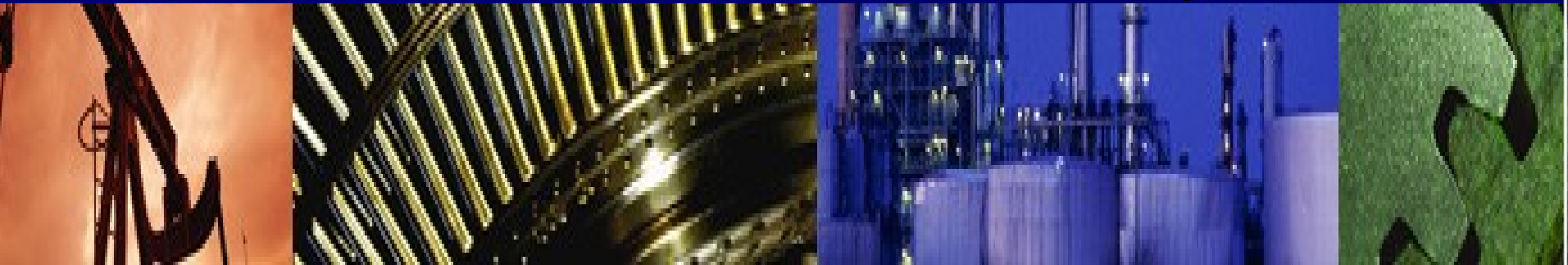


Alignment

Importance & Methods of Doing It

Bently Nevada



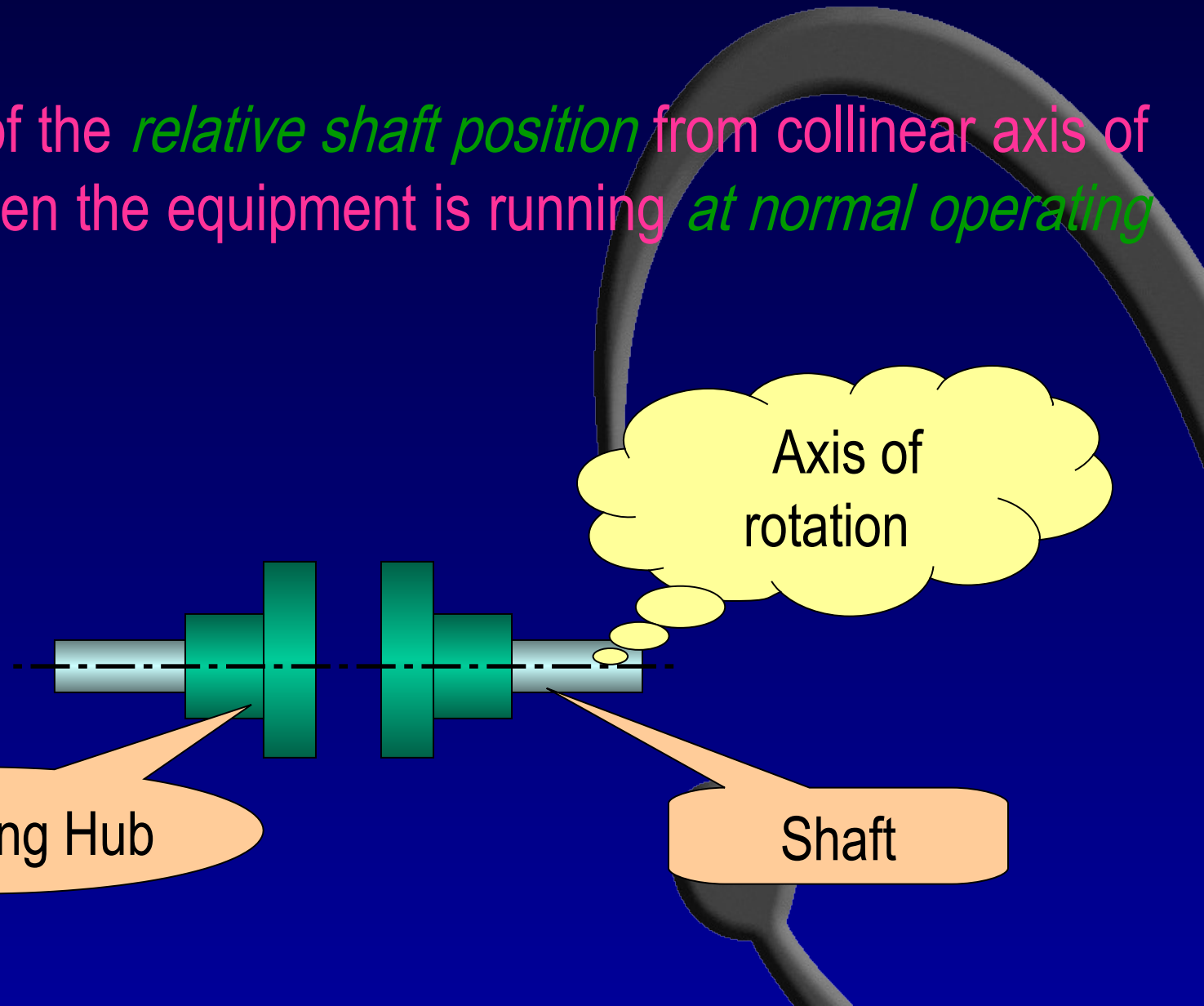
Click on the text to view the details.....

- Misalignment : Introduction...
- Types of misalignment...
- Methods of doing alignment...
- How to record & read alignment readings...
- Concerns for good alignment...
- Scientific diagnosis of misalignment...

End of presentation

What Is Misalignment?

- Deviation of the *relative shaft position* from collinear axis of rotation when the equipment is running *at normal operating conditions*.



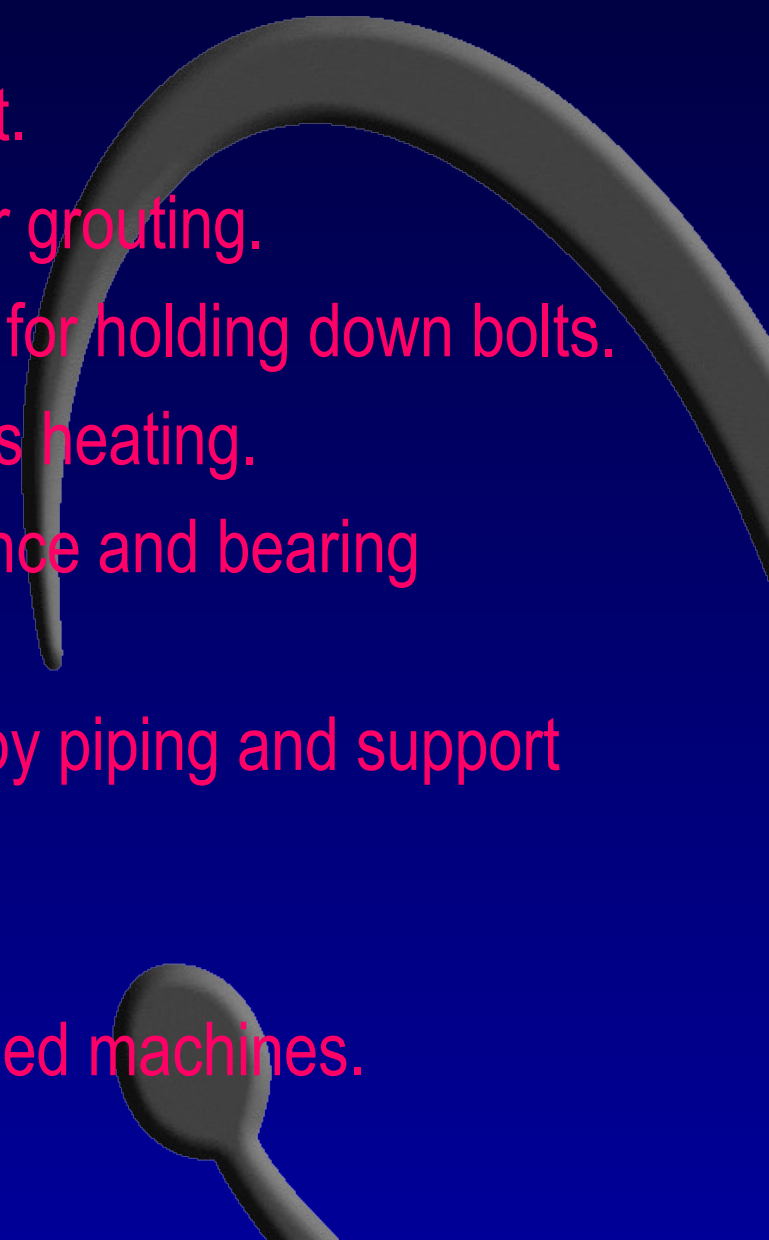
Effects of Misalignment

- @ 50 % of machinery malfunctions caused by it.
- Bearing loading differs then design.
 - Higher loading causes fatigue as a result of high stresses applied just below the load carrying surfaces and can be observed as spalling of surface metal.
 - Lighter loading may create instabilities inside bearing.
- Causes vibration and wear & tear of critical parts.
- Damage to outer race of the antifriction bearing.

Effects of Misalignment

- Breaks the lubricant film inside the bearing & increases the friction between moving parts. This results in increased power consumption.
- Increases the operating temperature of the machine.
- Generates Heat in the coupling.

Causes of Misalignment

- Poor workmanship during alignment.
 - Improper grouting or shrinkage after grouting.
 - Improper foundation or larger holes for holding down bolts.
 - Thermal expansion due to a process heating.
 - Vibration due to unbalance, resonance and bearing problems etc.
 - Forces transmitted to the machine by piping and support members.
 - Soft foot.
 - Improper alignment of directly coupled machines.
- 

How to Recognize Misalignment....Few Symptoms

- Excessive Radial & Axial vibrations.
- Premature bearing, seal, shaft and coupling failures.
- High casing temperature at or near the bearing or high discharge oil temperature.
- Repetitive failure of coupling elements & seals.
- Hot coupling while running & soon after shut down.
- Loose coupling elements, foundation bolts.
- Excessive amount of grease inside the coupling guards.
- Shafts are braking at or close to the inboard bearings or coupling hubs.

