DIFFICULT AND UNUSUAL BALANCE CASE HISTORIES

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ABM TECHNICAL SERVICES

Forward

This paper was inspired by an individual that had been balancing a few months that declared that he had “Mastered Balancing and was ready to take over his bosses job”

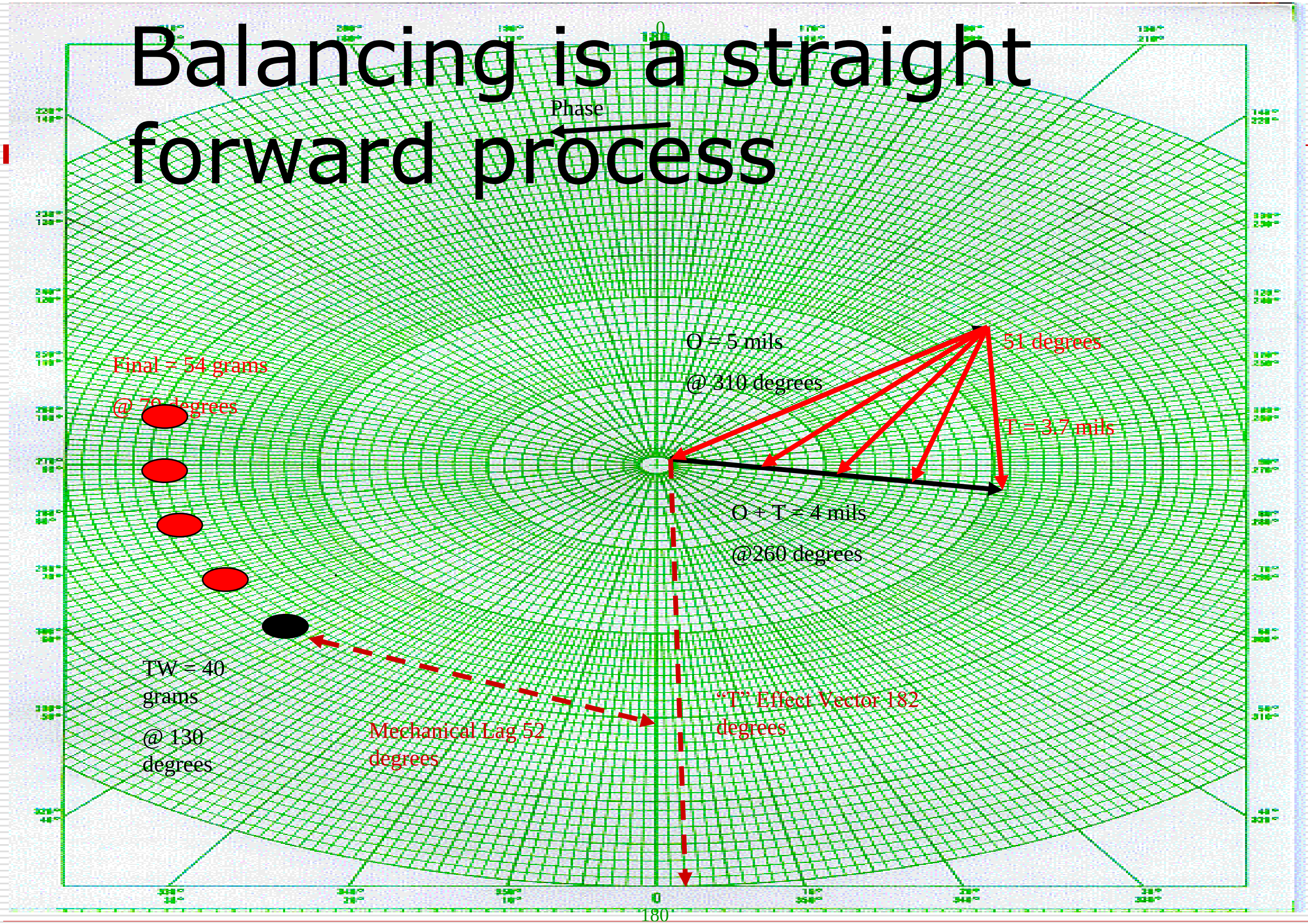
Balancing is often a very simple process

1: Initial readings are taken

2: A trial weight is installed

3: Based upon the results of the trial weight, a final solution weight is installed. The solution can be obtained by a graphical approach or by using a math based vector solution program.

Balancing is a straight forward process



HOWEVER

Working when working in the field things can get a bit more complicated.

Conditions that can significantly complicate the balance process

- Looseness in support structure
- Bearing looseness within housing
- Loose rotating components
- Rotor bows
- Thermal vectors in motors or generators
- Beats
- Non symmetric rotors
- Non symmetric support stiffness
- Overhung masses
- Multiple modes excited over speed range
- Resonances
- Non linearities
- Combinations of the above

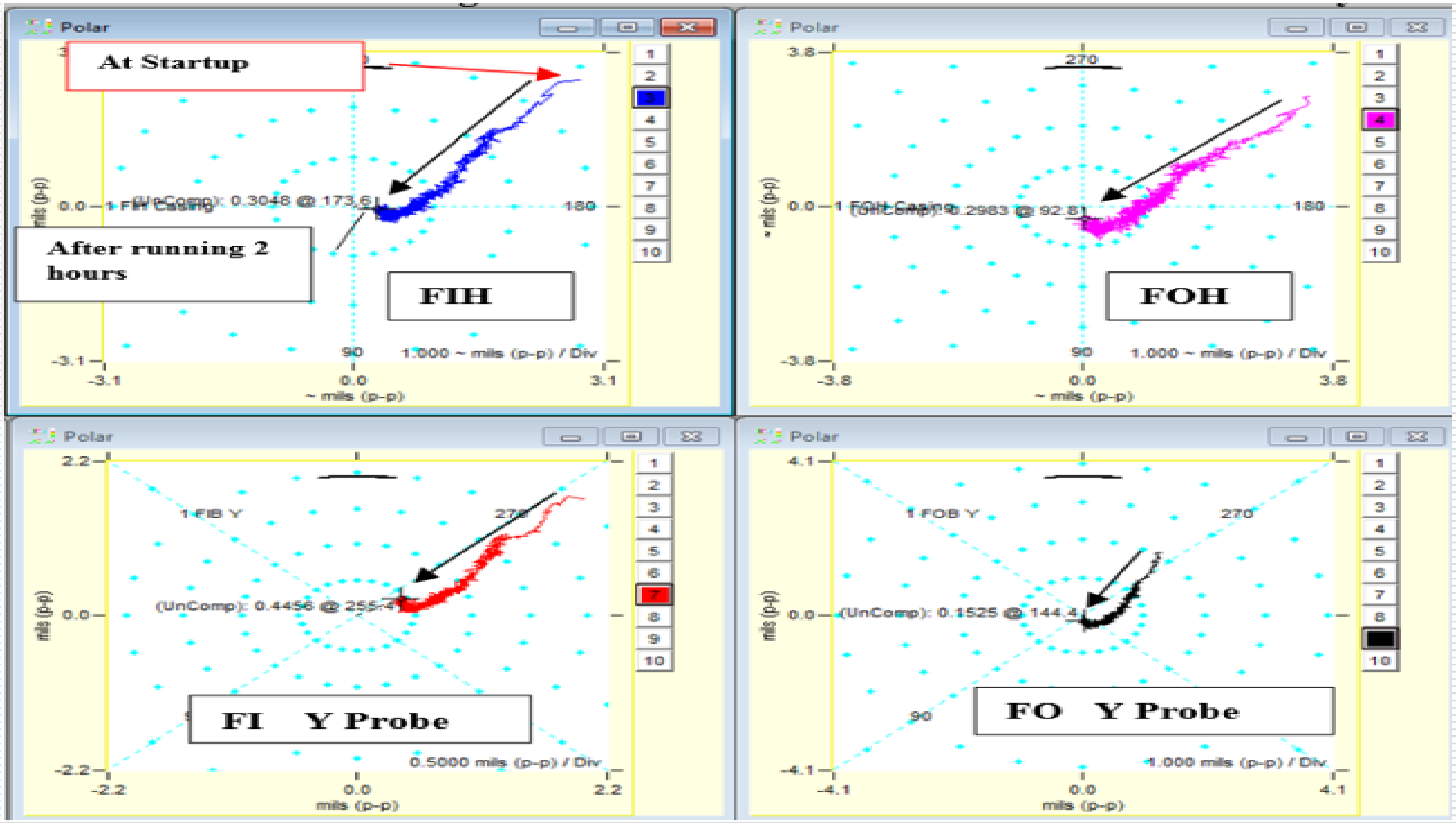
DEDICATION

This presentation is dedicated to the people on the front lines that have to get the job done when complications arise.

Case 1 5000 HP 890 RPM Scrubber Booster Fans

Problem- When the fans were started up, the manufacturer had difficulty in getting them balanced. Several tries over a period of two weeks were unsuccessful in getting the vibration down to acceptable levels.

Diagnosis of Problem:
Vibration would slowly change for up to eight hours.



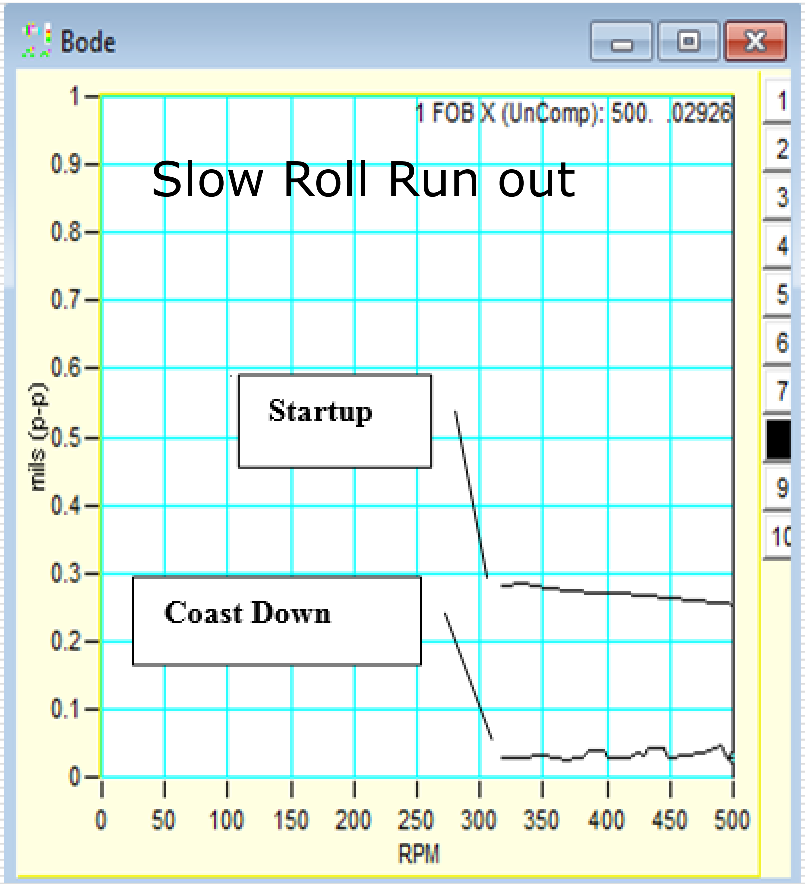
- The change in the vibration was so slow that the balancing personnel did not notice it and assumed that the fan was at steady state.
- This caused the original unbalance vector to be in error as well as any effects of the trial weights to be wrong.

