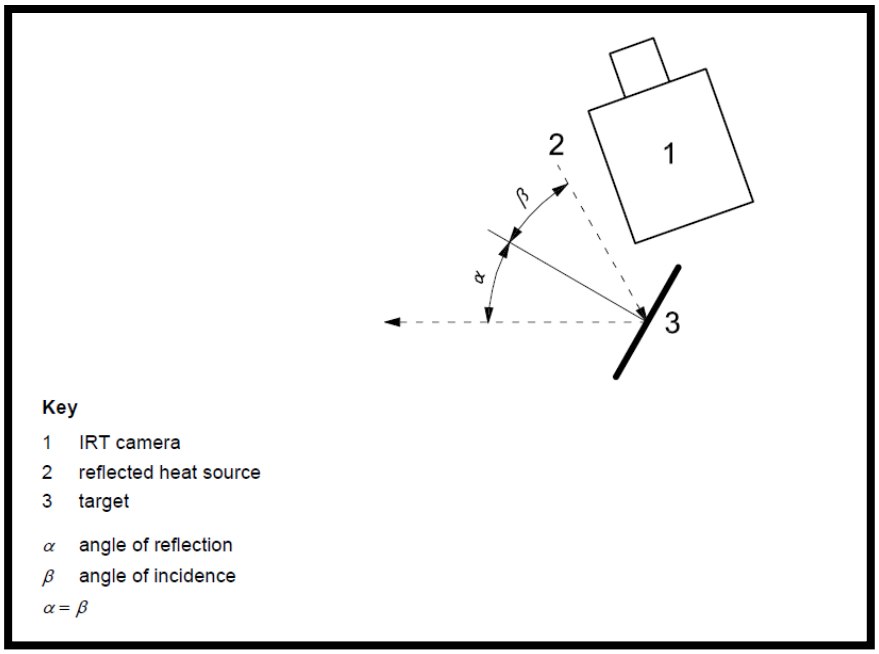


Figure 4: Position of the Camera and the Equipment

2.4.3 Wind Speed

Wind speed can change the temperature drastically that due to the convection radiation from the surface [11]. Due to this effect the workplace for the testing must be controlled to reduce the effect of wind speed on the temperature.

2.4.4 Relative Humidity

Relative Humidity is refers to the amount of the water in air at the particular temperature. However, the relative humidity just gives the minimal effect to the temperature. It may affect due to the rain and fog [11]

2.5 Components of Electric Motor

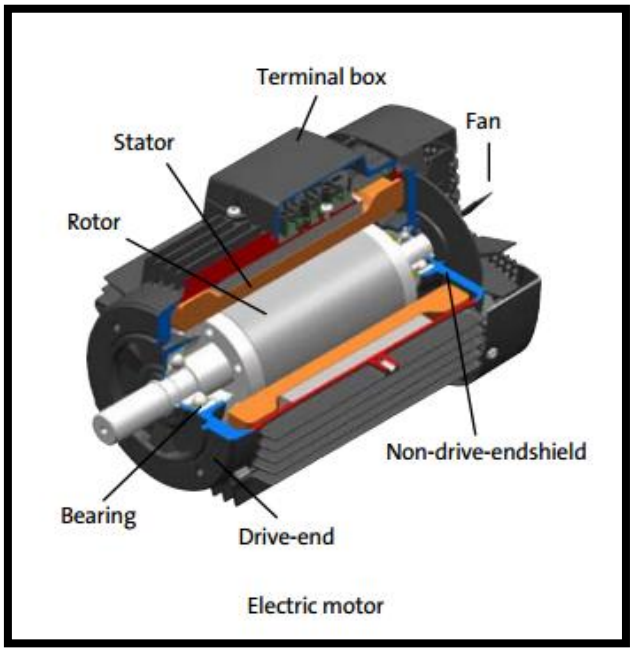


Figure 5: Components of motor [14]

Table 2: Components of Motor and its Function [14]

Components of Motor	Function
Terminal Box	• For connection and protection
Stator	• Stationary electrical part of motor. • Contains a number of winding
Rotor	• Rotating part of motor • Rotates with the motor shaft due to the magnetic field of motor.
Bearing	• Reduce friction and wear on rotating and stationary parts
Fan	For cooling system

2.5 Types of Motor Failures

Motors are one of the common used elements in almost all industrial. The performance of the motor affect the process of a system if it getting faulty. Motor typically fail due to these 3 categories which are low resistance, mechanical and over current [7]. First is a low resistance failure. According to the research, it is been estimated that about 90% of motor have problems occur at start-up and this problem caused by low insulation resistance [7]. Second is mechanical failure. Mechanical failure happen for a wide variety reasons such as inadequate lubrication, vibration, bearing failure and misalignment. Lastly is over-current which happens most often when operating conditions causes devices to draw more current than their rated load capacity. The table 2 below shows the summary of the stress [13]. Based on the table all the fault can be detected by the thermal approach.

Table 3: The Summary of the Stresses of the Components

Types of Stress	Stator Winding	Rotor Assembly	Bearing	Shaft
Thermal	/	/	/	/
Electrical / Dielectric	/	/	/	
Mechanical	/	/	/	/
Dynamic		/	/	/
Shear				/
Vibration / Shock	/	/	/	/
Residual		/		/
Electromagnetic	/	/	/	/
Environmental	/	/	/	/

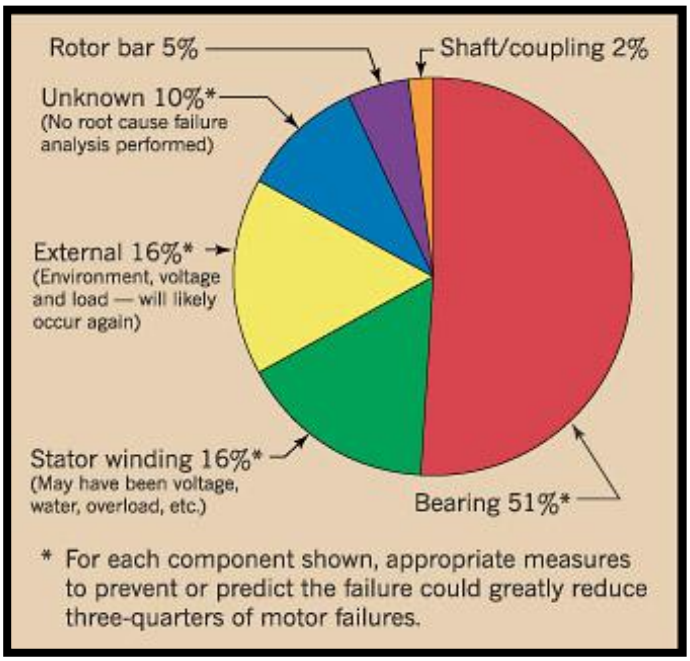


Figure 6: Failures Distribution Statistic from IEEE- Petro Chemical Paper

The figure 6 shows the failure distribution of electrical motor. The highest failure is due to bearing failure and followed by stator winding and external that due to environment. Thus, bearing and winding failure is chosen as the potential failures and the narrow the scope of the project.