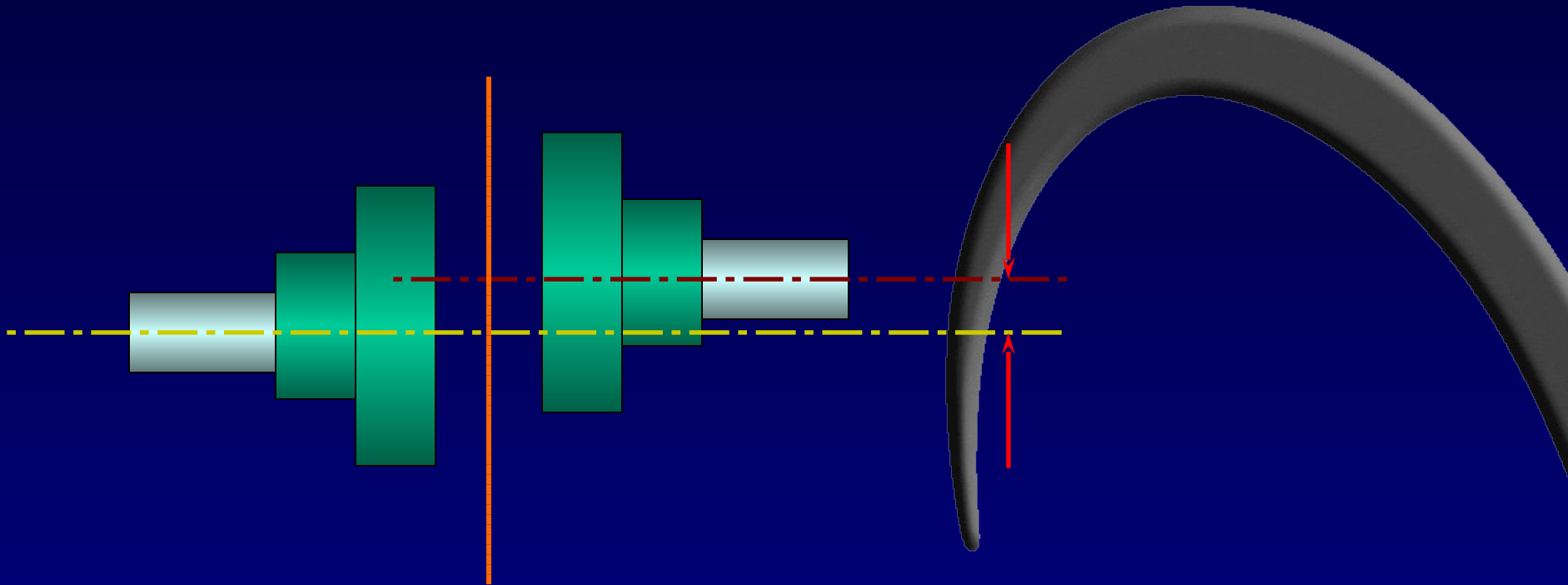
Return to main menu

Types of Misalignment

- Parallel or Off-set
- Angular
- Skew

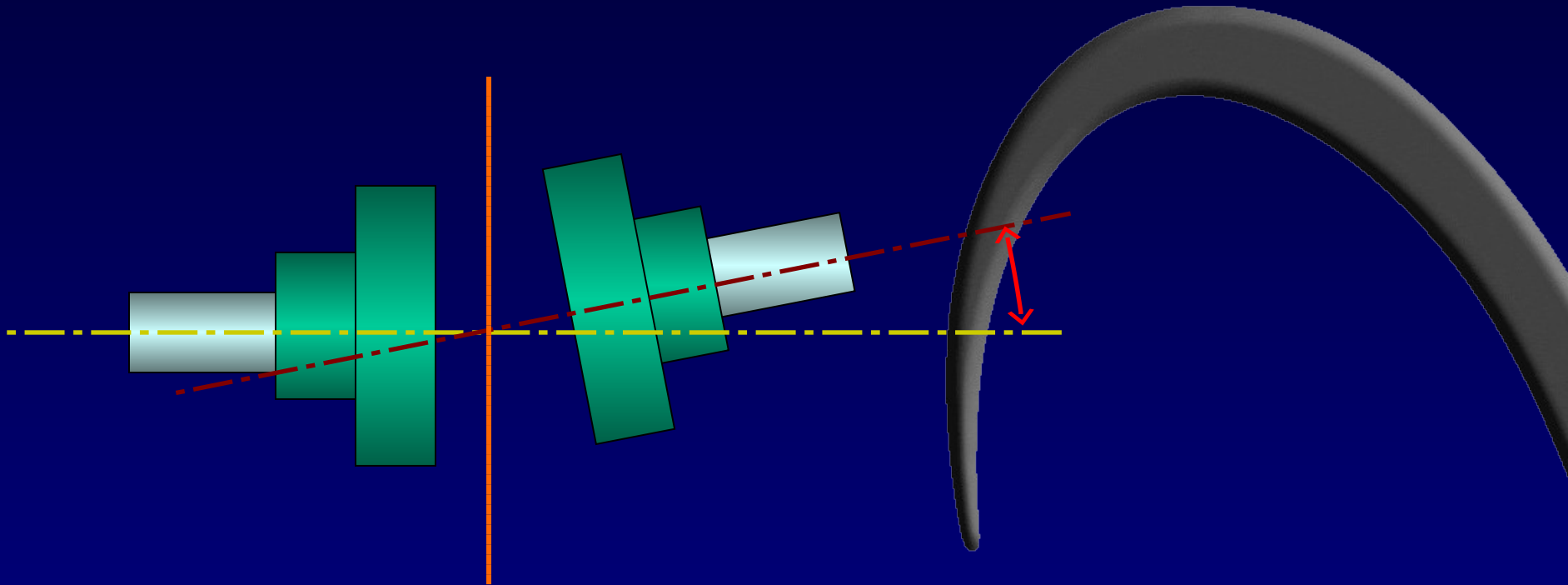


Parallel or Off-set Misalignment



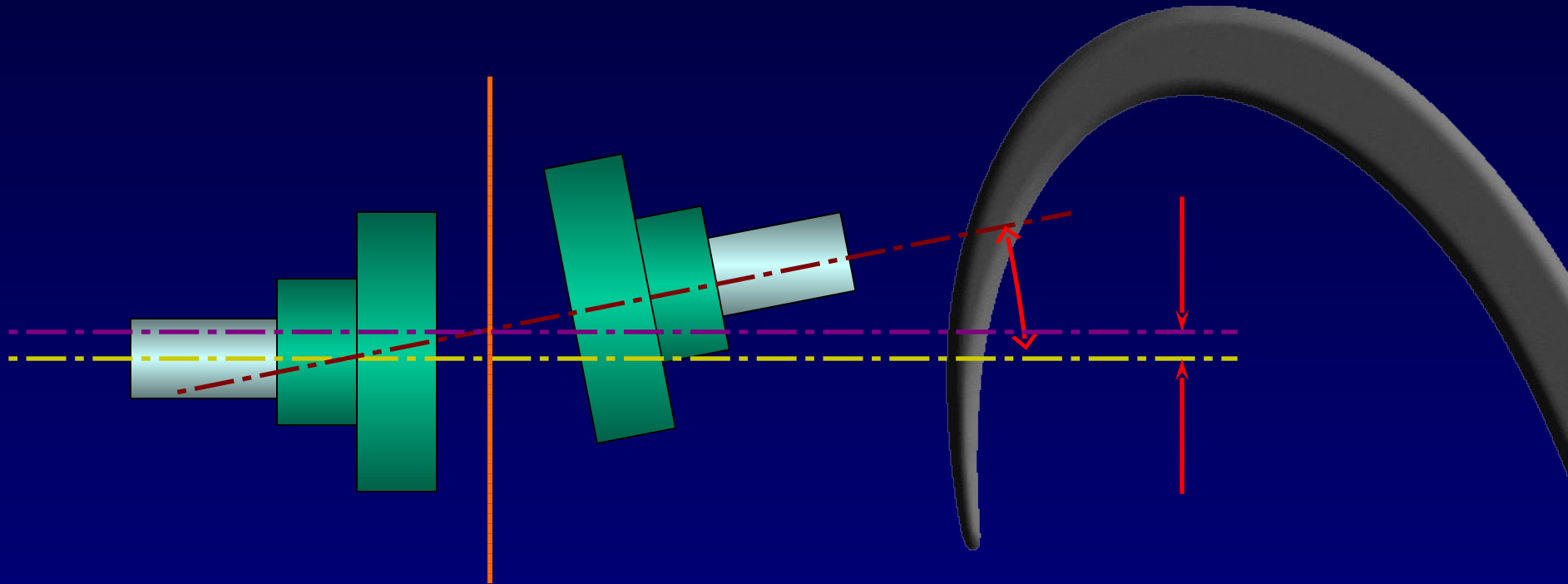
- Occurs when the shaft centerlines are parallel but displaced from one another.
- It consumes more power than the angular misalignment.

Angular Misalignment



- Occurs when the shaft are joined at a coupling in such a way as to induce a bending force on the shaft.
- It affects pin bush coupling more than tyre coupling.

Skew Misalignment



- Combination of offset & angular misalignment.
- Most common type of misalignment.

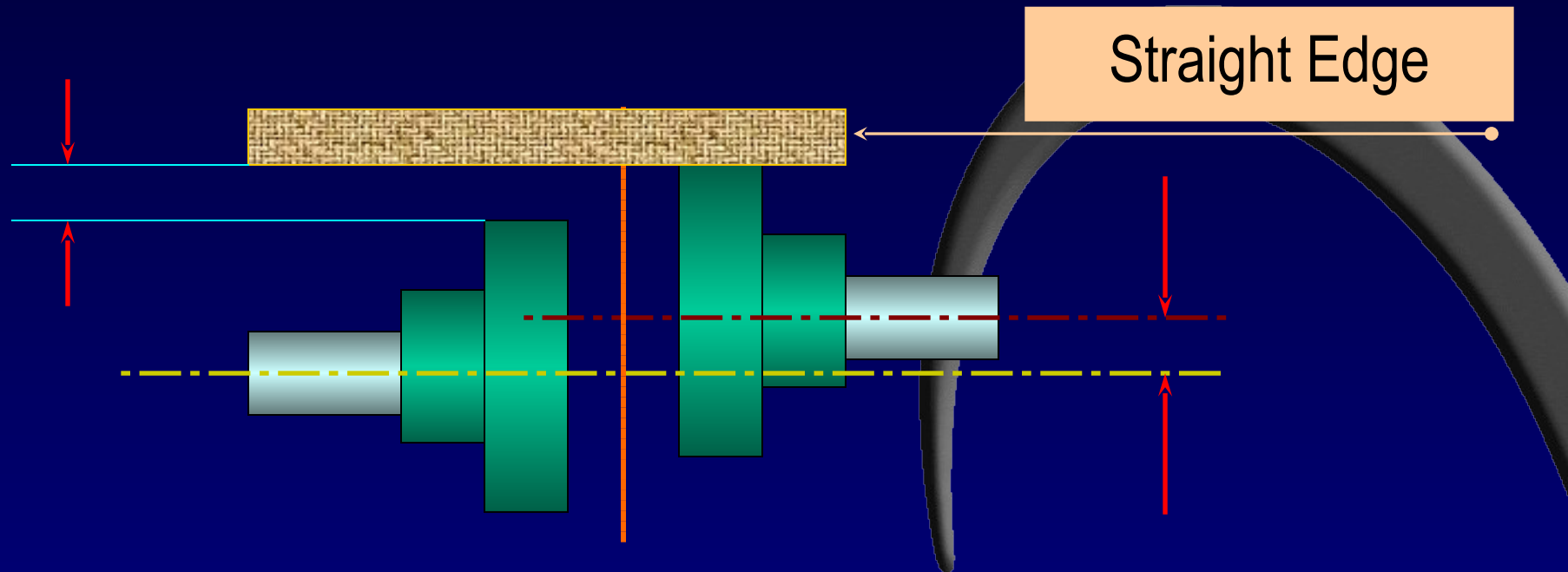
Return to main menu

Alignment Methods

- Approximate or Rough Alignment method
 - Use of Straight edge, Taper gauge & Filler gauges
 - Twin wire method
- Precision Alignment
 - Face & Rim Dial Indicator method
 - Reverse Indicator Method
- Laser Alignment method



Straight Edge, Taper Gauge & Filler Gauges

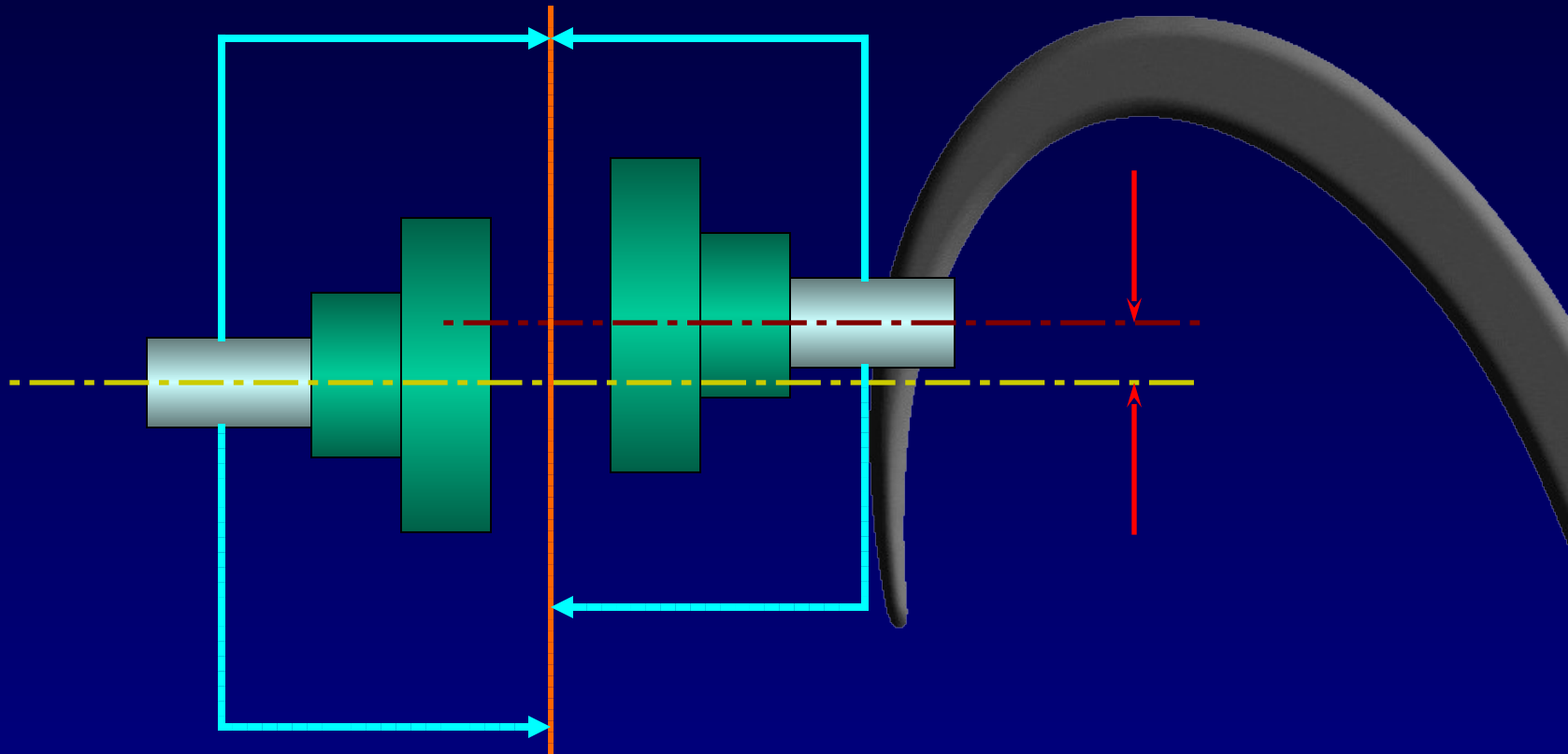


- Top & bottom coupling gap can be measured & adjusted accordingly.
- This tool can be used to rough align the machinery before precision measuring instruments are used.

