REVERSE INDICATOR COLD ALIGNMENT WITH GRAPHICAL PLOTTING

by

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INTRODUCTION

An update and a demonstration of the reverse indicator alignment method with graphical plotting are presented. Hot alignment methods are not covered, but it should be clear that heat rises (falls) can be plotted directly on the graph. Only sizing (scale) differentiates the alignment of pumps from compressors. The scaling presented herein is typical.

Reverse indicator tooling and an alignment training model will be discussed. The concentration here is on the pure steps of alignment. The training model allows the movement of a motor relative to a pump. The pump is fixed and the motor is the movable unit with the coupling feet (near) and outboard feet (far) adjustable by screw travel. Each foot can be adjusted vertically up and down with traversing indicators, as well as horizontally, left and right, with traversing indicators.

A flexible coupling remains in place as the shaft is rotated with reverse indicator bars in place. The reverse indicator weights are carried by the motor and pump shafts, i.e., the reach bar only supports its own weight, reducing "bar sag." Reverse indicator dials, as well as motor foot travel indicators, read out in mil subdivisions (1 mil $=0.001$ in $=25.4\mu$M).

While computer programs for two case alignment checking are available, it is not the preferred method for many situations. Graphical plotting is quite simple, equally as fast, leaves a clear maintenance record, can expand to any number of units in a train and allows for any combination of heat movements.

PRE-ALIGNMENT PREPARATIONS

If one has been successful in aligning equipment, considerable time and money has been expended prior to the actual alignment in the field. This time and money has always been cost effective in reducing downtime, easing frustration, improving accuracy and enhancing manufacturing and maintenance acceptability. As a guideline to those unfamiliar with alignment, a list of some of the pre-alignment steps are:

- The reverse alignment tooling to be used has been prebuilt or designs allowing variable adjustment have been verified for proper diameter clamping, reach, length of span, diameters to be cleared (coupling in place) and freedom from interference from obstructions (drain pipes, bearing housings, coupling guards, baseplates, etc.).
- Dial indicators have been checked for proper operation and full, easy travel. Calibration can be checked against a micrometer barrel pin.
- Equipment has been set on full non-rusting shims. These shims can be stainless steel (first choice), bronze or brass, aluminum alloy, or with a combination of plastic mesh (to ease removal/replacements).
- A shim thickness of $\frac{1}{4}$ in in three or four elements is a benefit. A starter pack consisting of a $\frac{1}{8}$ in and two $\frac{1}{16}$ in shims has been successfully used for several years. A five mil shim cloth (plastic weave) can be added, if desirable, on large feet without many bolt hole cut-outs.
- One early decision must have been the determination of the equipment to be moved and the equipment to be left in place. This can be a complex determination, but to suggest normal results, some examples are:

Train	*Moveable Unit*
Motor-Pump	Motor
Turbine-Pump	Pump
Expander-Pump	Pump
Motor-Gear-Pump	Motor and Pump
Turbine-Gear-Pump	Turbine and Pump

- A graphical plot (pre-drawn) has been made with each component accurately outlined, including shaft ends, casing support centers, coupling spans, reverse indicator actual spans, hot alignment targets and bearing centers (some equipment vendors show heat rises at bearing centers rather than support feet).
- Tooling for lifting/pushing and cleaning shim surfaces, plus taper gauges, taper supports, etc. have been arranged.
- Micrometers have been acquired for measuring shaft end separation, coupling lengths, limited-end-float plates and shim elements.
- Spare chock blocks and chock block shims have been located if sole plates are to be aligned prior to grouting. This would preclude equipment feet being in place, including shim packs. This bypasses any "soft foot" shortcomings. A "soft foot" is caused by a casing or frame having one (or more) feet being too short. For example, if three out of four feet were released-measured-retightened sequentially with a spring-up of four mils,

and the fourth foot had a spring-up of seven mils, then a three mil shim under the fourth foot would correct the "soft foot" (preventing casing twist).

- A clean place to work which is out of inclement weather has been set up with a flat surface (construction building vertical wall), long straight-edges (rulers), ten division graph paper, calculators, pencils, circle templates, etc. supplied.
- Magnetic or clamp dial indicator bases are needed at each foot when movements are to be made. Four bases are required per casing. Casings are to be pushed, not hammered.

PREGRAPH PLOT

A pregraph plot should be made which uses either vendor predicted thermal movements or the aligner's precalculated heat movements. This pregraph depicts the equipment which increases (rises) in temperature (steam turbine) drawn *below* a hot operating line. Conversely, equipment such as a cold service pump, which reduces in temperature (falls), are depicted as a line drawn *above* the hot operating line reference. For a known tooling, with known sag, predicted readings *with* and *without* sag can be predrawn as a guide to field measurement. This increases the speed to get bracketed readings for an *unknown* heat movement measurement starting point. For example: if one designs *low sag* bars, then any reading between pure (sag corrected) and impure (sag added) measurements would be an acceptable starting position.

