

HIGH VIBRATION AT A VERTICAL AGITATOR

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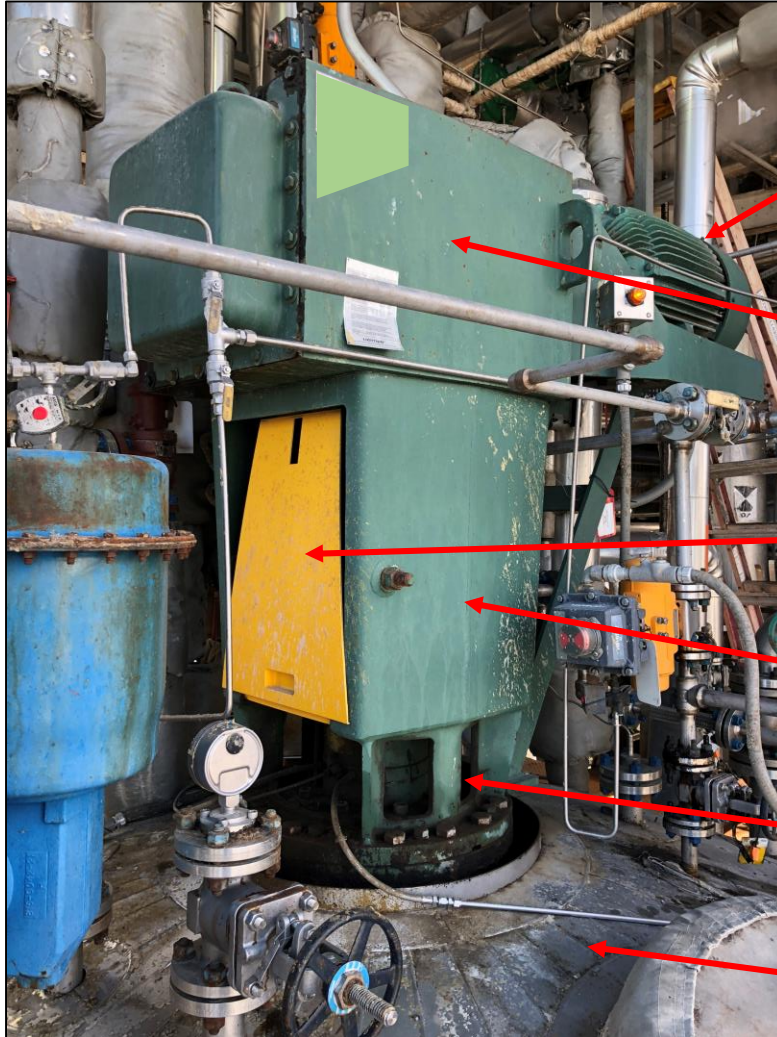
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INTRODUCTION

- High horizontal vibration levels were noted at a vertical agitator that mixed product at a chemical plant.
- The agitator was bolted to the top center of the tank.
- The agitator was driven thru a right angle gearbox via a motor operating at ~ 1,780 rpm.
- The reduction of the gearbox was 21.1:1 giving an agitator speed of ~ 84 Rpm.
- Spectral analysis on the agitator showed the highest vibration occurring at the motor in the horizontal direction with dominant vibration occurring at the motor speed of ~ 1,780 rpm.
- Vibration levels were very low at the gearbox input bearing, but higher at the opposite end of the gearbox (opposite motor end).
- After analysis of the route vibration data, the recommendation was made to verify the alignment condition between the motor & gearbox and inspect the coupling for wear or damage.
- When follow-up measurements after the alignment & coupling check were completed found similar vibration levels, a more extensive analysis was pursued.

