

# Using Vibration Analysis To Identify & Help Correct An ID Fan Foundation Problem

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# MACHINE & PROBLEM DESCRIPTION

- Large induced draft fan, directly driven by a VFD controlled induction motor.
- Normal operating speeds were from 500 – 900 rpm with most typical being 600 – 800 rpm.
- Job began with a call to balance this fan.
- Others had tried unsuccessfully to balance it in the past.
- Plant had run the motor solo prior to my arrival and solo motor levels were significantly lower leading us to believe the problem wasn't the motor.

# PHOTO OF FAN FROM REAR



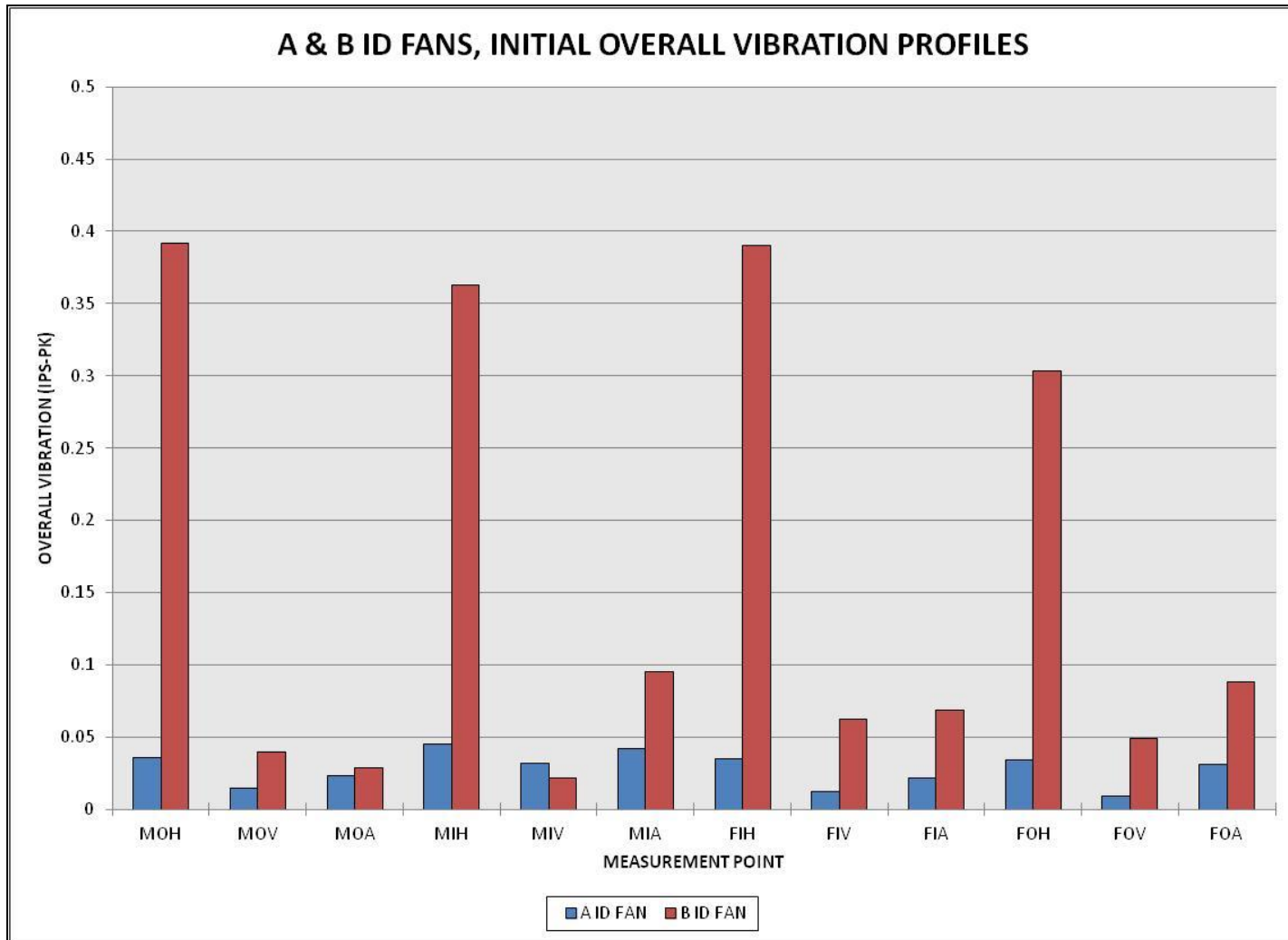
# ON-SITE INSPECTION & INITIAL DATA, p1

- Prior to any vibration measurements, on-site inspection of the B fan during operation noted *significant movement/vibration at the fan & motor bearings but also at the concrete foundation surrounding the entire machine.*
- The plant had two seemingly identical ID Fans (A & B) operating about 100 ft from one another. Only the “B” fan had a vibration problem.
- Vibration data was collected using both seismic & proximity probes that were permanently mounted at the bearings.
- Only the seismic data showed a significant vibration problem. Vibration levels at the proximity probes were not excessive.

