



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**STUDY ON THERMAL GROWTH EFFECT ON MACHINERY  
ALIGNMENT**

This report submitted in accordance with requirement of the Universiti Teknikal  
Malaysia Melaka (UTEM) for the Bachelor Degree of Manufacturing Engineering  
(Manufacturing Process) with Honours

By

**SAFUL BAHARI BIN HAMZAH**

**FACULTY OF MANUFACTURING ENGINEERING**

**2009**



## UNIVERSITI TEKNIKAL MALAYSIA MELAKA

### BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK:

"STUDENT ON THERMAL GROWTH EFFECT ON MACHINERY ALIGNMENT"

SESI PENGAJIAN:

2008/2009 Semester 2

Saya SAIFUL BAHARI BIN HAMZAH

mengaku membenarkan laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM / tesis adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM / tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. \*Sila tandakan (✓)

SULIT

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TIDAK TERHAD

\_\_\_\_\_  
LOT 1860, JALAN BARU,  
KG WAKAF LANAS,  
16800 PASIR PUTEH,  
KELANTAN

\_\_\_\_\_  
Cop Rasmi:

Tarikh: \_\_\_\_\_

Tarikh: \_\_\_\_\_

\* Jika laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak organisasi berkenaan dengan menyatakan sekali sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

## DECLARATION

I hereby, declared this report entitled “Study on thermal growth effect on machinery alignment” is the results of my own research except as cited in references.

Signature : .....

Author’s Name : SAIFUL BAHARI BIN HAMZAH

Date : 10 APRIL 2009

## **APPROVAL**

This report is submitted to the Faculty of Manufacturing Engineering of UTEM as partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) with Honours. The members of the supervisory committee are as follow:

.....  
(En Mohd Shahir Kasim)  
(Official Stamp of Supervisor)

## **ABSTRACT**

Shaft alignment is a technical skill that requires expensive measurement instrument and calculation capabilities. Shaft alignment is very important to maximize equipment reliability and longer life span, because misalignment introduces a high level of vibration by moving part creates friction that built up heat causing the machinery housing to expand and need for frequently repair. This expansion called thermal growth factor. By neglecting the thermal growth factor, alignment process will be simpler but unsatisfactory result will be introduced and for short time misalignment symptom will appear. This show that the relationship thermal growth with shaft alignment very closely. For observation, the value of vibration data was used based on machine classes by compared ISO 2372 standard. From the vibration severity, can knowing the machine “healthy” .Any different indicated before and after thermal growth factor was taken. In shaft alignment technique, reverse dial indicator method was used by solving using two type of technique, graphical modeling solving and mathematical solving.

## **ABSTRAK**

Penjajaran aci merupakan teknik yang memerlukan alat ukuran yang mahal dan kemampuan dalam pengiraan. Penjajaran aci adalah sangat penting untuk memaksimumkan kegunaannya dan jangka hayat, ini kerana ketidak jajaran memberikan kadar getaran yang tinggi dengan menjadikan pergeseran yang berlaku menghasilkan hawa panas menyebabkan perumahan mesin mengembang dan memerlukan pembaikan yang kerap kali. Perkembangan ini dipanggil faktor “thermal growth”. Dengan mengabaikan faktor “thermal growth”, proses penjajaran akan lebih mudah tetapi menghasilkan keputusan yang tidak tepat dan dalam jangka masa pendek gejala ketidak jajaran akan muncul. Ini menunjukkan ada hubungan yang rapat diantara peningkatan suhu dan penjajaran aci. Sebagai pemerhatian, nilai getaran yang digunakan adalah berdasarkan kelas mesin dengan membandingkan piawai ISO 23/72. Daripada ketegasan gataran ia menunjukkan “kesihatan” mesin . Sebarang perubahan yang muncul sebelum dan selepas faktor peningkatan suhu dicatatkan. Dalam teknik penjajaran aci, kaedah “Reverse Dial Indicator” telah digunakan bagi penyelesaian dengan menggunakan dua teknik iaitu penyelesaian model graf dan penyelesaian matematik.