2.5.1 Winding Failure

Most of the winding failures are subjected by various stresses that act on the stator winding [15]. There are thermal, electrical, mechanical and environmental stresses. The failures happen when the insulation of the winding burnt and lead to the motor failure.

2.5.2 Bearing Failure

Bearing is a component that helps in reducing the friction on rotating and stationary part of motor. It is also used as the support to the shaft. There are several types of bearing such as roller bearing, ball bearing, sleeve bearing and needle bearing. The bearing failure is due to the friction created due to the unbalance load, voltage, overload and lack of lubrication [14]

2.6 Condition Subjected to Motor Failure

In order to validate the failure of the motor specifically bearing and winding failure, identifying the condition that lead to the failure is important. The two conditions are overload and misalignment.

2.6.1 Overload Condition

Overload is due to the over-current failures. This failure happen when the operating condition forced the device to use more current than their rated load capacity [7]. This situation usually occurs suddenly and leads to the failure. The over-current will increase the resistance to the equipment and when it reaches the maximum, the equipment will fail. Increasing in the resistance will also produce the friction to the bearing and cause the temperature rise. From this situation the condition of the equipment can be monitored by using the IRT inspection.

2.6.2 Misalignment Condition

Misalignment of shaft on the rotating equipment can affect the performance of the motor. The offset occur between two shafts create the friction that lead cause of premature bearing failure [12]. There are four categories of the misalignment which are vertical offset, horizontal offset, vertical angularity and horizontal angularity. In industry, the misalignment always occur s between the two machines which is the static and the rotating equipment. For example of the misalignment is between the motor and the pump. They are coupling together and function well. However, when the misalignment occurs it will lead to the bearing failure and winding failure.

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

Methodology is the step of procedures that have to follow in order to complete the project. The methodology of the project can be divided into two parts which are research and experimental. For research methodology, information gathering is retrieved from books, online articles, industrial papers and journals.

3.2 Project Design and Activities

The project is begun by designing the simple motor circuit that contains a single phase motor, regulator, locker brake, and misalignment rod. The set up is representing the motor operation in real life. After everything is done, the IR camera and thermocouple are installed to detect the surface temperature and body temperature respectively. The temperatures are recorded and then analyze to validate effect of temperature in detecting the failure of motor.

3.2.1 Experimental Set-up

Figure 2 below show the schematic illustration of the experimental apparatus. The AC motor and the wires are connected to the regulator. The Infrared camera is located about 60^{O} to the motor about 1 m in distance. The camera cannot arrange parallel to the motor to get the sharp and accurate images. Besides, the emissivity and reflection temperature is determined before the experiment is started due to the limitation of infrared camera on the emissivity and refection of light that can affect the reading of the surface temperature.

Figure 7: The Apparatus Set-up for Experiment

3.2.2 Types of Faults

Based on the study, there are 2 possible faults that can be created which are overload and misalignment. Table 3 below gives s the details of the faults.

Table 4: Details of Faults

No of Fault	Types of Fault	Explanation
Fault 1	Overload	Applied by install the brake locker to create the overload condition, then resulting in short circuit.
Fault 2	Misalignment	Applied the rod on the shaft and the other end of a shaft is locked to create a load. The misalignment is controlled by varies the degree of the locked part of rod.

3.3 Project Testing and Evaluation

To validate the use of the IR approached in detecting the fault of motor, first, the working temperature has to be determined. Working temperature is the temperature at which the motor operate normally or in other word operating temperature. The temperature determines can be used as the baseline or references in order to compare the temperature during the fault created which are overload and misalignment. There are three testing will be carried out through the project.

A. No-Load Test

Procedures:

1. The power supply is connected to the motor and then the switch is on.

2. The IR camera is used to capture the surface temperature for every 30 minutes.

3. The reading on the thermocouple is recorded.

4. The motor is switched after 3 hours.

Once the data is recorded, the graph of temperature versus, time interval is plotting to determine the working temperature of the motor under the normal condition. The result is then will set as a reference and used in comparison with the motor temperature under fault condition.

B. Overload Test

Procedures:

1. The apparatus is set-up as the figure 8.

2. The power supply is connected to the motor and then, the switch is on.

3. The IR camera is used to capture the surface temperature for every 5 minutes.

4. The reading on the thermocouple is recorded.

5. The motor is switched after 30 minutes.

Figure 8: The Apparatus Set-up of Overload Testing

Overload testing is done by locked the rotor of the motor to the brake locker. This will increase the resistance to the motor shaft, as it will prevent the shaft from rotated. As a result, the load will increase and overload criteria is occurred. This can be determined through the temperature collected during the overload condition. The graph of temperature against the time is plotted to determine the relationship of time effect to the temperature distribution under overload condition. The infrared images

collected also used to compare the temperature of the infrared camera with the actual temperature display by the thermocouple.

C. Misalignment Test

Procedures:

1. The apparatus is set-up as the figure 9.

2. The power supply is connected to the motor and then, the switch is on.

3. The degree of the shaft is set at $0^{o,}$ and the IR camera is used to capture the image for every 5minutes.

4. The experiment is repeated by varied the degree of the shaft with 10^{o}, 20^{o}, 30^{o}

5. The IR camera is used to capture the surface temperature for every 5 minutes.

6. The reading on the thermocouple is recorded.

7. The motor is switched after one hour.

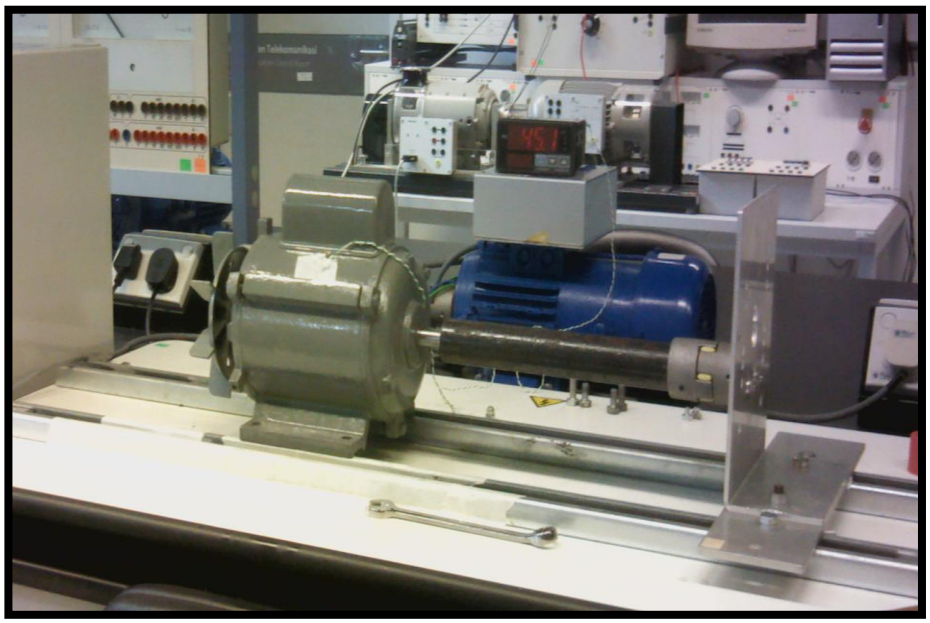
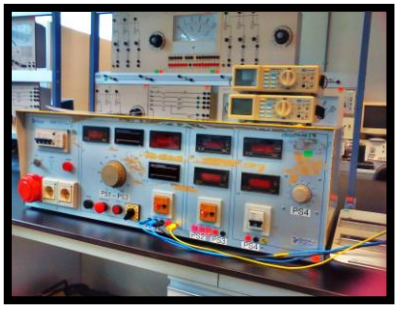
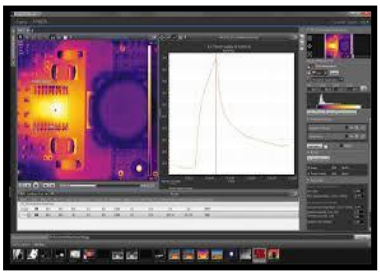


Figure 9: The Apparatus Set-up for Misalignment Testing

In this testing, the motor is added the additional shaft that connected to the shaft of motor and other end locked to the brake locker. The misalignment is created by adjusting the degree of the brake locker. The data collected will be compared with the reference and also the infrared images. Then, the graph of temperature against the time is plotted to determine the relationship of time effect to the temperature distribution under misalignment condition.

3.4 Required Tools

TOOLS	FUNCTION
Thermal Imaging (IR) Camera 	Primary tools to detect the motor failure for the testing object
Motor 	To create the fault purposely. *Specification of the motor* **Type:** Single Phase Asynchronous Motor **Nominal Volt:** 240 V **Nominal Current:** 2.5 A **RPM:** 1400rpm **Insulation Class:** F
Regulator 	To provide power supply and maintain the value of voltage and current.
FLIR 	Software used to analyze the infrared images

3.5 Project Activities

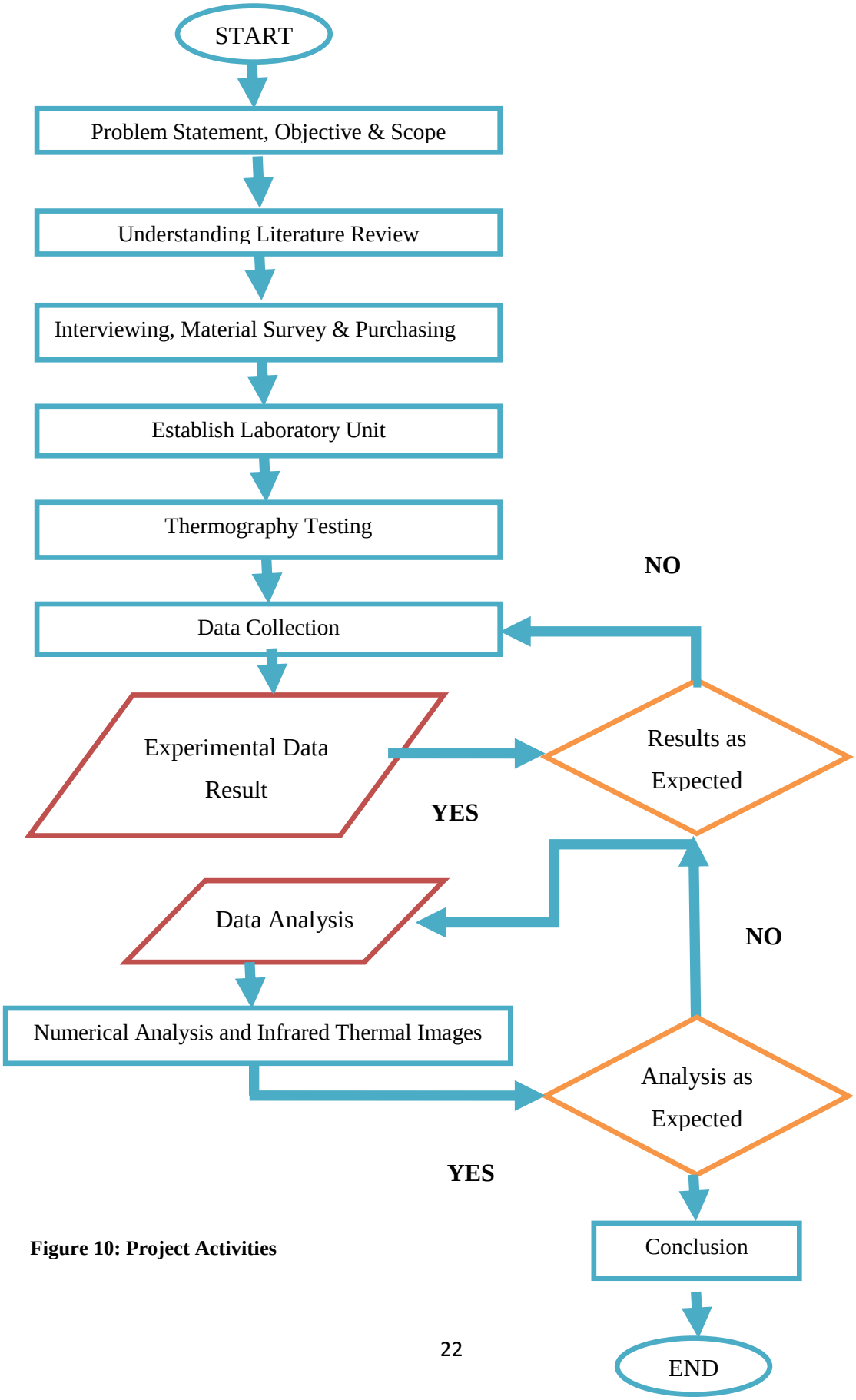


Figure 10: Project Activities

3.6 Key Milestone

Milestone is made to observe the progress updates of the activities to be completed smoothly within the time frame. Below are the key milestones for this research project must be achieved in order to meet the objective of this project.