ALIGNMENT TOLERANCE

One must develop an acceptable alignment tolerance. For a maximum tolerance worst case limit, one can review the coupling manufacturers' stated alignment capabilities. For example, a vendor could state a ½° maximum limit for a flex plane in pure parallel misalignment. Since the tangent of ½° is 0.00873, the offset required to displace that flex unit (gear or convolutions) would be approximately nine mils per inch of flex plane separation. For a coupling with a five inch Basic Shaft End separation (BSE) spacer, assume a six inch flex plane span, with the offset required to reach the manufacturer's ultimate limit being 6 in × 9 mils/in of separation or 72 mils (0.072 in or 1.8 mm). However, this is often a locking (binding) limit for the coupling and should be considered an *extreme* limit.

The tolerance (Table 1), used successfully since 1964, has been 1 mil/in of separation (1 μm/mm) for pumps or equipment operating below 5000 rpm. For equipment running at above 5000 rpm, a ½ mil/inch of separation (½μm/mm) tolerance should be used, which is typical of turbo-compressor alignment (1/16 of the above ½° limit).

Table 1. Summary of Alignment Tolerance.

	Alignment to Flex Plane Ratio
Pumps through 2 pole, BFW, injection pump speeds	1:1000
Equipment above 5000 rpm	1:2000

ALIGNMENT DEMONSTRATION

In the demonstration, the motor will (1) start in good alignment to the pump. The motor will be (2) misaligned by a precalculated movement corresponding to the desired position of the motor relative to the pump. (3) Reverse indicator readings will be taken, with the sag corrected and plotted. (4) The deviations will be determined at the support locations between the motor's *actual* position and the *desired* motor position. This will be done vertically and horizontally. The motor will be (5) repositioned to the desired position and rechecked.

A demonstrated motor driven pump has the following dimensions:

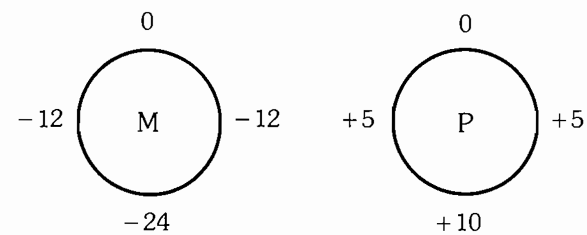
OB Motor Foot to IB Motor Foot	12 in
IB Motor Foot to Reverse Indicator or Stem	4 in
Reverse Indicator Span	10½ in
Reverse Indicator Stem to IB Pump Foot	5½ in
IB Pump Foot to OB Pump Foot	12 in
Basic Shaft End Separation (BSE)	2½ in

NOTE: If hot alignment targets were to be used, the obvious first consideration would be the location at each equipment foot on the right and left hand sides or 8 targets and 16 measurements (18 if axial growth is included).

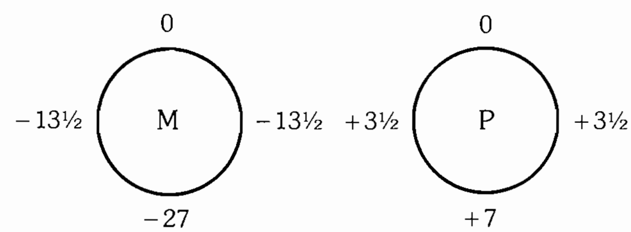
Direct shaft reading sensors for hot measurement would reduce the number of measurements to eight for lateral alignment, and ten if axial thermal growth is needed for coupling prestretch considerations.

Precalculation Growth

Not having any vendor growth information, the following estimated growths were plotted: Motor rise (each foot)—4 mils, pump discharge (coupling end)—9 mils, and pump suction (outboard end)—2 mils fall, i.e., the inlet is colder than ambient conditions. No horizontal movement is predicted, but might have to be allowed later, based on experience and measurements. The pure reverse indicator readings would be:

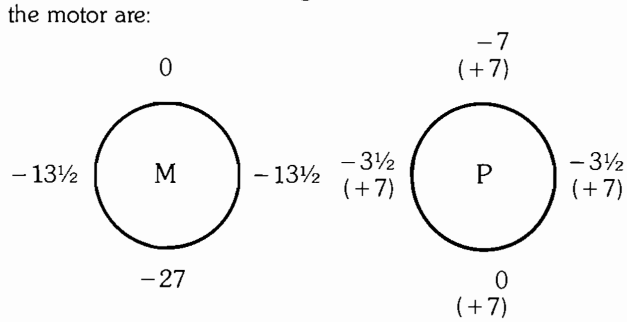


Assuming a peak sag of 1½ mils (3 mils Total Indicator Reading (TIR)), this uncorrected reading would be taken in the field as:

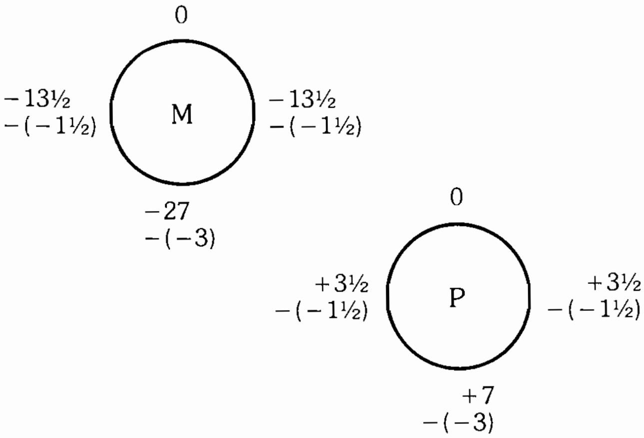


Applying a sag correction (subtraction), these readings are handled in this manner. Sag is always a minus sign measurement, minus 1½ mils peak (for side correction) and minus 3 mils TIR (for bottom corrections). Since sag is subtracted, then side readings receive $-(-1\frac{1}{2}) = +1\frac{1}{2}$ mil and bottom readings receive $-(-3) = +3$ mil corrections.

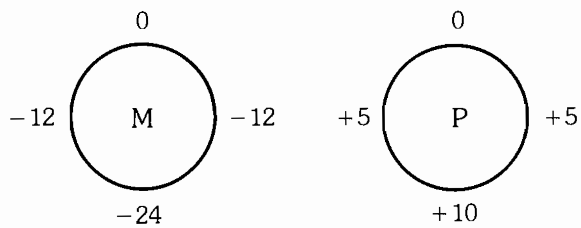
Reverse indicator readings with the dual bracket zeroed at the motor are:



To move the zero location to the top of the shaft, add the equivalent of the top value, but of opposite sign, to all readings around the circle. Subtract the sag readings from the side readings at the peak value [−(−1½) mil] and bottom reading of TIR sag [−(−3) mil].



Pure corrected readings for plotting would therefore be:



Additional information about reverse indicator bars, attachments and sag correction appears in APPENDIX A.

Basic Rules in Plotting and Reading

• All readings taken are viewed from the same position. In this case, it is from the motor end bell, looking towards the coupling and the pump.

• Vertical readings will be zeroed on the top. Horizontal readings will be zeroed, for offset determination, on the left.

• Reverse indicator dial indicators will be read by rotating the coupled shaft in the normal rotation direction (here it is clockwise) through 90° quadrants (12 o'clock, 3 o'clock, 6 o'clock, 9 o'clock and 12 o'clock, for zero rechecks).

• When the reverse indicator brackets are in the starting position, the dial read at the motor (top—12 o'clock) will be zero and entered in the base circle labeled "M." The indicator at the pump shaft will be zeroed at the bottom (6 o'clock) and will be entered on the base circle labeled "P" as zero at the bottom (6 o'clock). After taking both sets of readings, the pump readings will be corrected to put the zero at the top of its base circle. This is done by adding a value to each of the four quadrant readings which is *equal to the top reading,* but *opposite in sign.*

• Readings taken from the plot to the dial indicator are "doubled". Readings taken from the *sag corrected* dial indicators for shaft position plotting will be "halved". The example will illustrate these concepts.

• Compressing (pushing in) the dial indicator stem will cause the indicator needle to move clockwise, reading a "plus" reading.

• Extending (spring pushes stem out) the dial indicator stem will cause the indicator needle to move anti-clockwise, reading a "minus" reading.

• Three typical indicators are shown in the APPENDIX B. One indicator is furnished with a center zero stroke position in variable travel lengths and with a revolution counter to record each time 100 mils are passed. "Plus" readings are in *black* numerals, "minus" readings are in *red.* It is made by Brown and Sharpe, as they are the only vendor out of eight contacted to agree to provide this face with a single cost silk screened face.

• A dial indicator must be set and zeroed near its center of stroke travel in order to prevent reaching its travel limit (bottoming out). The stem travel range must accommodate twice the offset misalignment to afford an accurate reading. If this criterion is not obtained, either a better *rough* alignment is necessary *or* a longer range dial indicator is needed.

• Good basic machinery practices must be carried out while aligning equipment. These practices have been published in the past. The technique for quickly determining any movements is the main intent and offers the main cost savings.

EXAMPLE INSTRUCTIONS FOR DRAWN-IN PLOTTING MAP

A "mock" example condition will be plotted here as a guide, should one forget the steps.

Step 1

Plot the expected design heat rise for the motor and pump on Figure 1. Values used here are those from the precalculation growth mentioned previously.

(a) The motor feet rise 4 mils at each foot. On the vertical lines at the motor feet, plot *down* from the Hot Operating Line (HOL) 4 mils and place "dot." Connect the two "dots" and extend the line across to the pump indicator line and mark this intersection, which is 4 mils down also.

(b) Pump *rise* is 9 mils at the coupling end (indicator line) and 2 mils *fall* at the suction foot (cold service). On the pump indicator line, plot *down* (inverse of rise for cold position) 9 mils and place a "dot." On the outboard (OB) pump foot vertical line, plot *up* 2 mils (this end will fall from the HOL) and place a "dot." Connect these two "dots" for the pump and extend a straight-edge across the span to the motor's indicator vertical line and mark the intercept with a "−." The above two parts of this step are indicated on the plot in Figure 2 by arrows.