## **DEDICATION**

*Specially dedicated for my beloved father, my mother, and who are very concerns, understanding patient and supporting. Thank you for everything to my supervisor Mr. Mohd Shahir Bin Kasim. The work and success will never be achieved without all of you.*

## ACKNOWLEDGEMENT

In the name of ALLAH, The Most Gracious and The Most Merciful. Alhamdulillah, praise to ALLAH S.W.T that with His Blessing, had given me great patient and perseverance to complete this project paper successfully.

My heartfelt thanks and gratitude to my beloved advisor, Mr. Mohd Shahir Bin Kasim for all the exceptional assistance guidance and advice given throughout the preparation of this project paper. His undivided support and patient are greatly appreciated and remembered.

A warm gratitude is also dedicated to my family and friend who had given their help and support in making this project paper success. I also would like to convey my biggest thanks to all FKP technicians for supporting me throughout my project Thank you so much and may ALLAH S.W.T bless you all. Wasslam



# TABLE OF CONTENT

	<b>Page</b>
Declaration	iv
Approval	v
Abstract	vi
Abstrak	vii
Dedication	viii
Acknowledgement	ix
Table of Content	x
List of Table	xv
List of Figure	xvi
List of Equation	xix
List of Abbreviations	xx
<b>1.0 INTRODUCTION</b>	<b>1</b>
1.1 Background of Study	1
1.2 Problem Statement	6
1.3 Objective of the Research	7
1.4 Scope of Study	7
1.5 Structure of Study	8
1.5.1 Chapter 1: Introduction	8
1.5.2 Chapter 2: Literature Review	8
1.5.3 Chapter 3: Methodology	8
1.5.4 Chapter 4: Result and Analysis	9
1.5.5 Chapter 5: Discussion	9
1.5.6 Chapter 6: Conclusion and Recommendation	9

	<b>Page</b>
<b>2.0 LITERATURE REVIEW</b>	<b>12</b>
2.1 Introduction of Alignment	12
2.1.1 Type of Alignment	13
2.1.2 Misalignment Deviation	14
2.1.3 To Find the Maximum Misalignment Deviation or Alignment Tolerance	15
2.1.4 Eight Basics to Align Machinery	17
2.1.5 Alignment Technique	18
2.2 Introduction of Vibration	20
2.2.1 What is Vibration	20
2.2.2 Time Period Sample	21
2.2.3 How Vibration Is Measured	23
2.2.3.1 Type of Force That Occur On Rotating Machinery	24
2.2.4 Transducer Selection	25
2.2.4.1 Velocity Transducer	26
2.2.5 Using Vibration Analysis to Detect Misalignment	27
2.2.6 Limit and Standard of Vibration	28
2.2.6.1 ISO 2372 Standard	28
2.3 Introduction of Thermal Growth	29
2.3.1 Thermal Compensation Target	30
<b>3.0 METHODOLOGY</b>	<b>32</b>
3.1 Objective of the Case Study Define	32
3.2 Equipment and Tool	33
3.2.1 Dial indicator	33
3.2.2 Mounting Hardware	33
3.2.3 Shim	34
3.2.4 Digital Vibration Detector	34
3.2.5 Alignment Machine Model	35
3.2.6 Infrared Thermometer	36

	<b>Page</b>
3.2.7 Digital Height Gauge	37
3.3 Flow Chart for Alignment Process	38
3.3.1 Flow Chart for Reverse Dial Indicator Alignment Process	39
3.4 Method of Alignment	40
3.4.1 Safety	40
3.4.2 Clean Up	40
3.4.3 Rough Soft Foot Correction	41
3.4.3.1 Measuring the Gap Condition around All of the Foot Bolt	41
3.4.3.2 Correcting the 'Soft Foot' Problem and Verifying to Eliminate	42
3.4.4 Correcting Indicator Sag	43
3.4.5 Rough Alignment	44
3.5 Vibration Data Collecting	46
3.5.1 Flow Chart for Generate Data	46
3.6 Alignment Technique	50
3.6.1 Reverse Dial indicator Method	50
3.6.2: Validity Rule	54
3.6.3 Tolerance of Alignment	54
3.6.4 Compensation Thermal Growth	55
3.6.5 Determining Correction or Amount of Shim	56
3.6.5.1 Vertical Movement	56
3.6.5.2 Horizontal Movement	57
3.7 Graphing and Modeling Alignment Techniques	58