PHOTO OF VERTICAL AGITATOR



Motor & Motor Base

Right Angle Gearbox

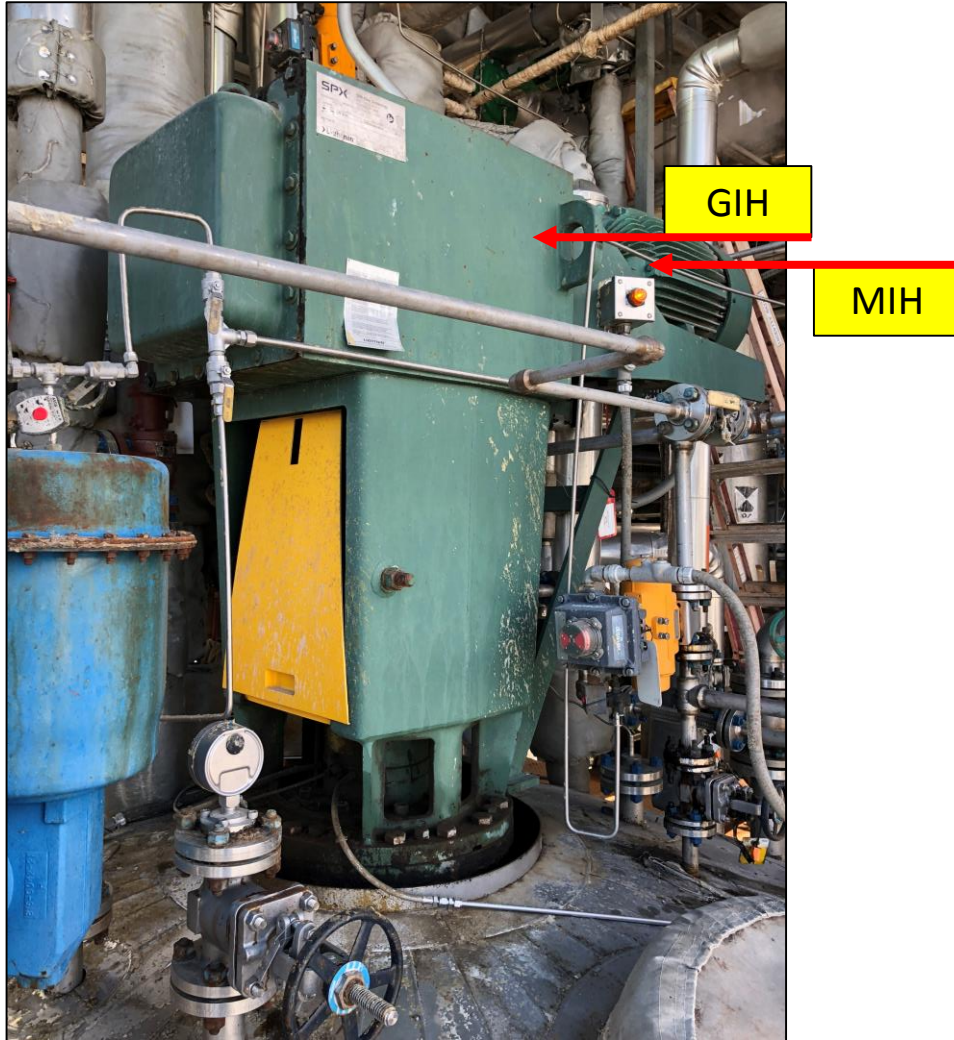
Plastic Access Door (seal & agitator coupling)