Example of effect of time upon a balance shot

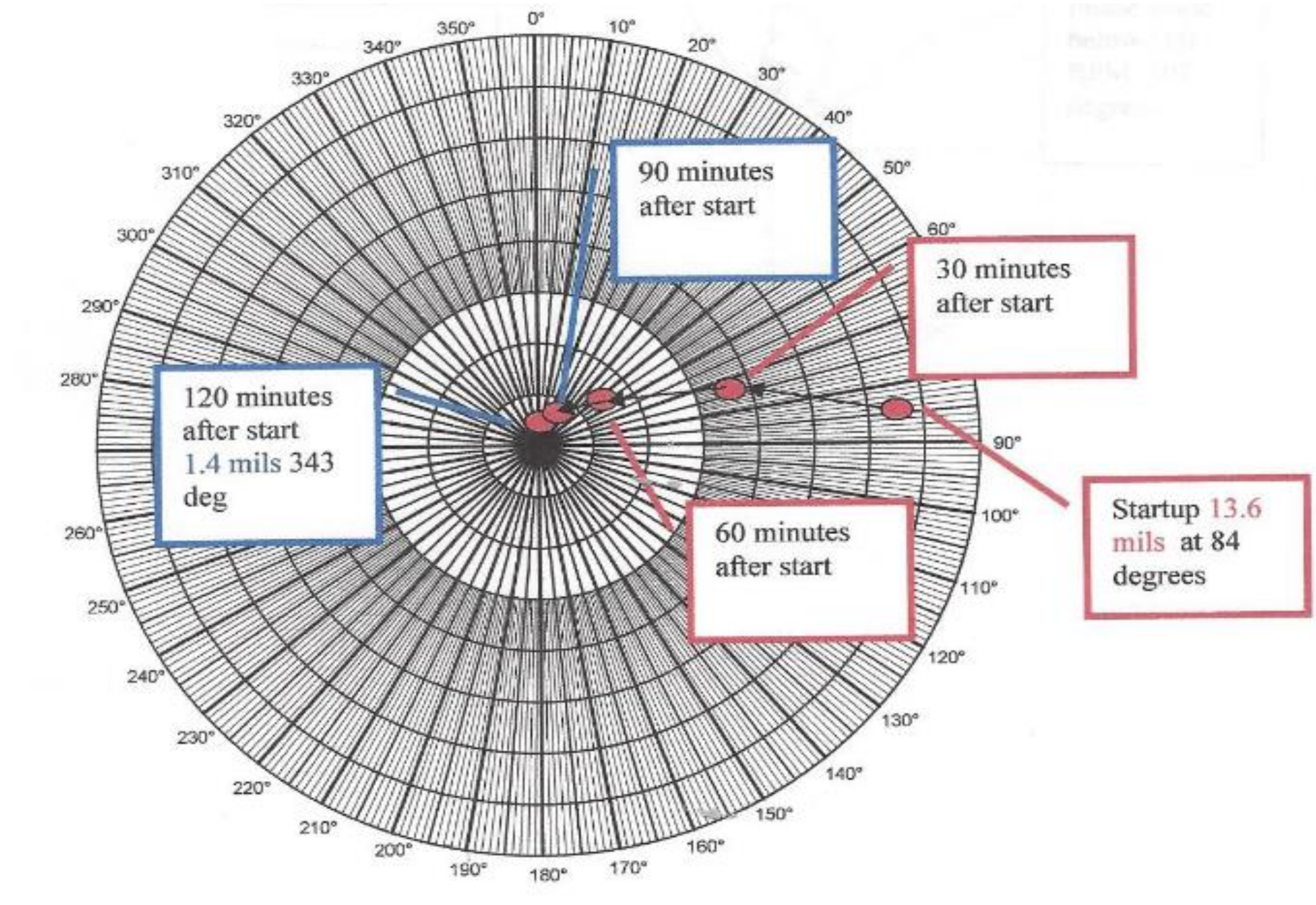
Weight Installed- 50 oz @ 115 deg

Amplitude and Phase upon initial startup
Inboard Horizontal 9.5 mils @ 90 degrees
Outboard Horizontal 13.6 mils @ 84 degrees Very high upon startup
After 30 minutes
Inboard Horizontal 4.1 mils @ 87 degrees
Outboard Horizontal 6.5 mils @ 78 degrees
After 60 Minutes
Inboard Horizontal 1.7 mils @ 57 degrees
Outboard Horizontal 3.1 mils @ 52 degrees
After 90 Minutes
Inboard Horizontal 1.0 mils @ 337 degrees
Outboard Horizontal 1.5 mils @ 354 degrees
After 120 Minutes
Inboard Horizontal .9 mils @ 325 degrees
Outboard Horizontal 1.4 mils @ 343 degrees Very low after bow cleared

Root Cause- Rotors were bowing, Figure below shows a comparison between startup & coast down runout. Solution- Be very patient when taking balance data.



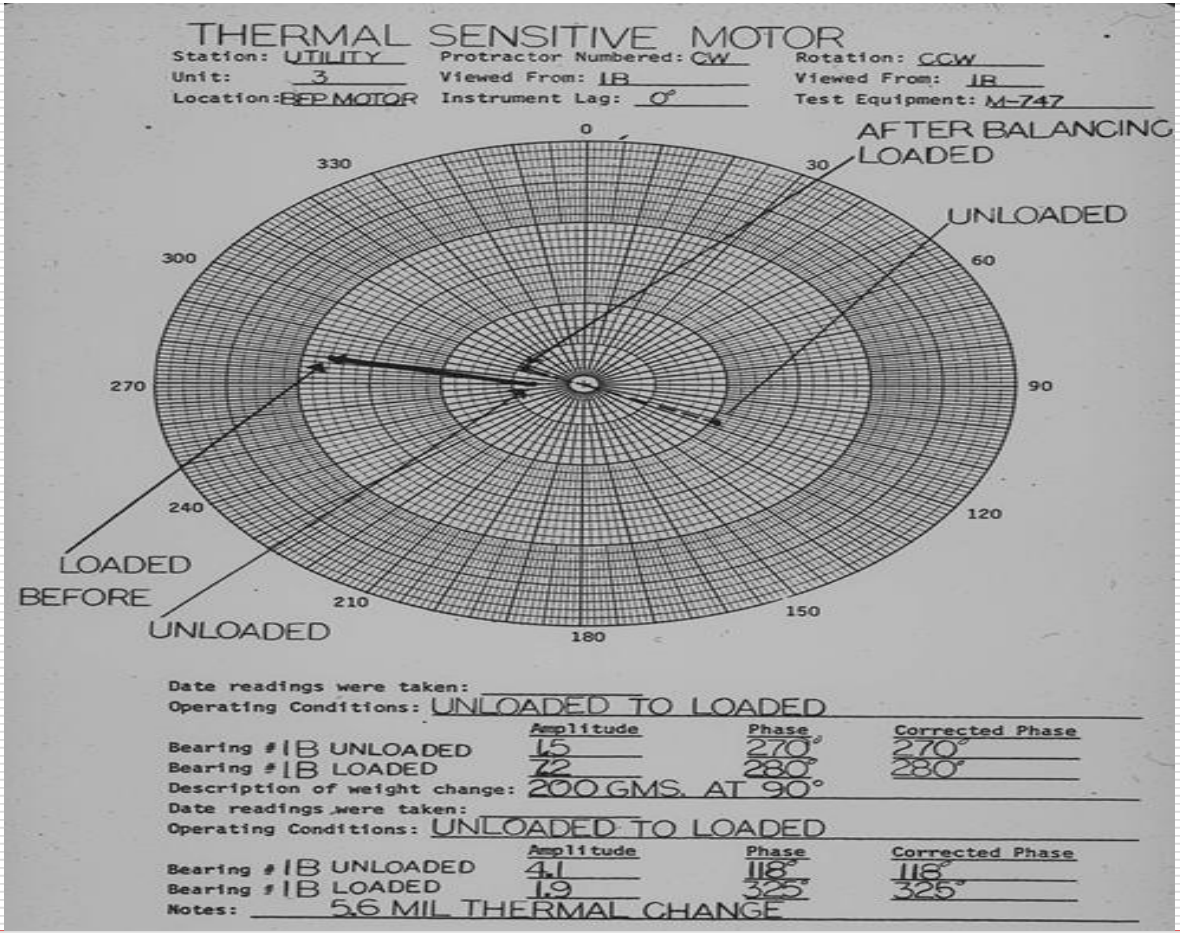
Final Balance shot response change as bow cleared.



Case 2- 8000 HP Feed Pump Motor

- Following a motor refurbishment
  - Vibration would increase with load
  - Prox probe level reached 7.8 mils
  - 45 minutes of operation would destroy bearings.
  - Motor returned to motor shop to low speed balance rotor again.
  - Field results were the same- Bearings destroyed
  - Motor rotor sent to high speed balance pit and balanced at speed
  - Field results were the same- Bearings destroyed

Problem-Large thermal vector
Solution-Compromise balance



THERMAL SENSITIVE MOTOR

Station: UTILITY — Protractor Numbered: CW — Rotation: CCW
Unit: 3 — Viewed From: 1B — Viewed From: 1B
Location: BFP MOTOR — Instrument Lag: 0° — Test Equipment: M-747

Date readings were taken:
Operating Conditions: UNLOADED TO LOADED

	Amplitude	Phase	Corrected Phase
Bearing #1B UNLOADED	1.5	270°	270°
Bearing #1B LOADED	7.2	280°	280°

Description of weight change: 200 GMS. AT 90°

Date readings were taken:
Operating Conditions: UNLOADED TO LOADED

	Amplitude	Phase	Corrected Phase
Bearing #1B UNLOADED	4.1	118°	118°
Bearing #1B LOADED	1.9	325°	325°

Notes: 5.6 MIL THERMAL CHANGE

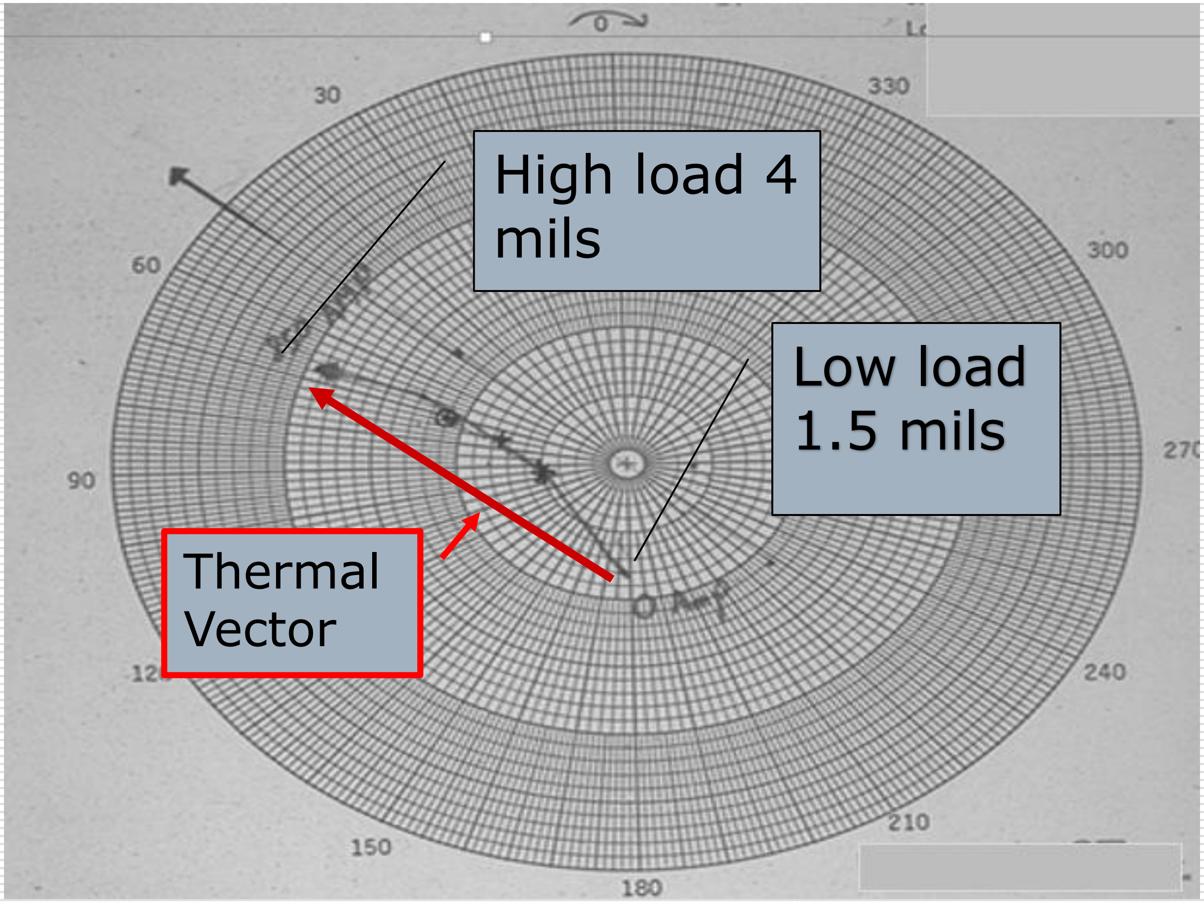
Root cause of problem

- Motor shop had dropped motor on first shop visit. They though there was no damage.
- Drop had caused laminations to short at point of impact
- Eddy currents caused a hot spot to develop.
- Localized hot spot caused expansion which resulted in rotor bowing with load thus causing an imbalance condition that changed with the load.
- Compromise balance offset thermal vector.