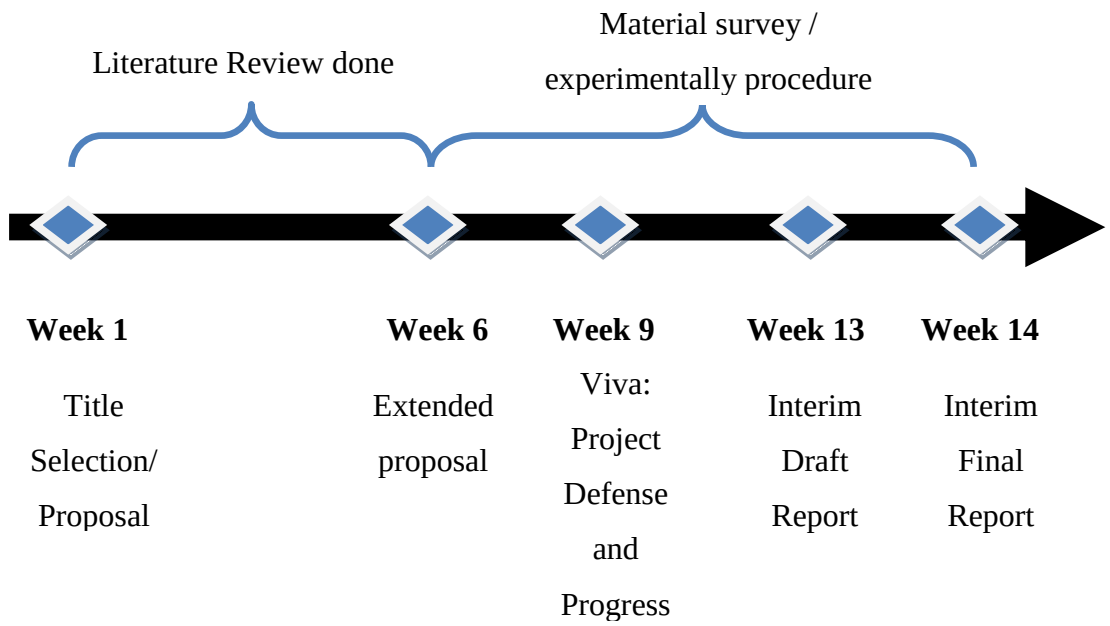


Figure 11: Key Milestone for the Final Year Project 1

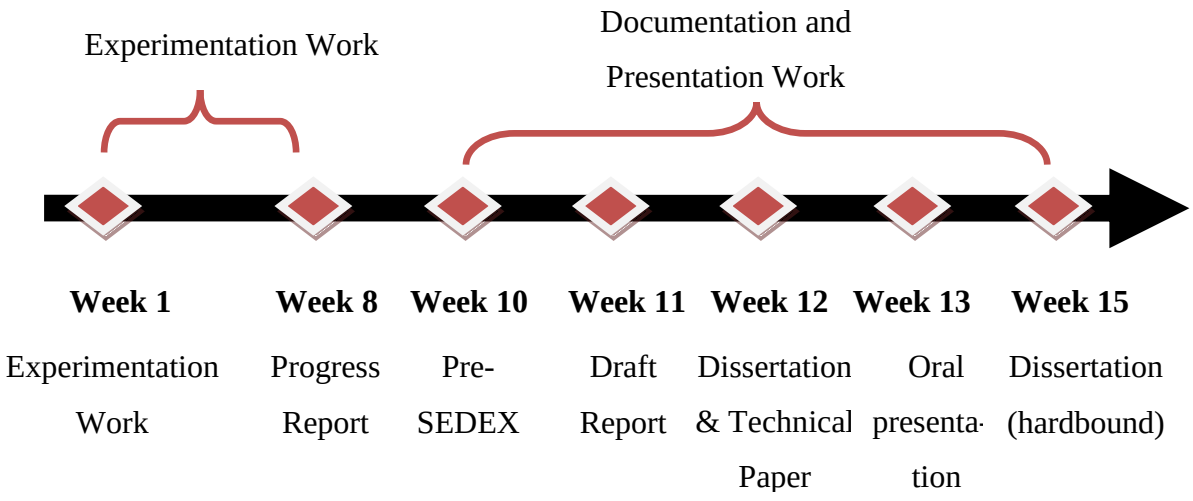


Figure 12: Key Milestone for the Final Year Project 2

3.7 Gantt Chart

FINAL YEAR PROJECT I (FYP-I)															
NO.	**DETAILS OF WORK**	**WEEK**													
		1	2	3	4	5	6	7	**MID SEM BREAK**	8	9	10	11	12	13	14
1	**Selection of Project Title**	■	■													
2	**Preliminary Research Work and Literature Review**		■	■	■	■										
3	**Submission of Extended Proposal Defense**						●									
4	**Preparation for Oral Proposal Defense**							■								
5	**Oral Proposal Defense Presentation**									■						
6	**Detailed Literature Review**									■	■	■	■	■		
7	**Preparation of Interim Report**			■	■	■	■	■		■	■	■	■	■		
8	**Submission of Interim Draft Report**														●	
9	**Submission of Interim Final Report**															●

● Suggested milestone ■ Process

Figure 13: Gantt Chart of Project (FYP 1)

FINAL YEAR PROJECT II (FYP-II)																
NO.	**DETAILS OF WORK**	**WEEK**														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	**Commencement of Experimental Work** - Experimental set-up & procedure								**MIDSEM BREAK**								
2	**Experimental Work** - Establish Calibration of database - Thermography Test on motor failure (overload, inadequate lubrication and misalignment.																
3	**Submission of Progress Report**									●							
4	**Data Analysis** -- Ensure result to achieve project objective																
5	**Submission of Draft Report**																
6	**Submission of Dissertation & Technical Paper**																
7	**Oral Presentation**																
8	**Submission of Final Dissertation**																●

● Suggested milestone Process

Figure 14: Gantt Chart of the Project (FYP 2)

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Data Collection & Analysis

Data gathered through the experiment will be analyze and interpreted. A detailed approach must be done to analyze data accurately. In this experiment there are two sources of data which are IR image and thermocouple value. Figure below show the step of the IR image to be analyzed.

The IR image capture will show the temperature distribution as well as the location of the fault. The analysis can be done by interpreting the temperature distribution that would lead to failure of the motor.

4.2 Experiment Results

From the data gathering through the experiment, there are three graphs were made to investigate the temperature distribution with the time. All the data gathered were tabulated and plotted in graph. There are several assumption were made for the entire experiment.

1. Reflection correlation is made to avoid the distraction to the surface temperature.
2. The emissivity is determined and set to be constant for entire experiment with the value of 0.97.
3. The effect of ambient temperature is negligible.

