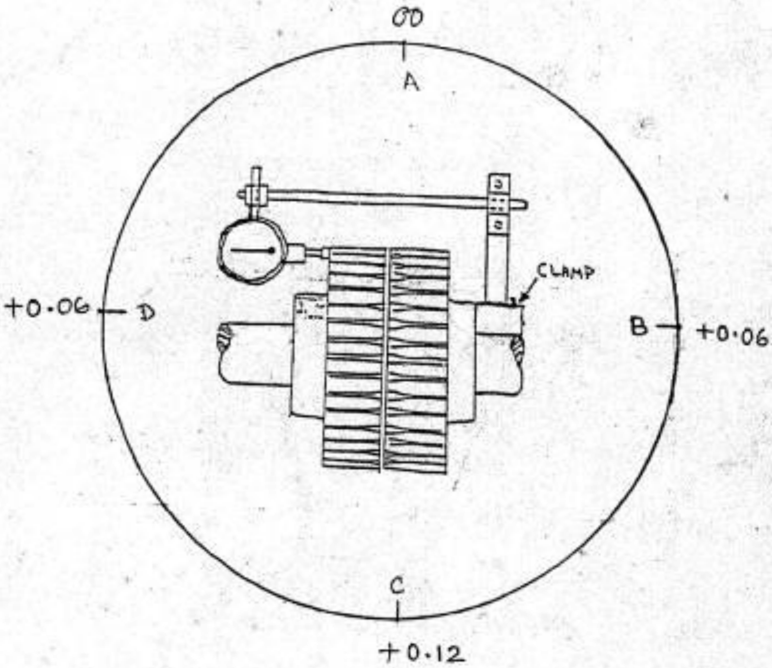
Reading Material
on
Machine Alignment



Steel Authority of India Limited
Rourkela Steel Plant
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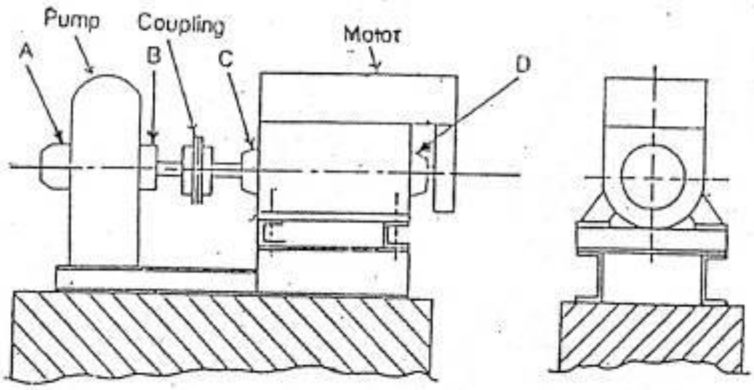
1. INTRODUCTION

A rotating equipment has a driving unit and a driven unit. The driving unit may be an electric motor, a hydraulic / pneumatic motor or turbine / IC Engine. The driven unit may be a pump, a fan, a gear box or other rotating machine. Electric motor is a very common form of driving device. Here the electrical energy is converted into mechanical energy, which in turn is transmitted to the driving shaft in the form of rotary motion.

Now, there should be some media of transmission of the rotary motion of the driving unit to the driven unit. Coupling is a device, which is used to connect two shafts together either rigidly or flexibly to transmit torque or turning effort. For maximum efficiency in power transmission the driving and driven units must be aligned properly. Couplings can easily reflect the condition of equipment i.e. units are aligned or misaligned.

The procedure to bring the centerlines of driving and driven shafts into one line is called alignment.



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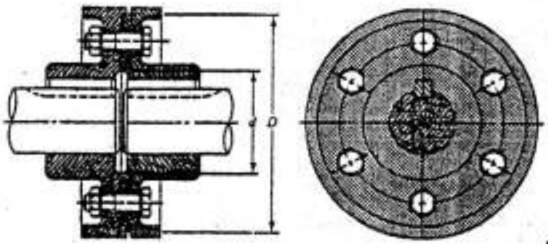
2. COUPLING

Couplings are broadly classified into two groups.

Rigid couplings – These are used to connect two shafts, when they are in perfect aligned condition. Any misalignment in the machine shafts causes damage to the coupling or its parts. Best examples are Flange coupling and Muff coupling. These couplings give a solid connection.



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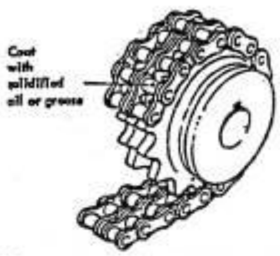
Flexible couplings – These couplings have the benefit of protecting the driving and the driven machinery from detrimental effects arising out of misalignment of shafts, sudden shock loads, end float, shaft expansion or vibration. Various types of flexible couplings are in use such as-

Pin and bush coupling	Gear coupling
Chain coupling	Tyre coupling
Bibby coupling	Eupex coupling
Star coupling	Multidisk coupling etc.