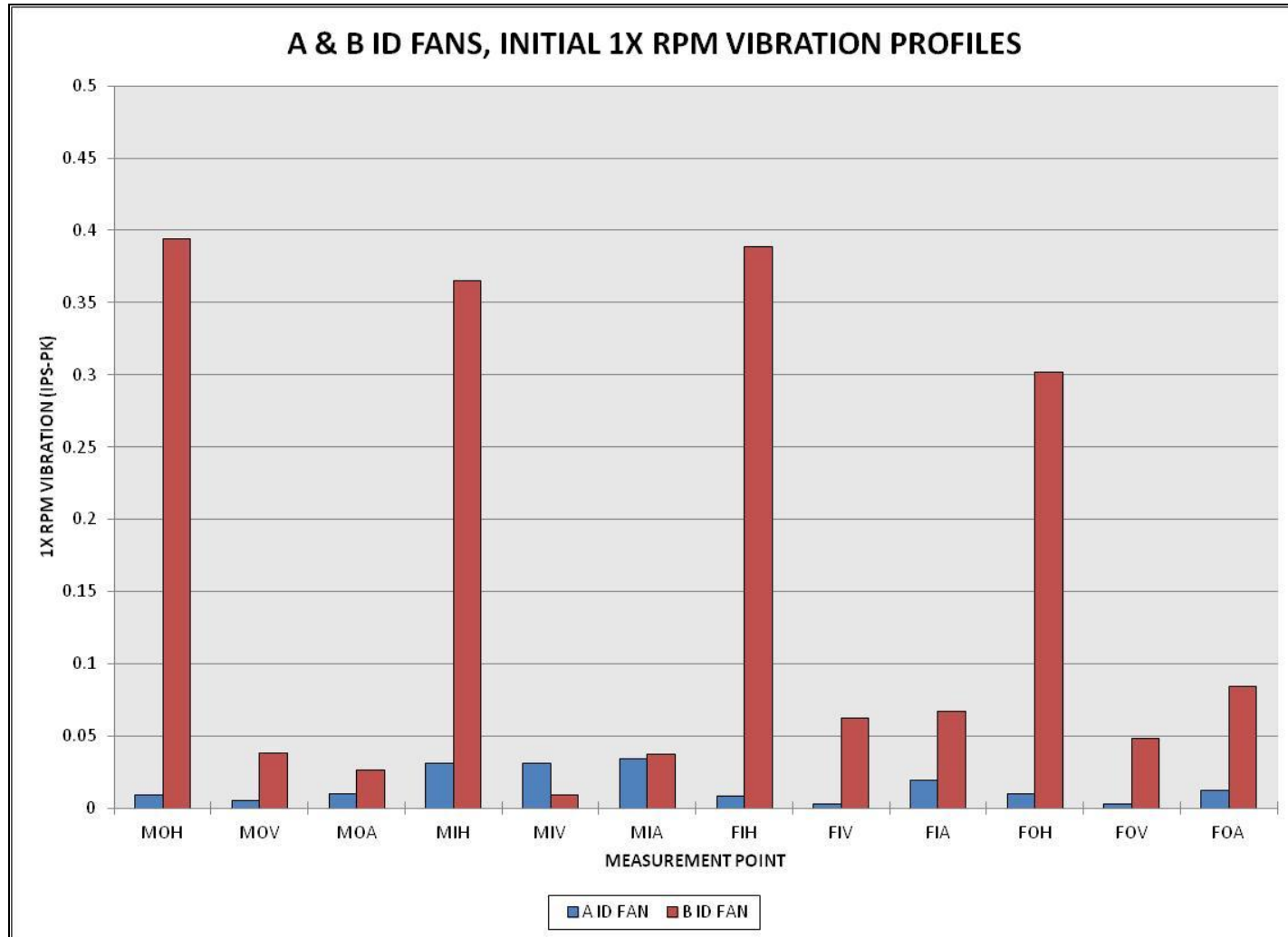
# ON-SITE INSPECTION & INITIAL DATA, p2

- Vibration spectral data showed *dominant vibration occurring at 1x rpm with no significant vibration occurring at any other frequency.*
- Coast-down data showed 1x rpm levels *increasing significantly with increasing speed.*
- 1x Peak/Phase data showed high *in-phase* vibration in the *horizontal* direction at both motor & fan.
- Vibration levels in the *horizontal* direction across the entire machine were much higher than either the vertical & axial directions (see profile plots).