Step 2

(a) To extract the *vertical* numbers for the *pure* (sag corrected) reverse indicator reading (top two circles), one must *double* the actual peak units for a dial indicator reading (TIR). The difference from the motor's Desired Cold Position (DCP) and the extended pump shaft DCP at the vertical indicator line for the motor is *12 mils.* Doubling 12 equals 24, which is entered below the "M" circle. An indicator zeroed to the top of the motor shaft and rotated from the pump end to the bottom of the motor shaft would have to extend (reach), since the motor shaft is *above* the pump shaft extension. Therefore, the sign would be minus (Figure 2).

(b) The difference at the pump shaft indicator line and the extended motor shaft is 5 mils. Twice 5 mils = 10 mils, which goes below the "P" circle. An indicator zeroed on the top of the pump shaft and rotated to the bottom of the pump shaft would read (+), because the pump shaft is *lower* than the motor shaft extension at that point.

Step 3

Since *no* horizontal misalignment is planned, the difference between left and right (circle) readings will be zero. Further, since the algebraic sum of the two horizontal readings must equal the two vertical algebraic sums (0 and +10), the horizontal readings will be +5 and +5, i.e., $(+5-(+5)=0)$ and $(+5+5=10)$.

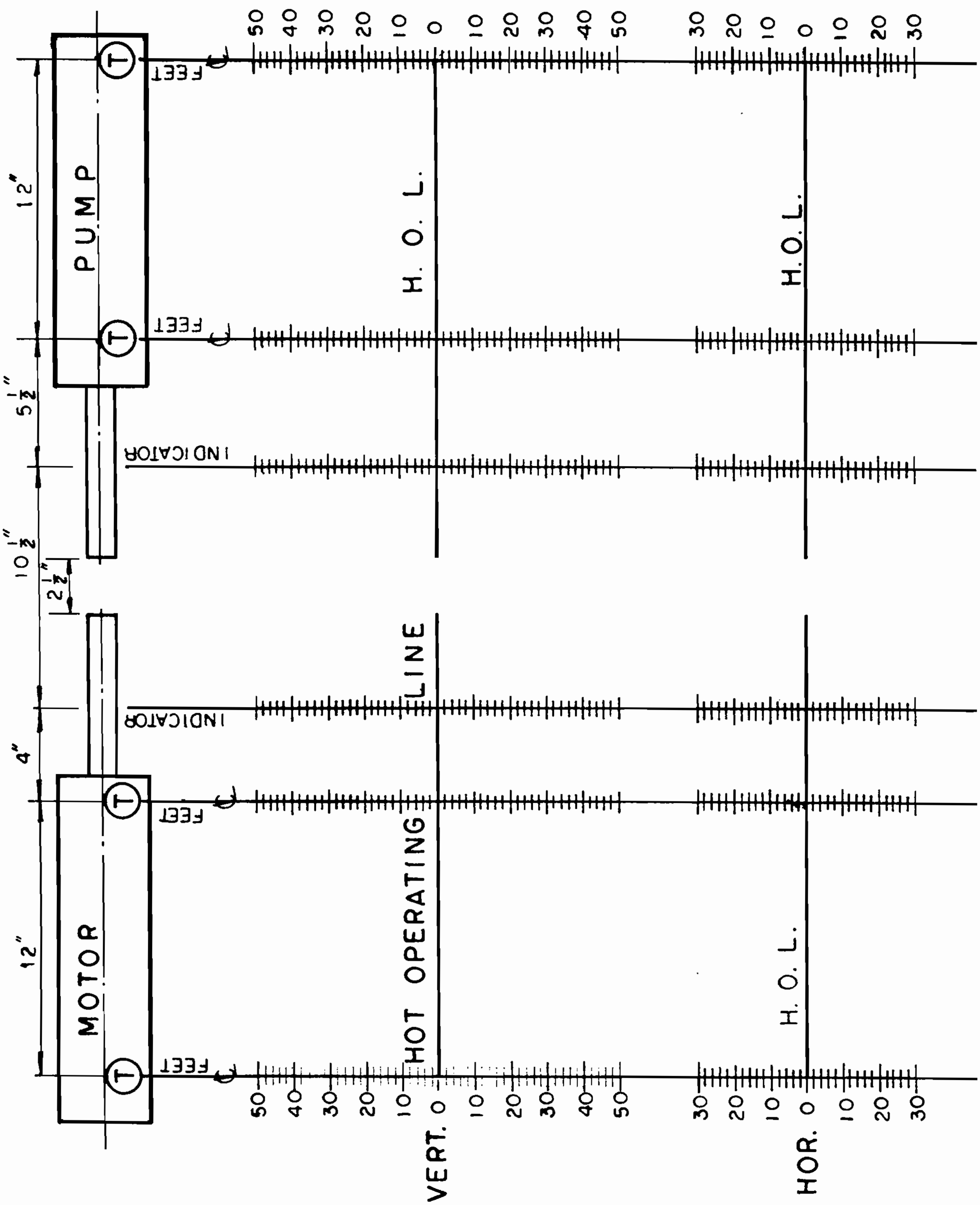


Figure 1. Typical Plotting Chart.

