due to uncertainty. This, in turn, has a direct impact on equipment availability and maintenance costs. Unfortunately, due to misconceptions and pressure from plant operators to get "back on line", it is still viewed as an unnecessary or expendable step in many plants today.

Alignment is a subject too vast, ranging to allow a comprehensive coverage of all of the areas associated with this field. Structural errors and machine errors often compound alignments. These defects can turn a simple job into an all day affair and also unsatisfactory results despite a conscientious effort and a considerable investment in manpower and downtime. Effects and classification of misalignments is discussed in this paper.

This paper covers Four-dial gage method, which overcome all typical reasons of unsuccessful and difficult alignments, which are observed in Thermal Power Station's Coal Handling Plants. The goal of this method is to provide the technician with the recommended approach for the quickest way with quality alignment.

2.0 Introduction: -

Rotating equipment (i.e., pumps, compressors and crushers etc.) is sensitive to the alignment to each other and to the smallest of changes due to operating conditions. Proper alignment is the largest factor in determining the life of bearings, seals and couplings. Even "flexible" couplings fail to completely absorb the additional stresses caused by misalignment. Misalignment causes these crucial components to become overloaded and break down prematurely, especially when operating at high speed. Generally using mechanical comparators i.e. dial indicators carries out the alignment in Thermal Power Station's Coal Handling Plants. Sometimes by using the feeler gages alignments are also carried out. Simple and more accurate method is use of dial gages. With different types of fixtures extended across the coupling, the shafts are rotated to several positions to determine the relative position between them. These positions are checked for radial and axial deviations. Since alignment is an iterative process (meaning that the misalignment should continuously decrease with each machine move), it is theoretically only a matter of sufficiently repeating alignment corrections until an acceptable solution is achieved. These conventional methods, such as using feeler gages and dial indicators are seems inaccurate and require a complicated, time consuming alignment process. A laser alignment system is generally proposed to overcome all these problems. In fact, quality alignment is not dependent on the type of measurement system used. Any good dial indicator set is sufficient to perform quality alignments. In contrast, the goal of alignment technique is to locate potential problems and quantify whether the problem must first be addressed in order to be able to successfully complete the alignment job.

2. Bent shaft.
3. Damage couplings or loose coupling.
4. Excessive bearing clearance or shaft rubs.
5. Uneven legs.

3.1.1 <u>Assembly or Manufacturing Error</u>: -

In a machine, alignment and load distribution are not perfect because of manufacturing error or tolerances in the housing, shaft and bearing elements. There are as follows.

- The squareness of the collar (and parallelism of the journal) to the axis of the shaft which is assembled to, or machined on the shaft.
- The alignment of shaft with the bearing and housing, which is a manufacturing tolerance stack-up of the bearing parts and the housing bores and faces.

3.1.2 <u>Bent Shaft</u>: -

The bent shaft affects alignment process by showing improper reading. The reading received violets data validity rule. The data validity rule [1] shown in following equation. This equation compares the readings taken at the four cardinal positions. See Figure No 1

Top + Bottom = Left + Right

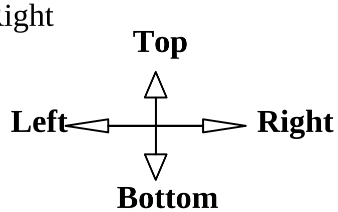

Figure No 1

3.1.3 <u>Damage or Loose Couplings</u>: -

The damage coupling affects alignment process by showing improper reading. Small deviations from the validity rule are to be expected. If the difference is more than 10%, it is possible that the coupling may be loose enough to provide excess torsional play ("backlash").

3.1.4 <u>Excessive Bearing Clearance Or Shaft Rubs</u>: -

The excessive bearing clearance allowed the shaft to move in axial or radial direction. Because of this alignment reading are effected. It is important to know the axial and radial movement of shaft before alignment.

3.1.5 <u>Uneven Legs</u>: -

Critical problem during alignment occurs when there is a gap between a machine foot and the foundation. One of the reasons for this is an uneven foot of machine. There are three types [1] of uneven foot. These are given below. See Figure No 2.