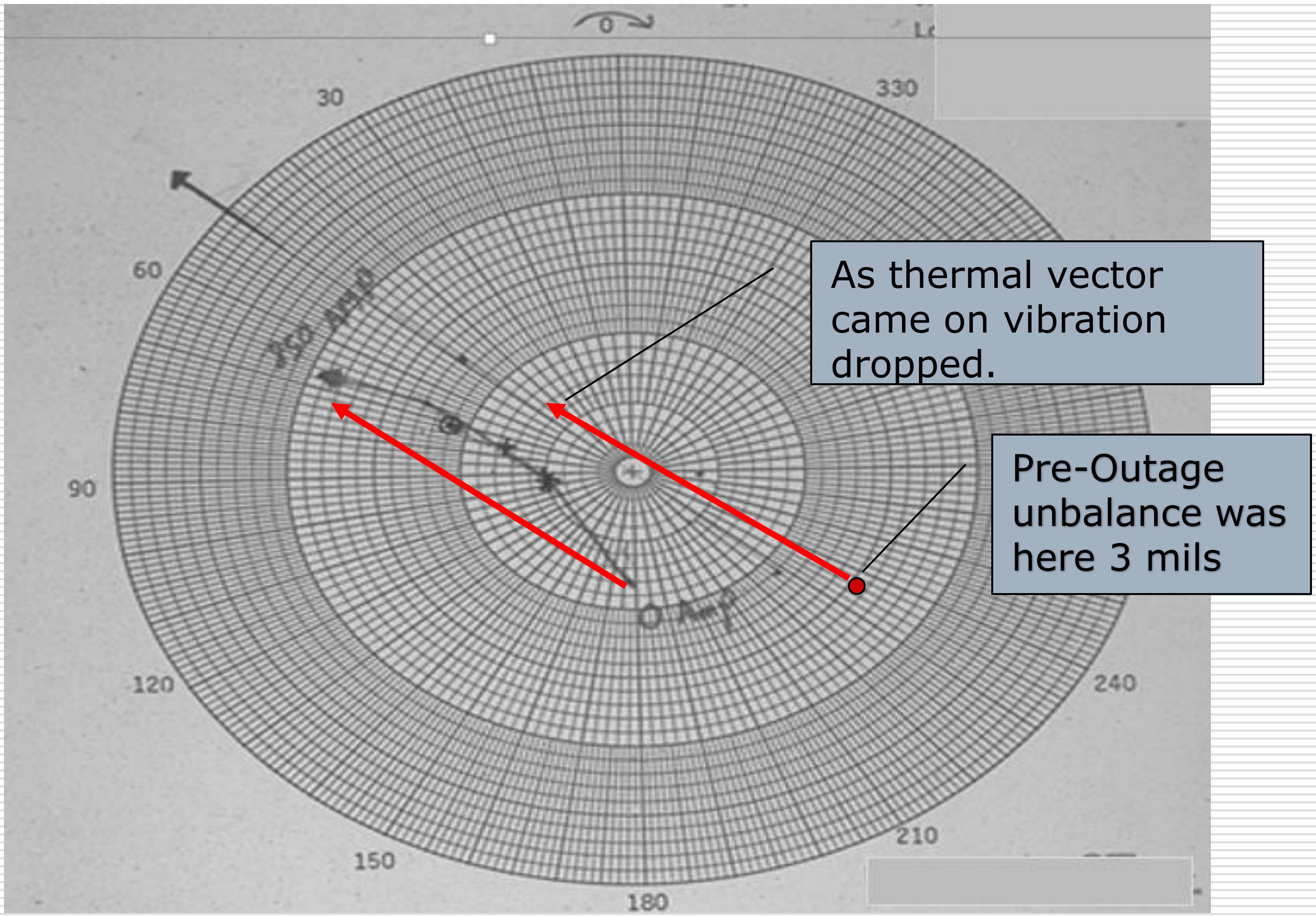
Case 3- Large Motor in Venuzuela- High vibration following an outage

- Received a call from Venezuela
- Conversation- The motor does not run well anymore ever since we balance it.
- Motor ran with 3 mils of unbalance so plant personnel balanced it down to 1.5 mils
- Problem- Once motor was loaded, the amplitude was 4 mils

Tape recorded data was sent to US and ran through a Bently Adre system



Field balance made vibration higher at full load.



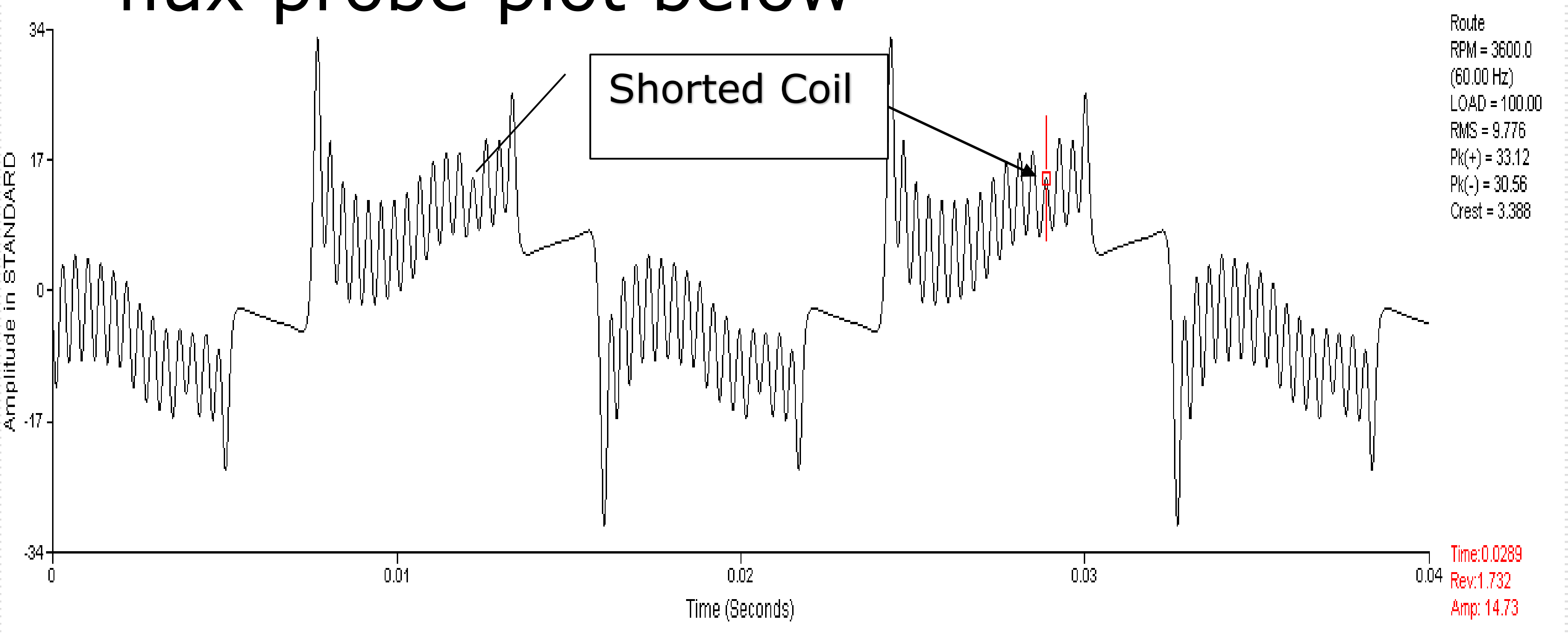
Fairly Common in 2 Pole motors above 1000 HP

- There are many examples of large thermal vectors in large 2 pole motors.
- They are often compromised balanced in the factor or in the field.
- Undoing the compromise balance in the unloaded condition results in high vibration at full load.

Case 4-650 MW Generator with 11 mil thermal vector

Problem- As Megawatt and var load increased, so did vibration

Problem Shorted coil as seen in flux probe plot below



Solution-Several compromise balance shots until rotor could be repaired.

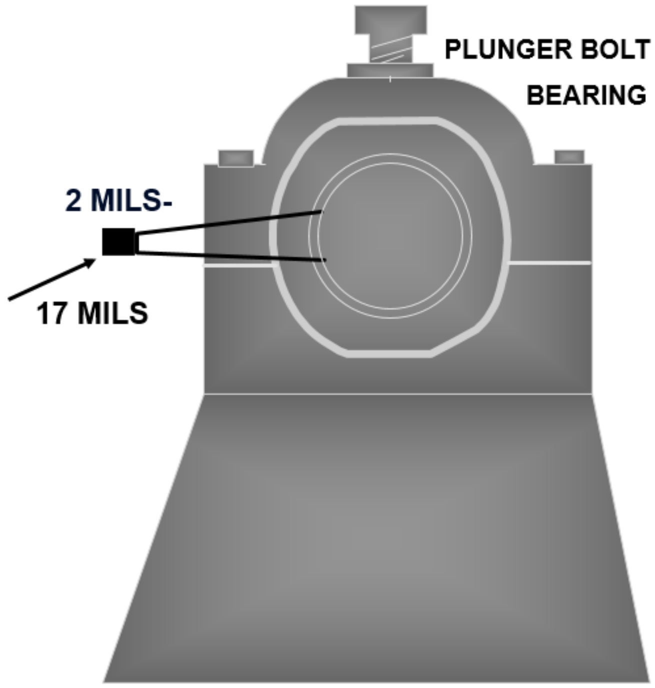
- Compromise balance shots allowed the generator to run for several months.
- In the end, the thermal vector was 11 mils. Compromise balancing ended up having the vibration level be at 6 mils unloaded and 5 mils loaded.

Case 5- A Difficult to balance 890 RPM 5000 HP ID Fan

- Plant personnel had made multiple attempts to balance this fan.
- No matter what they did, the amplitude would not come down to as low a value as they desired.
- The plant people were very experienced in balancing and had balanced large fans many times.

Problem- Bearing was loose in its housing.

LOOSE BEARING IN HOUSING COMPLICATES BALANCING



IF A BEARING IS LOOSE IN ITS HOUSING, A NONLINEAR SYSTEM IS CREATED AND BALANCING IS ALMOST IMPOSSIBLE

CASE HISTORY
A LARGE ID FAN COULD NOT BE BALANCED. THE CASING LEVELS WERE SLIGHTLY OVER 2 MILS, HOWEVER, WHEN SHAFT STICK LEVELS WERE MEASURED, THE AMPLITUDE WAS GREATER THAN 17 MILS. SINCE THE SHAFT TO INNER BEARING CLEARANCE WAS ONLY 8 MILS, THIS MEANT THAT THE BEARING HAD TO BE MOVING IN THE HOUSING. WHEN THE PLUNGER BOLT WAS TIGHTENED, THE CASING LEVEL ROSE TO 21.5 MILS. AFTER THE TIGHTENING, THE FAN WAS EASILY BALANCED.