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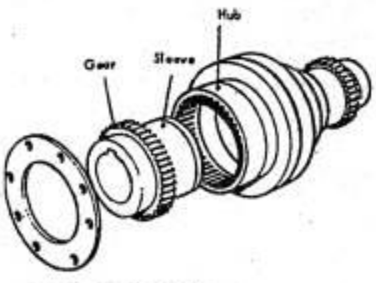

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REMEMBER :- FLEXIBLE COUPLINGS ARE DESIGNED TO ACCOMMODATE SLIGHT MISALIGNMENT, THEY ARE NOT INTENDED TO COMPENSATE FOR BAD WORKMANSHIP DURING THE ALIGNING PROCESS.

3. SHAFT ALIGNMENT

The procedure to bring the centerlines of driver and driven shafts into one line is called alignment. The geometrical centerlines of both the units should coincide with the actual centerline of rotation. But the task is not so easy. The error in such lining up is called misalignment.

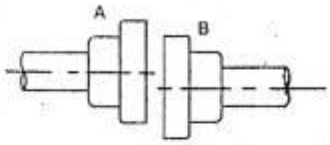
While no general rule can be laid down for permissible errors in lining up of units, it is recommended that -

- For flexible couplings, error on the face should be within 0.05 mm + 0.0002D and error on the peripheries be within 0.1 mm. (where D = shaft diameter)
- For rigid type couplings these figures should be halved.

NOTE: In certain machines the permissible error is recommended by the manufacturer and that must be followed.

3.1 TYPES OF MISALIGNMENT

Radial misalignment:
In this type of misalignment the centerlines of the driver and driven shafts are parallel but not in a line. The difference between the two centerlines is the amount of radial misalignment. This may occur in both the planes (vertical and horizontal).



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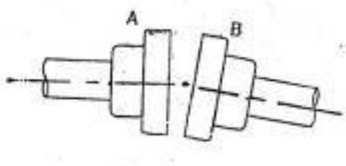
Angular misalignment:
In this type of misalignment centre lines of both the shafts are not parallel and at a slight angle to each other. The angle so formed is the angle of misalignment.



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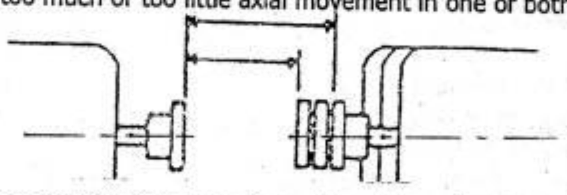
End Float:
Where there is too much or too little axial movement in one or both shafts.



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NOTE: Shafts can operate at angles using universal couplings. These types are not considered in this module.

4. CAUSES AND EFFECTS OF MISALIGNMENT

Causes: Any one of the three types of misalignment (i.e. radial, angular or float) can occur as a result of the following:

- Incorrect coupling installation
- Loosening of the holding down bolts
- Wear in the bearings or bearing housings
- Mechanical damage to the shaft or other component
- Loss of balancing of the rotating components

Effects: The following symptoms can be caused by misalignment.

- Excessive noise during operation
- Excessive vibration
- High lubrication usage
- Overheating of bearings, couplings and gears
- Heavy or uneven bearing wear
- Heavy or uneven wear or damage to coupling bolts, pins, springs, disks or rubber bushes
- In extreme cases, shearing of coupling bolts, shafts and the collapse of bearings.

NOTE:
Other types of failure such as bearing or coupling wear and incorrect lubrication also produce these symptoms. Therefore it is essential that any malfunction of equipment is carefully investigated and the true cause is correctly identified.

4.1 Vibration and Alignment

All operating machines give rise to vibration. Information about a machine's condition can be obtained by monitoring vibration level. Vibration is simply the motion of machine or a machine part back and forth from its position of rest. Vibration is the response of a system to some internal or external excitation or force applied to the system. Misalignment and vibration are closely related. Good alignment can prevent vibration to a large extent.