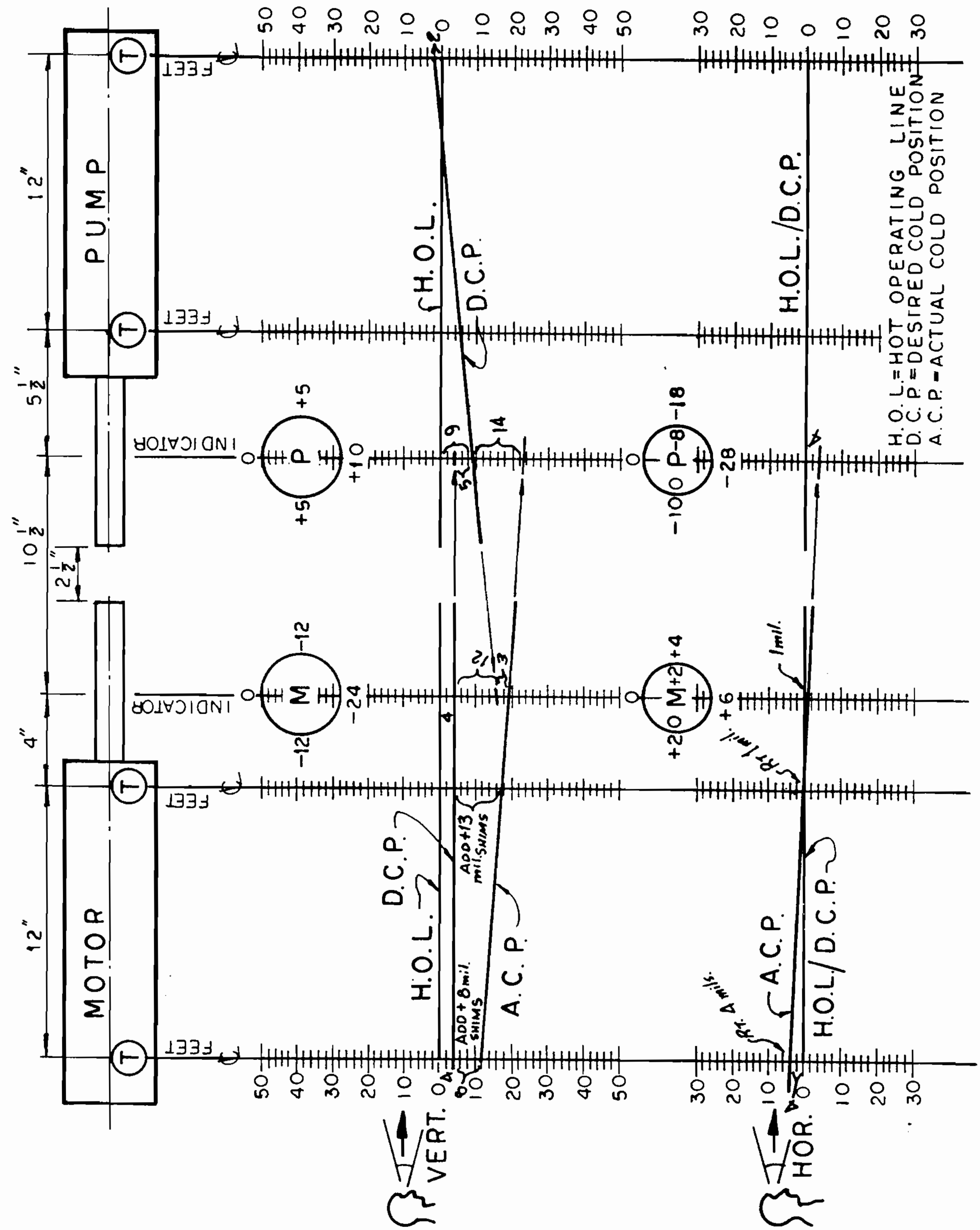
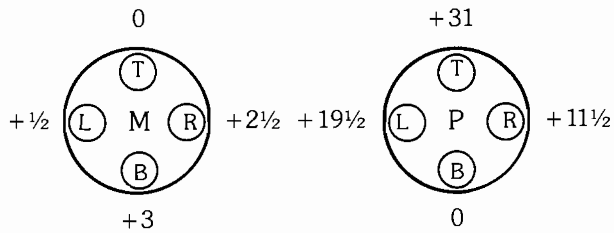


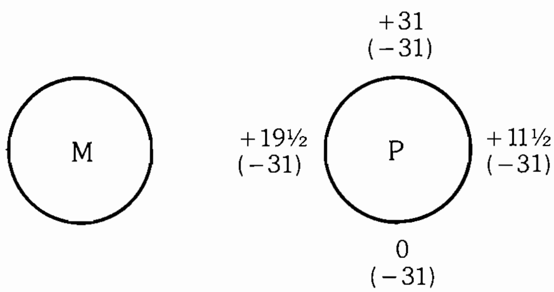
Figure 2. Example Plot.