Looseness

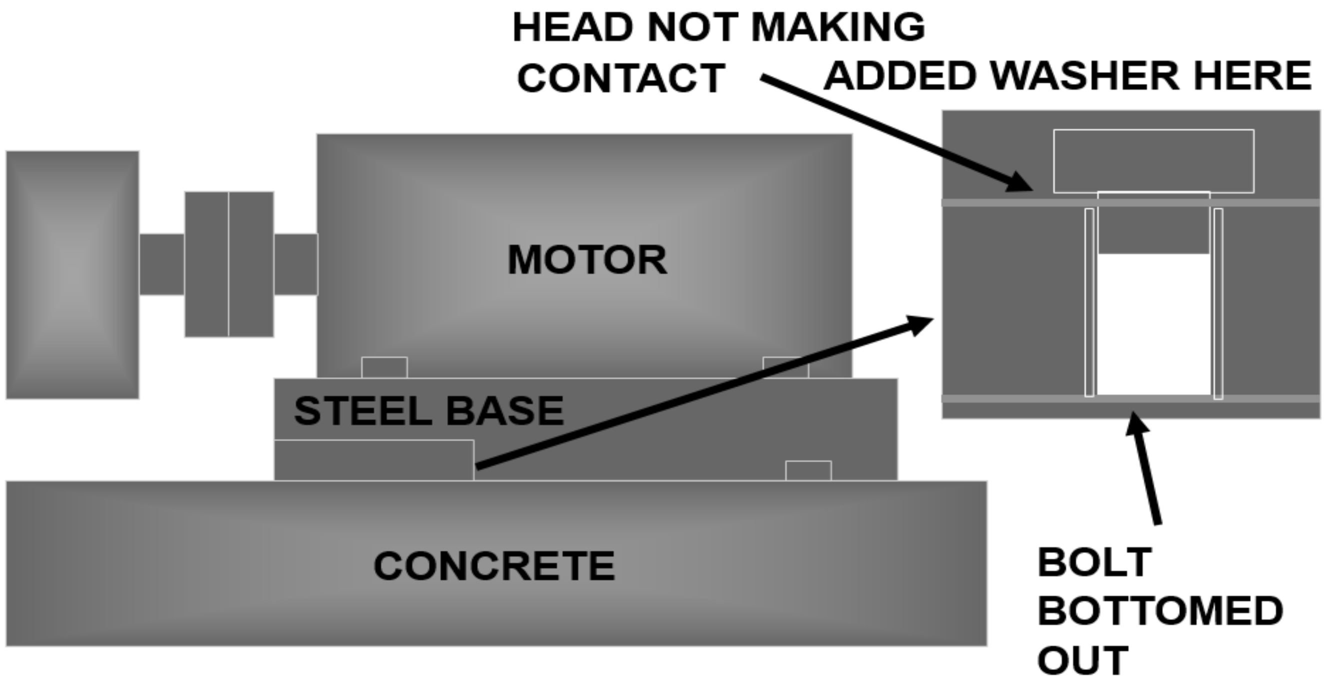
- Looseness of any sort is one of the greatest impediments to successful balancing.
- Looseness by its nature results in a non-linear system
- Types of looseness
  - Baseplate to grout
  - Bearing pedestal to base plate
  - Bearing within housing
  - Shaft to inner race looseness

Case 6- Mill Motor that could not be balanced in motor shop

- Mill motor had been sent to motor shops twice for refurbishment and balancing.
- In each case, vibration level on motor upon return was 8 mils.
- Total amount spent on motor $30000.

Problem-Base bolt bottomed out making it appear to be tight.

MOTOR VIBRATION WAS 8 MILS. BOLT WAS TIGHT BUT NOT MAKING CONTACT. WHEN WASHER WAS ADDED, VIBRATION DROPPED TO BELOW 1 MIL.



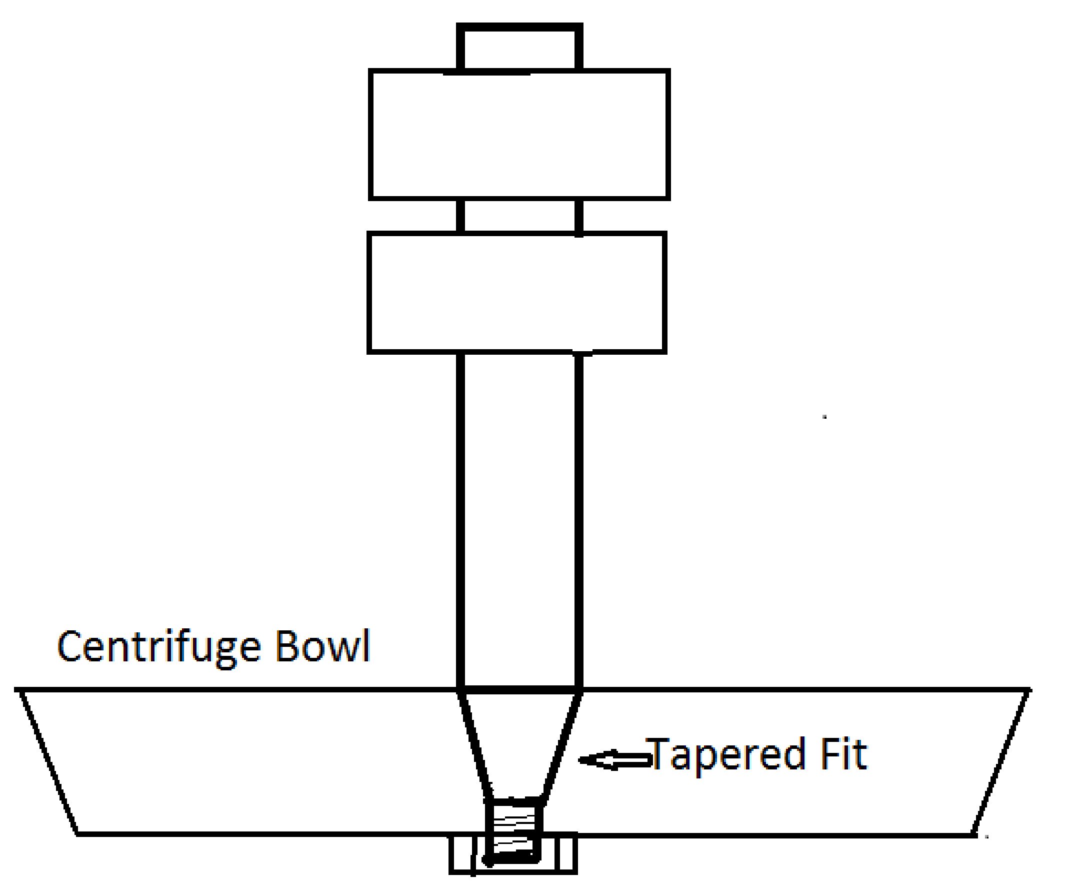
COMMENTS

- Look for simple things first
- Feel for looseness with fingers
- In this case torque wrench was not reliable because bolt bottomed out.
- Expensive Washer

Case 7- Stubborn Centrifuge with light switch effect

- Centrifuges often require balancing. It is usually not a difficult task.
- This particular centrifuge seemed impossible to balance.
- When weight was added to balance the rotating element, the phase would jump 180 degrees thus calling for the weight to be removed.
- This is the light switch effect. You push the switch to the center, then it flips to the other side.

Below is a diagram of the centrifuge.



Root cause of Problem

- It was discovered that the tapered fit between the centrifuge bowl and the shaft was loose. This allowed the bowl to move to one side causing unbalance.
- When the correction weight was added, the bowl would snap to the other side causing the phase to shift 180 degrees.
- The balancing was done with a strobe light system so the effect was dramatic in that the phase mark would instantly jump to the other side.

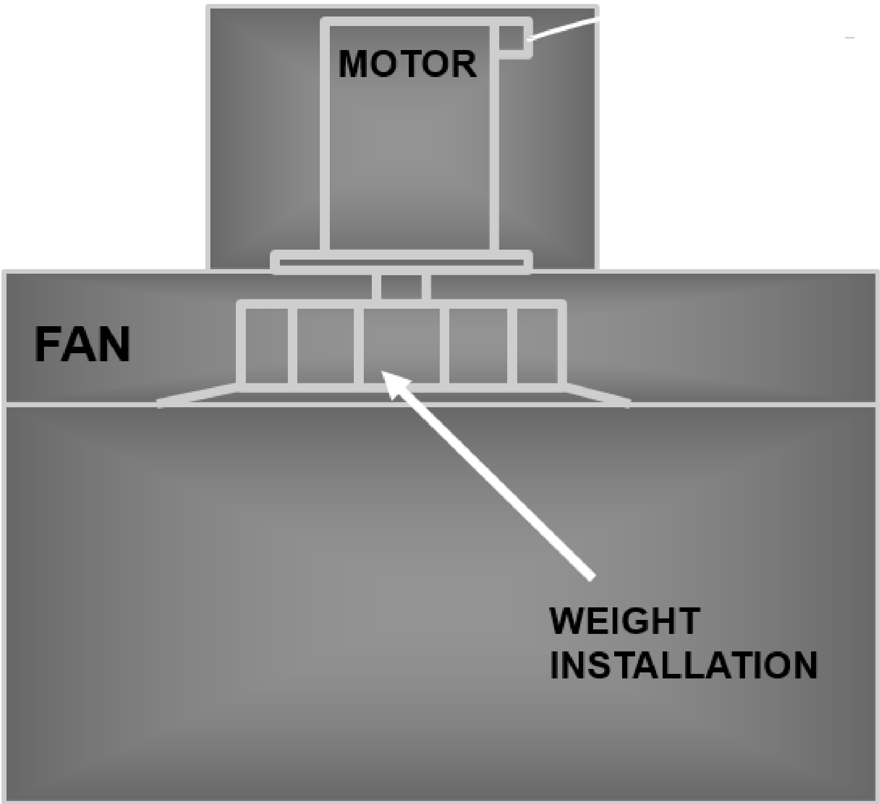
Case 8 No tach signal

- A compartment cooling fan on a gas turbine needed balancing.
- The unit fit into the roof of the turbine compartment. There was no visible shaft nor any way to see the rotor.
- The solution required the use of the 4 run no phase method of balancing.

FOUR RUN NO PHASE EXAMPLE

COMBUSTION TURBINE CONTROL ROOM VENT FAN

NO ACCESS FOR STROBE OR TACH PULSE DEVICE



ORIGINAL RUN 3 MILS
TRIAL WT 20 GRAMS
WITH WT. AT 0 DEG 3.7 MILS
WITH WT. AT 120 DEG 4 MILS
WITH WT. AT 240 DEG 2 MILS
SOLUTION ADD 52.8 GRAMS AT 250 DEG.

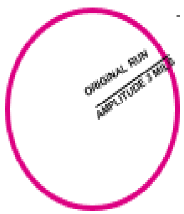
FINAL READING LESS THAN 1 MIL.