Causes of vibration

With few exceptions mechanical troubles in a machine cause vibration. Listed below are the most common problems that produce vibration. They are:

- Unbalance of rotating parts
- Misalignment of couplings and bearings
- Bent Shaft
- Worn, eccentric or damaged gears
- Bad drive belts and drive chains
- Torque variations
- Electromagnetic forces
- Faulty / damaged bearings
- Hydraulic forces
- Mechanical looseness
- Rubbing action

5. INSTRUMENTS AND AIDS FOR ALIGNMENT

INSTRUMENTS :

The following measuring instruments are commonly used when carrying out alignment tests.

a. A good quality steel rule used not only for measuring but also as a straight edge when carrying out quick alignment checks.
b. A set of feeler gauges, used to accurately measure gaps to determine the size of shims required.
c. A wedge gauge used to measure the gap between two couplings.
d. Suitably sized inside calipers, used to quickly determine:
    - internal diameter (bore size)
    - any ovality in plain or sleeve bearings
    - large gaps
e. Suitably sized outside calipers, used to quickly determine:
    - the external diameter of shafts, bearings etc
    - any ovality in shafts or couplings
f. Suitably sized vernier calipers, used to accurately measure large diameters or large bores.
g. Suitably sized micrometers, used to accurately measure outside diameters and the thickness of shims and packers.
h. Dial gauges (dial test indicators) used to accurately determine direction of movement and comparative movement.
i. A spirit level, used to identify errors in level of bed plates and shafts etc.

ALIGNMENT AIDS :

The following items other than measuring instruments are needed when testing for alignment:

a. A surface table used to provide a flat stable surface, which provides a datum or reference base.
b. A machined straight edge, used as datum or reference edge with which to line up components.
c. Vee blocks used to support a shaft when checking for straightness.
d. A try square used to set or check a 90-degree angle.
e. A scriber used to draw reference lines.
f. Magnetic and fabricated dial gauge stands to suit different alignment conditions.
g. Shims and packers used as inserts to increase or adjust/level the height of a bedplate.
h. A marker to mark points or lines on shafts and couplings.

6. ALIGNMENT METHODS

Surveys have shown that misalignment is directly responsible for machinery failure in over 50% of all cases. Much of this can be attributed to poor initial alignment procedure. In order to obtain accuracy in final alignment different initial alignment procedure must be followed.

SAFETY NOTE:

BEFORE CARRYING OUT ANY CHECKING ON SITE THE DRIVER AND DRIVEN UNITS MUST BE ISOLATED AND LOCKED OFF ELECTRICALLY AND MECHANICALLY AND A PERMIT TO WORK MUST BE OBTAINED FROM A RESPONSIBLE PERSON.

6.1 CHECKING FOR COUPLING SQUARENESS

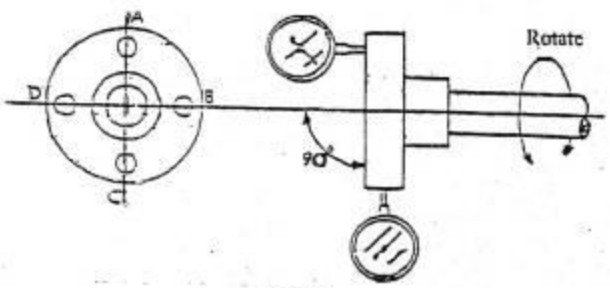
The coupling halves must be checked individually for squareness to their respective shafts.
Coupling squareness means -

- the coupling should fit to the shaft at right angle and
- the shaft and the coupling should be concentric.

Otherwise the faulty coupling may misguide to radial or angular misalignment during the alignment process.

Checking Procedure: -

Position the two dial gauges as shown making sure that the magnetic bases are clamped to the bedplate or other suitable fixed datum.



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Set the dial gauges to read zero.
Mark the couplings with chalk/marker at four equally spaced positions (at 90^0 intervals) around the shaft calling the points A, B, C, and D.

Rotate the shaft by hand through one complete revolution noting any movement of the dial indicators. Record the readings at the four points.
If there is no movement the coupling is correctly mounted.

If there is a movement the problem may be that:

- the coupling is not correctly mounted
- the unit is not level on the bedplate
- the shaft is moving in the horizontal plane due to the normal end float
- the shaft is bent
- the bearings are worn
- the coupling is distorted

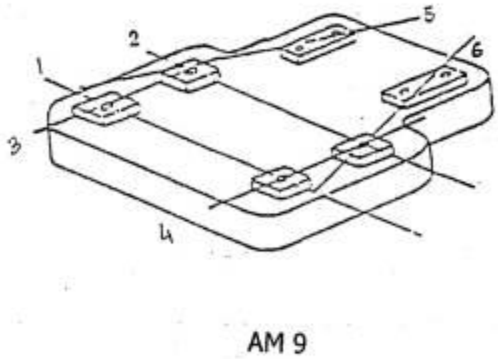
Repeat the process for the other half coupling.

Steps to be taken as remedy for above faults respectively.

- The coupling to be taken out and refitted properly.
- The unit to be replaced and bedplate level checked.
- Take reading properly.
- If possible straighten the shaft or replace it.
- Change bearings.
- If possible recondition the coupling or change.