A. No-Load Testing

Table 5: No- Load Data Result

Time (min)	Surface Temperature (^{O}C)		Different in Temperature (^{o}C)
	IR Camera	Thermocouple	
0	22.7	23.4	0.7
30	30.1	29.8	0.3
60	32.5	30.6	1.9
90	33.2	31.0	2.2
120	33.3	31.1	2.2
150	33.3	31.1	2.2
180	33.4	31.1	2.3

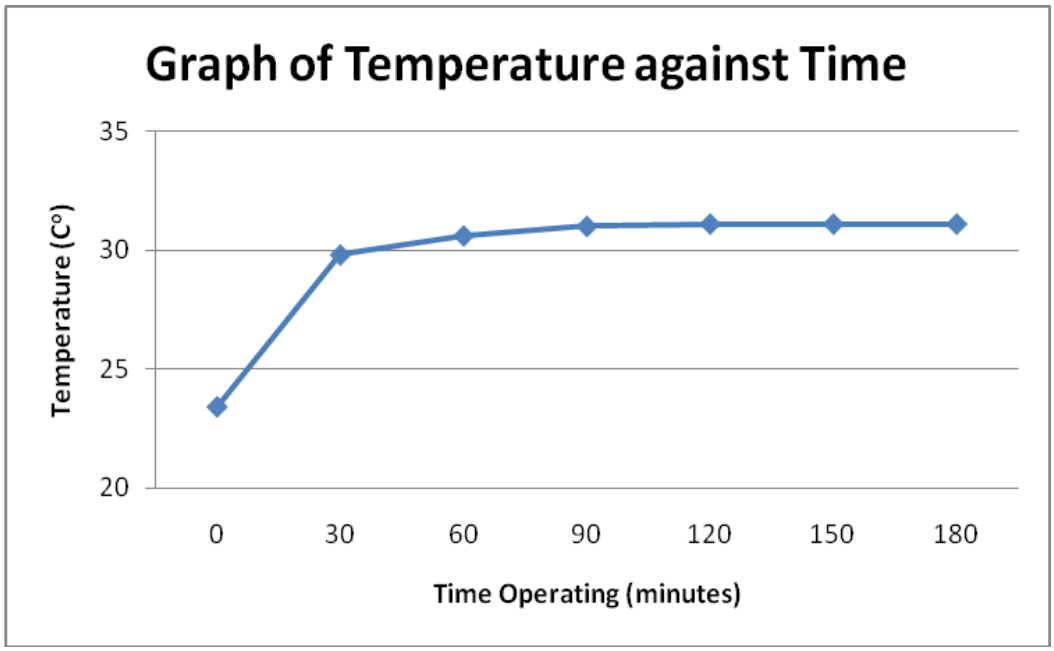


Figure 15: Graph of Temperature against Time

The figure 15 shows, the motor run with consistent temperature about 31^{o}C. It determines the temperature of the working temperature or the normal operating temperature of the motor. The graph will be used as reference temperature and compare with the temperature of the motor during fault. From this graph, the delta T or difference change of temperature can be determined by comparing with the temperature of overload fault and misalignment fault [4].

B. Overload Testing

Table 6: Overload Testing Data Result

Time (min)	Surface Temperature (^{O}C)		Different in Temperature (^{o}C)
	IR Camera	Thermocouple	
0	27.7	27.4	0.3
5	47.8	46.2	1.6
10	52.5	51.5	1.0
15	56.1	54.4	1.7
20	59.1	57.2	1.9
25	62.3	60.4	1.9
30	62.6	61.2	1.4

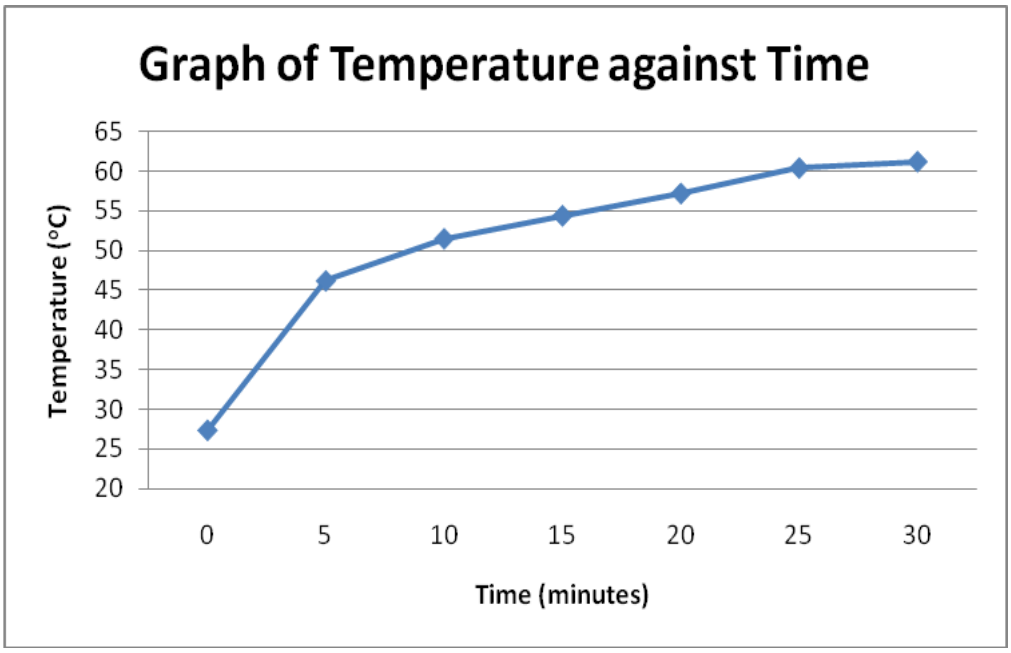


Figure 16: Graph of Temperature against Time under Overload Condition

C. Misalignment Testing

Table 7: Misalignment Data Result Figure

Degree (^{o})	Time (interval)	Surface Temperature (^{O}C)		Different in Temperature (^{o}C)	Different of temperature for each degree (^{o}C)
		IR Camera	Thermocouple		
0	1	24.7	24.6	0.1	3.2
	2	26.5	25.8	0.7	
	3	28.4	27.8	1.0	
5	1	30.8	29.4	1.4	8.1
	2	33.2	31.9	1.3	
	3	38.6	37.5	1.1	
10	1	41.8	40.7	1.1	10.6
	2	44.5	42.9	1.6	
	3	52.7	51.3	1.4	
15	1	54.8	53.7	1.1	12.7
	2	59.8	58.8	1.0	
	3	67.8	66.4	1.4	

The table 7 shows the data for the misalignment test, the degree of the angular misalignment is varies from align position to 15 degree. The temperature is recorded and the graph of temperature against time interval of 5 minutes is plotted. The table also

show the different of temperature for every 15 minutes time interval is increased as the degree of angular misalignment is bigger.