- Bent up foot
- Bent down foot

Figure No 2

When there is one or more uneven legs and they are not properly corrected before beginning the actual alignment, it may be difficult, even impossible, to achieve acceptable results.
Regardless of the method used to locate an uneven foot on the machine, it is always required to actually measure [1] the gap (size and shape) between the foot and the foundation. This is necessary to determine whether the uneven foot is parallel or bent as well as verifying that the foundation is level. With a parallel uneven foot, the correction typically involves inserting one or two shims. In the case of a bent foot or uneven foundation, it will required to create a "step shim" or “; shim pack" to completely fill the gap. See Figure No 3.

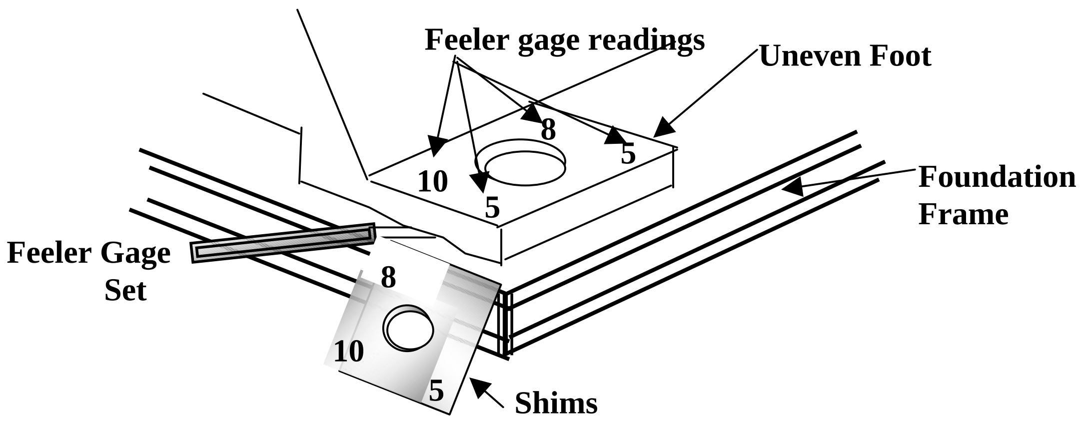

Figure No 3

3.2 <u>Structural Errors</u>: -
Following are the structural errors.

- Foundation frame distortion.
- Piping strain

3.2.1 <u>Foundation Frame Distortion</u>: -
After completion of alignment hold-down bolts are tightened. The machine frame actually distorts from its resting position as the hold-down bolts are tightened to secure the machine in place. This distortion puts the shaft in a bind and pre-loads the bearings due to change in position of machine. See Figure No 4

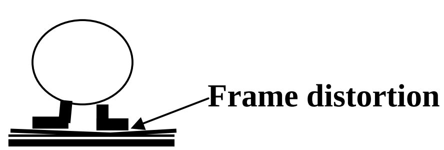

Figure No 4

hot fluid flows or pressurized fluid passes through pipe deflects. This shifts machine and tends to misalignment.

4.0 Effects of Misalignments: -

Shaft misalignment occurs when the centerlines of two (or more) rotating shaft are not precisely co-axial. Shaft misalignment can be classified by three different ways.

- Parallel Misalignment occurs when two centerlines of shafts are parallel but not intersect at the power transfer points.
- Angular Misalignment occurs when two centerlines of shafts intersect at power transfer points but are not parallel.
- A combination of both types of misalignment.

Misalignment causes generation of pre-load force [2] in radial and axial direction. The radial pre-load force is mainly generated and results in a constant force, which push shaft to one side. It can displace the shaft from the original position to a new position, and the pre-load forces lead to bearing and/or rotor failure. The radial pre-load force pushes shaft to the side and creates more friction loss on bearing balls, which raises the temperature of the lubrication system. Excessive bearing clearance is the result, which eventually leads to the destruction of the bearing. The formal constant air-gap between the rotor and the stator of the motor case disappear so that the rotor rubs the stator, and cause mechanical damage, or insulation failure causes by increasing in high temperature.

The axial pre-load force not only reduces bearing and coupling life but also results in shaft bending. Bearings are not usually designed to withstanding high axial forces and a consequence bearing life will be reduced.