Step 4

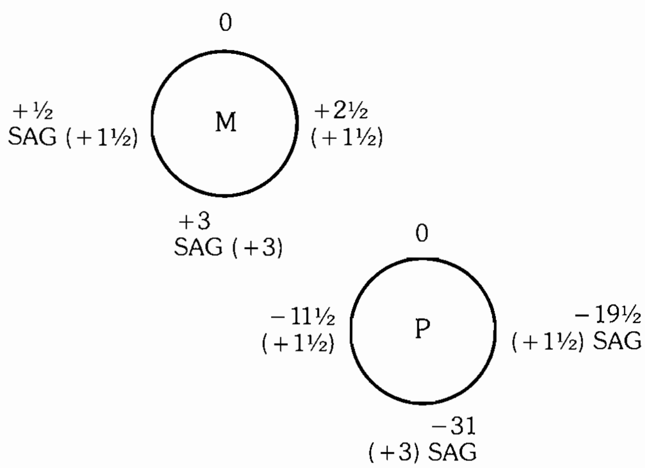
Take reverse indicator readings of the actual positions, zeroing the motor's dial indicator at the *top* and zeroing the pump's dial indicator at the *bottom*. The following reading, using 1½ mil sag bars (3 mil TIR sag), are taken:



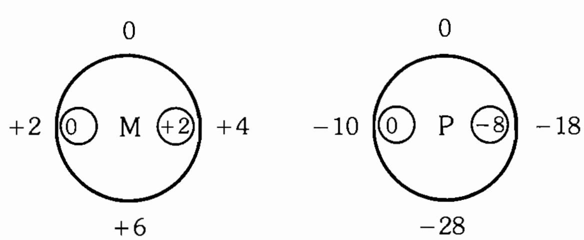
First, *correct* the right-hand pump readings (circle) to have the zero at the top. This is done by adding (−31) to all four readings around the circle.



The results are:



Subtracting (−(−1½)) from side readings and −(−3) from bottom readings, i.e., (+1½) and (+3) results in



The horizontal readings can be zeroed (for plotting) by adding (−2) to left and right motor readings; and +10 to left and right pump readings. Record values *inside* the circle.

Step 5

Plot the last readings which are *pure* readings. First, it must be known that the motor is to be moved, not the pump. Second, it is assumed that the pump is *on* the Desired Cold Position (DCP). Third, it takes two points to define the motor shaft Actual Cold Position (ACP). These two points will be determined on the *indicator lines* where readings are taken.

Vertical Alignment and Shim Determination

Vertical Location at Motor

The bottom reading is +6, which is halved to equal +3. Since it is *plus*, the motor must be *below* the pump extension at that point, so count down 3 mils on the motor indicator line and place a "dot."

Vertical Location at Pump

The bottom reading is −28, which is halved to equal −14. Since the readings is *minus*, the pump shaft must be *above* the motor shaft extension, so count 14 mils down from the pump shaft and place a "dot" on the pump indicator line.

By connecting the two dots with a straight edge, the ACP of the motor can be projected to the left.

Shim Corrections

Shims are determined on the vertical lines through the motor feet. The left outboard motor foot shows a difference between the *actual* and *desired* lines of *8 mils*. Further, to move the ACP *up* to the DCP, shims must be *added* (to raise). At the right inboard motor foot, one must add *13 mils* in shims.

Horizontal Alignment and Adjustment and Determination

Horizontal Location at Motor

The 0 to +2 horizontal readings halved are 0 to +1, which means that the motor lies 1 mil to the right of the pump shaft, which is not to be moved. A "dot" is placed to the right of the pump extension at the motor indicator line.

Horizontal Location at Pump

At the pump's indicator position, a 0 to (−8) offset is noted. Halving this gives 0 to (−4). This means that the motor shaft extension is 4 mils to the right of the pump shaft. Place a "dot" 4 mils to the right of the pump DCP. (Note: On the horizontal plot *right* is *down* and *left* is *up*—imagine one is looking down the shafts in plain view).

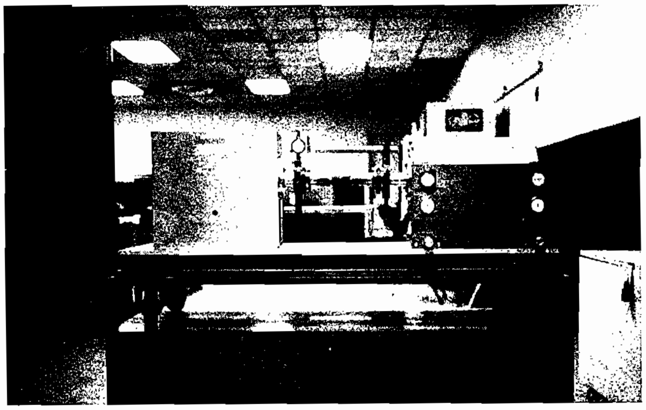
Connecting the two dots and extending the line to the left with a straight edge determines how much to move the ACP line of the motor to the DCP line of the motor. For this example, movement should be right 4 mils at the left (OB) foot, and right 1 mil at the right (IB) foot.