	<b>Page</b>
<b>4.0 RESULT AND ANALYSIS</b>	<b>61</b>
4.1 Soft Foot and Runout Value for Rough Alignment	61
4.2 Calculation Technique	62
4.2.1 Total Indicator Reading (TIR) Calculation	63
4.2.2 Vertical Movement	64
4.2.3 Horizontal Movement	65
4.3 Graphical and Modeling Alignment Technique	69
4.3.1 Side View	69
4.3.2 Top View	70
4.4 Results for Height and Vibration	71
4.4.1 Result for Temperature 3 Constant Whereas Temperature Bearing 4 Was Variable Temperature	71
4.4.2 Result for Temperature 4 Constant Whereas Temperature Bearing 3 Was Variable Temperature	80
<b>5.0 DISCUSSION</b>	<b>89</b>
5.1 Graphical and Modeling Technique with Thermal Growth	89
5.2 Energy Cost Saving and Labor Cost	92
5.3 Coupling Effect	93
5.4 Self Aligning Bearing	94
5.5 Motor Speed Effect	95
5.6 Reverse Dial Indicator Disadvantages	96

	<b>Page</b>
<b>6.0 CONCLUSION AND RECOMMENDATION</b>	<b>97</b>
6.1 Conclusion	97
6.2 Recommendation	98
<b>REFERENCES</b>	<b>100</b>
<b>APPENDICES</b>	<b>104</b>
Appendix 1	105
Appendix 2	107
Appendix 3	109
Appendix 4	111
Appendix 5	113
Appendix 6	115

# LIST OF TABLE

	<b>Page</b>
Table 1.1: Planning chart for PSM 1	10
Table 1.2: Planning chart for PSM 2	11
Table 2.1: Finding the maximum misalignment deviation.	16
Table 2.2: Common time period in second by machine speed.	22
Table 2.3: The common $F_{\max}$ setting for 1600 lines of resolution by machine.	22
Table 2.4: ISO 2372 Guidelines for machinery vibration severity and machine classes.	28
Table 2.5: Growth factor (mil/in/ <sup>0</sup> F) for common material.	31
Table 3.1: Specification of digital vibration.	35
Table 3.2: Motor specification.	35
Table 3.3: Infrared thermometer specification	36
Table 3.4: Acceptable radial runout limit	44
Table 3.5: Infrared radiation indicator	49
Table 3.6: Residual misalignment tolerance.	55
Table 4.1: Average of height and average vertical vibration bearing 3	72
Table 4.2: Average of height and average vertical vibration bearing 4	73
Table 4.3: Average of height and average horizontal vibration bearing 3	75
Table 4.4: Average of height and average horizontal vibration bearing 4	76
Table 4.5: Average of height and average axial vibration bearing 3	77
Table 4.6: Average of height and average axial vibration bearing 4	78
Table 4.7: Average of height and average vertical vibration bearing 4	81
Table 4.8: Average of height and average vertical vibration bearing 3	82
Table 4.9: Average of height and average horizontal vibration bearing 4	83
Table 4.10: Average of height and average horizontal vibration bearing 3	84
Table 4.11: Average of height and average axial vibration bearing 4	86
Table 4.12: Average of height and average axial vibration bearing 3	87

# LIST OF FIGURE

	<b>Page</b>
Figure 1.1: Misalignment condition	3
Figure 1.2: Angular mismatch	4
Figure 1.3: Parallel misalignment	4
Figure 1.4: Combined angular and parallel misalignment	5
Figure 1.5: Reverse dial indicator fixture and mounting	5
Figure 2.1: Misalignment type	14
Figure 2.2: Reverse rim dial method	19
Figure 2.3: Time waveform	21
Figure 2.4: Vibration amplitude	23
Figure 2.5: Vibration amplitude is expressed in four different ways: peak to peak, peak,RMS (Root mean squared), and average.	23
Figure2.6: Vibration frequency	24
Figure 2.7: Static force	25
Figure 2.8: Dynamic force	25
Figure 2.9: Frequency versus response amplitude for various sensor types	26
Figure 2.10: Plot of sensitivity versus transducer	26
Figure 3.1: Dial indictor.	33
Figure 3.2: Shim	34
Figure 3.3: Digital vibration	34
Figure 3.4: Alignment machine model	35
Figure 3.5: Infrared thermometer	36
Figure 3.6: Digital height gauge	37
Figure 3.7: Measurement gap using feeler gauge	41
Figure 3.8: Special wedges for correction	42
Figure 3.9: Checking foot point	42