4 RUN NO PHASE METHOD OF BALANCING

NO WEIGHT

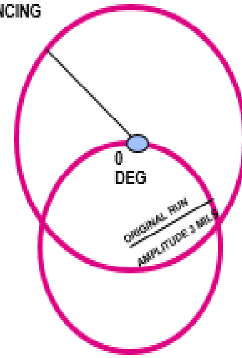
4 RUN NO PHASE METHOD OF BALANCING

STEP 1- RUN MACHINE ND DRAW A CIRCLE WITH A RADIUS EQUAL TO THE AMPLITUDE OF THE RUNNING SPEED COMPONENT



TRIAL WT. AT 0 DEG

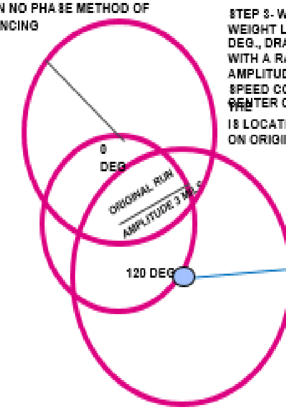
4 RUN NO PHASE METHOD OF BALANCING



STEP 2- WITH A TRIAL WT. AT 0 DEGREE DRAW A CIRCLE WITH ITS CENTER AT 0 DEGREE ON THE 1ST CIRCLE AND A RADIUS EQUAL TO THE AMPLITUDE COMPONENT OF THE RUNNING SPEED

TRIAL WT. AT 120 DEG

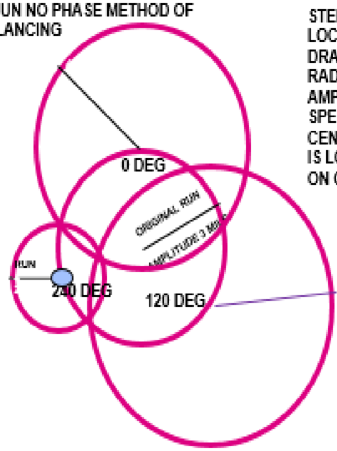
4 RUN NO PHASE METHOD OF BALANCING



STEP 3- WITH THE TRIAL WEIGHT LOCATED AT 120 DEG., DRAW A CIRCLE WITH A RADIUS EQUAL AMPLITUDE OF RUNNING SPEED COMPONENT. THE CENTER OF THE CIRCLE IS LOCATED AT 120 DEG. ON ORIGINAL CIRCLE.

TRIAL WT. AT 240 DEG.

4 RUN NO PHASE METHOD OF BALANCING



STEP 4-WITH TRIAL WT. LOCATED AT 240 DEG, DRAW CIRCLE WITH A RADIUS EQUAL TO AMPLITUDE OF RUNNING SPEED COMPONENT. THE CENTER OF THE CIRCLE IS LOCATED AT 240 DEG ON ORIGINAL CIRCLE.

SOLUTION

4 RUN NO PHASE METHOD OF BALANCING

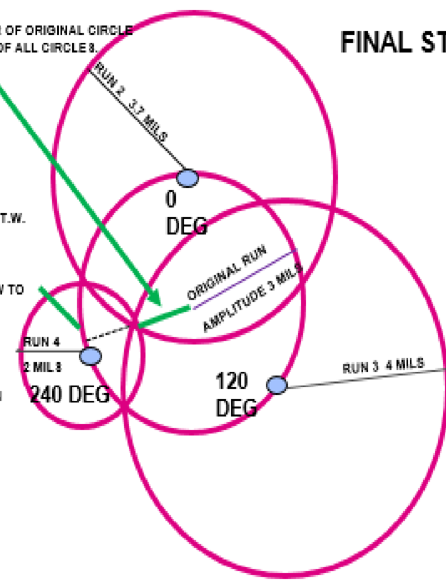
DRAW LINE FROM CENTER OF ORIGINAL CIRCLE TO INTERSECTION POINT OF ALL CIRCLES. EFFECT 1 MIL

SOLUTION:

CORRECT WEIGHT EQUALS

$$\frac{\text{ORIGINAL AMPLITUDE}}{\text{EFFECT}} \times \text{T.W.}$$

PROJECT EFFECT ARROW TO INTERSECTION POINT ON ORIGINAL CIRCLE TO FIND CORRECT LOCATION FOR SOLUTION WEIGHT



FINAL STEP

SOLUTION ADD 3 TIMES THE TRIAL WT AT 250 DEGREES

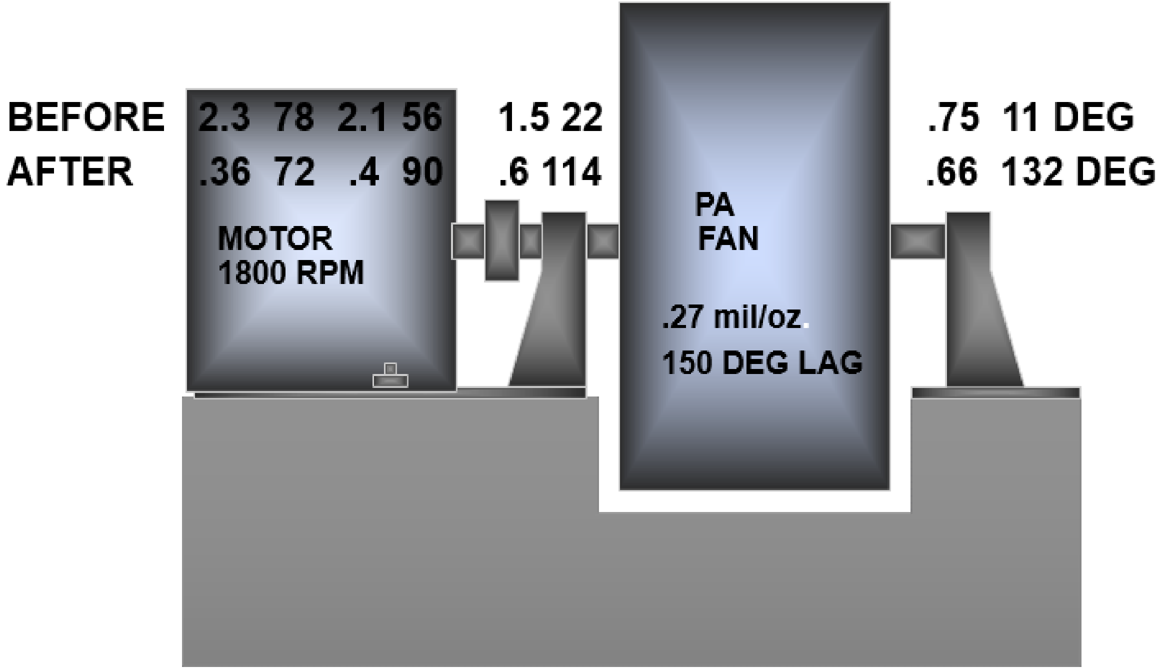
4 Run No phase balance steps

- Run machine & record amplitude at running speed. Draw a circle with that radius.
- Add weight at 0 degrees. Measure amplitude at running speed. Draw a second circle with its center on 0 degrees of first circle and with a radius equal to amplitude with weight at 0 degrees.
- Add weight at 120 degrees. Measure amplitude at running speed. Draw a third circle with its center at 120 degrees on first circle and with a radius equal to amplitude with weight at 120 degrees
- Add weight at 240 degrees. Measure amplitude at running speed. Draw a fourth circle with its center at 240 degrees on the first circle.
- Measure distance from center of first circle to intersection points of circles 2,3 & 4. That is the effect of the weight. Solution weight equals original amplitude divided by effect amplitude X the amount of trial weight.
- Angle is determined by drawing effect line out to edge of circle 1.

Case 9-Greater cross effect than direct effect on Primary Air Fan

- Problem. A motor was installed on a large Primary Air Fan. The amplitude on the motor was higher than the customer desired. All the vibration was at the machine’s speed.
- Personnel from the motor shop installed several balance shots in the motor, but the level would not come down.
- The source of the unbalance turned out to be the fan, even though it had lower levels than the motor.

CROSS EFFECT FROM FAN TO MOTOR



NOTE !

EVEN THOUGH MOTOR LEVELS WERE GREATER

1: FAN ANGLES LED MOTOR ANGLES

2: UNITS WERE ON A COMMON CONCRETE PEDESTAL

3: FAN POLAR MOMENT OF INERTIA IS MUCH GREATER THAN MOTOR'S

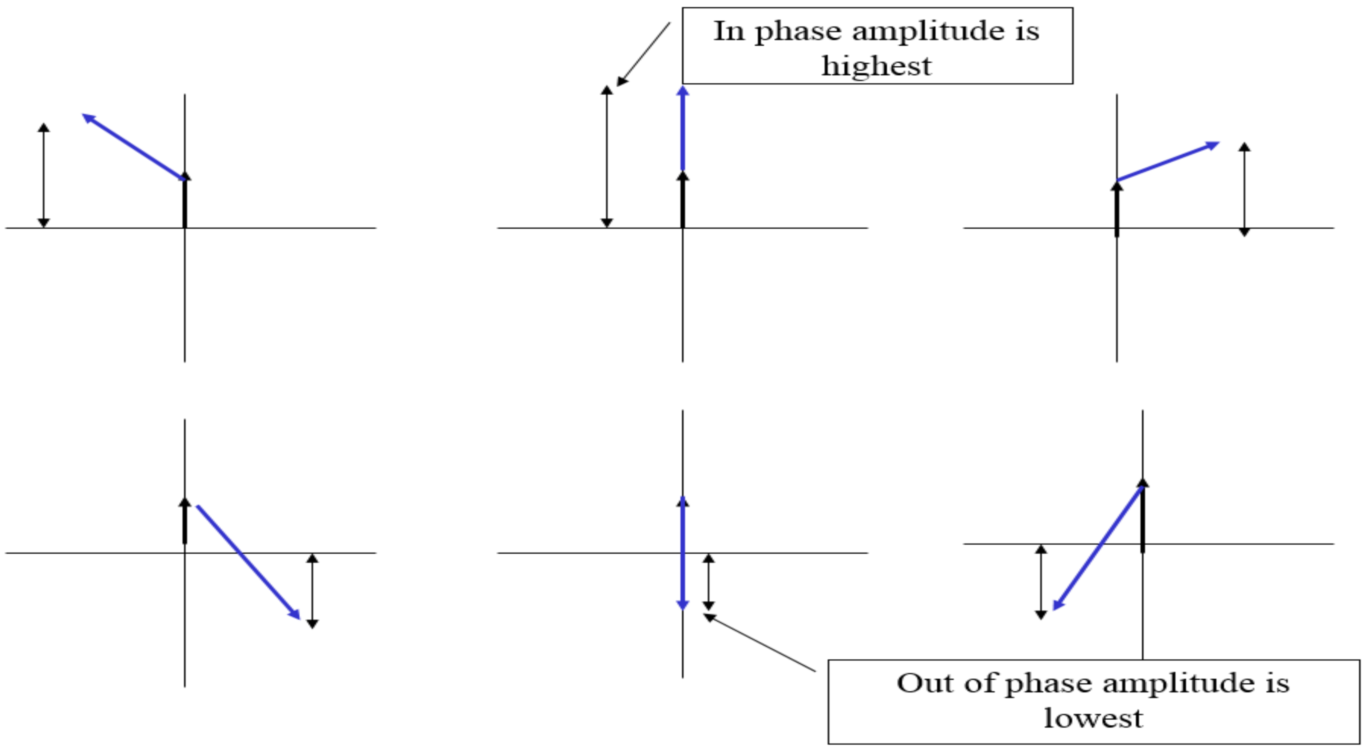
THE CHOICE WAS THEREFORE MADE TO BALANCE THE FAN

Case 10-Beat between two 20 ft long rolls

- Problem- At a paper mill in Washington State the floor would start to vibrate severely, then a minute or so later, the vibration would go away and the process would repeat on regular levels.
- The problem had been around for several years, but had gotten worse and was to the point it was affecting the quality of the process.
- The source of the vibration was the re-winder which consisted of two 20 ft long rolls. The rolls turned at slightly different speeds so that there would be tension on the paper.
- According the plant, there had been several unsuccessful attempts to balance the rolls.
- The rolls were on a common control system so could not be ran separately.