6.2 CHECKING THE BEDPLATE LEVEL

Bed plates are either castings or fabricated from structural steel products. Before placing the driver or driven units on the bedplate it must be checked for true leveling.
This can be checked by using a straight edge and spirit level in positions 1 to 6 (as shown in fig.). Where necessary appropriate shims are used to achieve a level base.



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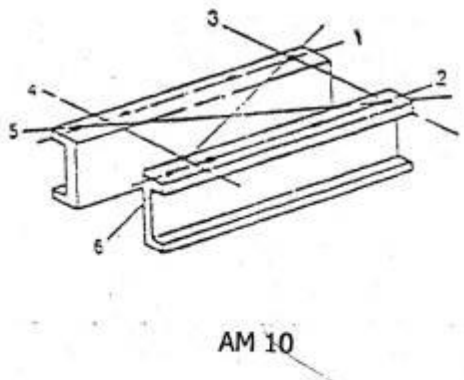

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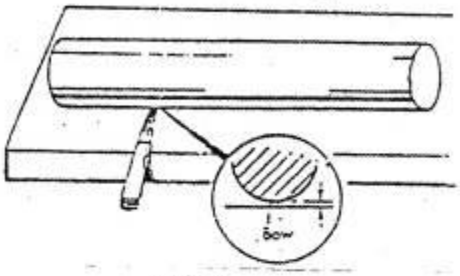
6.3 CHECKING A SHAFT FOR STRAIGHTNESS

A bent shaft causes excessive wear to take place in bearings and couplings Checking a shaft for straightness is normally carried out under workshop conditions with the shaft removed from the machine or its mountings.
Before checking a shaft for straightness remove any burrs or raised marks with a file or emery cloth, clean off any grease or dirt and check if the shaft has been centre drilled.

There are three main methods of checking a shaft for straightness.

They are:
(i) Using feeler gauges (used for short shaft)
Lay the shaft on the surface table ensuring that it is clean and dust free.



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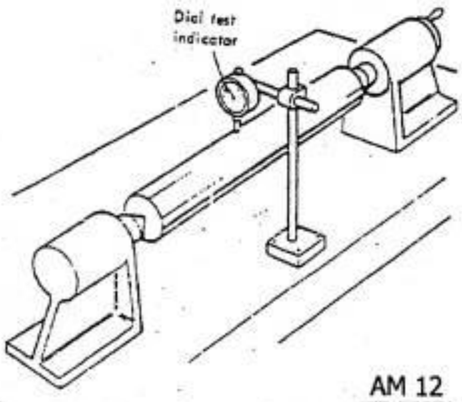
Using the feeler gauges check along the whole length of the shaft for clearance between the shaft and the surface table. If there is any clearance the shaft is bent or bowed.

Roll the shaft through 90^0 and repeat the check. Continue until the shaft has been rotated through one complete turn.

(ii) Between centers

This method can be used if the shaft has previously been centre drilled. It can be used for short and medium length shafts.



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Position the shaft either:

- between the centre of a lathe
- between bench centres clamped or attached to the surface table

Clamp a dial gauge to the surface table with the gauge pointer resting on the shaft at the centre point along its length.

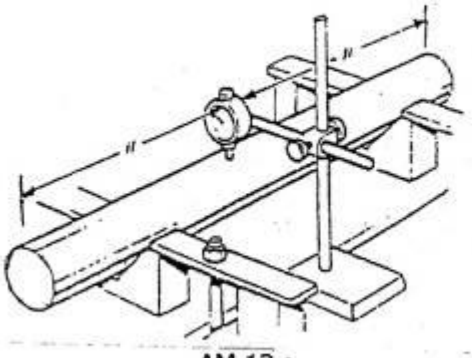
Rotate the shaft and note any variations in the indicator reading. A variation means that the shaft is either bent or not properly round.
Take readings at three different points. (both ends and middle)

Analyse the results as follows:

- Shaft is straight and round - if the readings do not vary at all the three points.
- Shaft is straight but oval - if the readings vary similarly at all the three points.
- Shaft is bent but round - if the readings do not vary at both the ends but vary at the middle.
- Shaft is bent and oval - if the readings vary at all the three points.

(iii) Using the Vee blocks

This method can be used for longer shafts and those that have not been centre drilled.
Support the shaft on vee blocks clamped or rested on the surface table.



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Clamp a dial gauge to the surface table with the gauge pointer resting on the shaft at the centre point along its length.

Rotate the shaft and note any variations in the indicator reading. A variation means that the shaft is either bent or not properly round as explained above.