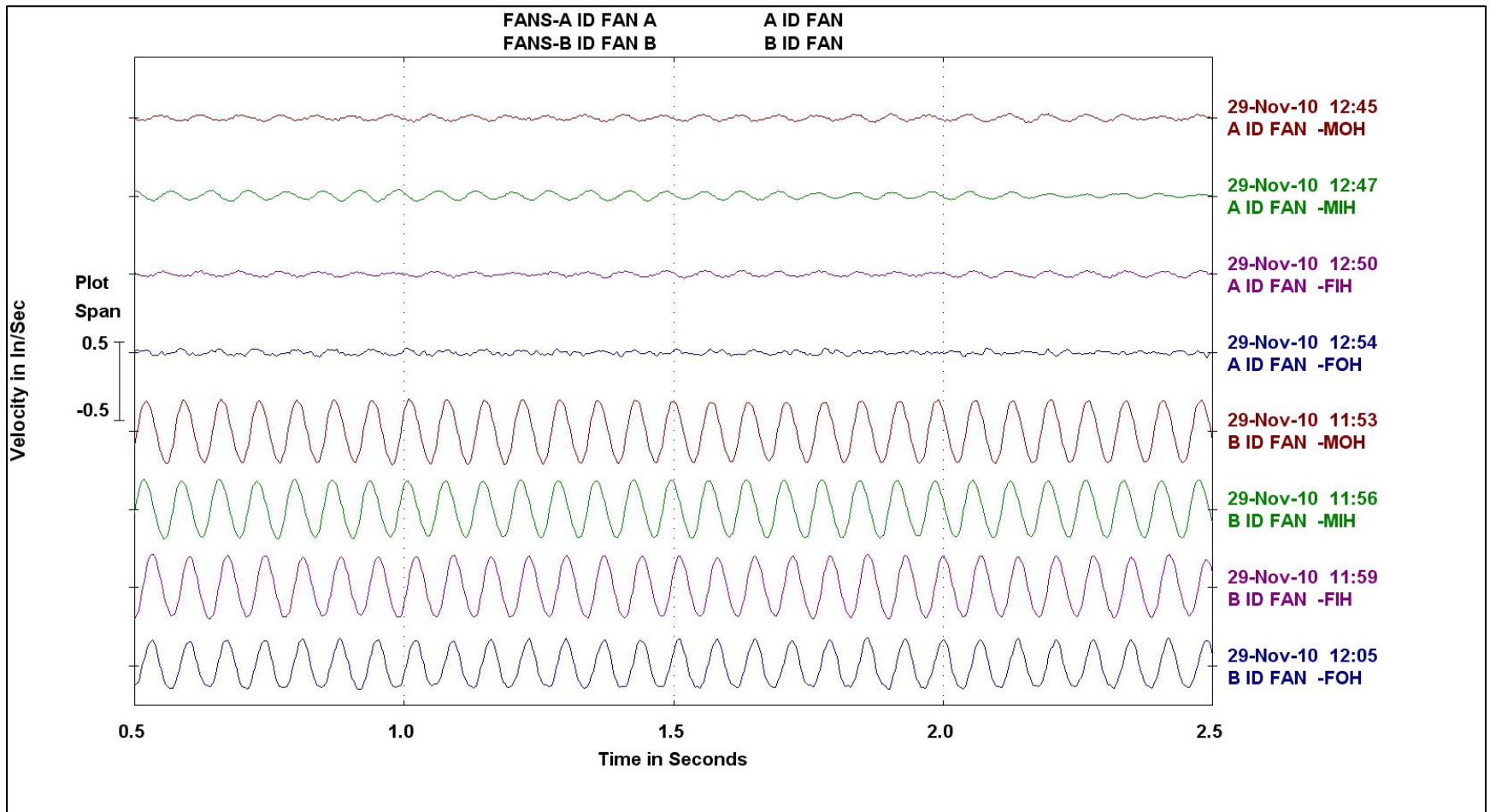
# INITIAL OA VIBRATION PROFILES - A & B ID FANS