Straight Edge, Taper Gauge & Filler Gauges

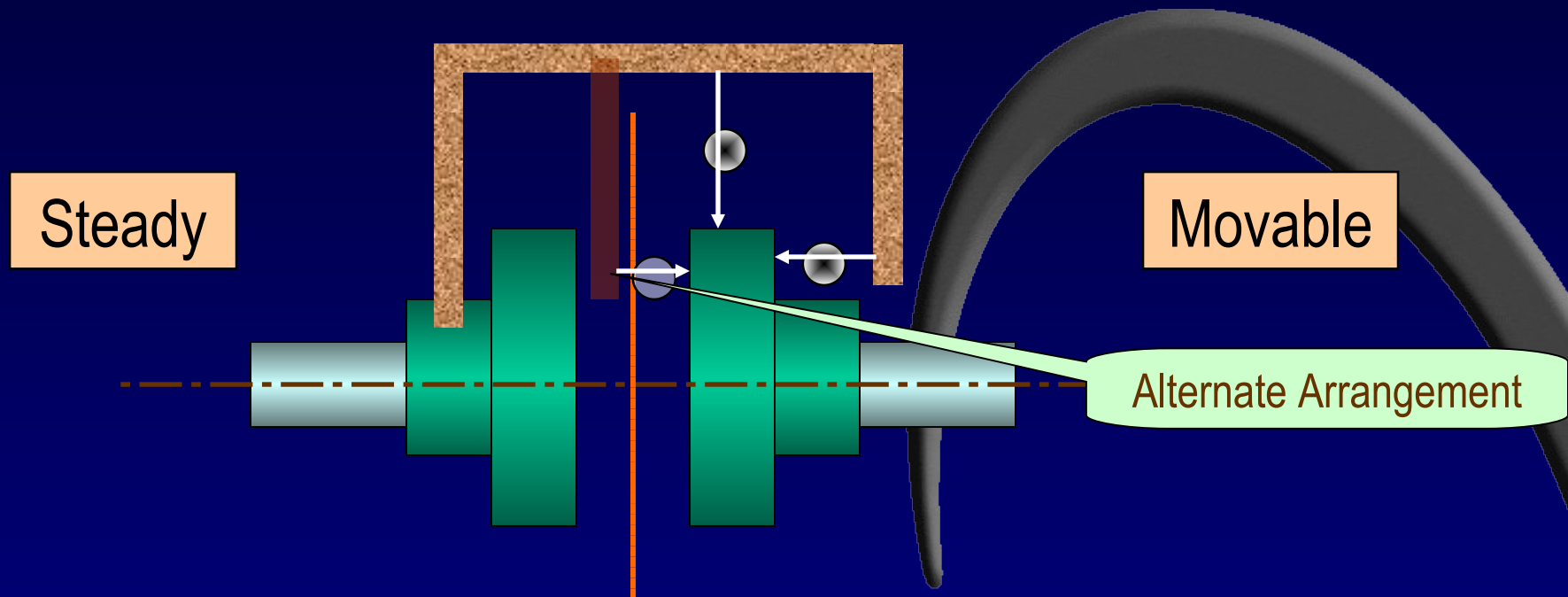
- When these instruments are used for alignment face & rim readings are affected considerably by...
 - Smoothness of coupling surfaces.
 - Trueness of coupling bore (concentricity and angularity).
 - Differences in outside diameters (OD) of the coupling halves.
- If coupling OD are different but shaft diameters are equal then straight edge can be used directly on the shafts before the hubs are installed on the shaft ends.

Twin Wire Method



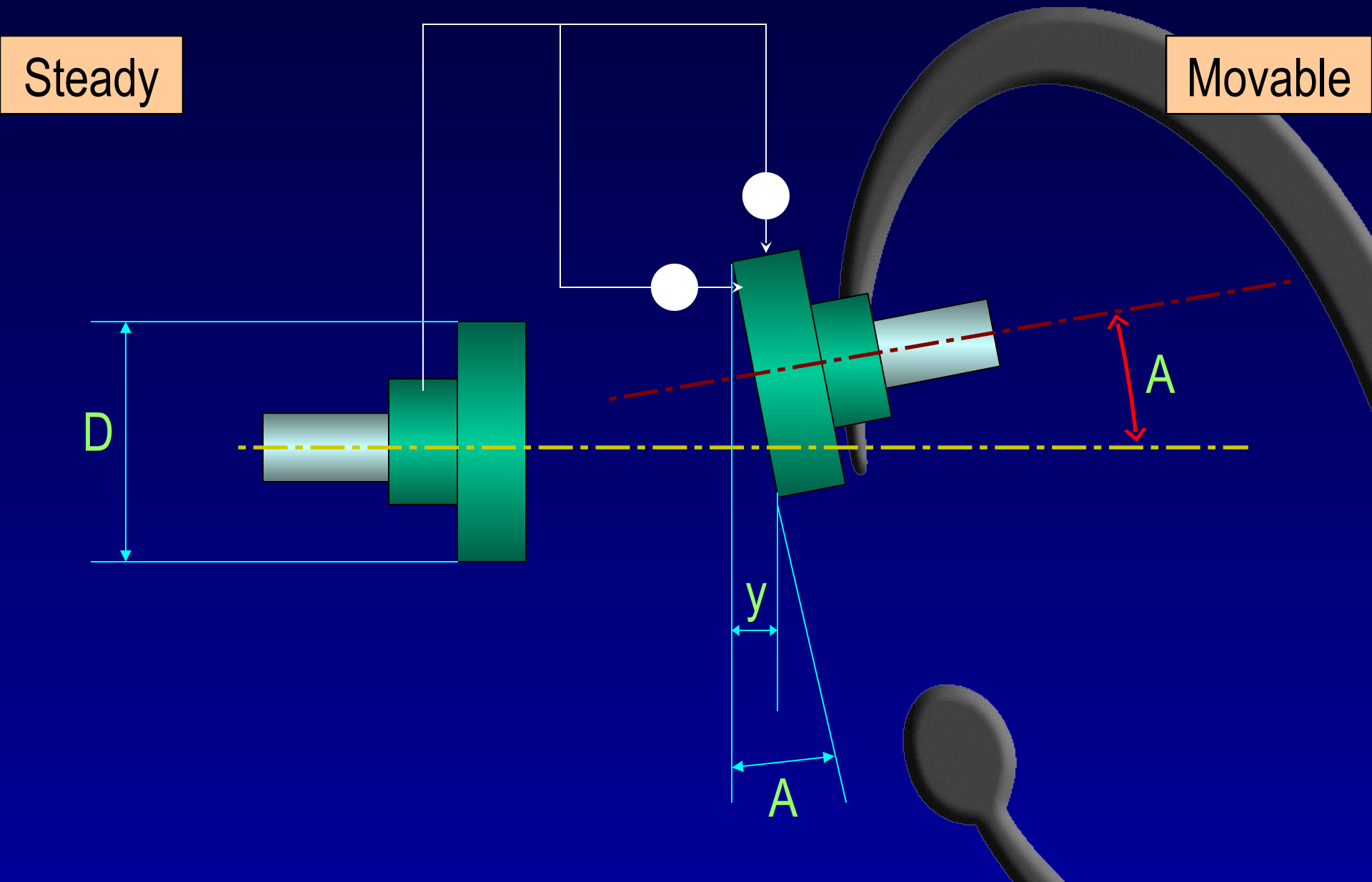
- This tool can be used to rough align the machinery before precision measuring instruments are used.
- Two wires are fixed on two shafts and after rotating 180 degree, the offset & angular misalignment can be measured.

Face & Rim Dial Indicator Method

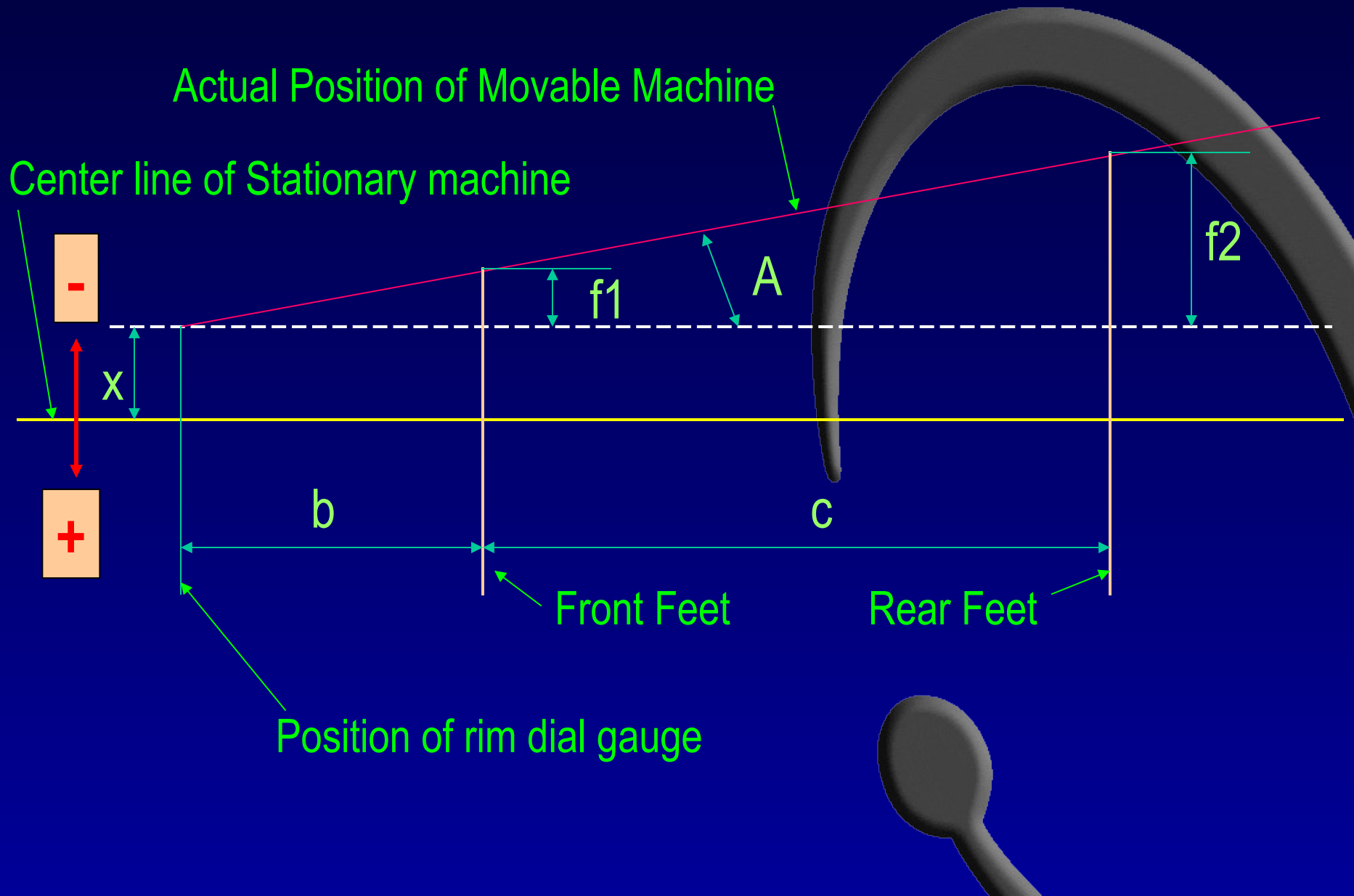


- Dial gauge fixed on the face will indicate angularity and dial gauge fixed on rim will indicate offset.
- Take the largest possible diameter on the face of coupling hub to take face readings. Record this for further moves.
- Sometimes two dial gauges are used for face readings to compensate for axial float.