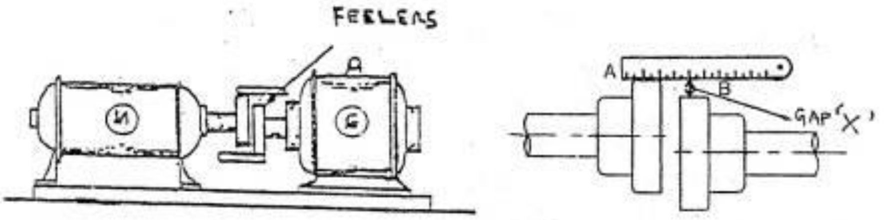
6.4 CHECKING ALIGNMENT OF MATING COUPLINGS AND THEIR SHAFTS

The harmful effect of misalignment on machinery is directly related to the rotating speed of the machines. With today's high RPM machines, alignment is very critical. High-speed machines require near perfect alignment for proper operation. However many technicians are still using the old 'rough' or 'trial and error' methods developed long ago for use with low speed machinery. Some of the recent and precise methods of attaining and maintaining proper machinery alignment are discussed here along with the rough methods.

6.4.1 ROUGH ALIGNMENT METHODS

(a) Checking the radial misalignment

Place a straight edge or steel rule to check across the top and bottom of the couplings.



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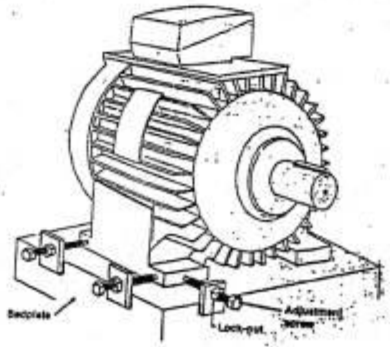
Use feeler gauges to measure any gap at point "X". If there is a gap, its width is equal to the thickness of shim to be placed under the unit to level the coupling halves.

Place the straight edge or steel rule across the sides of the coupling.
Use feeler gauges to measure any gap at the sides of the coupling.
Move the driver or driven unit (or both) sideways until the gap is eliminated.
This movement becomes easier when jacking bolts are provided in the base frame.



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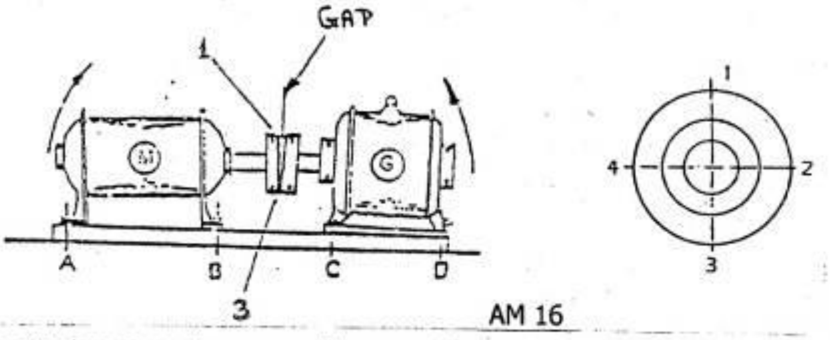
(a) Checking the angular misalignment

In ideal condition the face gap of both coupling halves should be equal at each and every point. Normally four points are taken at 90^0 intervals for such check i.e. top, bottom, left side and right side. (1,2,3 & 4 in Fig.)



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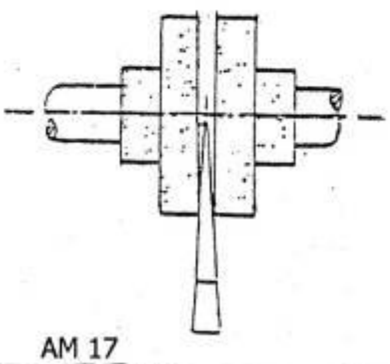
Use a wedge gauge to measure the gap at four points.
If the readings are not equal then the machine is having angular misalignment.
If the top gap is larger than the bottom gap, insert shims under the rear feet until the top and bottom gaps are equal.
If the bottom gap is larger than the top gap insert shims under the front feet until the top and bottom gaps are equal.
Tighten the holding down bolts and recheck the gaps.

(c) Checking the end float

Consult the manufacturer's instruction to know the required end float.
Check that the shafts have sufficient movement in the horizontal plane to provide the required end float.
Make sure that the shafts are pushed apart.
Using a wedge gauge, check the coupling gap at four points around the edge at 90^0 intervals.
Move the driving unit either in or out until the gap is corrected.



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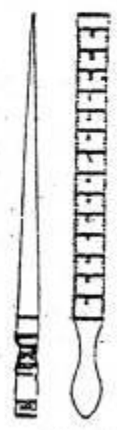

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Fully tighten the holding down bolts.