# INITIAL 1X RPM VIBRATION PROFILES - A & B ID FANS

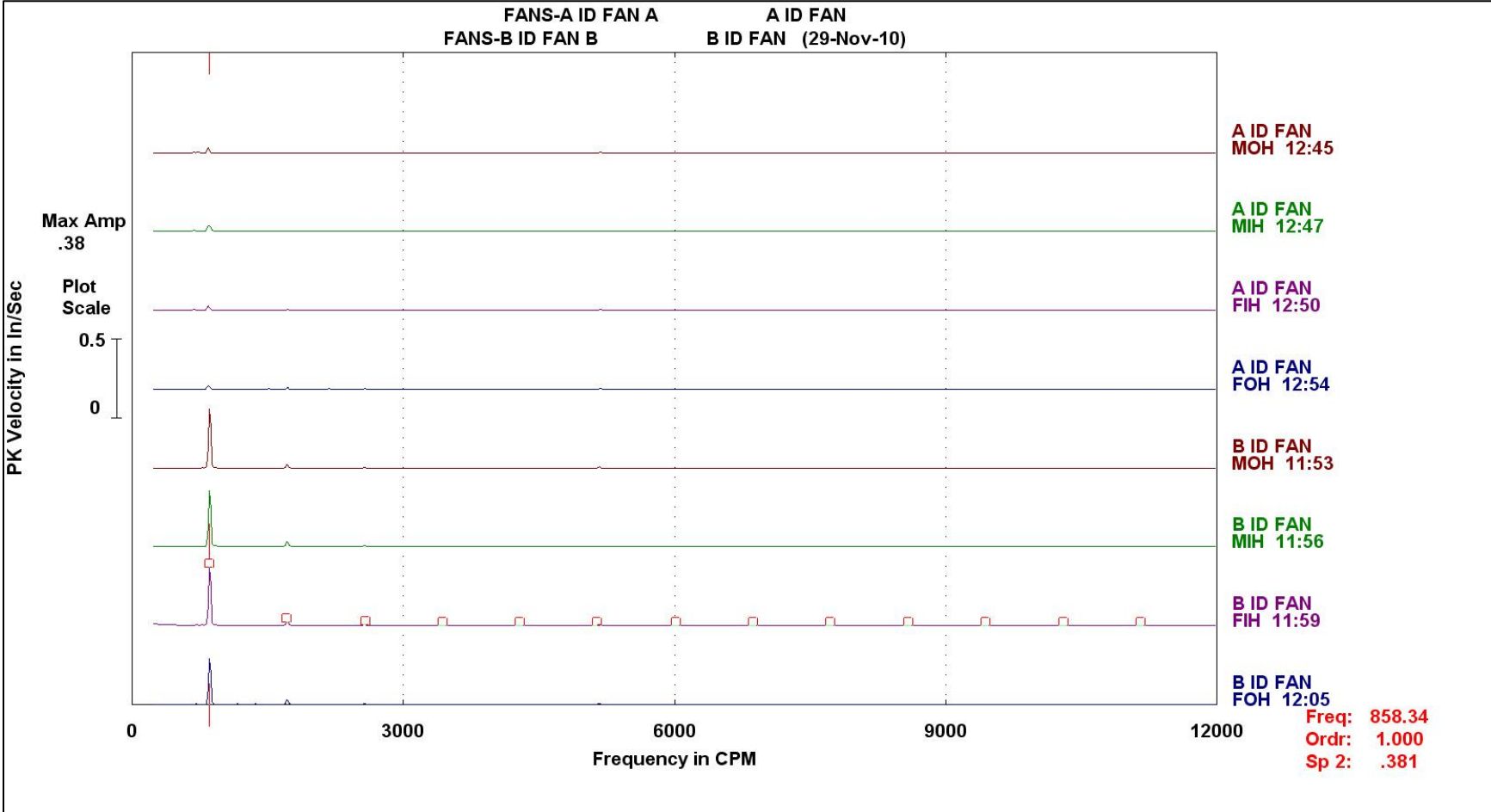


# INITIAL WAVEFORM DATA - A & B ID FANS

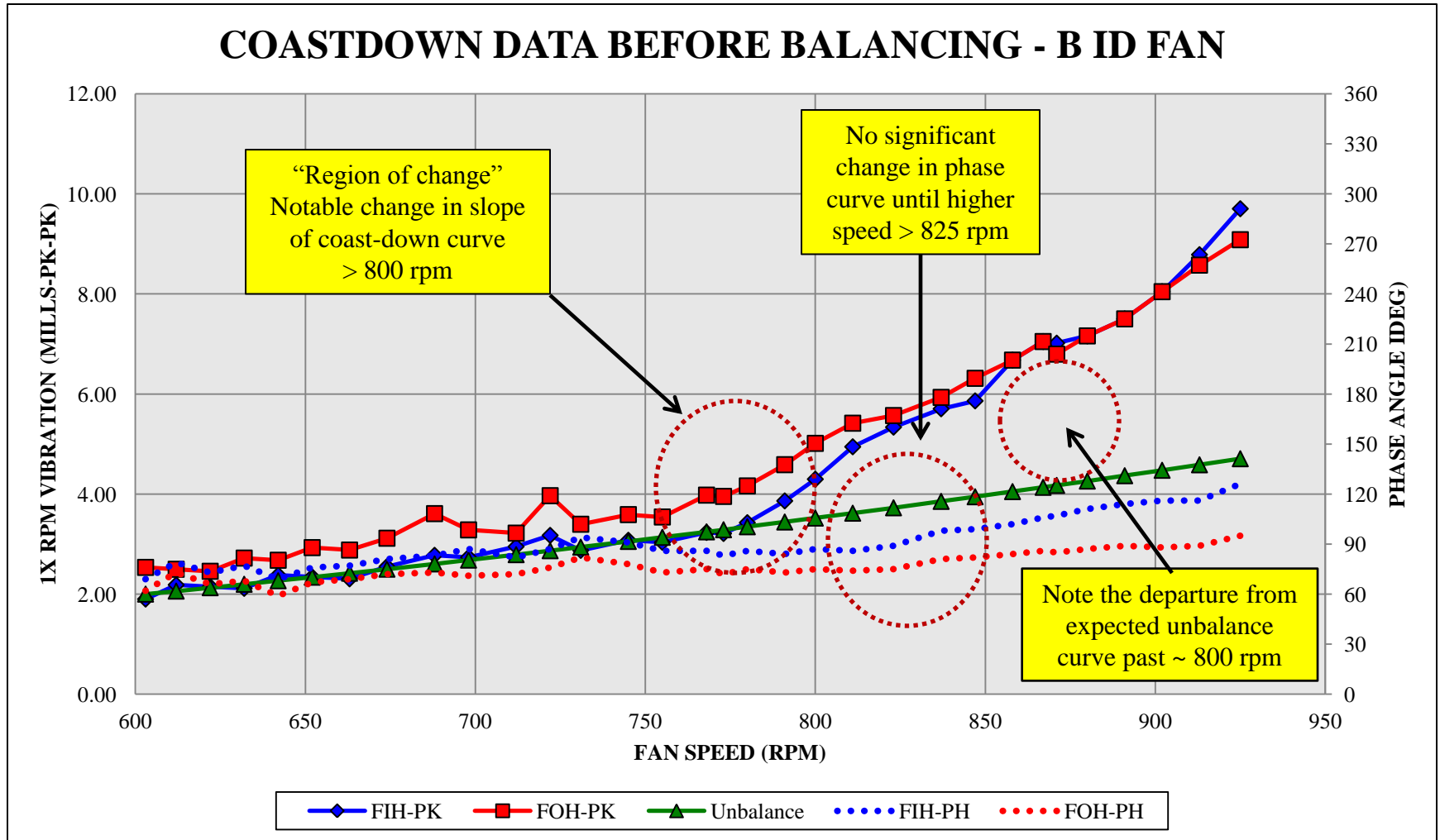




# INITIAL SPECTRAL DATA – A & B ID FANS



# COASTDOWN DATA, BEFORE BALANCING – B ID FAN



# INITIAL BALANCE PLAN

- Due to production concerns, balancing of the fan took place weeks later at a time better suited for the plant (lower demand).
- Due to the *non-linear* nature of the coast-down data collected, a two-step balancing process was decided upon as follows:
  - 1) Initial balancing would be performed at the slower speed of 675 rpm.
  - 2) Final (trim) balancing would be performed as needed at a higher speed (800 to 900 rpm).
- By first balancing the fan at a lower speed, we would lower the dynamic forces present at higher speeds and hopefully avoid the non-linear aspects of the system.