Agitator Supporting Column

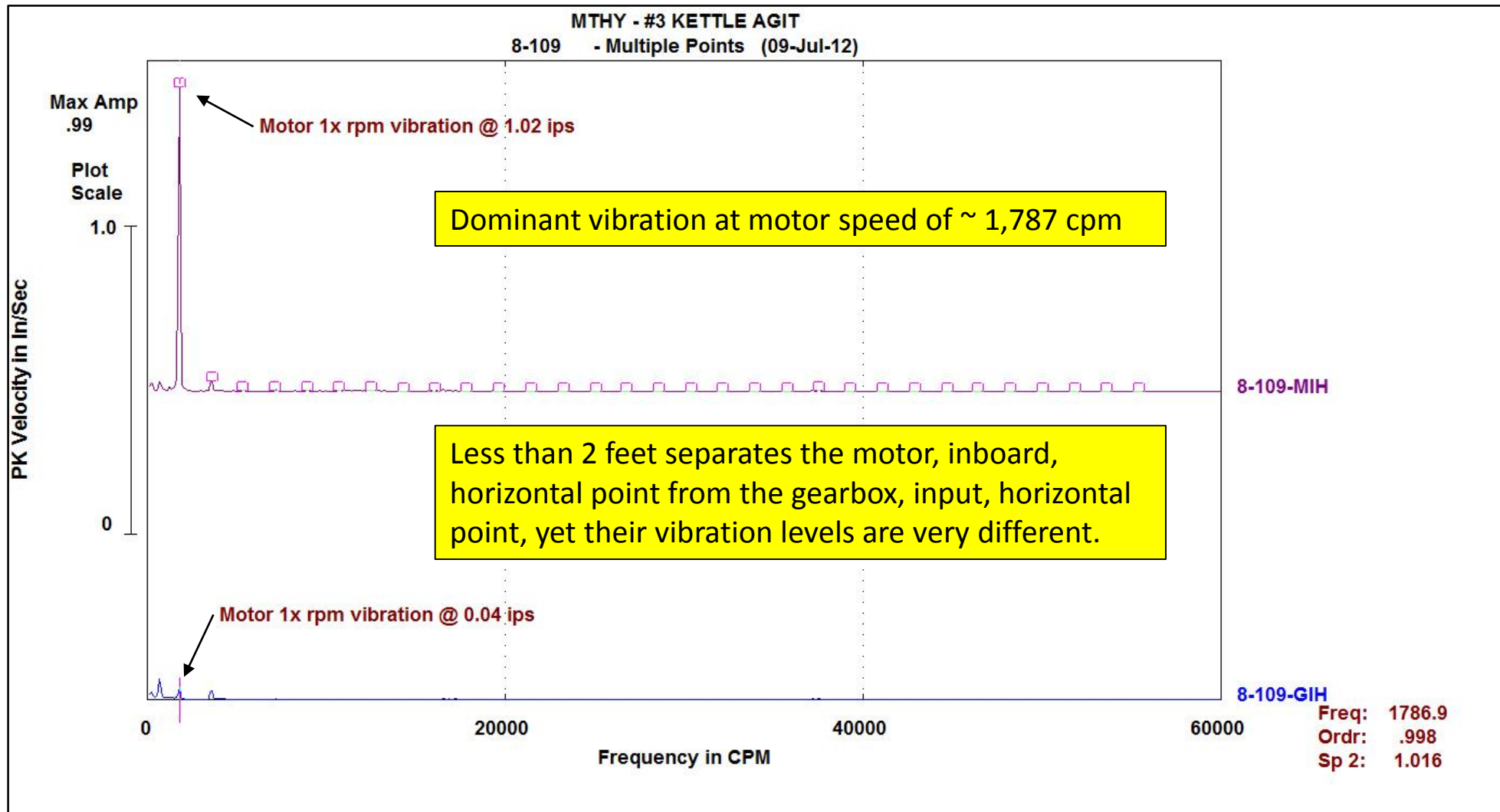
6-ea Individual Supporting Steel Plates

Tank

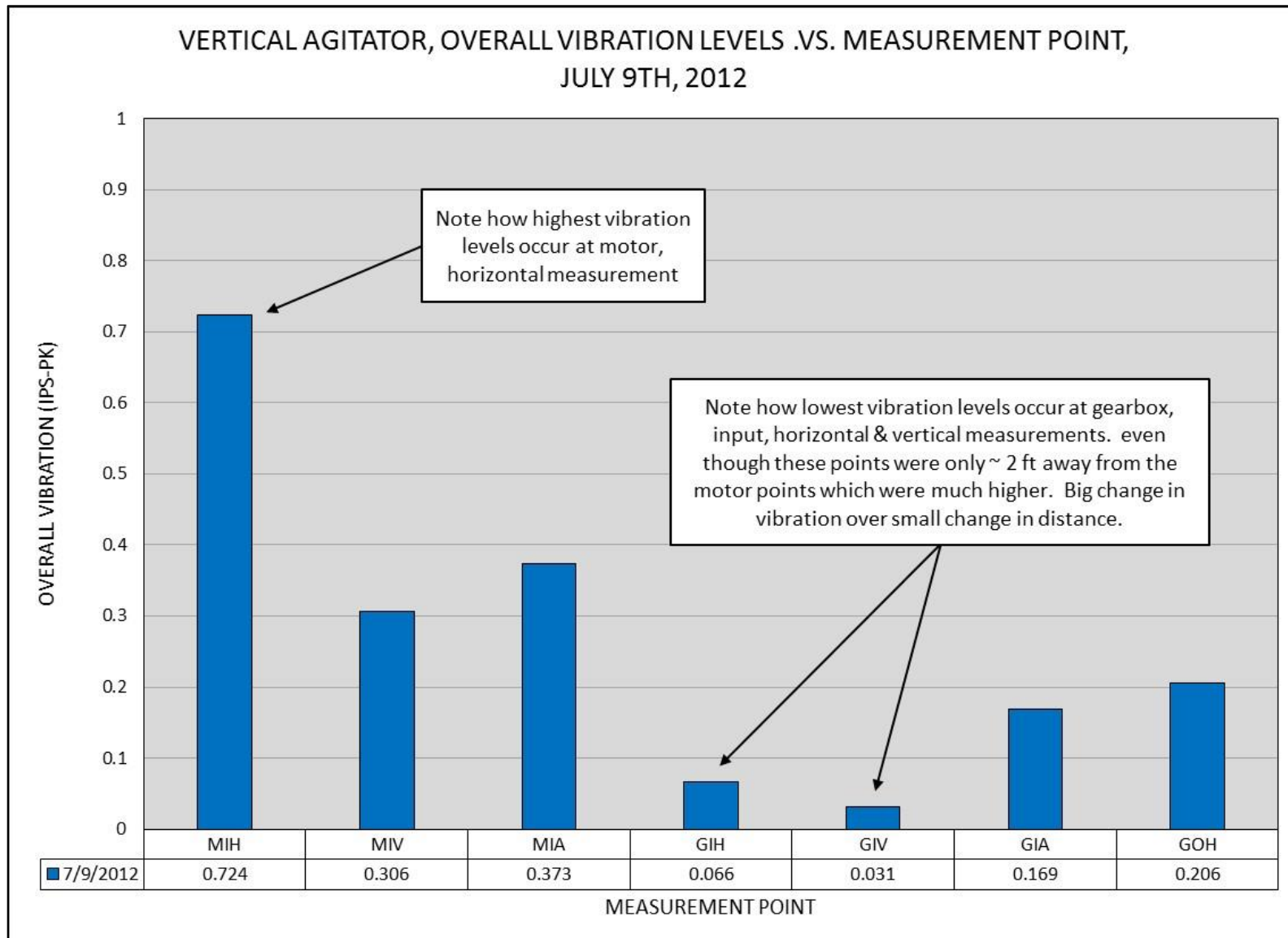
MEASUREMENT POINTS



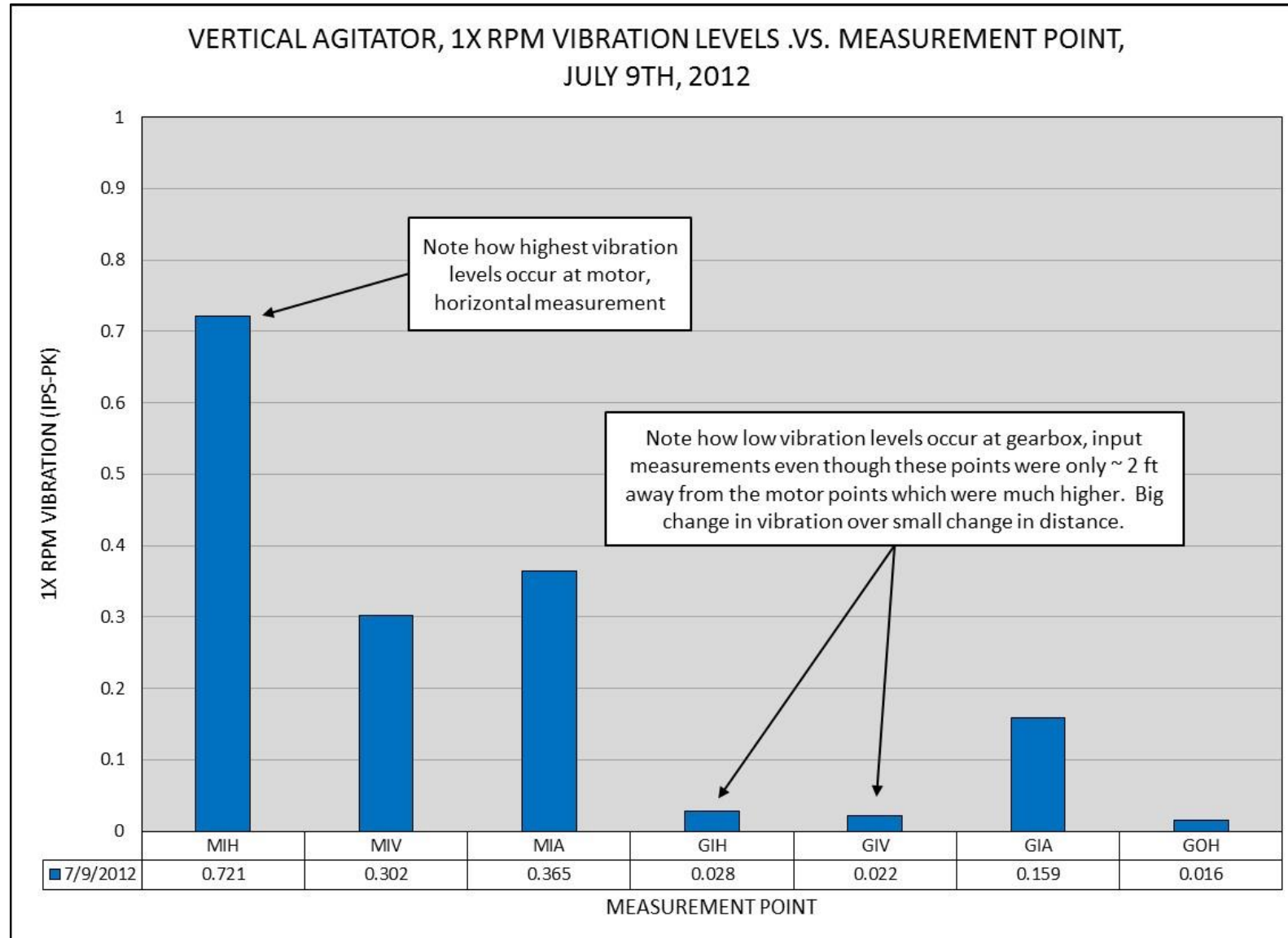
SPECTRAL DATA - MOTOR & GEARBOX, HORIZONTAL POINTS