6.4.2 PRECISE ALIGNMENT METHODS

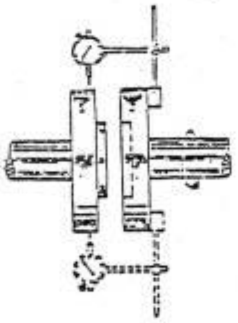
Though most modern methods have been developed to check and eliminate misalignment, use of Dial Test Indicator is still cheap and convenient for maintenance people. The metric DTI can read up to 0.01mm accuracy. Two common methods are in frequent use.

(A) THE FACE-PERIPHERAL INDICATOR METHOD

Probably the most widely used dial indicator method is the face-peripheral (or face and rim) method shown in Fig. It is advisable to take the face readings on the largest possible diameter on the face of the coupling and record this for calculating the equipment moves to improve the shaft alignment.

The following are the advantages:

- Only one shaft has to be rotated
- Good for large diameter couplings where the shafts are close together
- Easier to visualise the shaft positions



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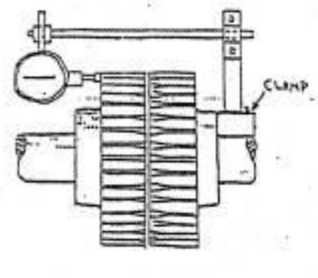

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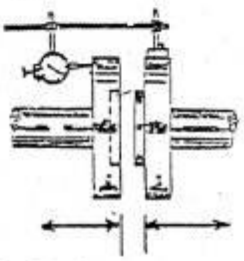

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PROCEDURE

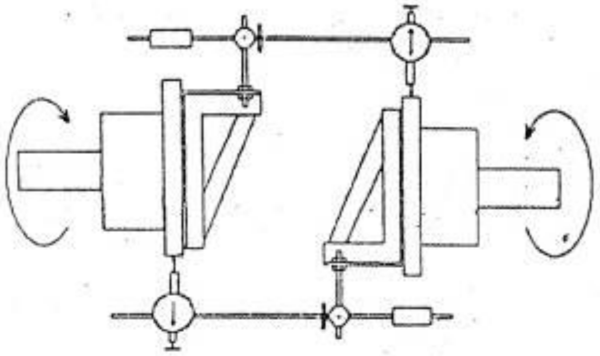
a. Attach bracket firmly to master coupling and position indicators on face and periphery of other coupling.
b. Zero the indicators at the 12 o'clock position.
c. Slowly rotate the shaft and bracket arrangement through 90^0 intervals stopping at the 3,6 & 9 o'clock positions. Record each reading (plus or minus)
d. Return to the 12 o'clock position to see if the indicators re-zero.
e. Repeat steps (a) to (d) to verify the first set of readings.
f. Using the readings of 12 & 6 o'clock position, calculate shim thickness at front and rear feet and insert shims.
g. Using the readings of 3 & 9 o'clock position, move the unit, as required towards left or right. This movement becomes easier when jacking bolts are provided in the base frame.
h. Tighten the holding down bolts and recheck for accurate alignment.

(B) REVERSE INDICATOR METHOD

The reverse indicator method is closely becoming the more popular method for taking shaft alignment readings and is illustrated in Fig.

The following are the advantages:

- Readings are more accurate than face peripheral method.
- The accuracy of the readings is not hampered by axial float of shafts.



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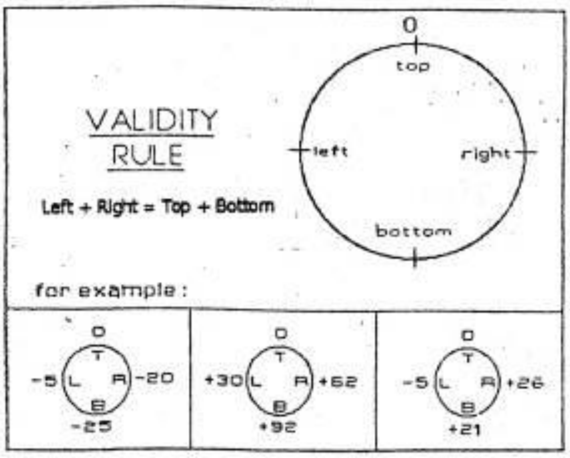
PROCEDURE

a. Attach brackets firmly to both the couplings and position indicators on periphery of the couplings as shown in the figure.
b. Zero the indicators at the 12 o'clock position.
c. Slowly rotate the shaft and bracket arrangements through 90^0 intervals stopping at the 3,6 & 9 o'clock positions. Record each reading (plus or minus) from both the indicators.
d. Return to the 12 o'clock position to see if the indicators re-zero.
e. Repeat steps (a) to (d) to verify the first set of readings.
f. Interpret the readings and calculate shim thickness at front and rear feet and insert shims.
g. Move the unit, as required towards left or right.
h. Tighten the holding down bolts and recheck for accurate alignment.