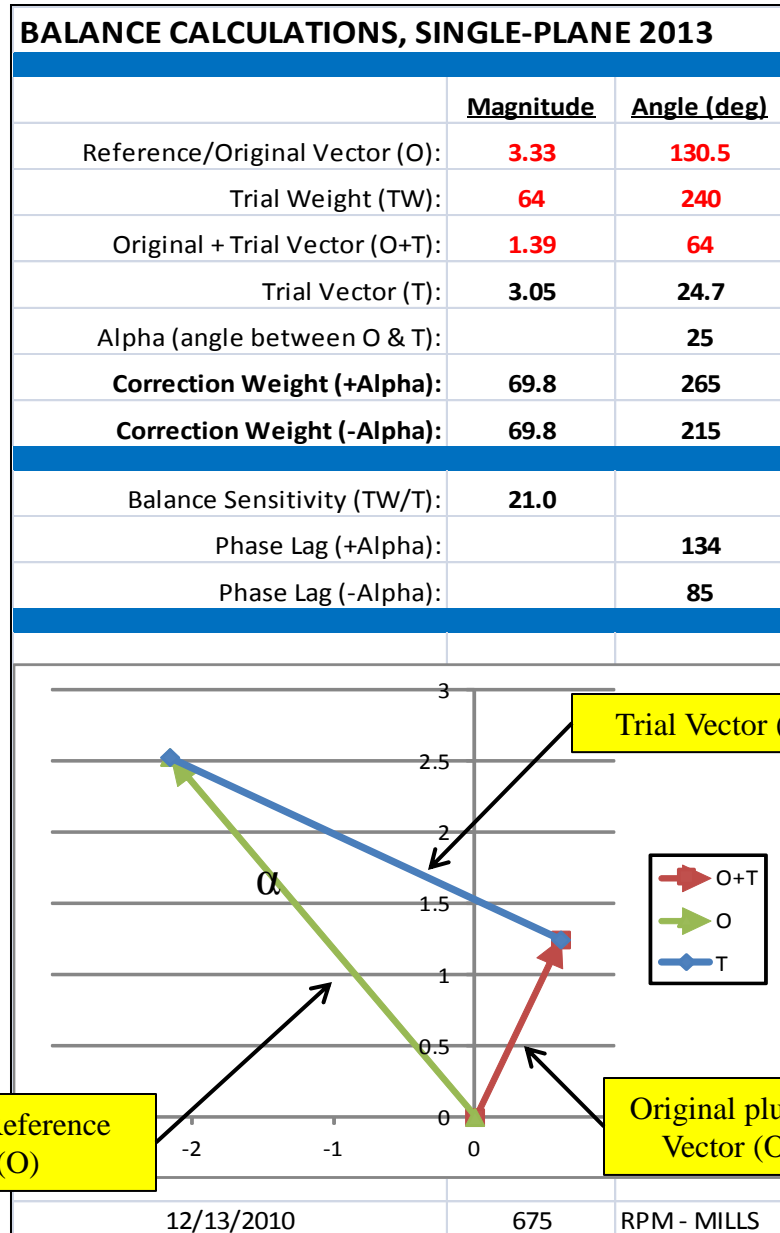
# 1<sup>ST</sup> BALANCE DATA, 675 RPM (DEC 2010)