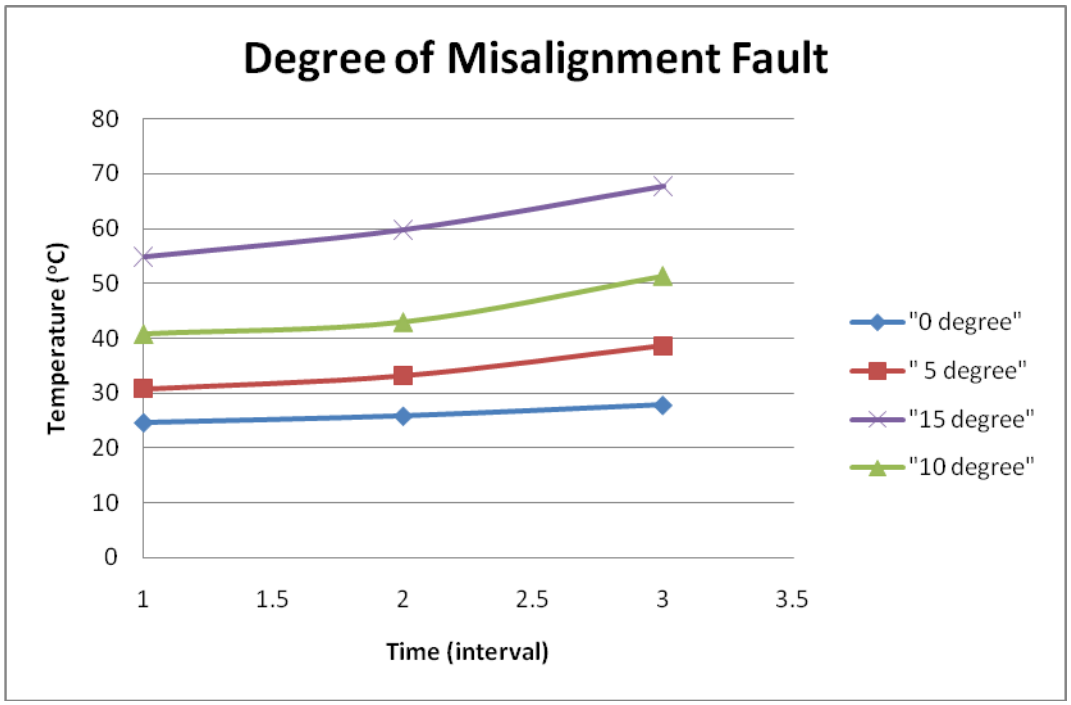


Figure 17: Temperature affected by the Degree of Misalignment Fault

The figure 17 shows, the temperature of the motor depending on the degree of the angular misalignment under the time interval. From the graph, the line represent the angular misalignment at 15 degree has experience the highest different change in temperature compare to the others degree of angular misalignment. It can be determined by analyze the slope of the line graph. From all of the lines, the highest value of the slope is temperature different on the misalignment at 15 degree. Thus, it can be concluded, the higher the degree of the misalignment, the bigger the temperature increased from the first time interval to the third time interval.

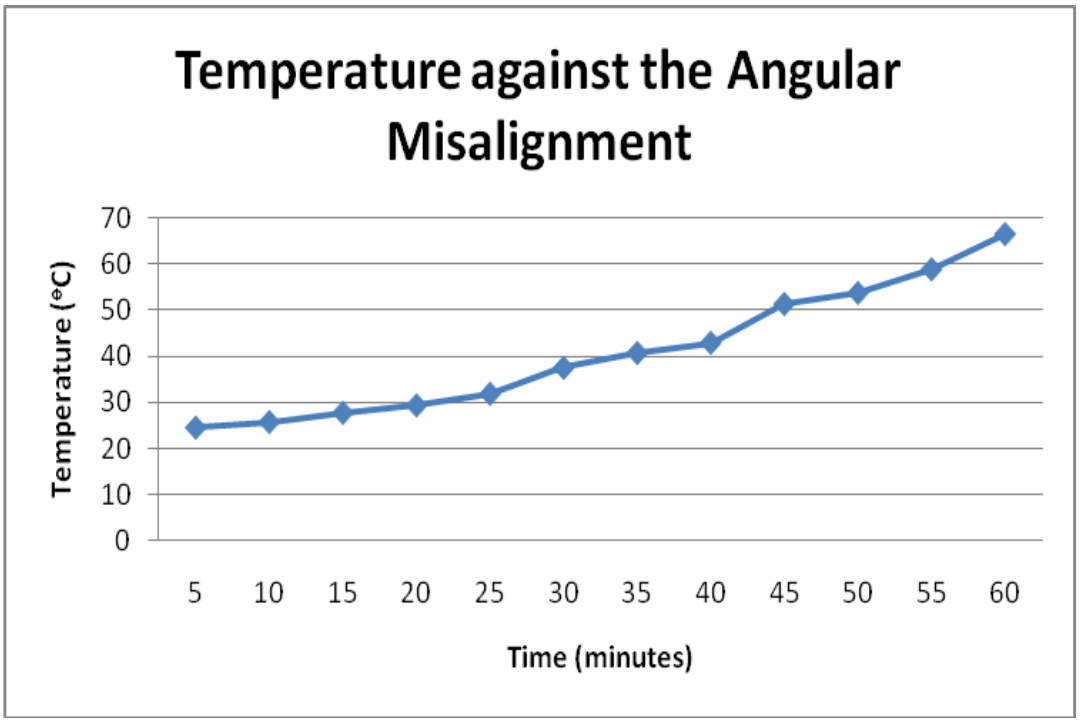


Figure 18: Graph of Temperature against the Angular Misalignment

The figure 18 above is from the previous data graph that shows the entire angular misalignment fault at every degree. The angular misalignment is increased for every 15 minutes and the reading is taken for every 5 minutes. From the result gather and the discussion, as the misalignment developed, it will cause the increasing in friction and hence, the temperature increased.