6.4.2.1 VALIDITY RULE

When performing any of the dial indicator methods as explained above, there is always a possibility that the readings obtained do not accurately reflect the true position of one shaft with respect to the other. Practically a variety of problems emerge that need to be considered, when taking the alignment readings.
In ideal situation, the reading should adhere to the validity rule that states that the sum of both side readings should be equal to the sum of top and bottom readings.

TOP reading + BOTTOM reading = LEFT reading + RIGHT reading



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However, the causes for the readings not to follow validity rule can be one or more of the following reasons:

- Defective coupling installation
- Deformation of coupling
- Bent shaft
- Loose bracket assembly
- Axial float of the shaft being rotated
- Sticky indicator stem
- Not taking true 90^0 readings
- Tracking on "elliptical" reading surface

In case the validity rule is not followed the process should be thoroughly checked and the true cause should be found out. After taking remedial steps the process should start again.

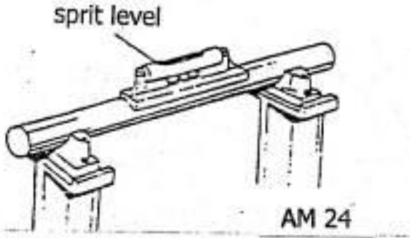
6.5 CHECKING THE ALIGNMENT OF BEARING HOUSINGS

The bearings of a shaft must be accurately aligned to facilitate the smooth running of the machine and to prevent undue wear and damage from occurring. Essentially the shaft must be:

a) perfectly round
b) level in height
c) in a straight line

(a) The roundness of shafts can be checked using one of the methods described in section 6.3 above.

(b) The level can be checked by placing a suitably sized spirit level on the shaft between the bearing mountings and noting the reading. Any correction can then be made by inserting or removing shims from under the bearing mountings.



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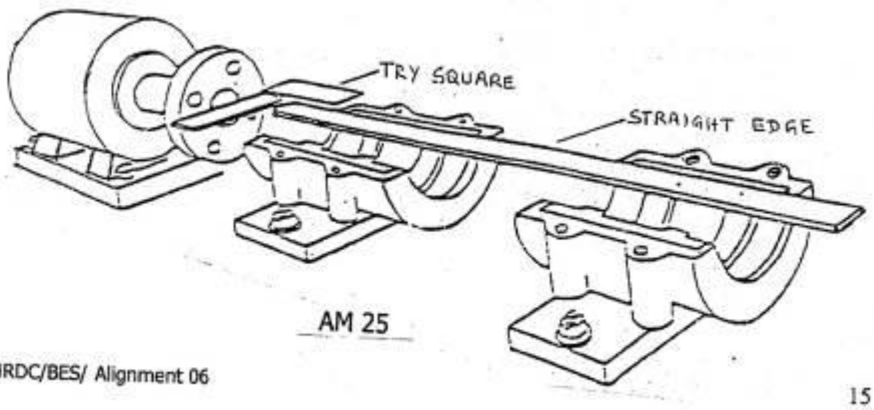
If there is more than two bearings (plain or sleeve bearings rather than roller or ball bearings) then care must be taken to check that all of the bearings are supporting the shaft correctly.
This can be done by applying marking compound to the bearing surfaces, lowering the shaft into position and rotating it by hand. The marking compound should be evenly coated on the shaft; lack of marking compound on the shaft means that the bearing block is too low.

(c) Checking that the bearing mountings are in a straight line
This check can be made by using a straight edge positioned across the inside of the bearing blocks as shown. The bearing block edges should all be in contact with the straight edge.



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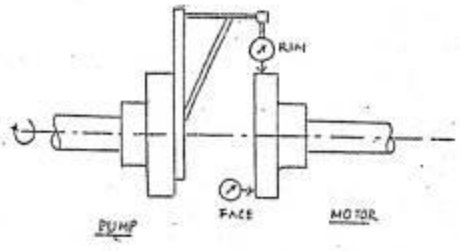
7. SHIM CALCULATION

This section describes the procedure for calculation of shims under front and rear feet of a driver unit (motor) using face and rim method. Here it is assumed that the driven unit (pump) is already set on its base and can be referred as master.