REWINDER AT PAPER MILL

2 ROLLS ELECTRICALLY LOCKED TOGETHER OPERATING AT NEARLY THE SAME SPEED OF 975 RPM.



The problem was that the rolls were beating with one another.

BEATS OCCUR WHEN TWO OR MORE SIGNALS ARE ADDED TOGETHER

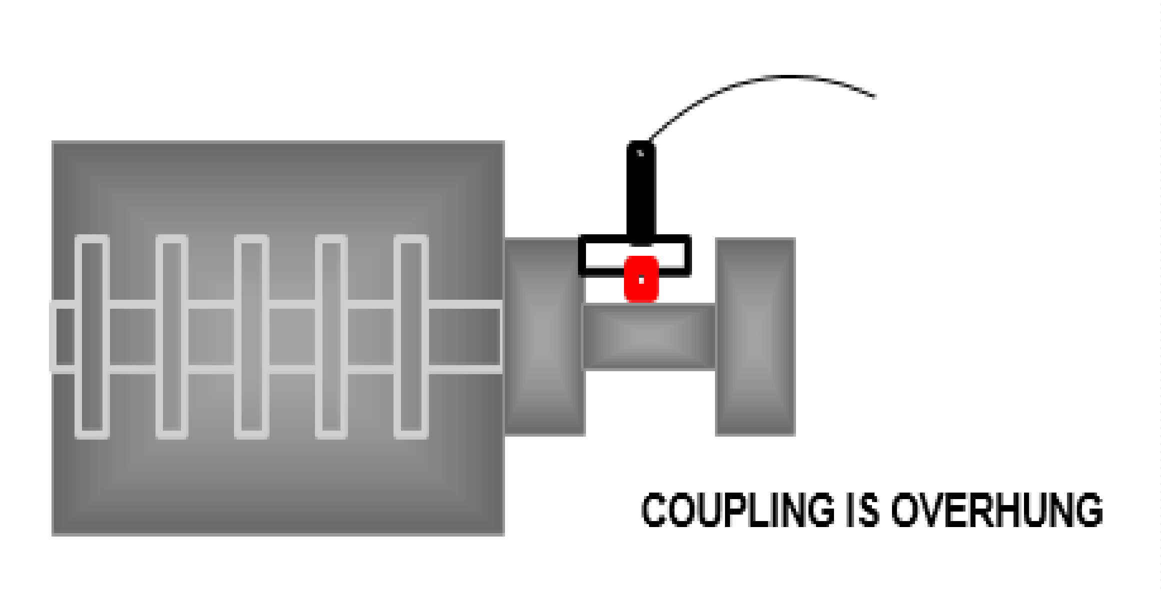
FORMULA FOR THE ADDITION OF TWO SIGNALS

$$Y = A * \sin(2\pi f_1 t) + B * \sin(2\pi f_2 t)$$

Solution- Synchronous Time Averaging

- Previous balance personnel used strobe equipment. The phase would rotate 360 degrees and the amplitude would go high then low making balance calculations impossible.
- By utilizing synchronous time averaging the signal from the non synchronized roll averages to 0 thus allowing one roll at a time to be balanced.
- The final vibration levels were .2 mils.
- When force calculations were made, it was discovered that when both roll unbalance forces were in phase that 4400 lb of force was being input into the floor 900 times per minute.
- Synchronous time averaging is very useful when more that one machine is operating in an area and they are running at nearly the same speed. Cooling towers are a good application for synchronous time averaging.

Case 11- Coupling Unbalance on two high speed machines



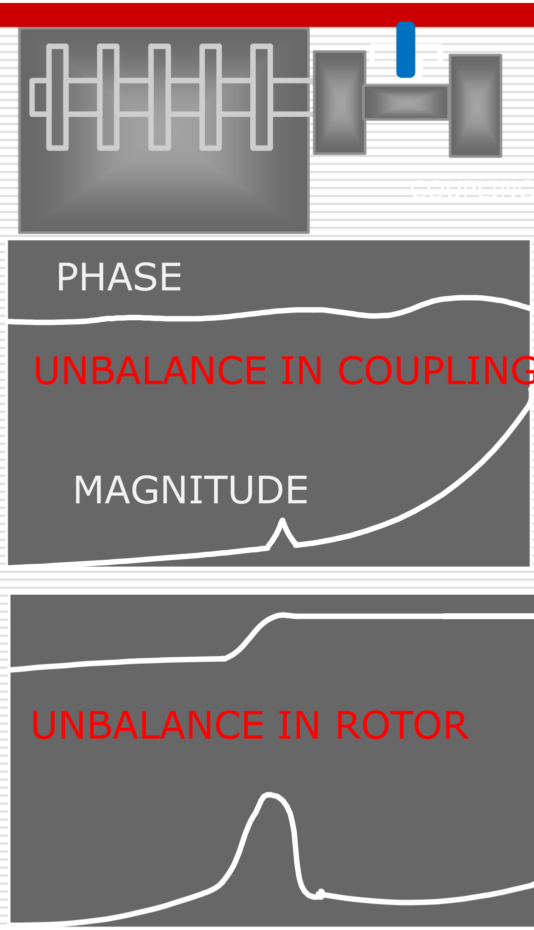
Coupling unbalance Example 1

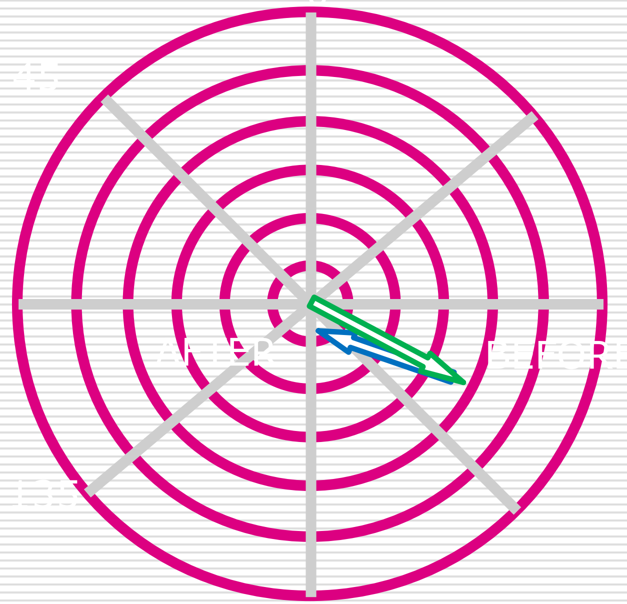
- A 6000 Hp turbine was in alarm following an overhaul. Proximity probe levels were only high on coupling end.
- A washer was installed on the coupling and the vibration was reduced to . 5 mil.
- The next outage, examination showed that after the first outage that the coupling match marks had not been aligned.
- After aligning match marks, vibration was high.
- Washer was removed and vibration came back down.
- Warning. On high speed compressors, match mark coupling and weight all bolts nuts and washers.

Coupling Unblance Example 2

- 10,000 RPM Ammonia Compressor
- High Vibration on proximity probes on coupling end only.
- No response through critical speed.
- From 8000 RPM to 10000 RPM amplitude rapidly increased, but phase did not shift.
- Customer had spend over $100000 on trying to solve this problem
- Solution was the addition of one 8 gram washer to a coupling bolt.
- Comment- A very expensive washer indeed.

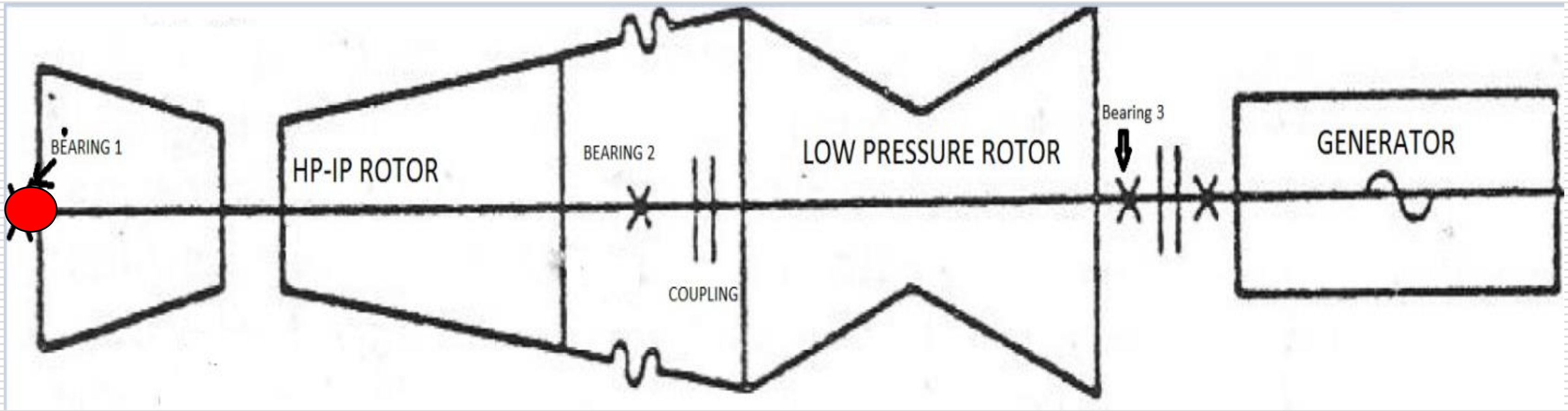
COMPRESSOR WITH UNBALANCE IN COUPLING





CASE 12-Cross effect saves the day

- Problem- A 100 Megawatt GE D-2 Turbine had high vibration on the HP Turbine.



Complicating Factors

- The HP-IP Rotor and the LP Rotor share a common bearing. Two rotors but only three bearings. Cross effect is large.
- Bearing 1 Level was high at over 5 mils, but past history showed that weight installed on the no. 1 balance plane had very little effect on the vibration on the no. 1 bearing
- This was the largest turbine in an old plant. If it could not be fixed well enough to run for another year until when money would be available to replace the rotor, then the entire plan might have to be permanately shut down.

Looking For a Solution

- Could cross effect from weight added to the LP rotor be used to reduce the vibration on the HP rotor?
- If so, could some sort of compromise shot be added that would lower the vibration on the HP-IP rotor without significantly increasing the amplitude on the LP rotor?
- The LP rotor was full of weights, some of them even piggybacked. Was there any way enough weight could be added?

Road to the solution

- Effect data from another D-2 Turbine was used to calculate the projected cross effects. Polar paper was then used to determine the direct effect of weight added to the LP turbine on the LP turbine and the cross effect of that weight onto the HP turbine. Within a few minutes using polar paper a solution was worked out that would lower the vibration on the HP Turbine without adversely effecting the LP turbine. The problem was that there were already large arcs of weight on both ends of the LP rotor where the weight was required.