	<b>Page</b>
Figure 3.10: Indicator Sag	43
Figure 3.11: Correction indicator sag.	43
Figure 3.12: Position of dial indicator for runout measurement	44
Figure 3.13: Calibrated eyeball	45
Figure 3.14: Straightedge method	45
Figure 3.15: Taper and feeler gauge method	45
Figure 3.16: Position of bearing number	47
Figure 3.17: Direction of vibration collecting data	48
Figure 3.18: Alignment machine model with reverse indicator method.	50
Figure 3.19: Reverse indicator method	51
Figure 3.20: Dial Indicator reading	51
Figure 3.21: Machine layout for alignment calculator	52
Figure 3.22: The validity rule	54
Figure 3.23: Graph preparation for alignment	59
Figure 3.24: Solution for vertical alignment.	59
Figure 3.25: Solution for horizontal alignment	60
Figure 4.1: Position of distance D1, D2 and D3	62
Figure 4.2: Correction direction for vertical movement	64
Figure 4.3: Correction direction for horizontal movement	65
Figure 4.4: Side view graphical technique correction	69
Figure 4.4: Top view graphical technique correction	70
Figure 4.5: Graph average vertical direction against temperature at bearing 3	72
Figure 4.6: Graph average vertical direction against temperature at bearing 4	73
Figure 4.7: Graph average horizontal direction against temperature at bearing 3	74
Figure 4.8: Graph average horizontal direction against temperature at bearing 4	75
Figure 4.9: Graph average axial direction against temperature at bearing 3	77
Figure 4.10: Graph average axial direction against temperature at bearing 4	78
Figure 4.11: Graph average vertical direction against temperature at bearing 4	80
Figure 4.12: Graph average vertical direction against temperature at bearing 3	81



	<b>Page</b>
Figure 4.13: Graph average horizontal direction against temperature at bearing 4	83
Figure 4.14: Graph average horizontal direction against temperature at bearing 3	84
Figure 4.15: Graph average axial direction against temperature at bearing 4	85
Figure 4.16: Graph average axial direction against temperature at bearing 3	86
Figure 5.1: Graphical technique	89
Figure 5.2: Position of shaft when temperature increased	91
Figure 5.3: Flexible coupling	93
Figure 5.4: External self aligning bearing in pillow block mounting	94
Figure 5.5: External self aligning	95
Figure 5.6: External self aligning bearing with own center	95
Figure 6.1: Rigid coupling	99
Figure 6.2: Laser alignment	99

# LIST OF EQUATIONS

	<b>Page</b>
Equation 1: Misalignment deviation	17
Equation 2: Relationship frequency and time	21
Equation 3: Total sample period	21
Equation 4: $F_{\max}$ setting	22
Equation 5: Thermal growth expansion	30
Equation 6: Vertical move at near foot (NF)	56
Equation 7: Vertical move at far foot (FF)	56
Equation 8: Horizontal move at near foot (NF)	57
Equation 9: Horizontal move at far foot (FF)	57
Equation 10: Linear equation for average height axial direction	79
Equation 11: Linear equation for average height axial direction	88

## LIST OF ABBREVIATIONS

CPM	–	Cycle per minutes
FF	–	Far Foot
HA	–	Horizontal Angularity
HO	–	Horizontal Offset
Hz	–	Hertz
MTBF	–	Mean Time before Failure
MTBM	–	Machine to be moved
MTBS	–	Machine to be shim
NF	–	Near Foot
RMS	–	Root Mean Square
RPM	–	Revolution per minutes
TIR <sub>HM</sub>	–	Total Indicator Reading on Horizontal Moveable
TIR <sub>HS</sub>	–	Total Indicator Reading on Horizontal Stationery
TIR <sub>M</sub>	–	Total Indicator Reading on Moveable
TIR <sub>S</sub>	–	Total Indicator Reading on Stationery
VA	–	Vertical Angularity
VO	–	Vertical Offset