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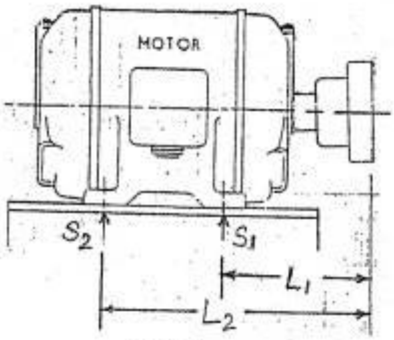
PROCEDURE: -

1. Mount indicator stand on pump coupling.
2. Set the indicators at the top of motor coupling face (12 o'clock position) and rim and set zero reading.
3. Check for soft foot and make corrections by:
   - Loosen and tighten each foot of motor, one at a time and note any change in dial indicator.
   - Use feeler gauges under each foot where a change was noted and add appropriate shims.
4. Rotate pump shaft 180^0 to bring the indicators to 6 o'clock position.
5. Record motor coupling face reading. This is TIR_F (Total Indicated Run-out on face).
6. Record reading on motor coupling rim. This is called TIR_R (Total Indicated Run-out on rim).
7. Repeat several times to obtain correct reading of TIR_F and TIR_R.
8. Measure dia of coupling where face reading was taken and name it 'D'.
9. Measure L_1 and L_2 (see fig. AM-27) or know it from RSN table.
10. Assume S_1 & S_2 are the shims required under front and rear feet respectively to eliminate angular misalignment vertically.
11. Calculate S_1 & S_2 as follows:
    - $S_1 = L_1 / D \times TIR_F$ and
    - $S_2 = L_2 / D \times TIR_F$
12. To correct radial misalignment vertically, the final shim size will be:
    - $S_1 + \frac{1}{2} TIR_R$ at front feet and
    - $S_2 + \frac{1}{2} TIR_R$ at rear feet.
13. To correct misalignment horizontally, repeat steps 4,5,6 and 7 but take the readings on 3 o'clock and 9 o'clock position. Rectify it by sliding the motor sidewise on the bedplate and check again. Use jacking bolts to save time.

EXAMPLE FOR SHIM CALCULATION

Let us calculate required shim sizes where the following readings have been taken and data given.

Diameter of coupling = 120 mm.
Motor front leg distance from coupling face (L_1) = 200 mm.
Motor rear leg distance from coupling face (L_2) = 450 mm.
Total Indicated Run-out on face (TIR_F) = 0.5 mm
Total Indicated Run-out on rim (TIR_R) = 0.06 mm



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$$S_1 = L_1 / D \times TIR_F$$

$= 200 / 120 \times 0.5$

$= 1.67 \times 0.5 = 0.835$ mm

$$S_2 = L_2 / D \times TIR_F$$

$= 450 / 120 \times 0.5$

$= 3.75 \times 0.5 = 1.875$ mm

At front feet, final shim size will be $S_1 + ½\ TIR_R$

i.e. $0.835 + ½ \times 0.06$

$= 0.835 + 0.03 = 0.865$ mm (Ans)

At rear feet, final shim size will be $S_2 + ½\ TIR_R$

i.e. $1.875 + ½ \times 0.06$

$= 1.875 + 0.03 = 1.905$ mm (Ans)

8. EFFECT OF TEMPERATURE ON ALIGNMENT

When there is a substantial difference between the running temperature of the driver and driven units, difference in heights of shaft centers may be appreciable. This can produce, particularly in large and close-coupled units, very heavy additional bearing loads. So allowance should be made such that the alignment will be correct under normal working conditions.

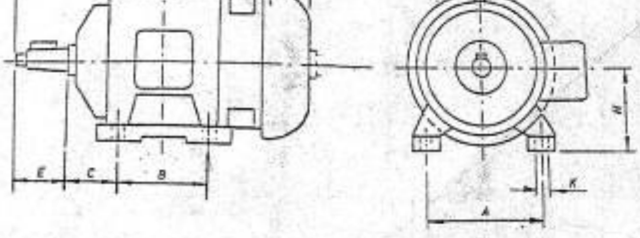
The co-efficient of linear thermal expansion of cast iron is 0.000011 per unit length per ^{0}C and that for steel is 0.000012.

In some machines fixed and floating bearing arrangement is provided to take care of the thermal expansion in axial direction.

9. ERECTION

It is necessary first for the driven unit to be erected in its final position and securely bolted down. While erecting the driven unit, the input shaft center height should be so fixed that at least 2 mm clearance exists below the base of the driver unit, for shimming purpose.

Shaft center height of electric motors (driver unit) can be known from IEC Frame size. [for frame size & other details refer RSN Tables]



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Now place the driver unit and align the output half coupling with that of the driven unit input using any one of the alignment methods.

When satisfied with the alignment, connect the power transmitting members (i.e. pin bush, spring, tyre, chain, bolt etc.).