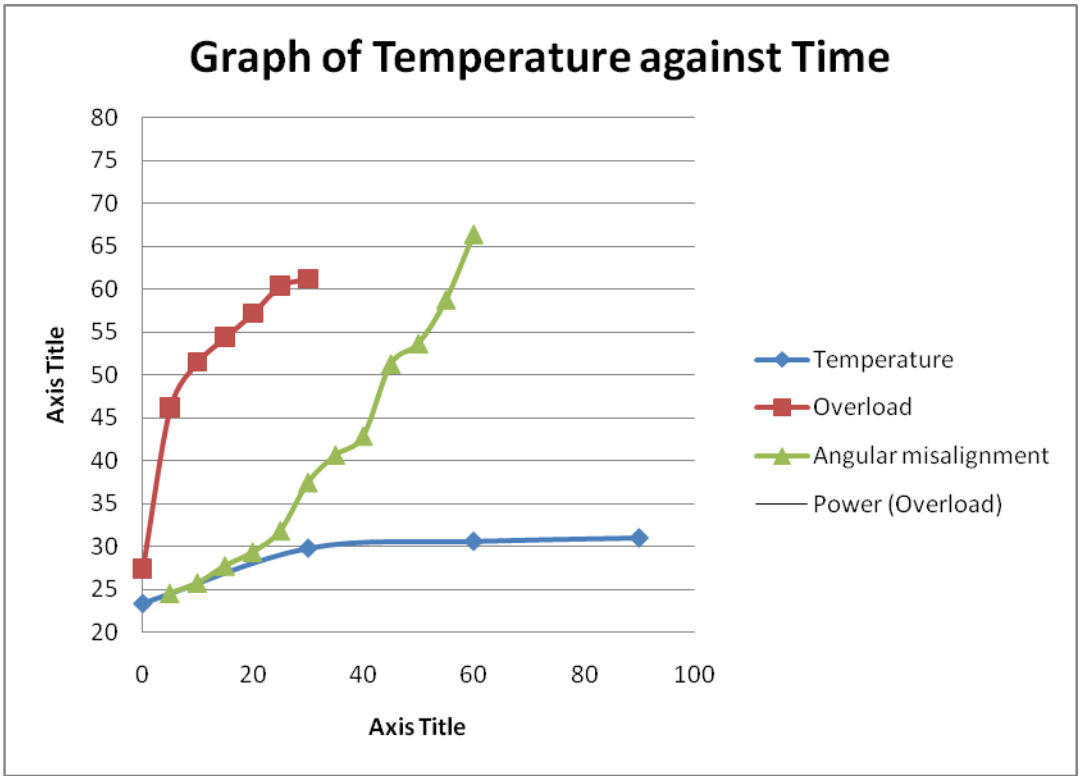


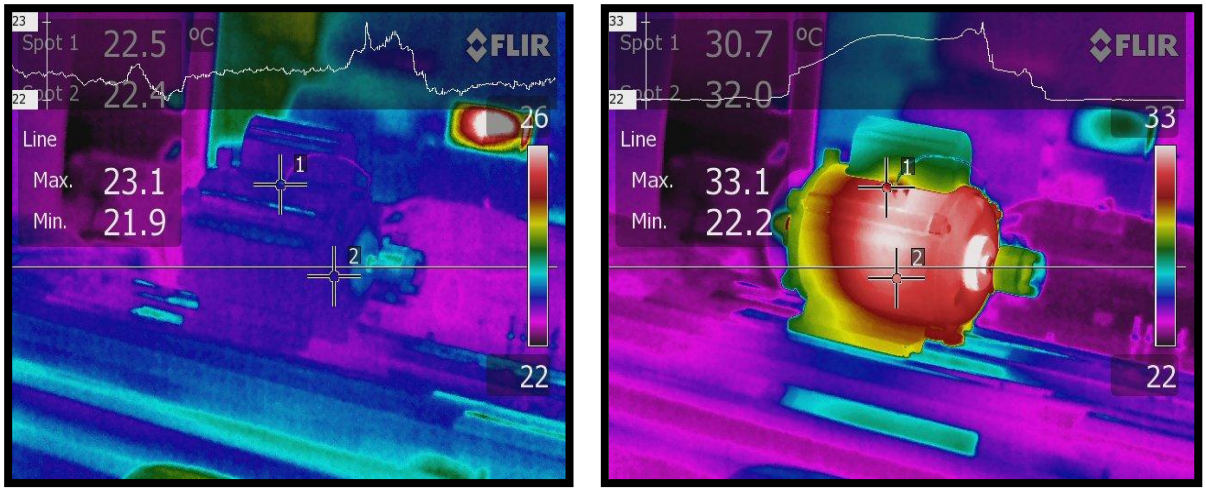
Figure 19: Comparison of Temperature of Motor between the Normal Condition and under Abnormally

From the data and analysis made, both faults which are the overload and misalignment had show the expected result as the temperature is increased when the fault occur on the motor. The figure 19 above shows the comparison between the temperature under overload and angular misalignment condition with the reference temperature or known as working temperature. From the graph, it can be interpreted; the motor is subjected to the friction force due to the faults created and affect the temperature of the motor.

4.3 Infrared Image Analysis

The purpose of infrared image in this project is to interpret the condition of the motor by comparing the surface temperature to the reference image. The infrared image emphasis the effect of the temperature when the object is subjected the fault created. This technique is known as qualitative temperature measurement system. The infrared image is used to compare the ΔT of the equipment between the "no-load" conditions and when experience the faults.

4.3.1 No-Load Condition.



(a) (b)

Figure 20: The IR Images under Normal Operating Condition,

a) The Temperature of Motor at the First minutes of Operating, b) The Temperature of the Motor after 3 hours of Operating.

Figure 20 shows the motor operating under normal condition. From the IR images it can be interpreted that, the color of infrared image represent the temperature distribution of the motor and determine the condition of the object.

Different colors of the infrared represent different thermal distribution. The figure 25a shows the temperature when the motor start operating while the figure 25b shows the condition of the motor after three hours operating. The condition of the motor is justified by the value of ΔT, by comparing the temperature difference between spot 1 and 2. The value of Δ T is based on the standard from International Electrical Testing Association. Based on the motor above, the value of Δ T is determined as below:

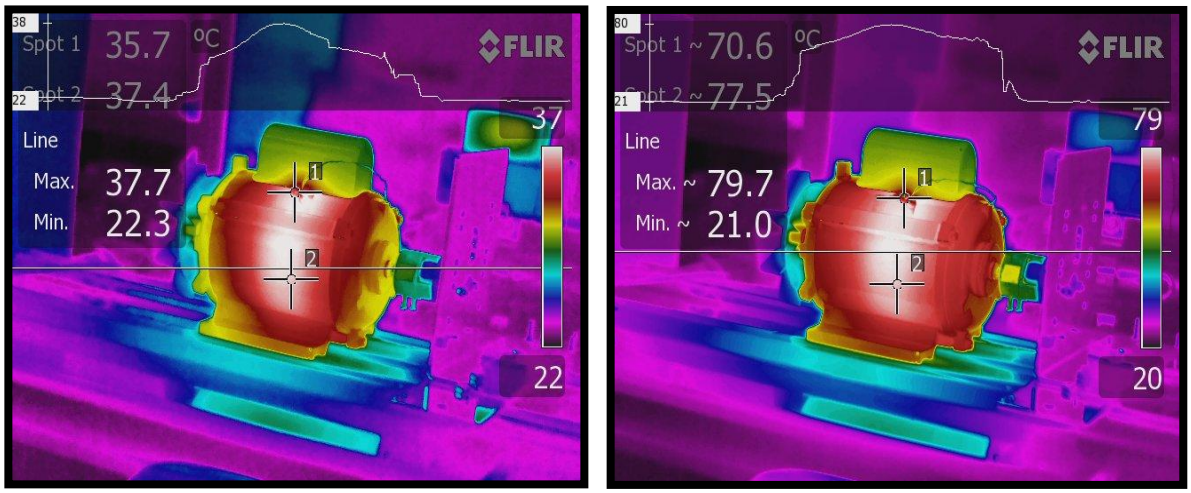
$\Delta T = T_2 - T_1$

$= 32.0^{o}C - 30.7^{o}C$

$= \mathbf{1.3^{o}C}$

According to the standard provided by NETA in Table 1, the value of Δ T is justified as the normal since the value of Δ T is less than 10 which is $1.3^{o}C$.