Face & Rim Dial Indicator Method



Face & Rim Dial Indicator Method



Face & Rim Dial Indicator Method

- Reduce problem to only parallel misalignment.
 - Remove f_1 amount of shim from front leg & f_2 amount of shim from rear leg.
 - $f_1 = (y * b) / D$
 - $f_2 = (y * (b + c)) / D$
- Correct parallel misalignment by removing equal amount of shim ($x/2$) from both front & rear leg.
 - Remember that total relative up/ down position shown by dial gauge is in actual double the parallel misalignment present. Hence correct half amount with shims.

Face & Rim Dial Indicator Method

- Stand left side of the movable machine facing to wards stationary machine.
- Fix the fixtures of the dial gauge on the stationary machine and put the dial pointers on the movable machine.
- Use clock method and take four readings at 12 o'clock, 3 o'clock, 6 o'clock & 9 o'clock.
- Do rough horizontal adjustments.
- Take the readings for vertical adjustment for 12 & 6 o'clock position. Rotate both the shafts with one reference. Make dial gauge zero at 12 o'clock.

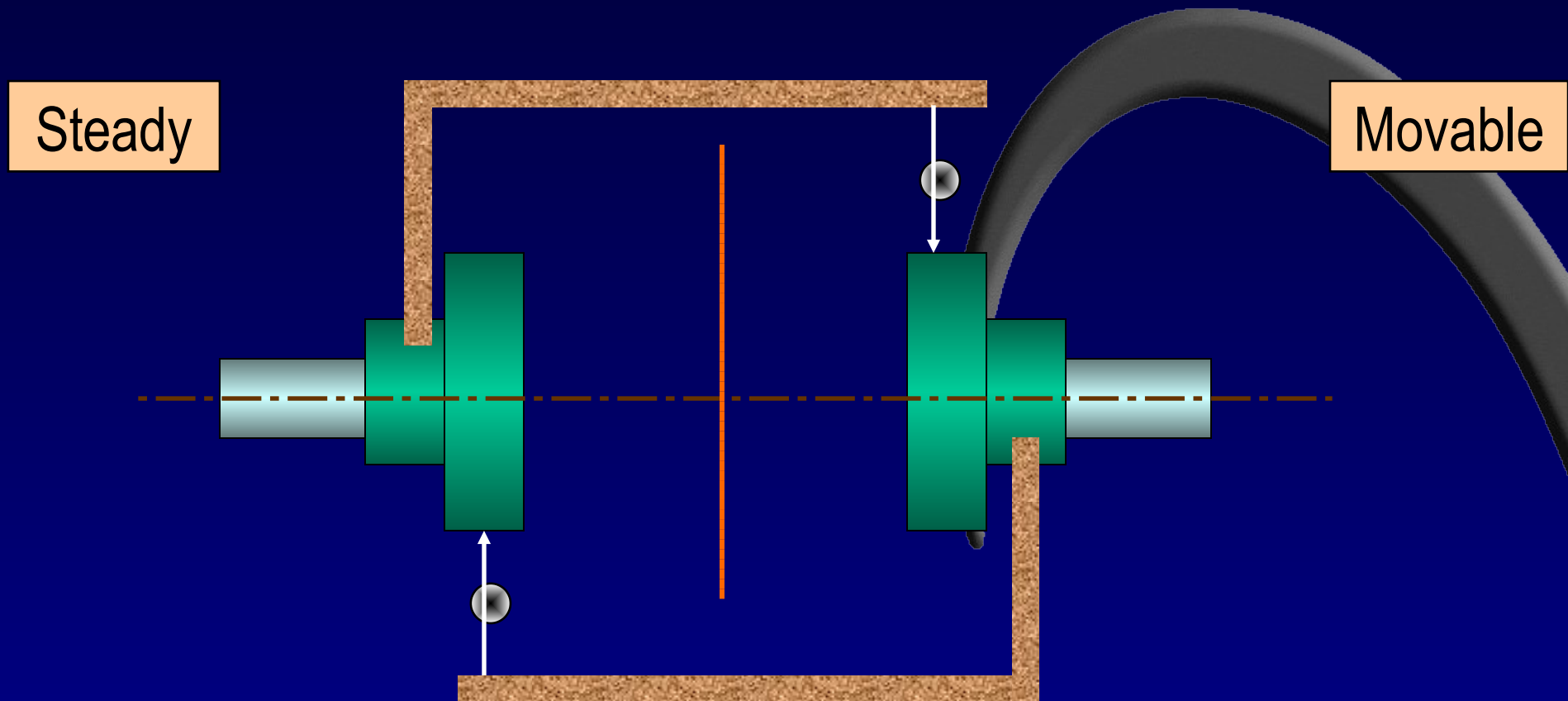
Face & Rim Dial Indicator Method

- First plot the rim readings as per sign convention shown in figure with some suitable scale.
- Consider the face readings and calculate the angle A , from relation $\tan A = y / D$.
- Plot the line at an angle as shown in figure and as per the sign convention. This is the original centerline of the movable machine.
- Do the shim adjustment as necessary.
- Similarly do the horizontal adjustments.

Face & Rim Dial Indicator Method

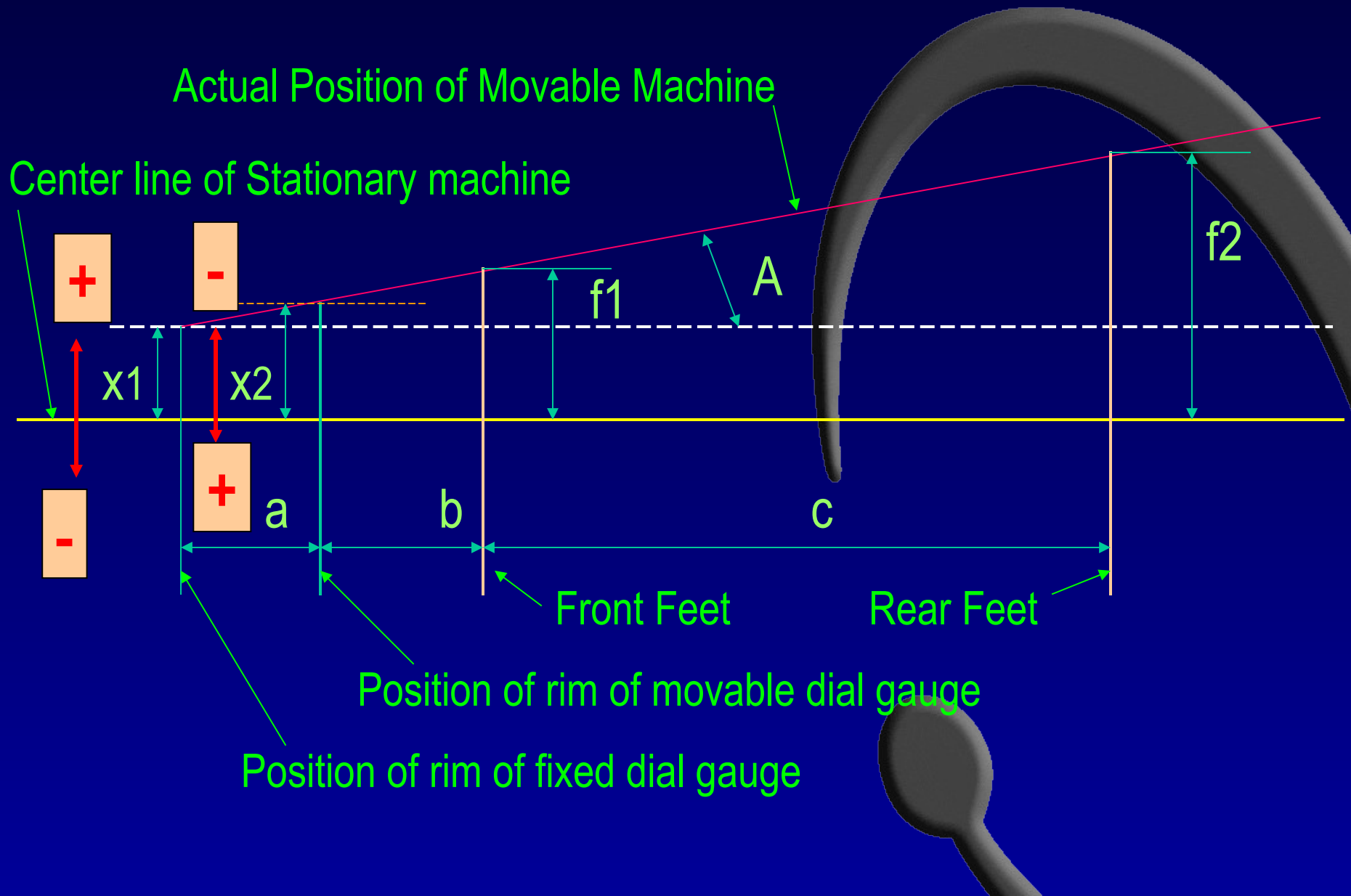
- Advantages.
 - Good for large diameter coupling hubs where shafts are close together so y & D will be larger.
 - Easier to visualize the actual shaft positions of the movable machine.
 - Can be used where one of the shafts cannot be rotated during alignment.
- Disadvantages.
 - Did not take care of axial float in motor bearings.
 - Requires removal of coupling spacer.
 - Not suitable for long distanced shaft.
 - Face & rim readings are effected by smoothness of the coupling halves & trueness of coupling bore if both shafts are not rotated.

Reverse Indicator Method



- Dial gauge is fixed on stationary as well as movable machine.

Reverse Indicator Method



Reverse Indicator Method

- Stand left side of the movable machine facing to wards stationary machine.
- Fix the fixtures of the dial gauge on the stationary machine and put the dial pointers on the movable machine.
- Use clock method and take four readings at 12 o'clock, 3 o'clock, 6 o'clock & 9 o'clock.
- Do rough horizontal adjustments.
- Take distances a, b, c and plot it on a graph paper as per scale on a straight line which indicates the centerline of the stationary machine.

Reverse Indicator Method

- Take the readings for vertical adjustment first by one by one dial gauge readings. Make the dial gauges zero at 12 o'clock position and rotate both shafts to 6 o'clock position. Use the sign conventions as shown in figure.
- First plot the reading of movable dial gauge (x2) & fixed dial gauge (x1) with suitable scale.
- Plot the line at an angle as per the sign convention shown in the figure extending up to rear feet. This will show the original centerline of movable machine.
- From the figure calculate the distance f1 & f2 and do shim corrections accordingly.
- Similarly do the horizontal adjustments.

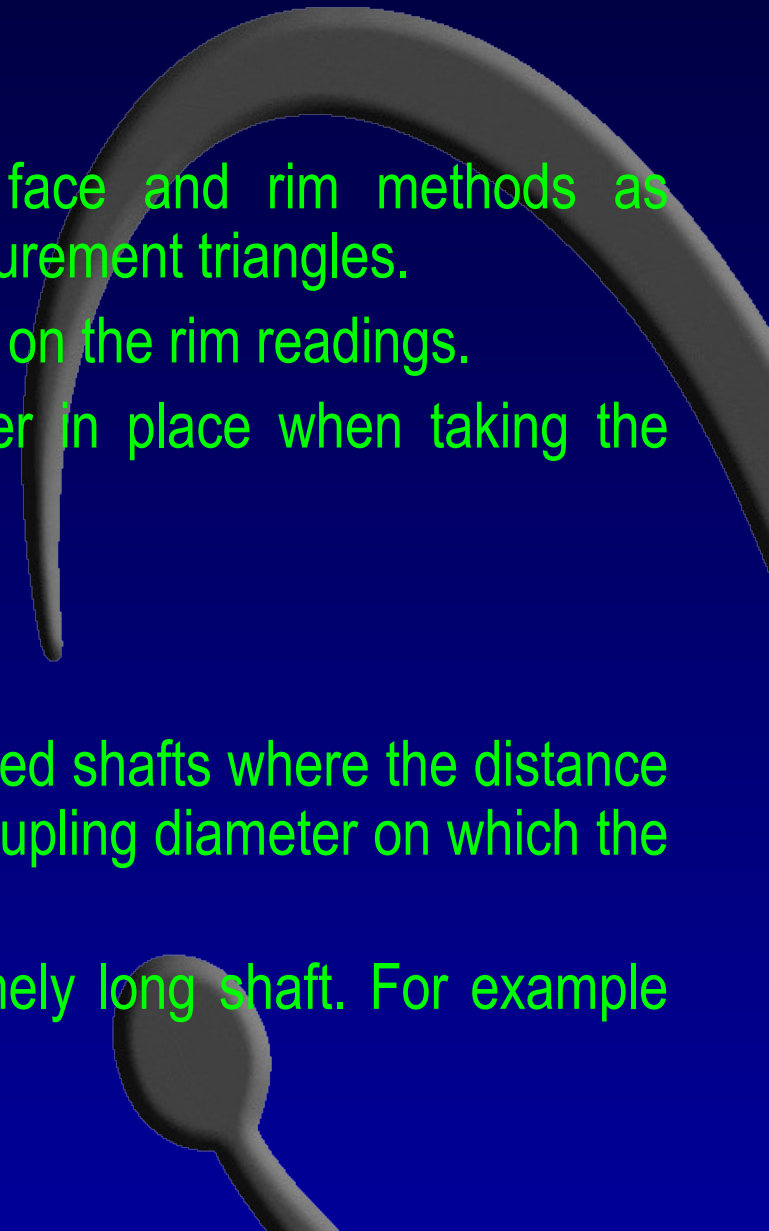
Reverse Indicator Method

- Advantages

- Geometrically more accurate than face and rim methods as readings are obtained on larger measurement triangles.
- Negligible effect of axial float of motor on the rim readings.
- Possible to keep the coupling spacer in place when taking the readings.