The ultimate goal of shaft alignment is to maximize the life of rotating parts of machine. The moving shaft wants little or no unwanted additional external force impinging on the rotor, bearings, couplings and seals.

5.0 Classification of Misalignment: -

There are some factors, which are uncontrollable like manufacturing [2] error. It is almost impossible to achieve the perfect alignment. However the tolerance guides allow rotating parts e.g. bearings, couplings and seals are to run within certain acceptable degrees of misalignment. Then if misalignment of rotating shaft is refined into the acceptable range. It will be good enough to operate the machine without problems.

Therefore misalignment can be classify [2] into four grades depend on the details from different manufacture including bearing manufacturers, coupling manufacturers, alignment system consultants and so on.

1. Unsafe: the degree of misalignment is outside the tolerance limit.

This method also identifies machine defects up-to some level. The Figure No 5 shows the mounting of four dial gages, by using the special fixture.

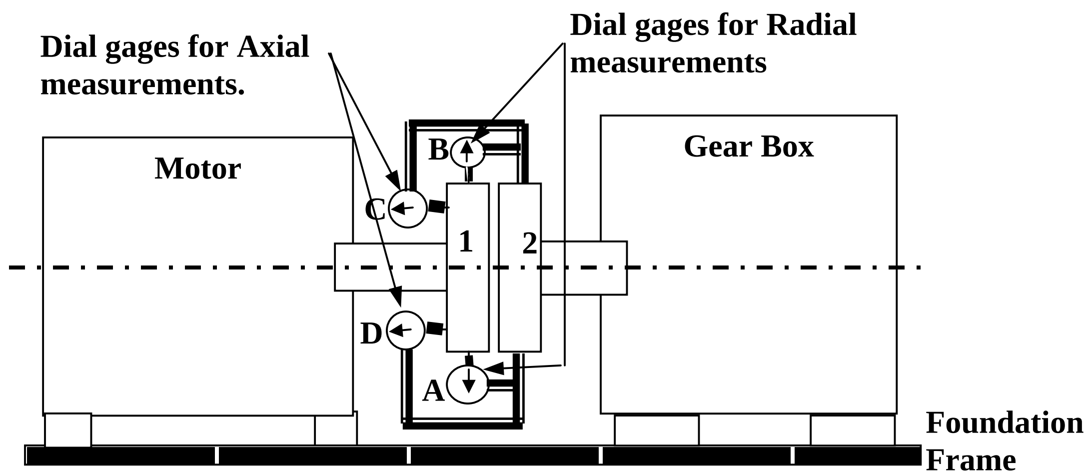

Figure No 5

Fix the dial gages as shown in Figure No 5. Dial Gage ‘A’ & Dial Gage ‘B’ are for Radial alignment check. Dial Gage ‘C’ & Dial Gage ‘D’ are for Axial alignment check. This alignment process is divided in two parts. These parts are given below.

1. Pre-alignment process.
2. Main alignment process.

6.1 <u>Pre-Alignment Process</u>: -

Before starting alignment process it is necessary to detect structural and machine error. It is also difficult to align the machine without first addressing these additional problems. For this reason, it is necessary to carry out pre-alignment process before starting main alignment. Following are pre-alignment process.

1. Set up error check
2. Bent Shaft or coupling check
3. Uneven machine leg corrections

6.1.1 <u>Set Up Error Check</u>: -

First check for zero matching. Zero Dial Gage ‘B’ & Dial Gage ‘C’ at the top position. Zero Dial Gage ‘A’ & Dial Gage ‘D’ at the bottom position. Rotate the shaft 360°, the entire dial should again read zero. It should repeat. If it does not read zero, then remove the dial setup error.

The following simple check is able to catch many set-up errors [1].

- Loose brackets

By keeping coupling half ‘2’ fix and Rotate the coupling half ‘1’ by 360°, Dial Gage ‘A’ & Dial Gage ‘B’ should again read zero. It should repeat. If it does not read zero. Then this can be combined or indivisusal result of shaft bent for coupling half ‘1’, loose coupling or damage couplings. If coupling is loose tight it or change damage coupling as per requirement. If coupling is intact then maximum reading will show the shaft bent.