Splitting Weights

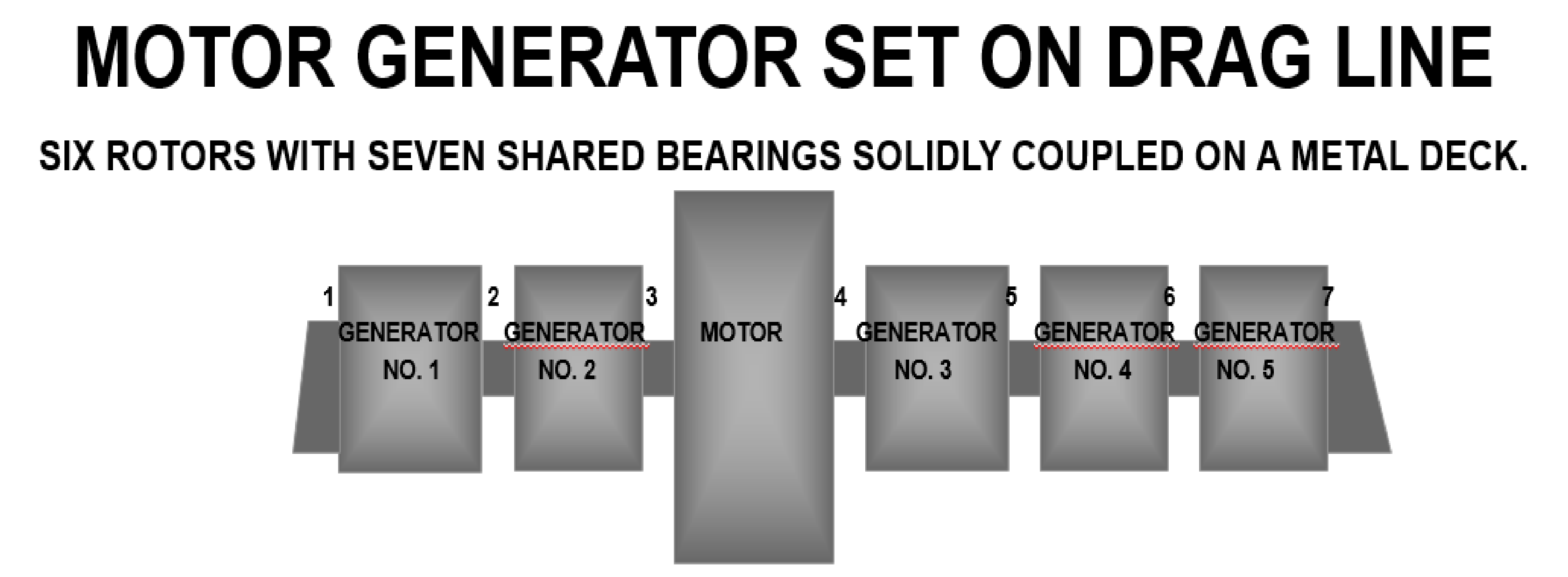
- Calculations showed that if 26 oz was added at 80 degrees and 21 oz at 230 degrees(both at the ends of solid arc of weights) it would have the desired effect of 13 oz at 133 degrees on one end of the LP rotor.   If 20 Oz was added at 260 degrees and 15 oz at 120 degrees on the other end of the rotor, that would have an effect of 12.9 oz at 211 degrees. Those were the desired effects that the polar plots indicated that were needed.
- After installation of the above weights, all the amplitudes were below 3.5 mils

Hail Mary succeeded

- This whole process was a bit of a desperate act. It does show how understanding of cross effect led to a solution. It also shows the need to understand how splitting of weights can be used to create the desired response.
- The turbine was able to run until the rotor could be replaced and the plant stayed in operation for 15 more years. Recently because of a mandate from the EPA the plant was closed. No compromise solution available when working with EPA.

Case 13- Cross effect in a drag line MG set

Drag line MG Sets consist of 6 rotors and 7 bearings.



A Balance Person’s Nightmare

- A typical MG train consists of a synchronous motor and 5 DC generators. These supply DC power to the hoists.
- There may be up to 5 MG trains on a large drag line.
- They are mounted on the same metal deck.
- They all run the same speed of 1200 RPM so synchronous time averaging does not help.
- Therefore up to 30 rotating elements turning the exact same speed on a common metal deck with each group of six rotors being supported by only seven bearings.
- The entire drag line including the 300 ft boom was shaking at 1200 cpm.

Narrowing things down

- It was noticed that the vibration levels were highest on one of the MG set trains.
- The highest level was 11 mils on one of the generator sets so a balance shot was installed in that rotor. The vibration went down in the vertical direction and up in the horizontal direction.
- A thought from Art Crawford popped into my mind. That thought was when in doubt go after the rotor with the highest rotating moment of inertia.

Solution

- The largest component on the MG set train of six rotors was the large synchronous motor.
- Weigh was added to the synchronous motor and all the solution vectors pointed in the same direction.
- 50 oz was added at a radius of 30 inches in the synchronous motor and the entire drag line calmed down.

Case 14- 500 Megawatt Turbine HP Rotor modal balance 2 modes

- Two Problems
  - HP Rotor of 500 Megawatt Turbine had 15 mils of vibration as it traversed its 1420 RPM critical speed.
  - After the turbine got to full speed, the vibration was also high at over 7 mils at 3600 RPM.

500 Megawatt High Pressure section rotor

1st Critical Speed Response both bearings in phase 13 & 15 mils

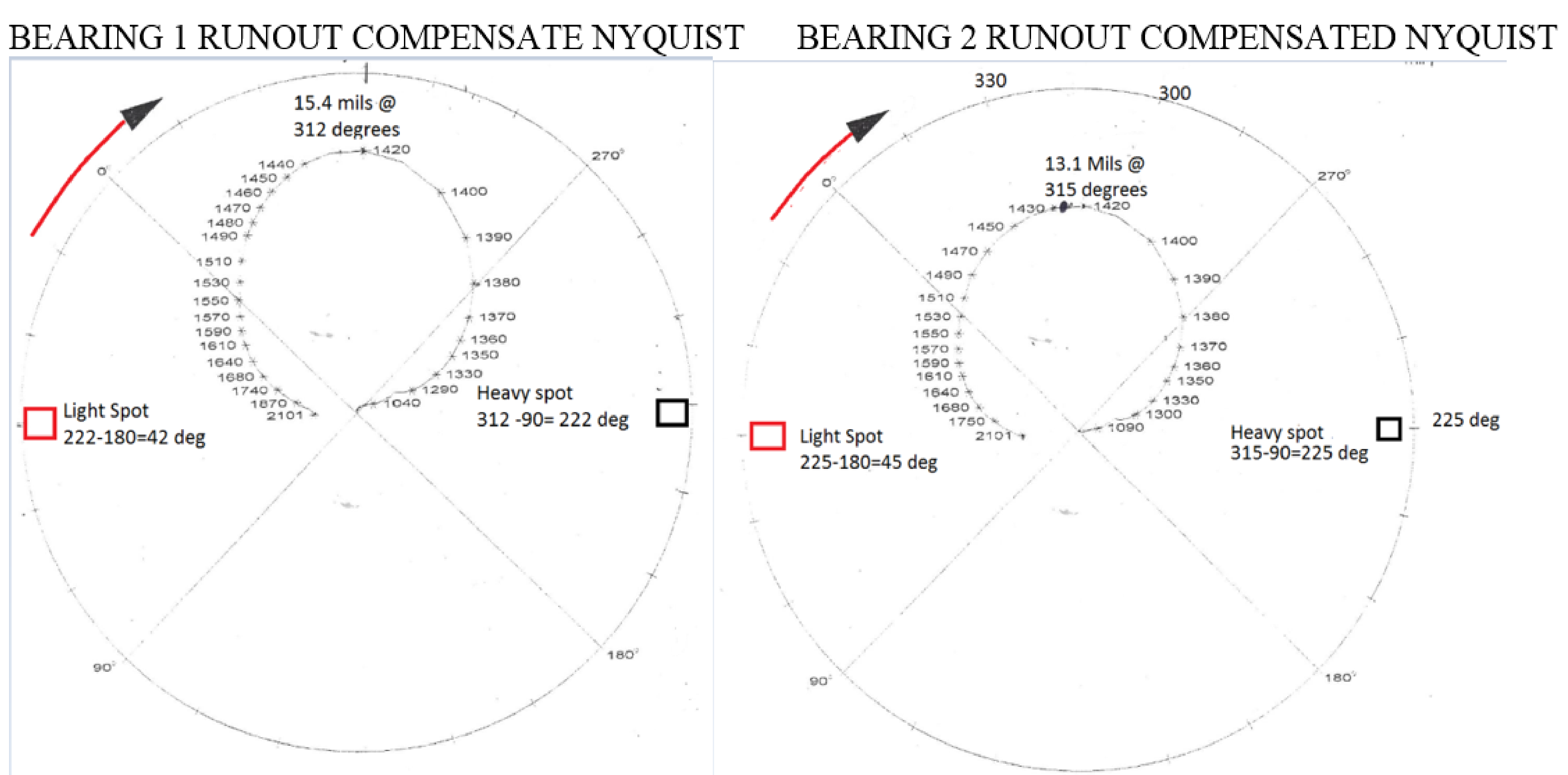


Figure 20 Nyquist plots showing 1st critical speed response

Solution to first mode critical speed response

- Vibration response was static in nature(phase angles were nearly identical) as would be expected at the 1^{st} critical.
- Past experience with this rotor design showed that the cause was a bow in the rotor. Since the rotor was bowed, the weight had to be installed in the mid rotor balance plane rather than in the end planes.
- A 90 degree lag at the critical speed was used to estimate the angle.

Solution Continued

- The inner and outer cylinder plugs were removed and 3 balance plugs weighing 9 oz each were installed. Note the temperature in that location was 1000 deg F. To insure that the plugs did not expand and get stuck halfway in the balance holes, they were preheated.
- Following installation of the weights, the critical speed response dropped from 15 mils down to 5 mils which was acceptable.

Full speed 2^{nd} mode shape balancing.

- Following the mid plane balance shot, the unit was brought to speed and the following readings were obtained:
- Bearing 1 Left Probe 6.3 mils @ 260 degrees
- Bearing 2 Left Probe 6.9 mils @ 80 degrees
- Note that phase angles are 180 degrees apart indicating excitation of second mode which would require a couple shot (equal amounts of weight in each end installed 18 degrees apart).

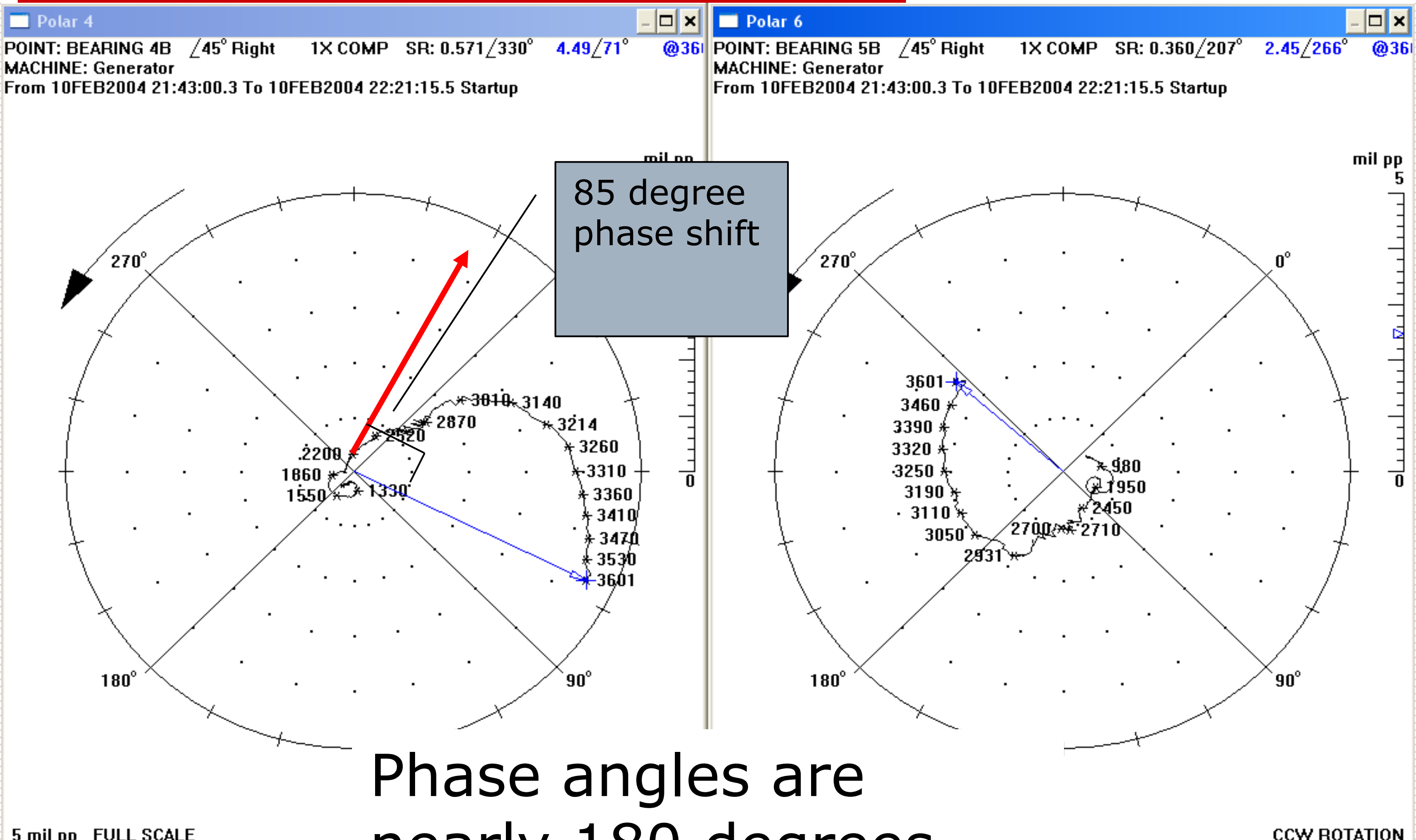
Solution

- Past experience showed that the couple sensitivity was 1.5 oz/mil and that the couple lag angle was 68 degrees.
- Based upon the full speed data and using the above values, 9.8 oz was added at 28 degrees in plane 1 and 9.8 oz/mil was added at 200 degrees in plane 2.
- Final results
- Bearing 1 left probe 1.4 mils at 165 degrees
- Bearing 2 left probe 2.4 mils at 0 dereees