# CHAPTER 1

## INTRODUCTION

This chapter describes the background research of shaft alignment, problem statement that induce the relationship of thermal growth effect on shaft alignment, objective of study also scope of study

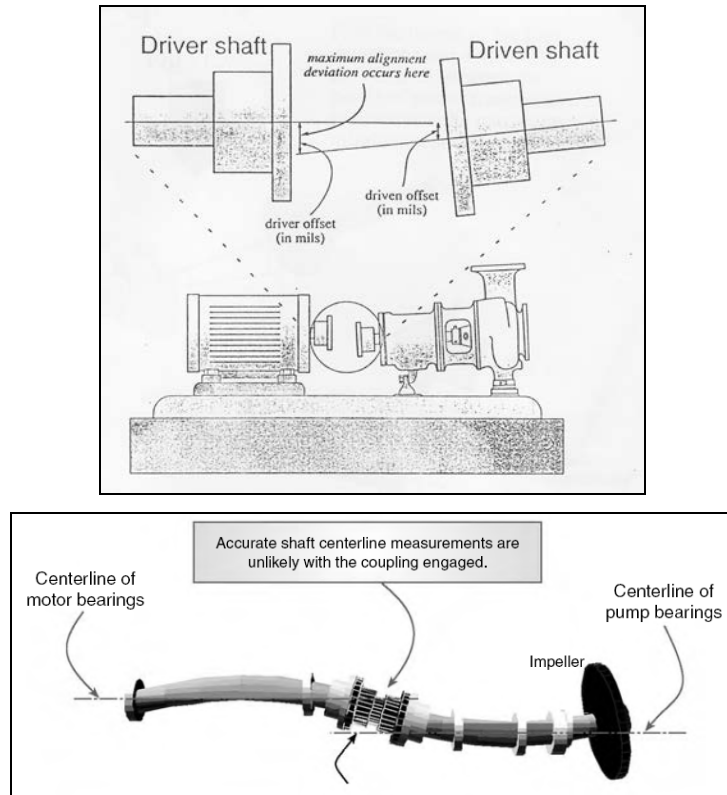
### 1.1 Background of Study

Shaft alignment is proper positioning of the shaft centerlines of the driver and driven component such pump, gearbox and airlock that make the machine drive train (Mobley.R.K, 1999). The basic alignment method are either shimming and/or moving the machine component. The objective of accurate alignment is to increase the life of rotating machine and to obtain the common axis of rotation at operating equilibrium for two shaft couple. To achieve proper alignment, machinery component commonly to fail must be operating within their design limit .It must accurately align to given result (Piotrowski.J, 2007):

- a) Reduce excessive axial and radial forces on the bearing to insure longer bearing life and rotor stability under dynamic operating condition.
- b) Eliminate the possibility of shaft failure from cyclic fatigue.
- c) Minimize amount of wear in the coupling component.

- d) Minimize amount shaft bending from the point of power transmission in the coupling to the coupling end bearing.
- e) Reduce power consumption.
- f) Lower vibration level in machine casing, bearing housing and rotor.

Shaft alignment means positioning of the rotational center of two or more shaft so stayed in collinear condition when normal operating condition. Collinear refers to the condition when rotational centerlines of two mating shaft are parallel and intersect (Moblely.R.K, 1999). Misalignment is defined when the deviation of relative shaft position from the collinear axis of rotation measured at the point of power transmission when equipment is running at normal operating condition (Piotrowski.J, 2007).Figure 1.1 below shows the condition of the two shafts when are slightly misalignment. When two shafts are subjected to misalignment condition, the coupling connecting of two shafts internally flexes together to accept the misalignment condition. The shafts rotate the internal parts of the coupling continually have to move around, bend in one direction then the other or stretch then compress. The problem that caused misalignments are cyclic fatigue of rotor component, excessive radial and axial force transmitted to bearing, shaft seal rubbing heavier at one side and mechanical seal rotating component not running concentric to stationery seal member. (Piotrowski.J, 2007).