4.3.2 Overload Condition



(a) (b)

Figure 21: The IR Image under Overload Condition

a) The Temperature of the Motor at the First minutes of Operation, b) The temperature of Motor after two hours under overload condition.

The Figure 21 shows the IR image under overload Condition. The temperature increased from 35.7 to the 70.6 within 30 minutes. To determine the condition of the motor, the value of Δ T is calculated.

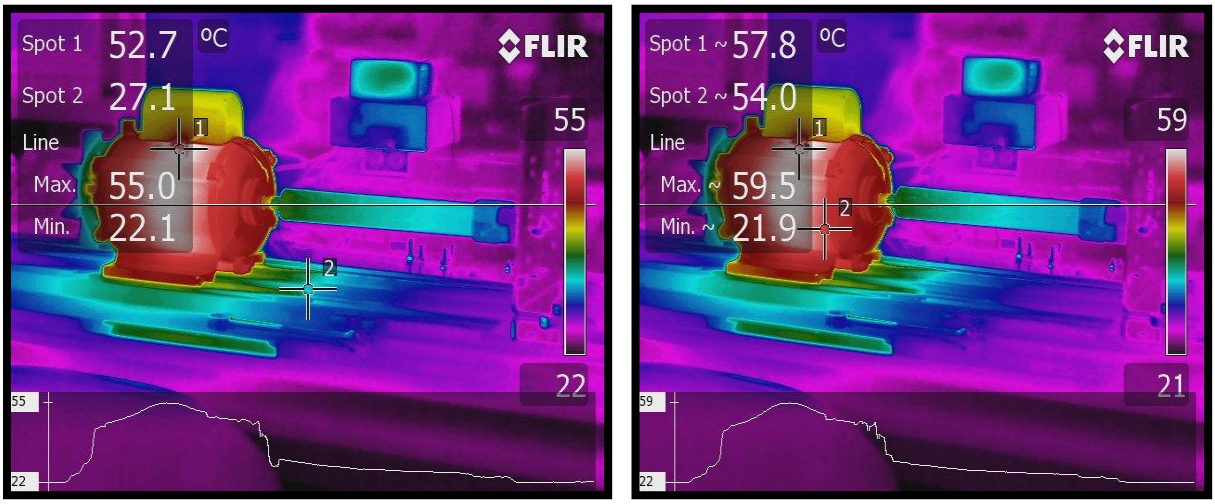
$\Delta T = T_2 - T_1$

$= 77.6^oC - 70.6^oC$

$= \mathbf{7.0^oC}$

Based on the standard of NETA, the motor is in the phase of possible deficiency as the value of Δ T is less than 10.

4.3.3 Misalignment Condition



(a) (b)

Figure 22: The IR Images under Misalignment Condition

The Temperature of the Motor at the early stages of Operation, b) The Temperature of motor after an hour.

The figure 22 shows the IR image under misalignment condition, the temperature increased throughout the testing. To determine the condition of the motor, the value of t he Δ T is calculated.

$\Delta T = T_2 - T_1$

$= 57.8^oC - 54.0^oC$

$= \mathbf{3.8^oC}$

Based on the standard of NETA, the motor is in the phase of possible deficiency as the value of Δ T is less than 10.

From the data analysis, the qualitative approach is relevant and can be used to validate the condition of the motors. These testing should be hold for a long time until failure, so the maximum Δ T is determined. In brief, the temperature can be a key parameter to detect the fault of the equipments.

4.4 Motor Failure

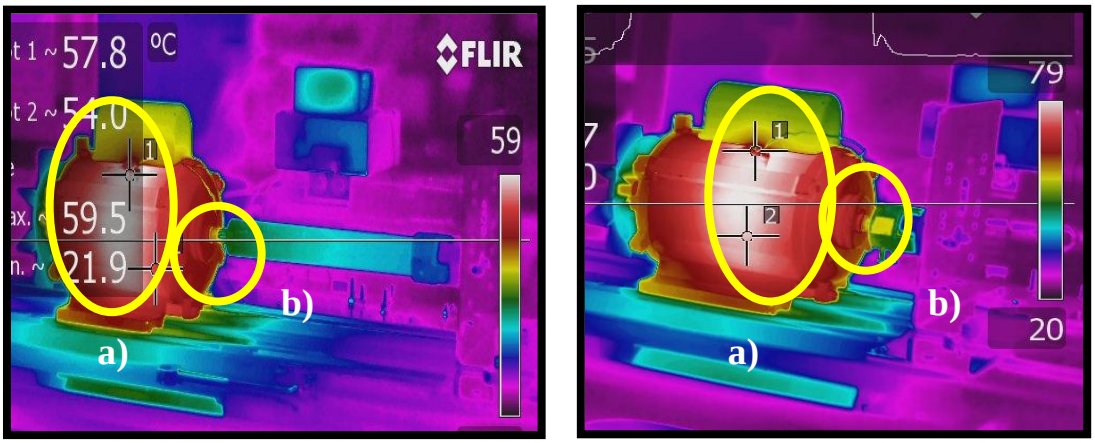


Figure 23: IR Images subjected to Bearing and Winding Possible Failure

From the figure 23, the misalignment and overload condition show the possibility to lead to the bearing and winding. The circle a) represents the potential failure at stator winding. From the both images, the highest temperature is captured around the winding area. This situation interpreted the deterioration in thermal happen when the motor is subjected on the misalignment and overload. The circle b) represents the potential failure of bearing. The bearing experience the increasing in temperature due to the friction produced from misalignment and overload condition. In brief, the friction created, affect the deterioration of thermal stress and finally lead to the failure of the motor.

CHAPTER 5: CONCLUSION & RECOMMENDATION

5.1 Conclusion

Throughout the result of testing, calculation and analysis, the infrared thermography is justified to be used as fault diagnosis of rotating equipment. Thus, the first objective is achieved. As conclusion, the temperature can be one of the parameter to be used in fault diagnosis.

However, for the second objective to establish the calibration process for motor failures, the progress only cover the 50 percent of the work due to the limitation of the time and wrong approach used. Thus, some recommendations are proposed for the way forward.

5.2 Recommendation

From this project, there are three recommendations to improve the quality of the IRT inspection.

1. A several improvement on the parameter of the procedures needs to be taken into the account for the accurate results obtained. For example the external effect that may affect the temperature reading such as the humidity and the wind speed.

2. From the result gathered, the failure of motor can be detected. However, it is better improvement if the IR camera can detect the failure just based on the location of the hot spot. Thus, it needs extensive studies.

3. The IRT is used to compare the difference temperature or delta T of the similar equipment. The diagnosis is just depends on the prediction of hot spot at full load and then, the fault is determined. The new method is needed to be explored in order to predict the reliability of the equipment. These are the good combination in the maintenance of the equipments.

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