- Disadvantages

- Both shafts have to be rotated.
- Should not be used on closed – coupled shafts where the distance between the shafts is less than the coupling diameter on which the dial gauge is taking reading.
- Difficult to obtain readings on extremely long shaft. For example cooling tower drive system.



Laser Alignment Method

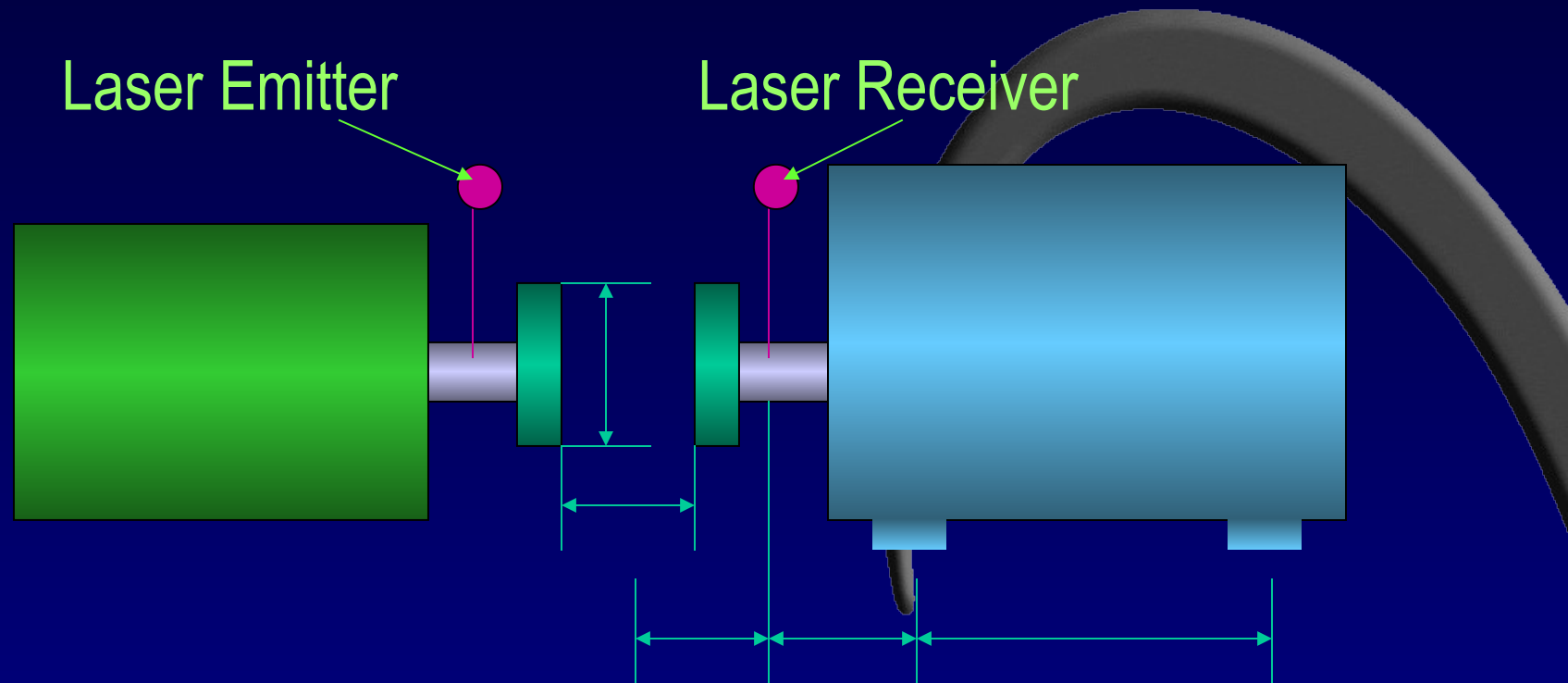
- Principle of operation
 - Consists of two transmitter & detector(TD) units and one display unit connected with TD.
 - Operating principle is similar to conventional reverse indicator method.
 - After mounting on two shafts, the transmitter prism can be adjusted both laterally and vertically to center the laser beam on the position sensitive detector (PSD).
 - Readings are obtained by generating a coherent beam from an infrared emitting semiconductor laser and reflected back in to the detector via a prism.
 - When two shafts are rotated 180 degrees the laser beams & detectors will describe two half circles. Center of these half circles represents rotational center of the shafts.

Laser Alignment Method

- Principle of operation

- The detectors measure the relative position of the two half circles. Display units calculates the irregularity from the distance between the two TD units and the difference between the measured value.
- Measured values are represented as offset and angular error on the display.
- Display unit also shows the position of the movable machine feet.
- Values can be displayed on real time scale.
- Shaft rotation as small as 60 degree can also give accurate readings.

Laser Alignment Method



Above figure shows input dimensions required for display units.

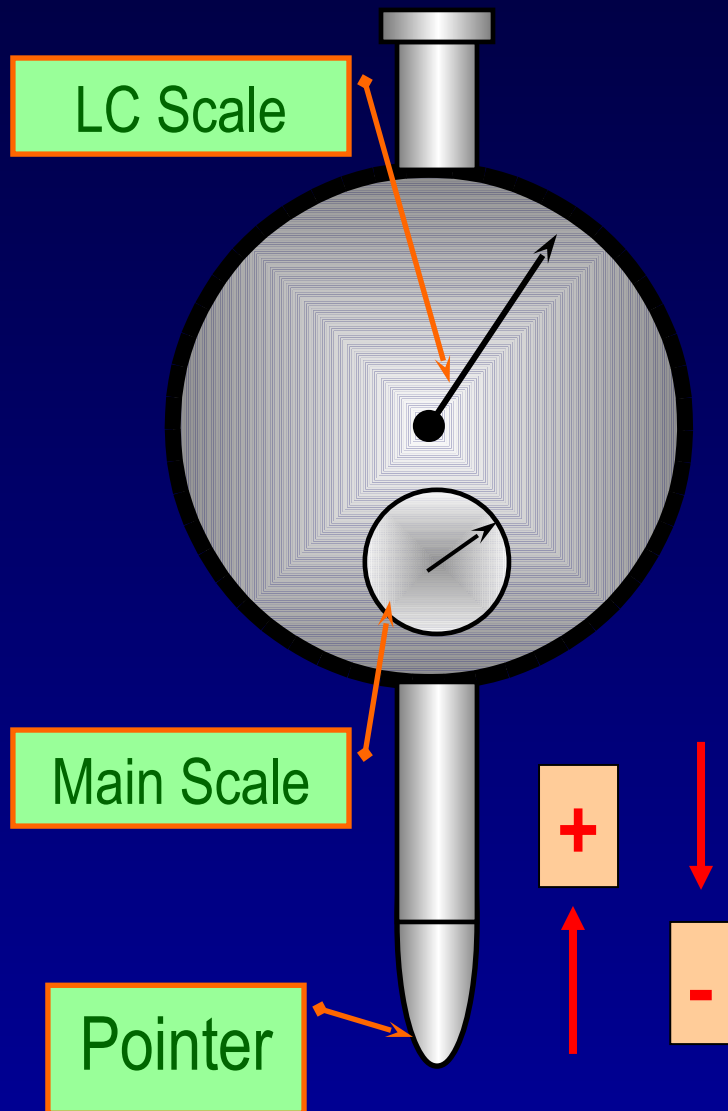
Laser Alignment Method

- Advantages

- Easy to use & interpret the results.
- Easy to fix and remove the entire system by quick connection fixture.
- No requirement of complex calculations, all done by machine.
- No indicator sag as linkages are replaced by optics.
- No need to remove the coupling spacer and DBSE of the range is 10 to 20 m can be possible.
- Readings not affected by float.
- Feature of detecting & correcting soft foot.
- Can be used for horizontal & vertical machines.
- Feature of using thermal alignment corrections for hot alignment.
- Feature of extra polating readings for doing corrections for stationary machine if not possible for movable machine.

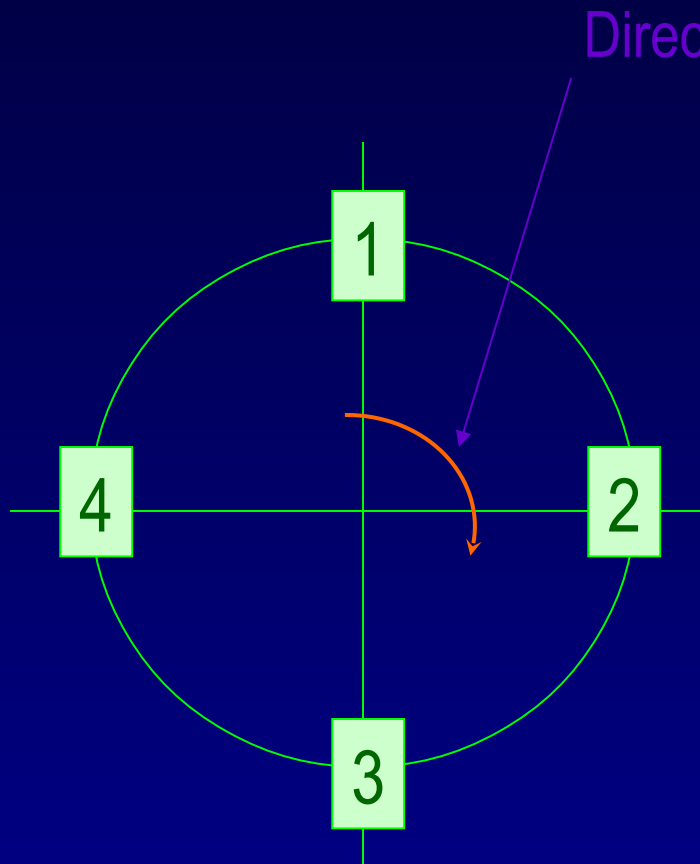
Return to main menu

Understand Dial Indicator First...



- Dial indicator have one graduated dial with two different scales. One for main scale and another graduated to least count (LC) of the dial indicator.
- Pointer up & down movement is read by adding LC to main scale.
- If pointer is pressed meaning moving up, scale pointer turns clockwise and it reads + ve.
- Always give pretension to pointer and record initial reading.

How to record & read alignment readings ?