**Figure 1.1:** Misalignment condition.

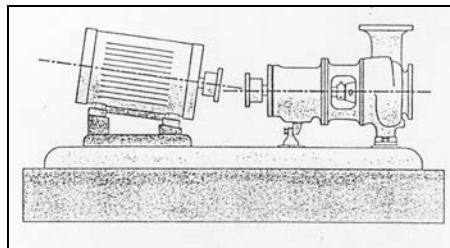
Although the machinery has been aligned properly during installation or during maintenance, misalignment still can occur in very short time potentially caused by foundation movement, accidentally bumping the machine with another equipment, thermal expansion, distortion from piping connection, loosened hold-down nut, expanded ground, rusting of shim and crack experienced at coupling, seal and bearing. The misalignment symptoms are (Piotrowski.J, 2007):

- a) Premature bearing, seal, shaft, or coupling failures.
- b) Elevated temperatures at or near the bearings or high discharge oil temperatures.
- c) Excessive amount of lubricant leakage at the bearing seals.
- d) Certain types of flexible couplings will exhibit higher than normal temperatures when running or will be hot immediately after the unit is shut down. If the coupling is an electrometric type, look for rubber powder inside the coupling shroud.
- e) Similar pieces of equipment seem to have a longer operating life.

- f) Unusually high number of coupling failures or them wears quickly. The shafts are breaking or cracking at or close to the inboard bearings or coupling hubs.
- g) Excessive amounts of grease or oil on the inside of the coupling guard.
- h) Loose foundation bolts, typically caused by a “soft foot” condition, are exacerbated by misalignment.
- i) Loose or broken coupling bolts. This is frequently due to improperly torque the coupling bolts and aggravated by a misalignment condition.

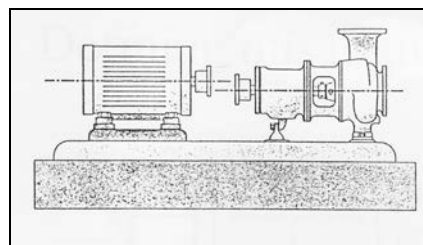
In alignment plant, has both offset and angular component covered four alignment parameter which are horizontal angularity (HA), the horizontal offset (HO), vertical angularity (VA) and vertical offset (VO). But in general misalignment problem, the common discussed are (Piotrowski.J, 2007):

- a) Angular mismatch, if centerlines of the two shafts were extended, would cross one another rather being superimposed or running along common line.



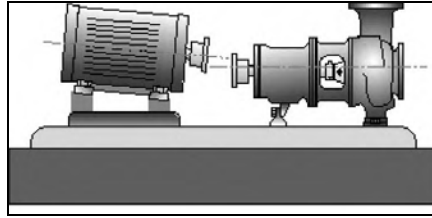
**Figure 1.2:** Angular mismatch.

- b) Parallel misalignment, which centerlines of two shafts are parallel but in the same line.



**Figure 1.3:** Parallel misalignment.

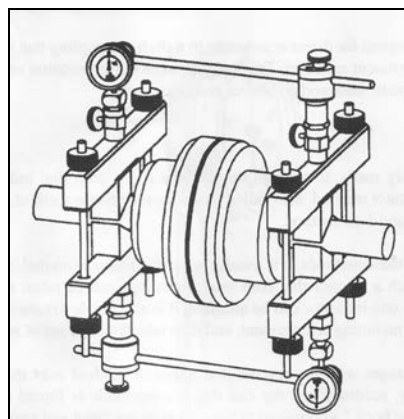
c) Combined angular and parallel misalignment



**Figure 1.4:** Combined angular and parallel misalignment.

Shaft misalignment may highly induce a thermal effect especially at shaft and bearing which causes rapid wear of machine bearing. The misalignment can be measure by the amount of offset and angularity which exists between them. The offset can be determined from the distance between the two rotational centerline either horizontal or vertical directions whereas angularity refer to angle between two centerlines.

In alignment technique, the Figure 1.5 shows reverse indicator method (also knowing as indicator-reverse method) was used to solve alignment problem. Reverse indicator method using dial gauge indicator measure offset at two points and the amount of horizontal and vertical correction for offset and angularity is calculated. (Mobley.R.K, 1999).



**Figure 1.5:** Reverse dial indicator fixture and mounting