6.1.3 <u>Uneven Machine Leg(s)</u>: -

The traditional way to locate a soft foot is by installing a dial indicator on the foot and watching the movement as you loosen the hold down bolt. This approach works fairly well in the case of a parallel leg [2] but may give an incorrect indication of bent foot. The method is developed to avoid influence of uneven leg(s) in main alignment process. It is required to drill a hole in each leg as shown in Figure No 6. and required size of taping is done. Then a full threaded bolt is inserted in the threaded hole. Jacking the bolt does the required corrections are done. See Figure No 7.Then checking the gap by feeler gage the shims are provided.

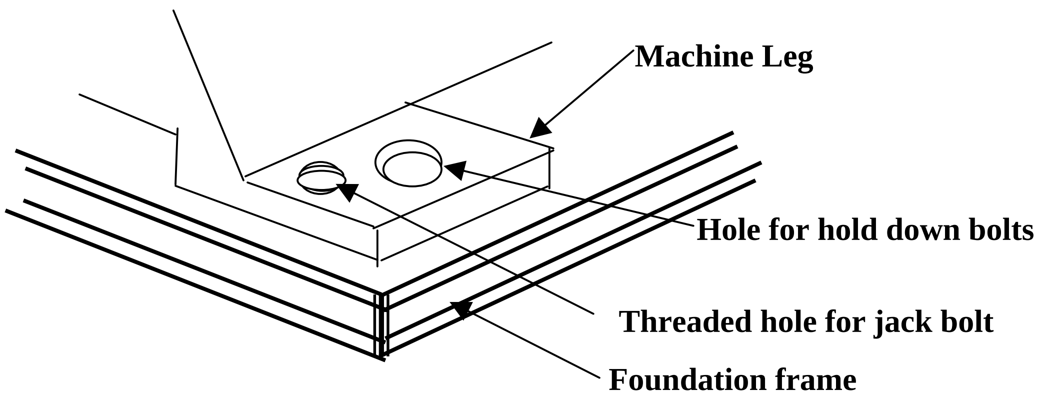

Figure No 6

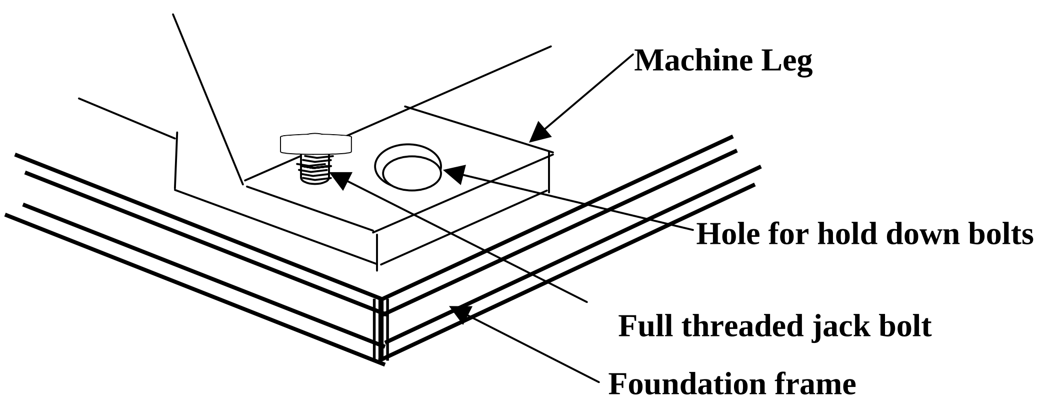

Figure No 7

Dial Gage ‘A’	A_{T1}	A_{T2}	A_{T3}	A_{B1}	A_{B2}	A_{B3}	A_{R1}	A_{R2}	A_{R3}	A_{L1}	A_{L2}	A_{L3}
Dial Gage ‘B’	B_{T1}	B_{T2}	B_{T3}	B_{B1}	B_{B2}	B_{B3}	B_{R1}	B_{R2}	B_{R3}	B_{1}	B_{L2}	B_{L3}
Dial Gage ‘C’	C_{T1}	C_{T2}	C_{T3}	C_{B1}	C_{B2}	C_{B3}	C_{R1}	C_{R2}	C_{R3}	C_{1}	C_{L2}	C_{L3}
Dial Gage ‘D’	D_{T1}	D_{T2}	D_{T3}	D_{B1}	D_{B2}	D_{B3}	D_{R1}	D_{R2}	D_{R3}	D_{1}	D_{L2}	D_{L3}