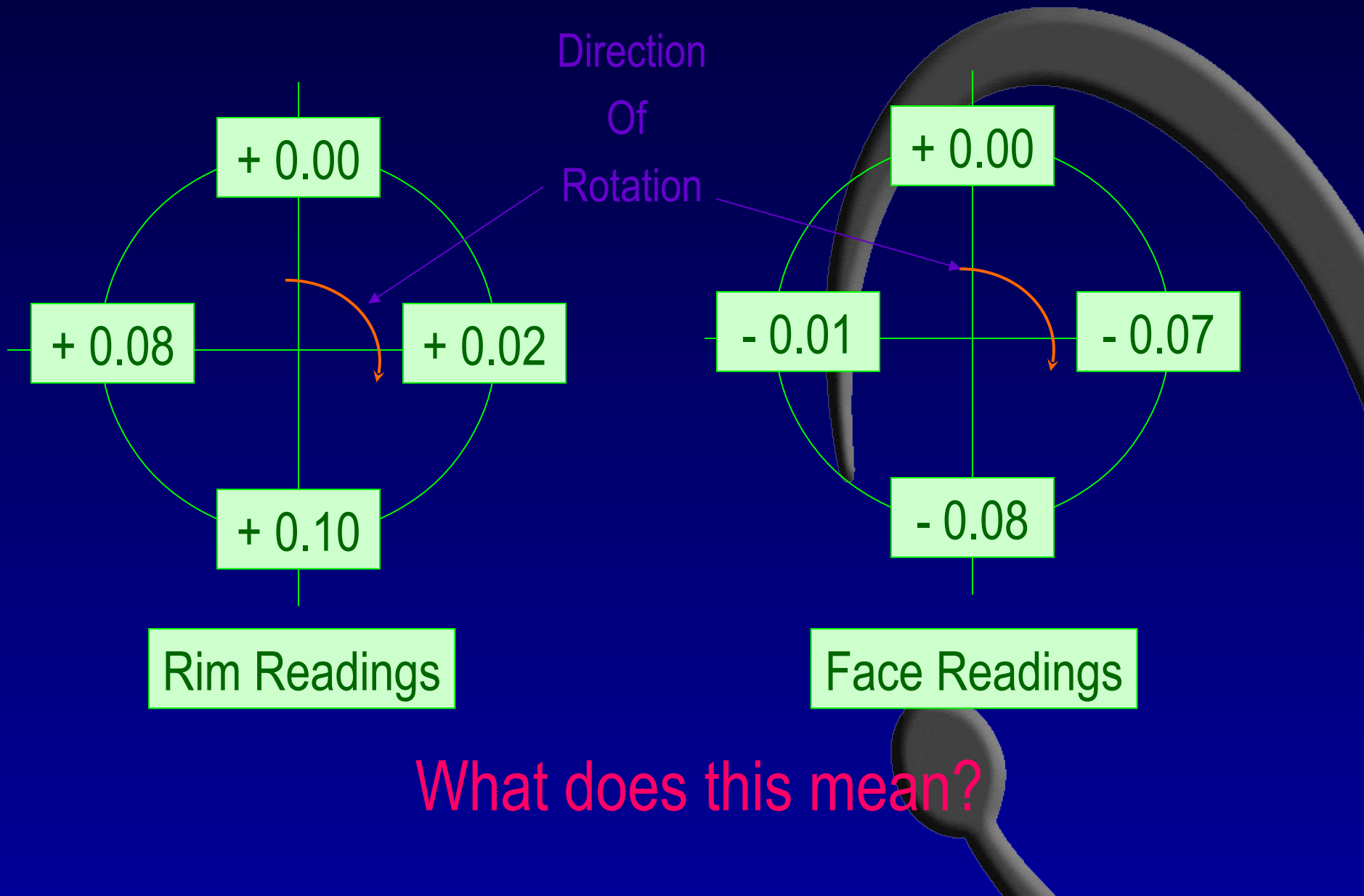


Direction Of Rotation

- @ Record the dial gauge readings at 1 to 4 positions.
- @ 1 & 3 shows relative top & bottom misalignment.
- @ 2 & 4 shows relative side wise misalignment.
- @ We consider 1 as reference or 0 dial reading.
- @ Thumb rule : $(2 + 4) = (1 + 3)$.
- @ We align the m/c to bring 1 to 4 in tolerance range.
- @ View from moving to stationary machine.
- @ Rim readings show radial misalignment.
- @ Face readings show axial misalignment.

- Understand the type of misalignment based on face & rim dial Reading.
- It is a good practice to correct axial misalignment first & radial then after.

Face & Rim Dial Indicator Method

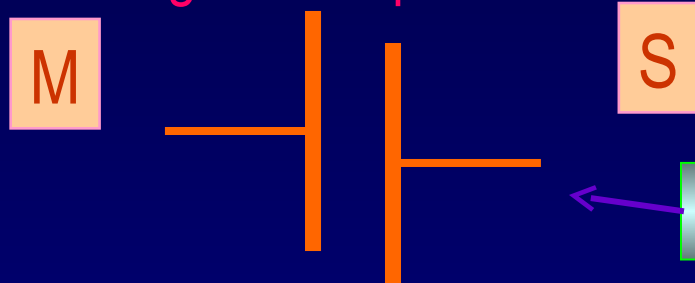


Face & Rim Dial Indicator Method

Rim Readings

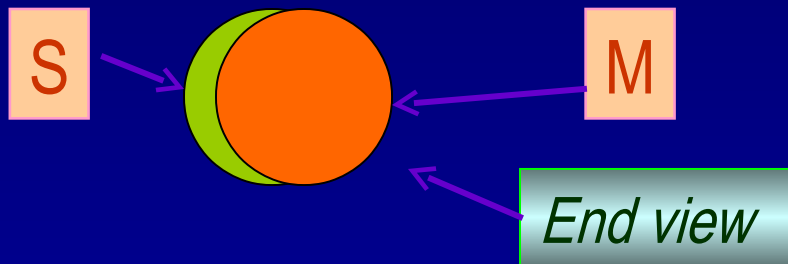
Top-bottom misalign = 0.10;

Moving m/c is up.



Side view misalign = 0.10;

Moving m/c is little right side.



Face Readings

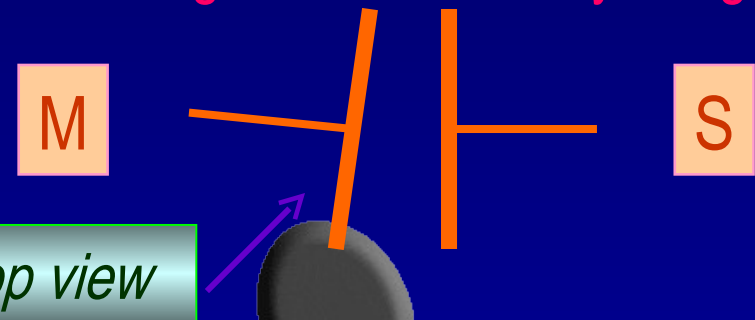
Top-bottom misalign = 0.08;

Moving m/c is away at bottom.



Side view misalign = 0.08;

Moving m/c is little away at right.

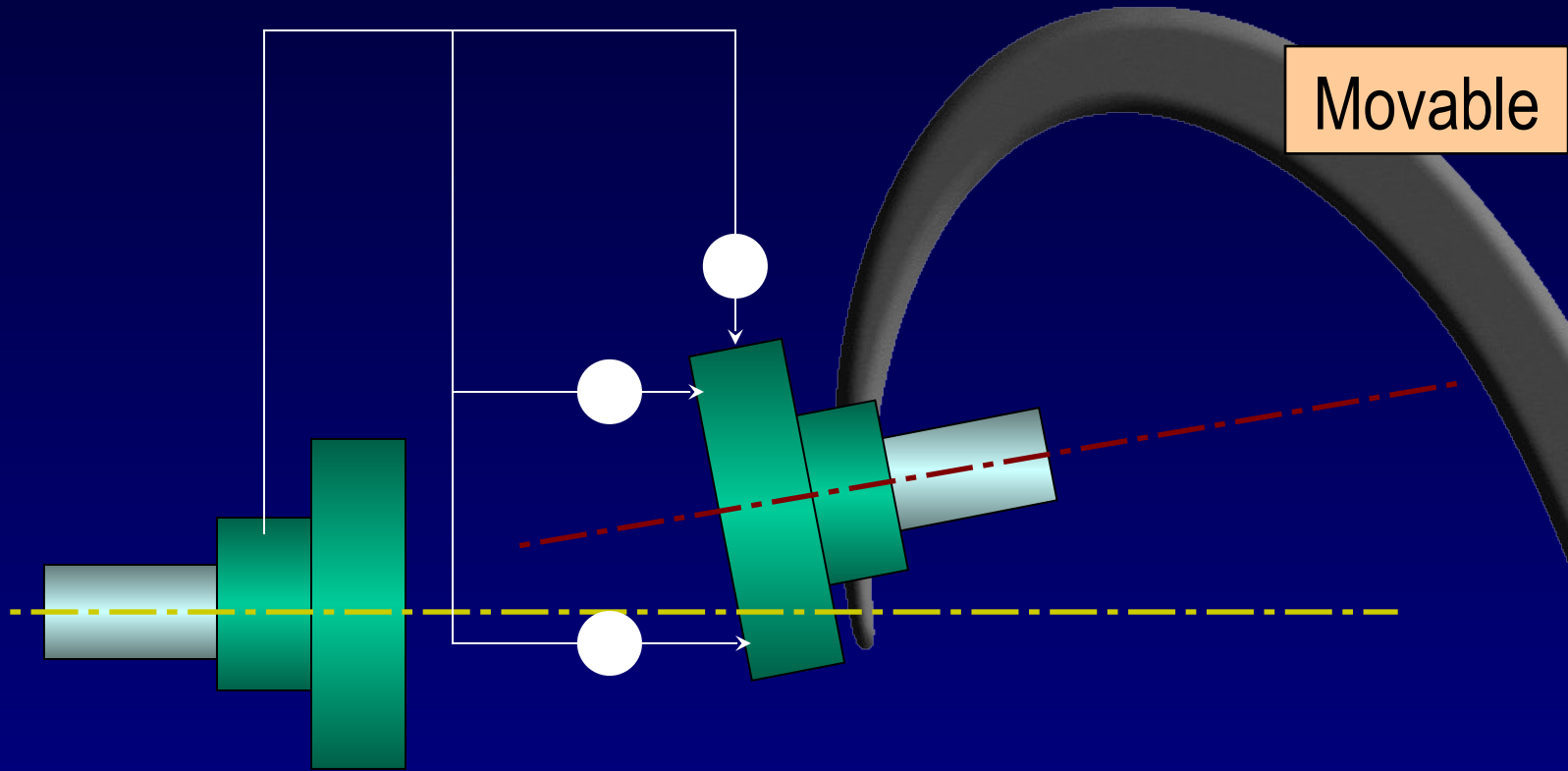


Axial misalignment need to be corrected first and then the parallel.

Face & Rim Double Dial Indicator Method

Steady

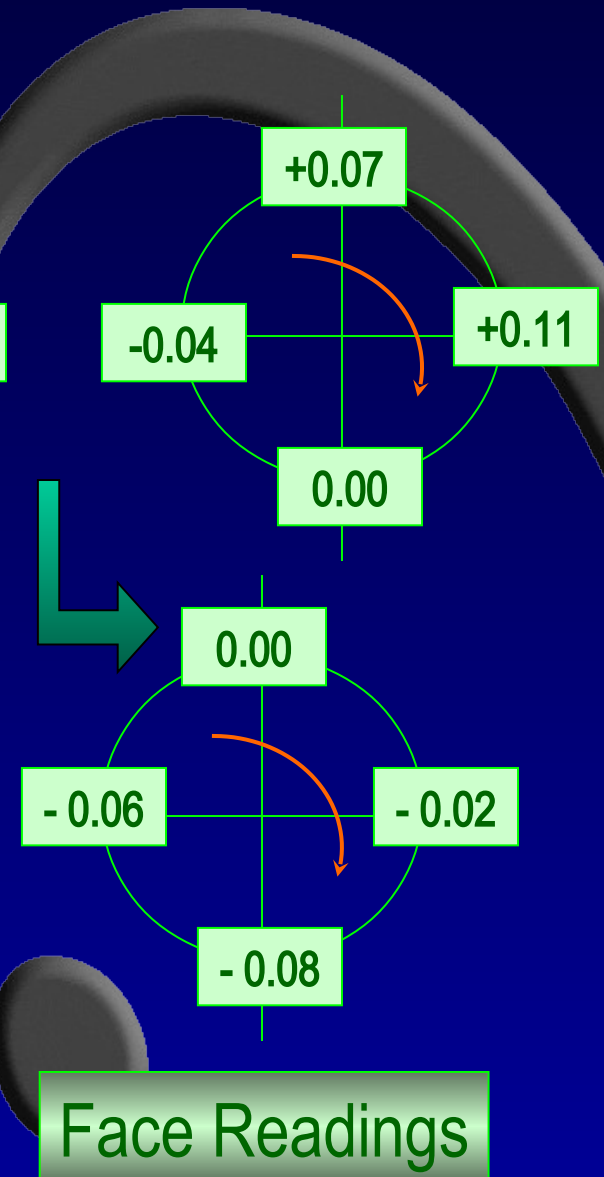
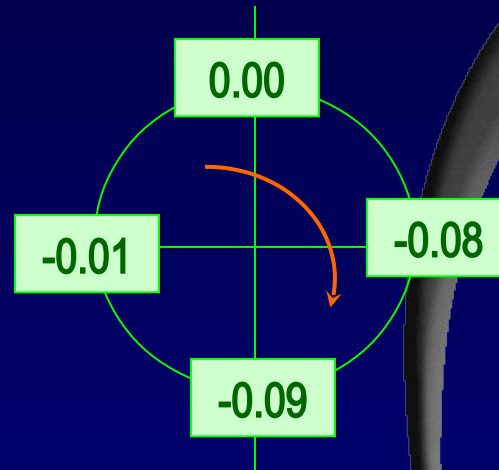
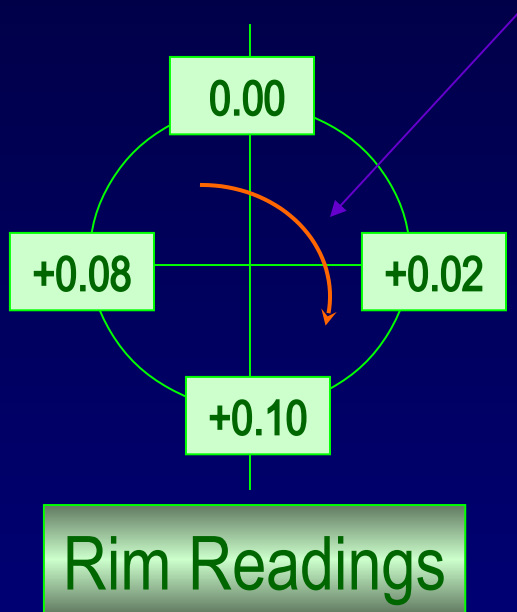
Movable



It is a common practice to use two dials for face readings to get rid of the axial float in the rotor. Subsequently, two readings are taken as half after subtracting corresponding position dial readings.