$$CW = TW * O / T$$

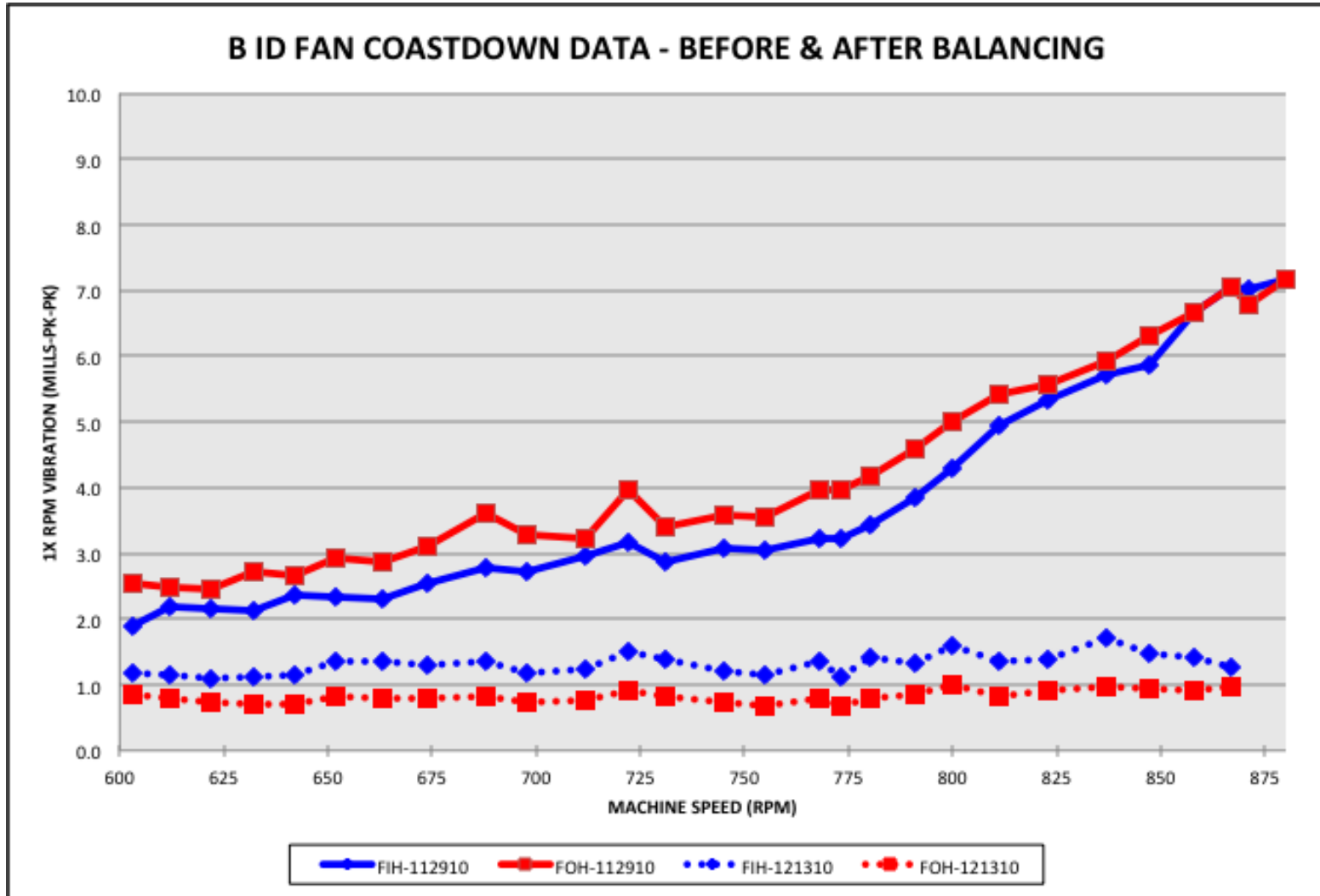
$$\theta CW = \theta TW + \alpha$$

$$SENSITIVITY = TW / T \text{ or } CW / T$$

$$PHASE LAG = \theta CW - \theta O$$



# COASTDOWN DATA, BEFORE & AFTER 1<sup>ST</sup> BALANCING



# INITIAL BALANCE RESULTS & CONCLUSIONS

- Balancing of fan reduced 1x rpm vibration levels by 80 to 85% with final levels at or very near 1 mills-pk-pk.
- Fan was run thru its normal operating speed range after the initial balance @ 675 rpm and even at 900 rpm, its levels were acceptable so no trim balance was necessary.
- Conclusions from the balance report listed concerns as to the integrity of the foundation due to the following:
  - 1) Significant vibration felt in the surrounding area (pedestals, foundation & ground) around the fan prior to balancing.
  - 2) Much higher horizontal versus vertical or axial levels across entire machine.
  - 3) Extreme difficulty experienced by others who previously attempted to balance this fan.
- Recommendation was made to have the foundation evaluated by a civil engineering firm and follow their recommendations towards improving its stiffness & integrity.

# DECISION MADE TO EVALUATE & IMPROVE FOUNDATION, p1

- Fan was balanced *six times* over two years due to high 1x rpm vibration.
- Each time balancing successfully reduced vibration @ 1x rpm, but it didn't take long until high vibration returned (3 to 6 months) and balancing was needed again.
- During this time no significant problems were noted from the A ID Fan nearby which experienced the same operating conditions.