Conclusions

- This case history is an excellent example of balancing separate modes.
- The first step was to attack the first mode with a shot to the center of the rotor to reduce the critical speed.
- The second step was to install a couple shot to reduce the running speed motion that was the result of the excitation of the 2nd mode shape.

Case 15- Balancing 2nd mode unbalance in the generator of a Frame 7 Gas Turbine.



Phase angles are nearly 180 degrees apart.

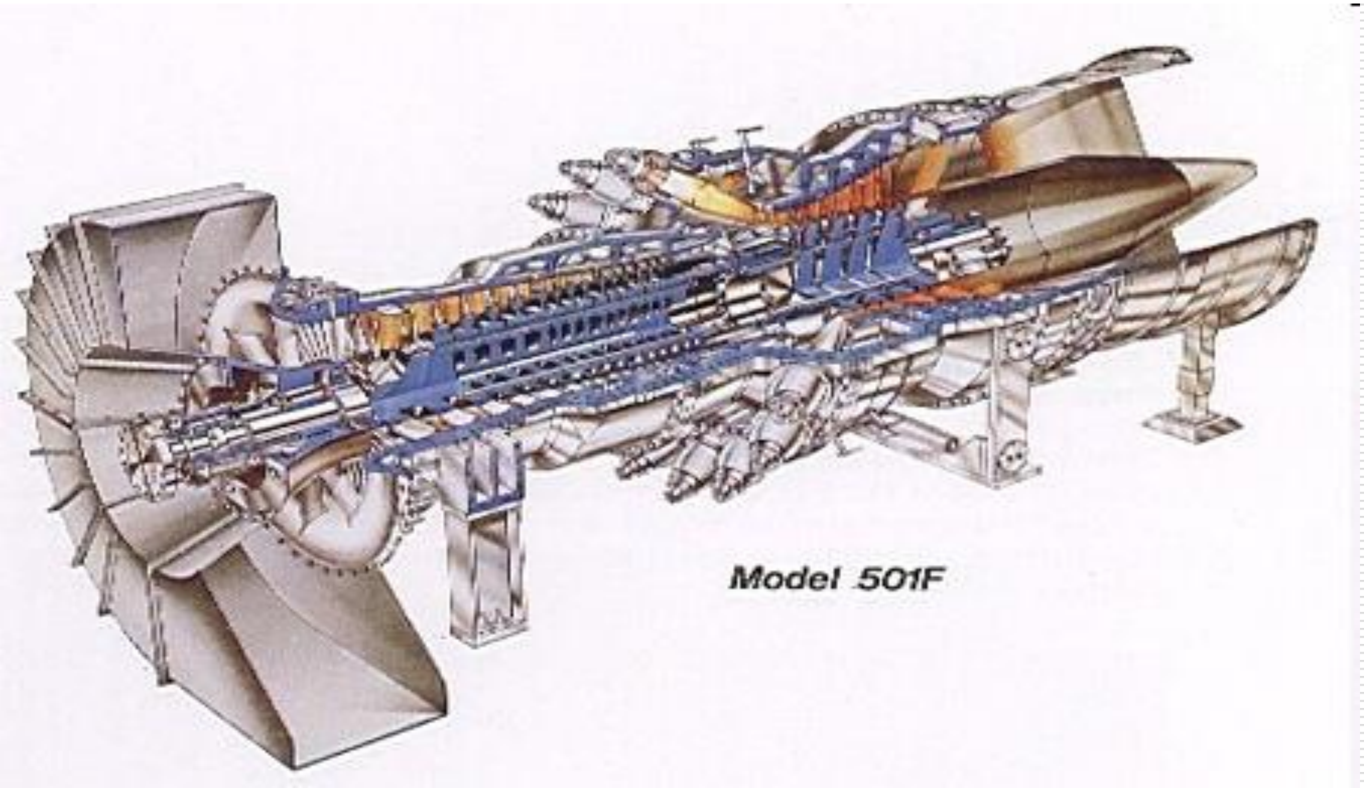
Information obtained from Nyquist Plots

1: The second mode is being excited. Note that the phase angles from one end of the rotor to the other end are almost 180 degrees apart. (The vectors point in the opposite direction).
2: The rotor goes through approximately 85 degrees of second mode phase shift.
These two pieces of information tell the analyst to install a couple shot (equal amounts of weight 180 degrees apart) and that the second mode lag angle is 85 degrees.
Using these two pieces of information, it was possible to place the weights in the correct location on the first balance attempt. This was in spite of having no previous history on this unit.

Solution and Comments

- By using the information in the Nyquist plot, it was determined that couple shot was required and that the lag angle was 85 degrees.
- The generator was balanced in one shot. This approach can save a great deal of time as compared to a two plane trial weight balance approach. Large generators are cooled with hydrogen which must be purged with carbon dioxide then air to install the weights then the process reversed following the installation. The amount of time saved can therefore be several days.

Case 16-501 Gas Turbine Cross effect greater than direct effect



4 Times as much cross effect as direct effect from exhaust end balance shot.

When balancing gas turbines, if you have not balanced one before, the best thing to do might be to disregard your common sense. The reason for this is because the cross effects from one end to the other are often much greater than the direct effects. To state this more clearly, if the amplitude of the unbalance is high on one end of the turbine, then it is quite likely that the solution weight will need to be installed on the opposite end. The following are the lag angles and sensitivities from a Westinghouse 501 Gas Turbine.

Exhaust end balance shot on exhaust end	18.0 oz/mil	25 degree lag
Exhaust end balance shot on compressor end	4.7 oz/mil	46 degree lag
Compressor end shot on compressor end	18.0 oz/mil	353 degree lag
Compressor end shot on exhaust end	8.6 oz/mil	30 degree lag

In this example, if weight was added to the exhaust end, then it would have nearly 4 times as much cross effect on the compressor end as it had direct effect on the exhaust end.

Discussion

Discussion: Large steam turbines and generators which have symmetrical rotors and relatively symmetrical bearing stiffnesses respond well to static-couple balance techniques. Gas turbines are a totally different animal. Their rotors are not symmetrical nor are their bearing stiffnesses. The best approach to balancing large gas turbines is to get prepared to use a true dual plane approach. On the first try, add weight in the end opposite to where the amplitude is the maximum. After reading the response, determine if it is possible to reduce the levels on both ends to acceptable values by making adjustments to the trial weight. If not, then add weight to the opposite end and perform the dual plane calculation.

Case 17 Human error can be a critical factor

- 7000 HP 885 RPM ID Fan on Variable speed drive that operated at critical speed .
  - Fan blades were re-tipped and major repairs were made to fan wheel.
  - Organization that did the work had spent several days trying to balance the fan with poor results. Crew was exhausted and were not adding enough trial weight.
  - When balance job was taken over, specific instruction were given to fan crew as to where to install the trial weights.
  - Data was taken at 600 RPM, a trial weight was calculated and the lag angle was determined by observing the phase shift from 600 RPM down to 300 RPM.

SOMETHING IS WRONG HERE

- The results were not good. That was peculiar since many fans had been balanced by the prescribed technique with a high level of success.
- A second shot was installed, again with unexplainable results.
- While installing the next trial shot, by looking in the fan it was noted that the mechanics were rotating the fan the wrong way for the installation of the balance weight. The phase orientation had been explained clearly to the mechanics and it took several tries to get them to realize that they had not been installing the weights in the prescribed locations.

Results

- Once the orientation problem was resolved, the fan was easily balanced. It ended up taking 23 lbs of weight to balance it. Luckily this fan was on a VFD so it could be balanced at a low speed then trimmed at a higher speed. Back calculations showed that had it been brought to full speed in the unbalance condtion that it would have vibrated at 92 mils.
- Two factors caused this problem. The first was that the mechanics who were very good guys were completely exhausted. The second is that the safety people would not let the balance people in the fan to check things out because they had no SCBA training. It did not seem to matter that the unit was off line and wind was sucking into the fan. There was absolutely no reason to require SCBA training in these circumstances.

Recommendations

If the balance person cannot get into a fan, it is recommended that an exterior phase reference be put outside rather than relying on numbering of the blades.

Some reasons for balancing errors

1: Tach pulse hardware that moves with time. When an unbalanced machine is ran for the first time or after an unsuccessful trial weight, the vibration can be quite high. Most tach pulse photocells are mounted on a magnetic pickup with a flexible connection. When high vibration is present, the magnet can slide or the connection move. If not noticed, this can result in a change of phase that was not due to the trial weight. The solution that is calculated is therefore not valid.

2: Tach pulse failures that can be the result of RF interference from variable frequency drives, static discharge, or excessive water vapor in the air.

3: Inadequate pulse width to allow for calculation of phase. This can happen on high speed machines that have too narrow a piece of reflective tape or too narrow of a key phaser notch.

4: Sloppiness in installing a protractor on a shaft. Accurate installation of both the trial and solution weights is vital.

5: Personnel getting mixed up in regards to the direction of rotation of the shaft. This is a particular issue when installing weight in opposite ends of a rotor.

6: Fatigue. This can be the single most important issue.

7: Being rushed. Many times balancing can get on the critical path to getting a facility back into production.

Difficulty Classification-The Dirty Dozen

Description	Difficulty	Comments
1: Simple single plane balancing	1	Always check rotation and base bolts
2: Simple dual plane balancing	2	Record responses carefully
3: Cross effect from another machine	2	Use synchronous time averaging
3: Thermal vector present	3	Balance at load
5: Shaft bow	3	Wait until readings stabilize
6: Nonlinear response	3	Two steps first lower level, then restart process

Dirty Dozen Continued

7: Operates near resonance	4	If possible balance off resonance
8: Multiple modes	4	If possible use static couple technique
9: Asymmetric properties	4	Most likely multi-plane balance program
10: Flimsy low damped support	4	Make small gradual moves- accept higher levels
11: Loose rotating component	5	Forget it
12: Fatigue	5	Get rest or consult with someone else

Final Comment

There are of course nightmare scenarios. For instance, you could have a large electric motor that runs near a critical, that has a thermal vector, cracked rotor bars that cause a beat, and also has bearings loose in the housing and a rotor loose on its shaft combined with sitting on a bad base. I think I will ask the new guy that inspired this paper "who had mastered balancing" to take that one on.