Face & Rim Double Dial Indicator Method

Direction of Rotation



Position 1 to 4 are in the direction of rotation starting from 0 dial reference. For two axial dials, 0 dial references are 180 degree opposite as shown.

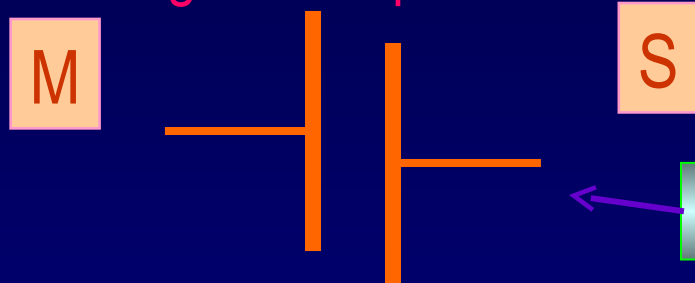
Final axial readings will be half value of the difference between readings of same position. E.g. for position 3 final reading is, $(-0.09) - (+0.07) / 2 = (-0.08)$

Face & Rim Double Dial Indicator Method

Rim Readings

Top-bottom misalign = 0.10;

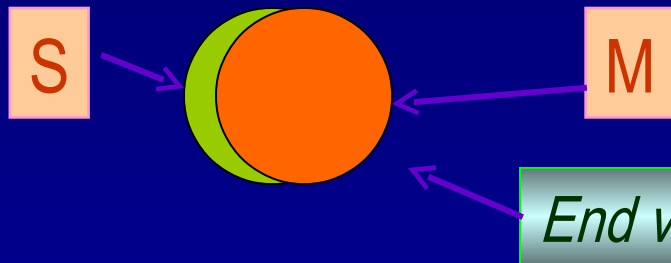
Moving m/c is up.



Side view

Side view misalign = 0.10;

Moving m/c is little right side.

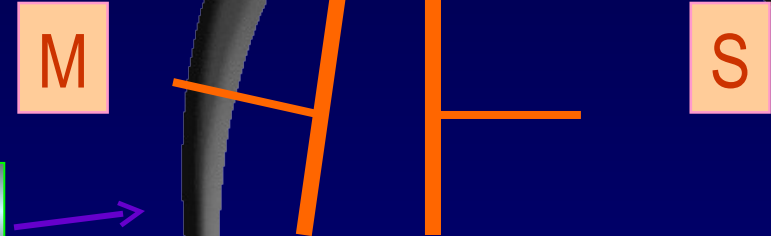


End view

Face Readings

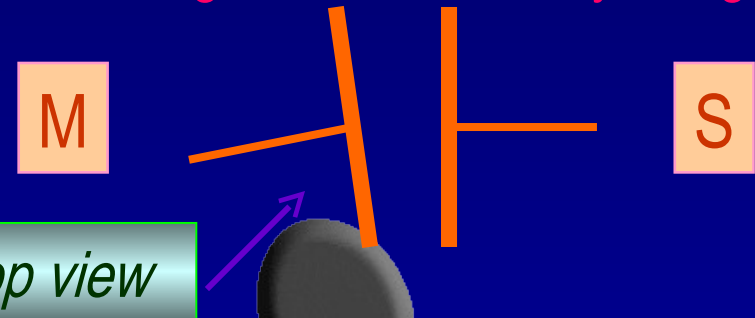
Top-bottom misalign = 0.08;

Moving m/c is away at bottom.



Side view misalign = 0.08;

Moving m/c is little away at right.



Top view

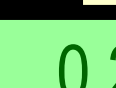
Axial misalignment need to be corrected first and then the parallel.

Laser Alignment Method.....

Static machine vertical position
viewed from side and resting on feet

Movable machine vertical alignment
viewed from side and resting on feet

Vertical alignment as viewed from Side

V		-0.11		-0.09		0.21		0.23
		MM		MM				
H		-0.09		-0.04		0.20		0.22

Horizontal alignment as viewed from Top

Static machine Horizontal position
viewed from top with four machine feet

Movable machine horizontal alignment
viewed from top with four machine feet

Laser Alignment Method.....

Vertical gap = 0.11 mm
at bottom

Vertical offset = 0.09 mm.

Movable machine low

Front feet vertical
position = 0.21 mm high

Rear feet vertical
position = 0.23 mm high

V		-0.11		-0.09		0.21		0.23
		MM		MM				
H		-0.09		-0.04		0.20		0.22

Horizontal gap = 0.09 mm
nearest viewer

Horizontal offset = 0.04 mm
toward viewer

Front foot horizontal
position = 0.20 mm
away from viewer

Rear foot horizontal
Position = 0.22 mm
away from viewer

- Positive values are upwards or away from viewer
- Negative values are downwards or toward viewer

Return to main menu

Alignment Tolerances

- The tolerances are the maximum allowable deviation from desired values, whether zero or targeted offset for thermal growth.
- Best practice is to use the alignment tolerances as specified by equipment manufactures.
- The table below can be helpful if no limits are specified.

	Offset	Angular
RPM	mm	mm/100 mm
0000-1000	0.13	0.10
1000-2000	0.10	0.08
2000-3000	0.07	0.07
3000-4000	0.05	0.06
4000-5000	0.03	0.05

Axial Float of Shaft

- Almost all machines with journal or sleeve bearings have some float, but it may be manageable, by applying sufficient pressure at the end of the shaft during its rotation to keep it firmly seated against the thrust bearing or plate.
- In case of large machinery or machinery which needs to be energized to obtain the desired rotation, application of sufficient pressure on the shaft is often difficult and dangerous.
- However, axial float doesn't affect the rim readings much as compared to face readings.

Axial Float of Shaft

- If axial float is manageable, a choice of methods for both of the two dial indicator method can be used. However, if the distance between the points of contact of the two dial indicators set to take rim readings for the reverse indicator method is larger than the diameter of travel of the dial indicator set up to take face readings for the face & rim method, then reverse indicator method should be used.

Different Types of Couplings

- Flexible : Tyre, Pin bush, Lovejoy, ESBI Valkan
 - Semi Flexible : Fluid
 - Rigid : Geared, Resilient, Hydraulic, magnetic
-

Flexible coupling can handle some misalignment but will generate heat and it will increase forces on the shaft.

This will create vibrations and coupling elements, seals, bearings will fail prematurely.

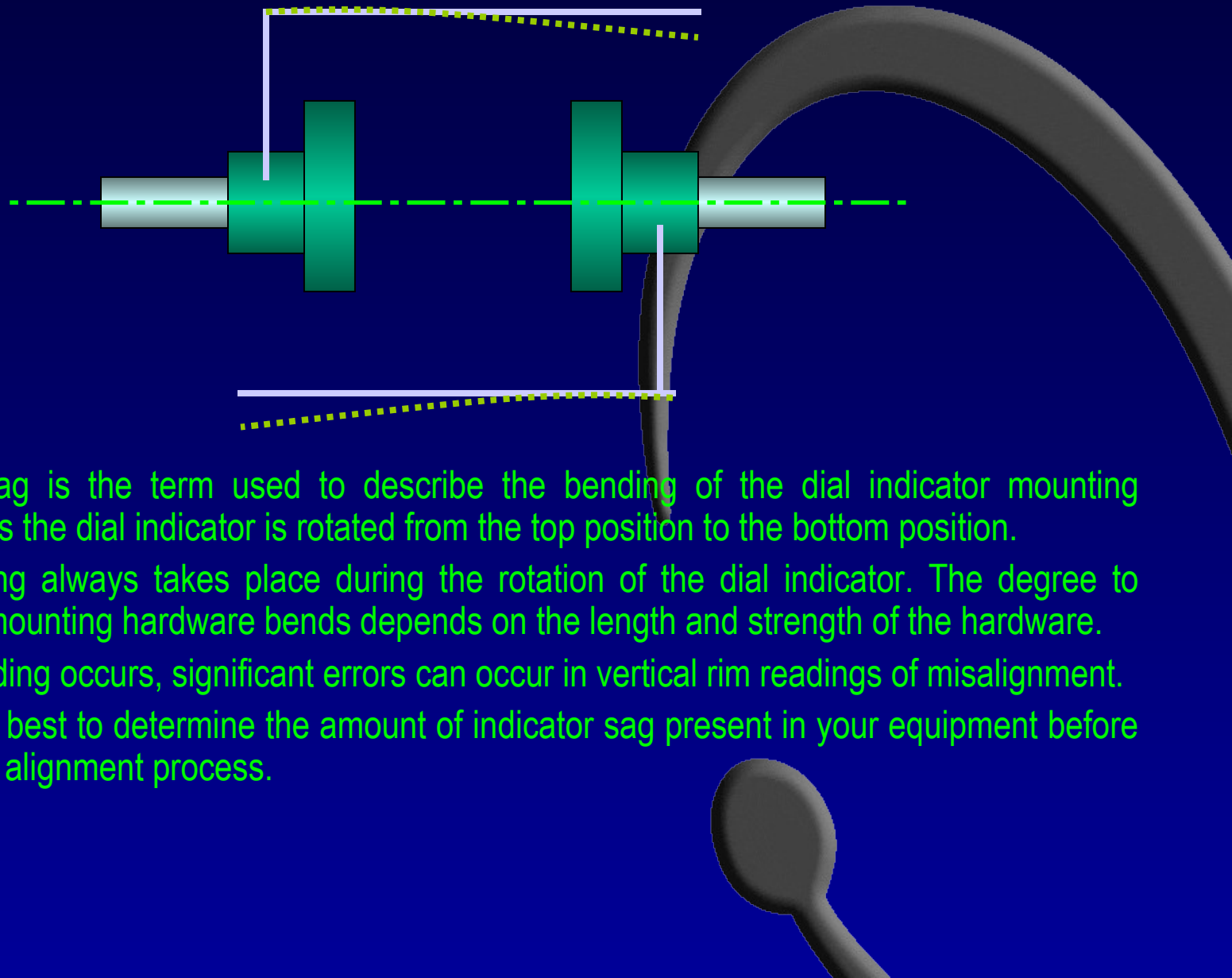
Shaft Alignment Vs. Coupling Alignment

- If all couplings are bored straight and true through their exact center with perfectly machined rim and face, it may be possible to align the two coupling halves and obtain correct machinery alignment.
- But irregularities in the machining process and even the forces imposed on the coupling halves during installation have large margin of error. Coupling alignment should be avoided because of this.
- This is not to say that dial indicators should not be placed on the coupling halves to obtain measurements; But two shafts should be rotated simultaneously to obtain the desired readings. In this manner, the couplings actually become an extension of the shaft centerlines and irregularities do not affect the readings.

Alignment With Shaft-mounted Brackets

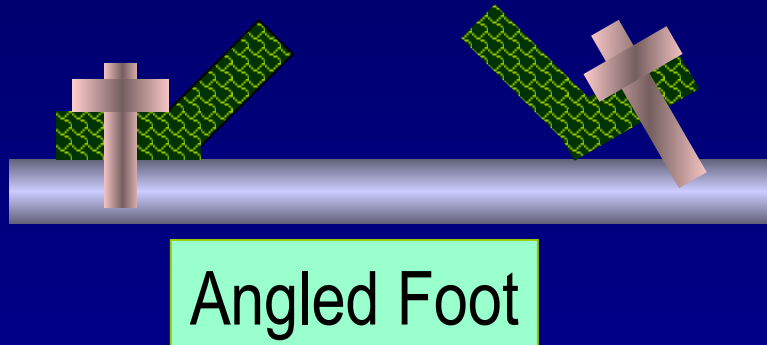
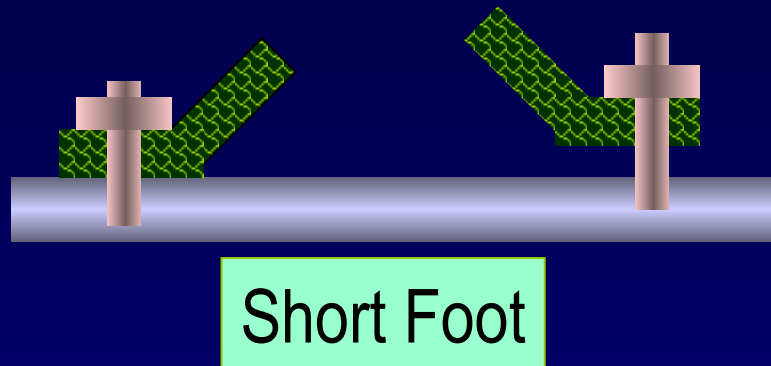
- Any object that is securely attached to the shaft and rotated with the shaft, in theory, becomes a part of the shaft. So specially designed brackets can be used for alignment.
 - They are adjustable, and can be easily mounted on shafts of varying size. Also dial indicators can be mounted on them.
 - The use of brackets permits easy and accurate “indicator Sag” checks.
 - Because brackets with attached dial indicators can be quickly installed and flexible couplings do not have to be disassembled to obtain readings, more accurate “Hot alignment” checks can be made.
 - They can be mounted either on shaft or coupling hubs, provided they are not loose.