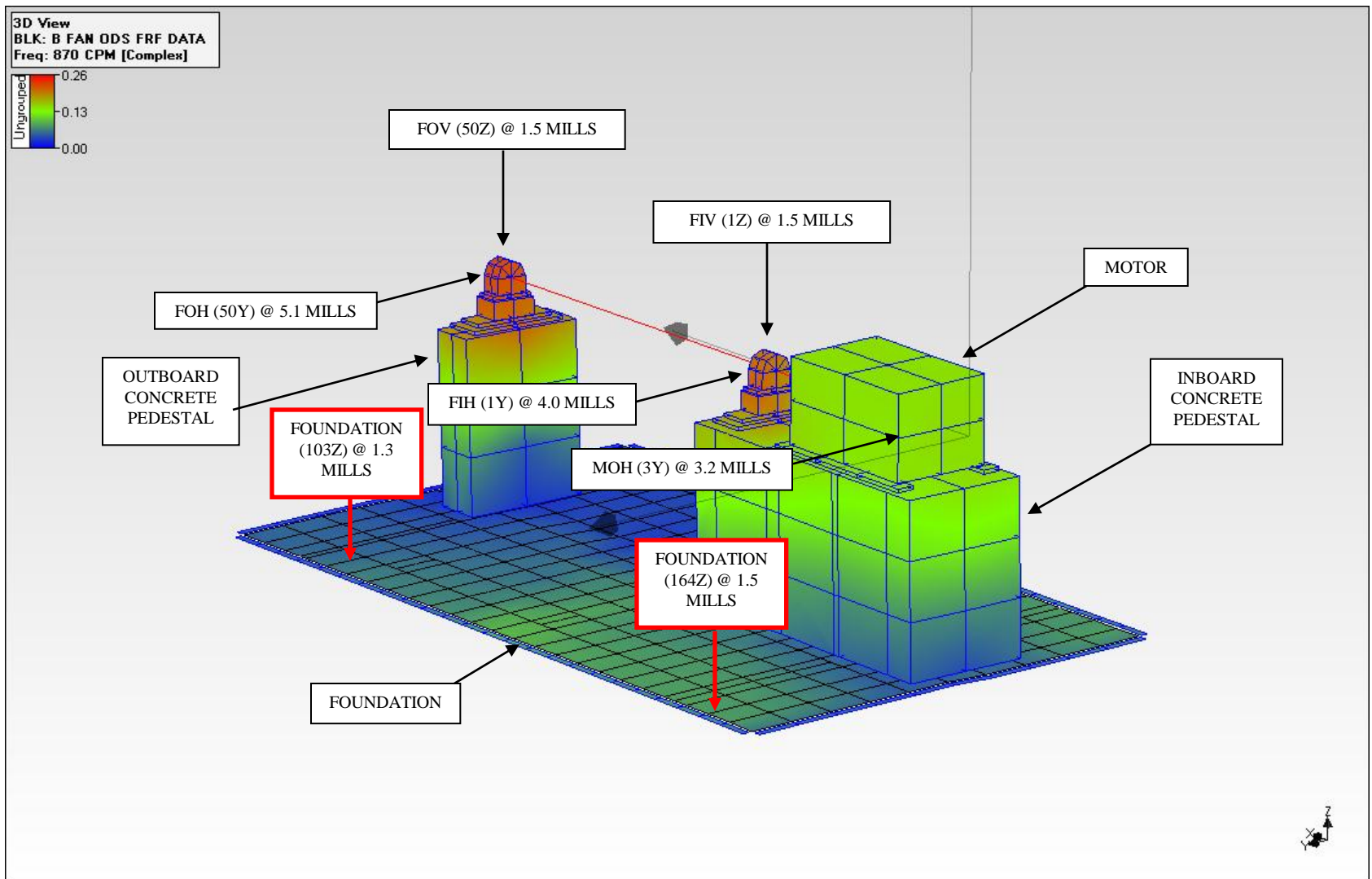
## DECISION MADE TO EVALUATE & IMPROVE FOUNDATION, p2

- The decision was made to evaluate & correct as necessary the potential foundation problem.
- The civil engineering firm that originally installed the fan was contracted to perform the evaluation.
- Cease Industrial Consulting was contracted to assist the civil engineering firm as needed in pinpointing problems with the foundation.



# TEST SETUP – ODS ANALYSIS OF FAN

- After consultation with a structural engineer at the civil engineering firm, a test setup for an in-depth ODS analysis of the fan foundation was decided upon as follows:
  - 1) Prior to the ODS analysis, the fan would be balanced to a very low level of unbalance (< 1 mill vibration).
  - 2) A known amount of unbalance (50 oz @ 56" radius → 2,800 oz-in of unbalance) would then be intentionally placed at a known location on the fan wheel to provide a *known, dominant dynamic force* within the system.
  - 3) The fan would then be run at a constant speed of 900 rpm and ODS measurements would be collected on the fan & motor bearings, bases, pedestals & all over the surrounding foundation to provide a good “picture” for how the entire machine/foundation system vibrated when subjected to a known dynamic force.
  - 4) Because we knew the exact amount of applied force (4,000 lbs @ 900 rpm) and exactly where it was applied (thru the fan bearings), the measured vibration levels (deflections) at each point could be used as experimental data to aid the accuracy of an FEA analysis of the fan/foundation system.