CONCLUSION

Reverse indicator methods far exceed face-and-run techniques for some obvious reasons. Some of those reasons are:

1. One is not concerned with, nor handicapped by, rotor axial float in the reverse method.
2. There is generally a higher accuracy due to the high ratio of measurement span to casing foot span.
3. Reverse indicator alignment depends on the accuracy of a shaft rotating true in its bearings, which is good.
4. By turning both shafts together, out-of-round surface errors can be eliminated. By allowing the dial indicators to clamp onto brackets and sense the reach bar, a controlled surface is offered and bar sag is reduced. Further, rough (nicked, scratched, tool marked) surfaces on the shaft or the coupling no longer present problems.
5. Reverse indicator plots allow one to *map* the steps with improvement in stepwise understanding. It is logical to view the steps in a visible presentation.

APPENDICES



Reverse Indicator Trainer

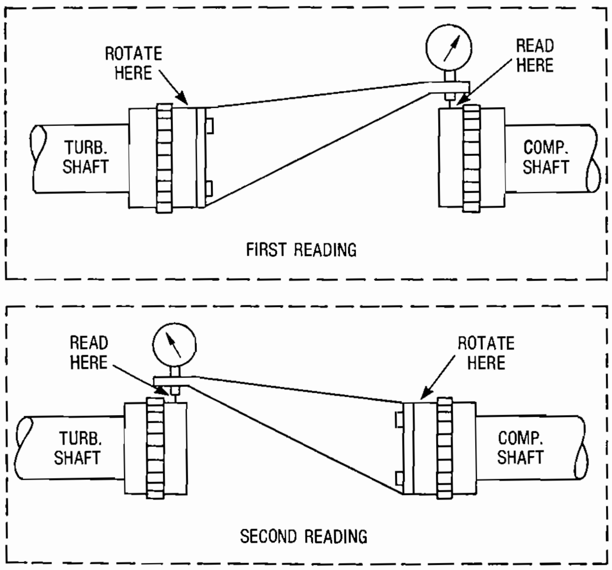


Fig. 1—Steps in taking reverse indicator readings.

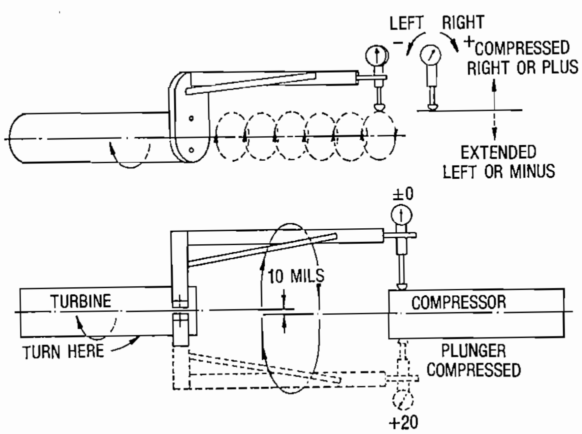
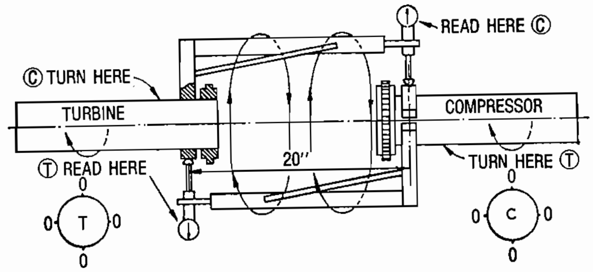
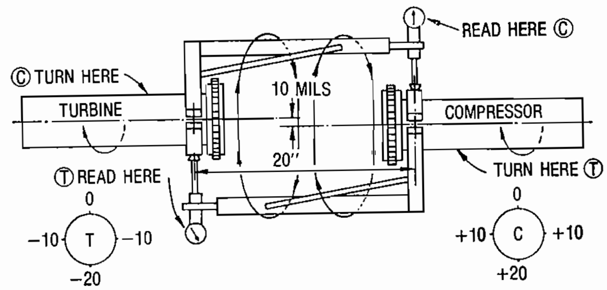


Fig. 2—An indicator bar with dial indicator becomes an extension of the shaft. Zeroing the indicator at the top will cause an indicator reading of twice the shaft offset.

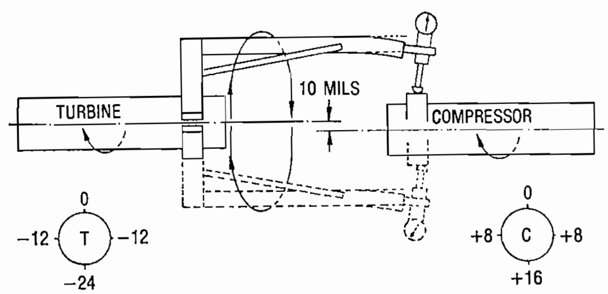
A. Example Clarified.