Indicator Sag



- Indicator sag is the term used to describe the bending of the dial indicator mounting hardware as the dial indicator is rotated from the top position to the bottom position.
- This bending always takes place during the rotation of the dial indicator. The degree to which the mounting hardware bends depends on the length and strength of the hardware.
- As the bending occurs, significant errors can occur in vertical rim readings of misalignment.
- It is always best to determine the amount of indicator sag present in your equipment before starting the alignment process.

Soft Foot

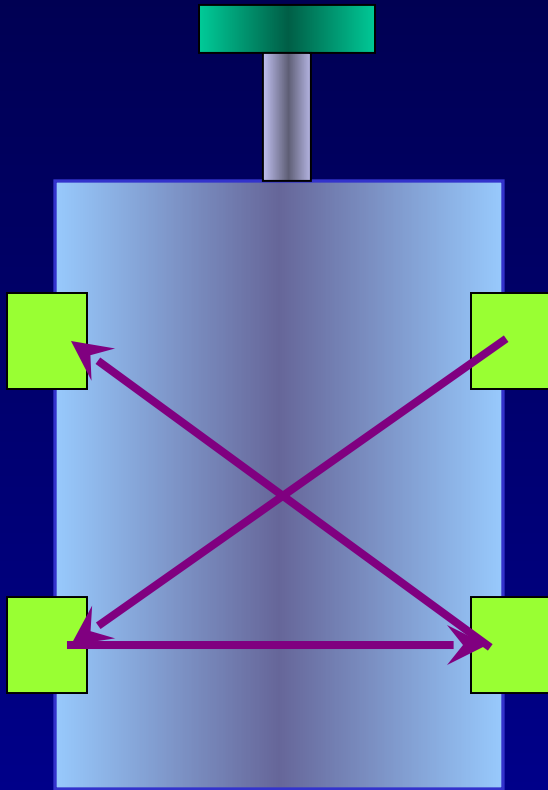


- It is the term applied to that conditions that exists when all four or six feet of the machine are not supporting the weight of the machine.
- If this is not corrected prior to alignment, will lead to frustration, loss of time and running in this way may yield cracks at the soft foot due to fatigue resulting from loose nut/ bolts.

Soft Foot

- **Determining & correcting Soft-Foot**
 - Remove all dirt, rust and burrs from the bottom of the machine's feet, the shims to be used.
 - Set the m/c in place, but do not tighten the hold-down nuts. Attempt to pass a thin feeler gauge underneath each of the four feet. Determine exact amount of gap beneath the foot feeler gauges and place the amount of shims. This will be considered as being the initial soft-foot correction.
- **Final Soft-Foot correction**
 - Tight all hold down nuts in sequence with a torque wrench.
 - Measure the movement of each foot with dial indicator after loosening it one by one. Add the additional shims as per the movement noticed.
 - Retighten the hold down nut and repeat the entire process once more, to be sure no movement is present as soft-foot.

Tightening of Holding Down Nuts



- Correct tightening sequence will help to insure that any unequal stresses that may cause a shifting of the movable machine during the tightening procedure.
- Tighten all nut-bolts with same amount of force.
- Loosen them in opposite sequence.
- Always tighten the nuts before you take readings, though final adjustments are not done.

Hot Alignment

- When machine is subjected to high temperature it will grow upwards resulting in level differences between the cold & hot state and can create misalignment in hot condition.
- One way of achieving the correct alignment in hot condition is to pre misalign the machine in cold state based on the calculation of thermal growth of stationary & movable machine.

Thermal Growth

- Thumb rule for calculating thermal expansion
 - 1.0 mm for every meter length for 100 degree C rise.
- Axial Expansion provision in Bearing
 - Increase in temperature will result in thermal expansion of the rotor.
 - Adequate provisions are given by OEMs to respond it in hot condition.
- Duct Loading due to thermal Expansions
 - Thermal expansion of Pipelines & Ducting may impose forces on the casing.
 - Expansion joints, spring supports etc. are the used practices to counter them.

General Rules for Good Alignment

- Be sure that machine base and bottom are clean and free of any rust or burrs. Wire brush/ files may be used for this.
- Use only clean shims without any burrs.
- Minimize the number of shims by using appropriate thickness.
- Check & correct soft-foot prior to alignment.
- Always use correct tightening procedure for holding down nuts.
- Determine the amount of indicator sag before starting the alignment.
- Always try to put dial pointer at 90 degree angle to the surface.
- Use jack bolts for lifting & shifting the machine for up-down, side wise or angular movement.
- Maintain Distance between shaft end (DBSE) while alignment, =
Coupling spool length + ((Total Axial float of connecting m/cs)/ 2)

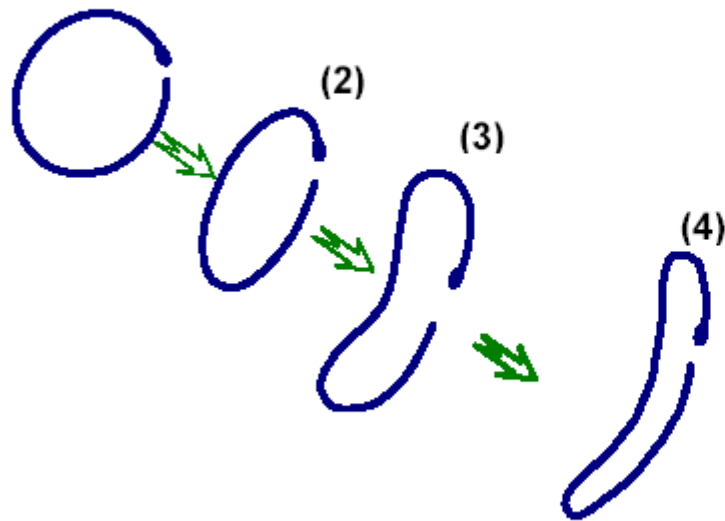
Return to main menu

Scientific Diagnosis of Misalignment

- Changed preload condition as viewed from Orbit

A. Abnormal Orbital Motion

(No Resonance Near Twice Rotative Speed)

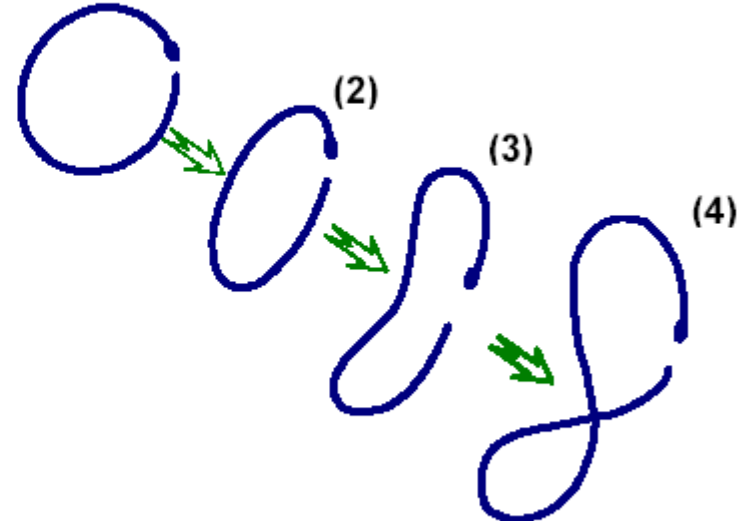


Rare

Common

Rare

(Resonance Near Twice Rotative Speed)



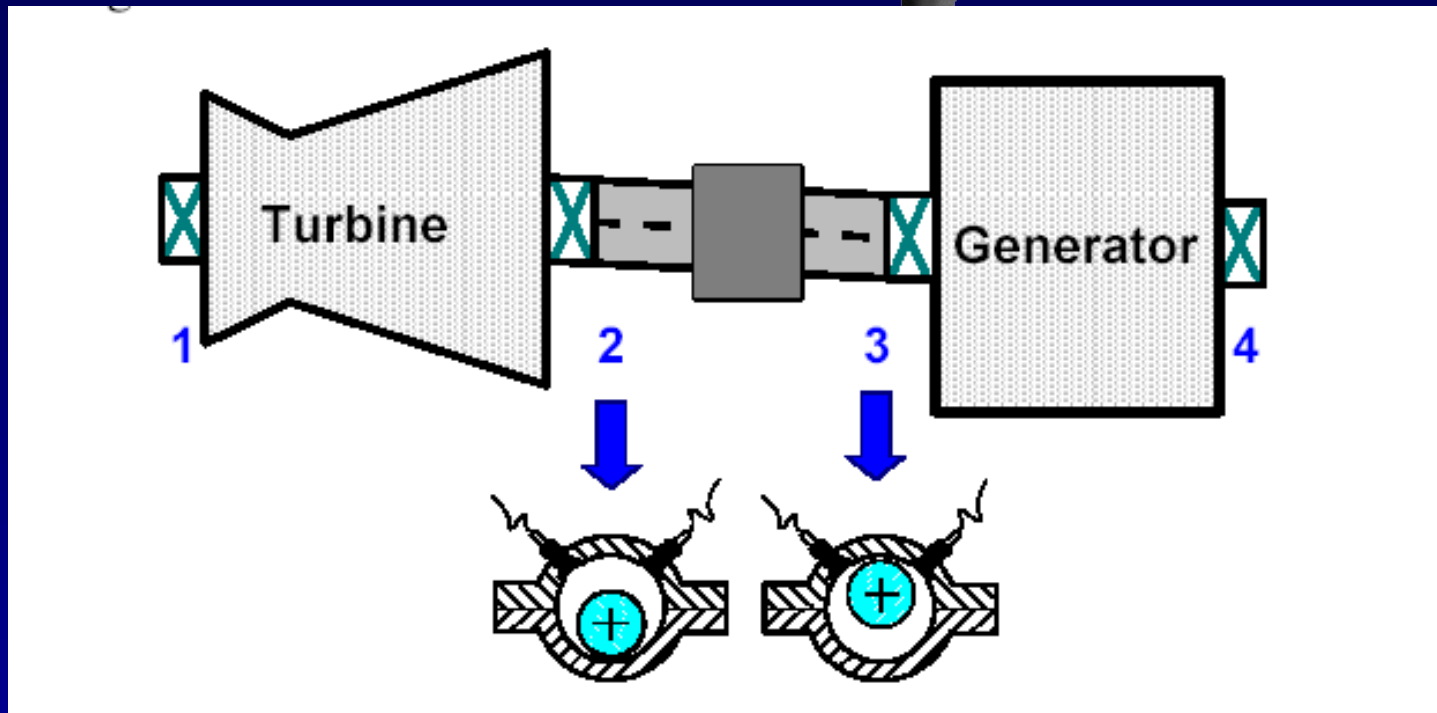
Rare

Common

Rare

Scientific Diagnosis of Misalignment

- Changed shaft centerline position across the coupling as viewed from the average shaft center line plots



Return to main menu

Scientific Diagnosis of Misalignment

- By vibration spectrum analysis (Look for Changes...) Applicable for Casing Vibrations Mainly where we don't have Shaft C/L across the coupling and orbits:
 - There is high energy, low frequency radial & axial vibration amplitudes.
 - Misalignment can causes axial / radial vibration at the running speed frequency (1X) mainly.
 - Pure parallel misalignment can produces radial vibration at twice or three times the running speed frequency (2X, 3X)
 - Relative phase for 1x, X-Y casing probes might be much higher than 90 degree...approaching to 180 deg based on severity of the preload

Scientific Diagnosis of Misalignment

- Wear Particle Analysis (Oil Analysis..a supporting tool)
 - Curly cutting wear particle of aspect ratio – 5:1 to 50:1 might be seen in the Ferro gram.

Thank you !!!

Bently Nevada