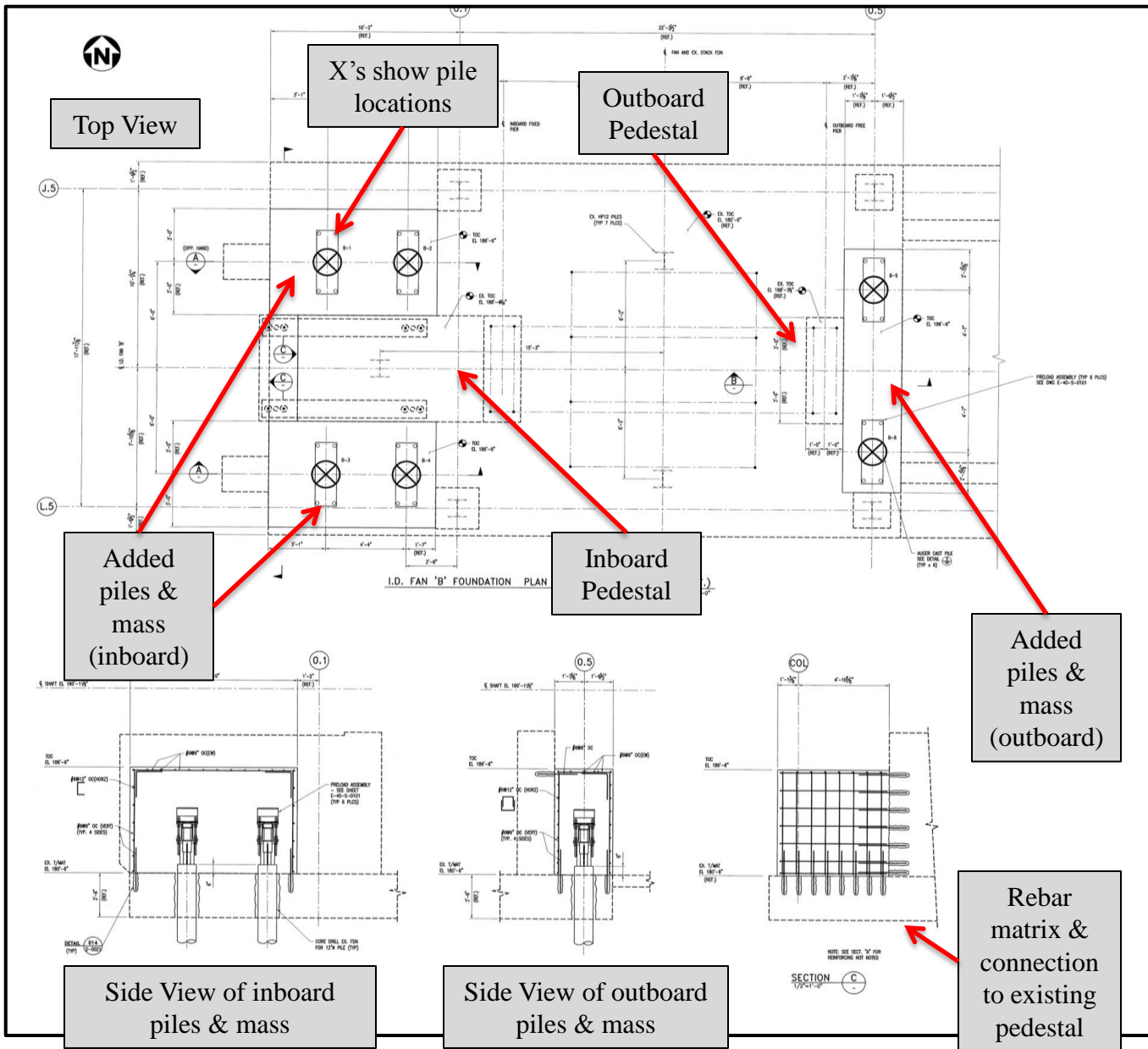
ODS Model of B ID Fan. Vibration levels are at 1x rpm (~ 900 rpm). Condition is with ~ 50 oz weight attached to fan wheel at ~ 56" radius (2,800 oz-in of unbalance) applying an estimated centrifugal force of 4,000 lbs on the machine in the radial directions. Note how vertical foundation levels are similar to vertical measurements at fan bearings.

# FOUNDATION IMPROVEMENTS

- An FEA analysis of the fan/motor/foundation system was performed with the ODS test data being used to refine the FEA model.
- The foundation was improved by adding 6-ea new piles on either side of both the inboard & outboard concrete pedestals (see figure below).
- Large masses composed of a rebar/concrete matrix were added & attached to the new piles. These new masses were also attached to the existing pedestals.
- The table below shows data pertaining to both the old & new foundation designs:

# COMPARE OLD & NEW FOUNDATIONS

	<b>Weight (lbs/tons)</b>	<b>Foundation/Rotor Ratio</b>
Fan Rotor Weight	34,000/17	
Old Foundation Design	99,000/50	2.85:1
New Foundation Design	156,000/78	4.5:1
	Industry Recommendations	≥ 4:1



# FAN BALANCE SENSITIVITY CALCULATIONS: BEFORE & AFTER FOUNDATION MODIFICATIONS

BALANCE DATE	FAN BALANCE SPEED (RPM)	BALANCE SENSITIVITY (OZ/MILLS-PK-PK)
12/13/10 – “B” ID FAN	675	21
5/18/11 – “B” ID FAN	800	17
8/18/11 – “B” ID FAN	800	21
5/18/12 – “B” ID FAN	750	19
5/18/12 – “B” ID FAN	885	11
8/5/12 – “B” ID FAN	900	10
11/2/12 – “A” ID FAN	894	31
11/6/12 – “B” ID FAN	900	36

Before Foundation Modifications

A Fan measurement (sister machine)

After Foundation Modifications

# WHY DID THIS MODIFICATION WORK?

- From Newton's 2<sup>nd</sup> Law Of Motion:  $F = m * a$  or when we rearrange the equation we get the following:  $a = F/m$
- Thus, when we increase the mass (m), in general, we will lower the acceleration levels (a).
- Also, from Hooke's Law:  $F = k * x$  and rearranging this equation we get the following:  $x = F/k$
- Thus, when we increase the stiffness (k), in general, we will lower the displacement levels (x).
- By upgrading the foundation we may very well have moved a potential fan natural frequency higher (> 900 rpm) thus reducing or eliminating its amplification of our vibration levels.

# PHOTO OF FAN **PRIOR TO** FOUNDATION MODIFICATIONS





# PHOTO OF FAN **AFTER** FOUNDATION MODIFICATIONS



# SUMMARY

- Vibration analysis was used successfully to *identify* a weak foundation for a large ID fan.
- ODS analysis was used both as a *visual aid* to the foundation problem and to help *refine an FEA model* of the fan/foundation system.
- The effectiveness of the redesigned foundation has been proved by much *higher balance sensitivity measurements* on the fan at identical speeds and by the fact that *the fan has run for well over a year now with no balance problems.*