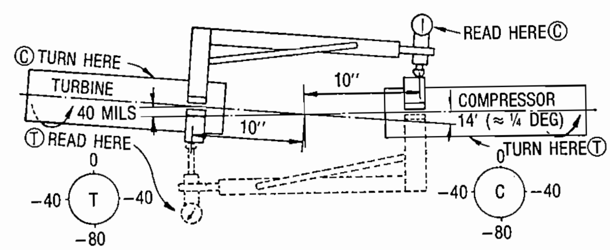
Example 1—This illustrates the readings obtained with zero misalignment and zero sag in the indicator bar.



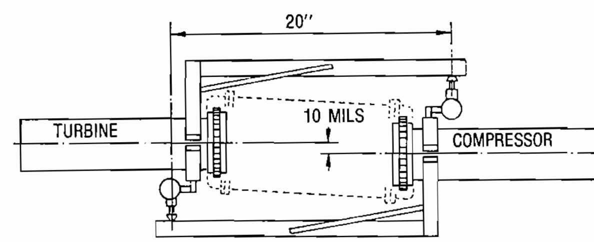
Example 2—Reverse indicator readings with the right side shaft 10 mils low of left shaft and zero angularity misalignment.



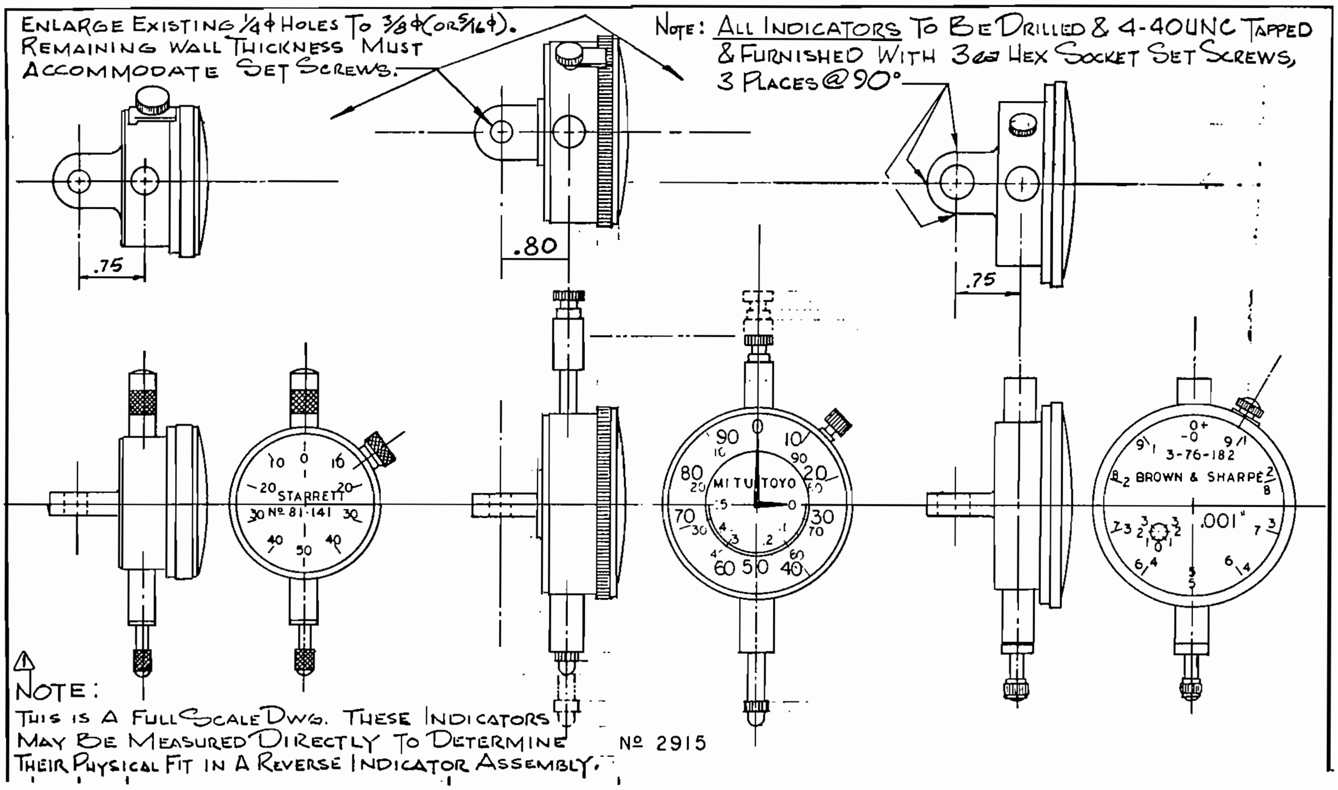
Example 3—Error in true offsets of Example 2 caused by a 2 mil sag in the indicator bar.



Example 4—Reverse readings taken with symmetrical angular offsets.



Example 5—One technique for reducing indicator bar sag. Indicator weight is held by machinery shafting.



B. Typical Dial Indicators.

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