Table No 1

If $A_{T1} + A_{B1} = A_{R1} + A_{L1}$ & $B_{T1} + B_{B1} = B_{R1} + B_{L1}$ Then there is no error. But one of them is not satisfied then there is a machine error. This type of error is may be due to following reasons.
Excess bearing radial clearance or shaft rubs at bearing seat.
If $C_{T1} + C_{B1} = C_{R1} + C_{L1}$ & $D_{T1} + D_{B1} = D_{R1} + D_{L1}$ Then there is no error. But one of them is not satisfied then there is a machine error. This type of error is may be due to following reasons.
Axial movement of one of the shaft in bearing or low bearing loading.
By keeping these errors the alignment can be carried out. Carry out alignment corrections. Then check second set of readings.
If $A_{T2} + B_{B2} = A_{B2} + B_{T2}$ & $A_{L2} + B_{R2} = A_{R2} + B_{L2}$
$C_{T2} + D_{B2} = C_{B2} + D_{T2}$ & $C_{L2} + D_{R2} = C_{R2} + D_{L2}$
Then there is no further necessary for alignment corrections. But one of the equations is not satisfied then carry out alignment corrections until an acceptable solution is achieved.

6.2.1 <u>Alignment Curves</u>: -

After receiving the set of readings the curve is plotted. These curves are shown in Figure No 8.
For comparison of values, the values should be assumed non-vector values.

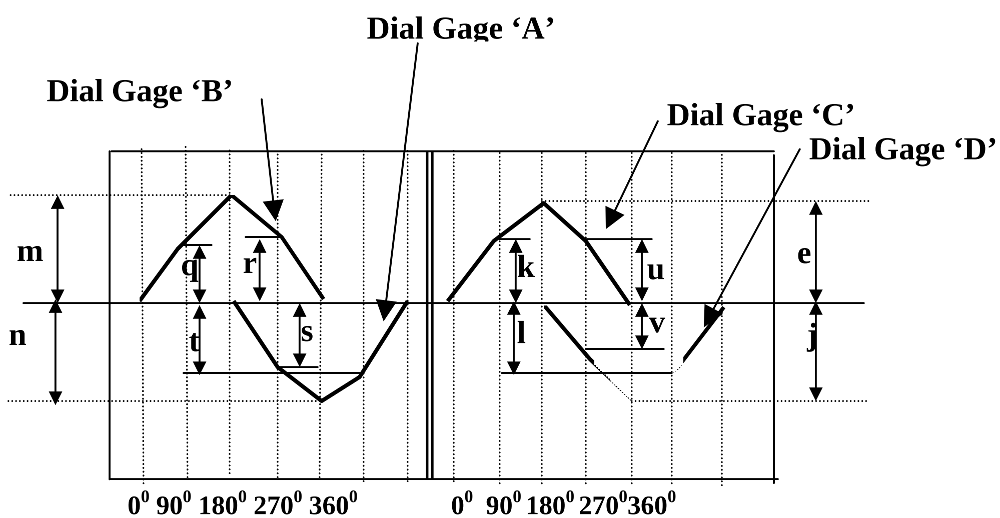

Figure No 8

& In e, j, k, l, u, v, which is the greater, is the axial movement of shaft. This can be combined or indivisusal result of improper bearing loading and relative movement of shaft with respective inner race of bearing. This axial movement can be less than actual axial movement.

7.0 Conclusion: -

The quality alignment is not dependent on the type of measurement system used. It depends upon alignment technique, which locate potential problems and quantify whether the problem must first be addressed in order to be able to successfully complete the alignment job. Shaft misalignment effects the life of rotating parts of machine.

Four-dial gage method provides the technician the recommended approach for the quickest way with quality alignment.

For this method it is necessary to record all four cardinal readings.

This method is useful only for shaft-to-shaft alignment of Thermal Power Station's Coal Handling Plants. It can be used up to some extent to other area.

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2. Research paper on "Misalignment and vibration detection in Electrical Machine" by M. Pusayatanont, Department of Electrical and Electronics Engineering, Ubonratchatani University.