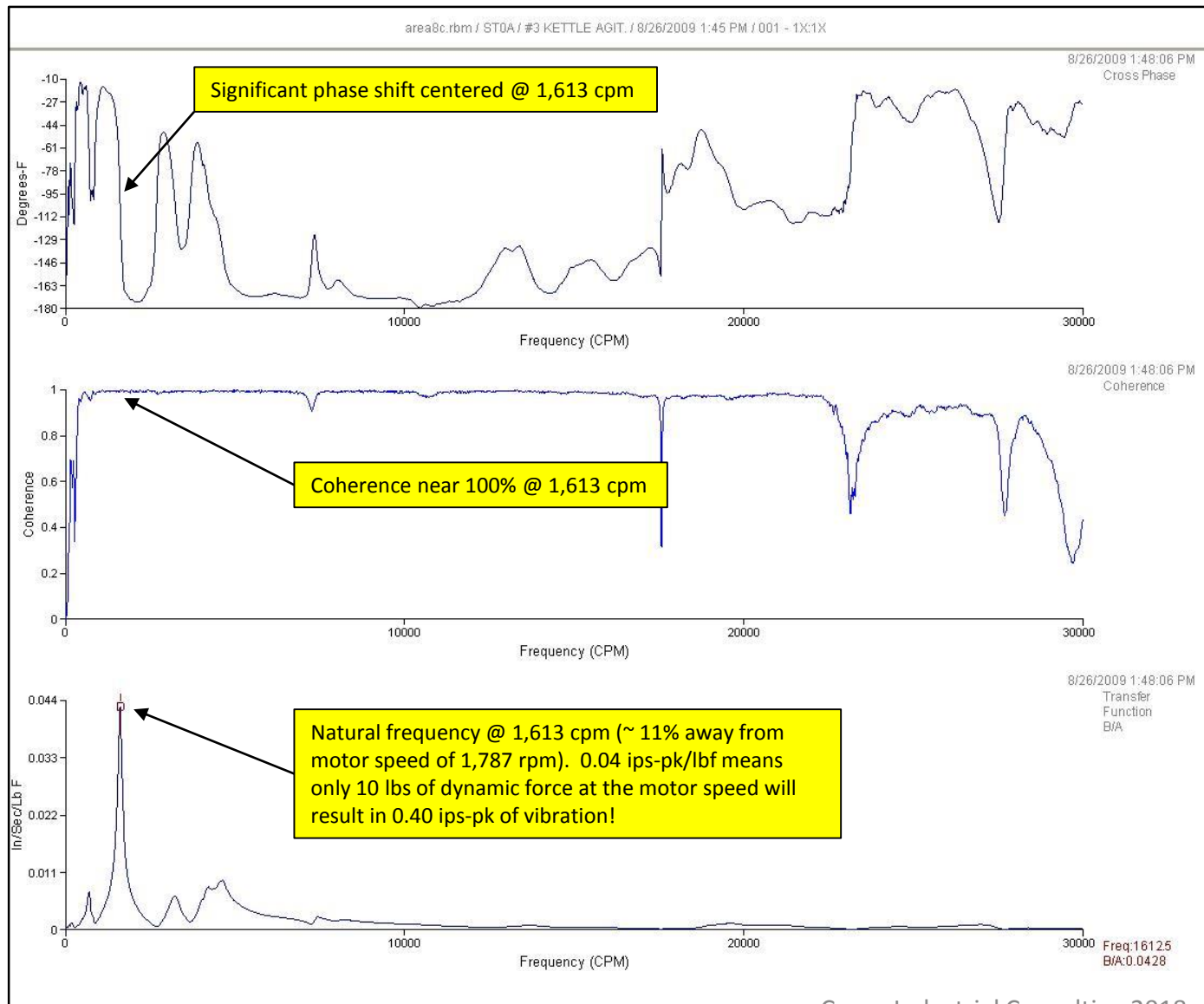
MACHINE PROFILE PLOT – OVERALL VIBRATION LEVELS



MACHINE PROFILE PLOT – 1X RPM VIBRATION LEVELS

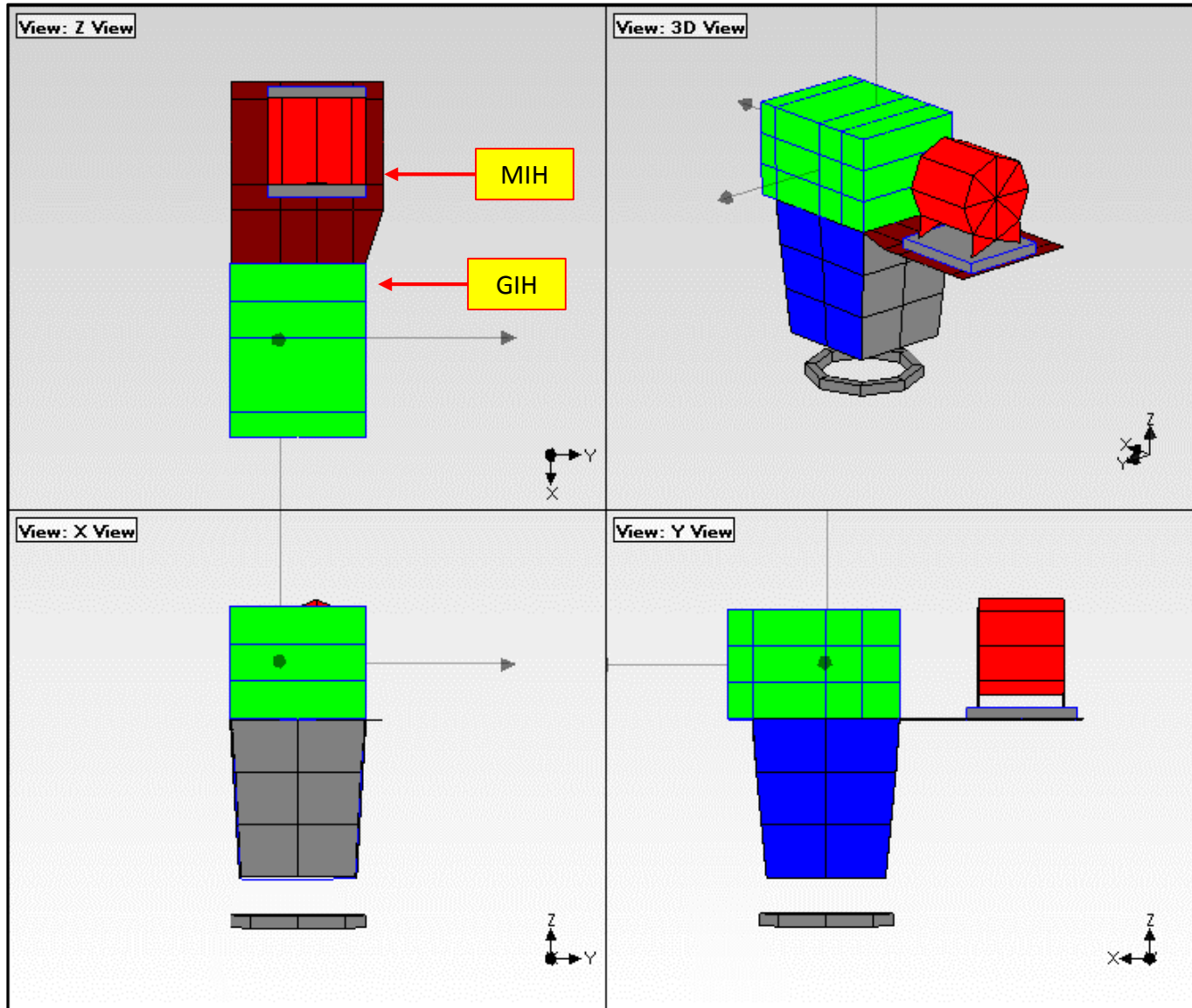


IMPACT TESTING AT MOTOR INBOARD HORIZONTAL POINT (MIH)



- Impact testing was performed at the vertical agitator.
- The plot at left shows the results from impact testing at the motor, inboard, horizontal point (MIH).
- Note the high peak at 1,613 cpm at bottom associated with high coherence at the middle plot and a significant phase shift at the top plot.
- The agitator has a strong horizontal natural frequency centered at 1,613 cpm. This natural frequency is only 11% away from our motor speed of 1,787 rpm meaning resonance at the motor speed is likely occurring here.
- The amplification at this natural frequency is high at 0.04 ips/lbf meaning if only 10 lbs of dynamic force is input at 1,613 cpm, 0.40 ips of vibration will result.
- So from this impact testing we knew resonance was occurring at the motor speed, but we didn't know the **shape** or **mode** of this resonance.

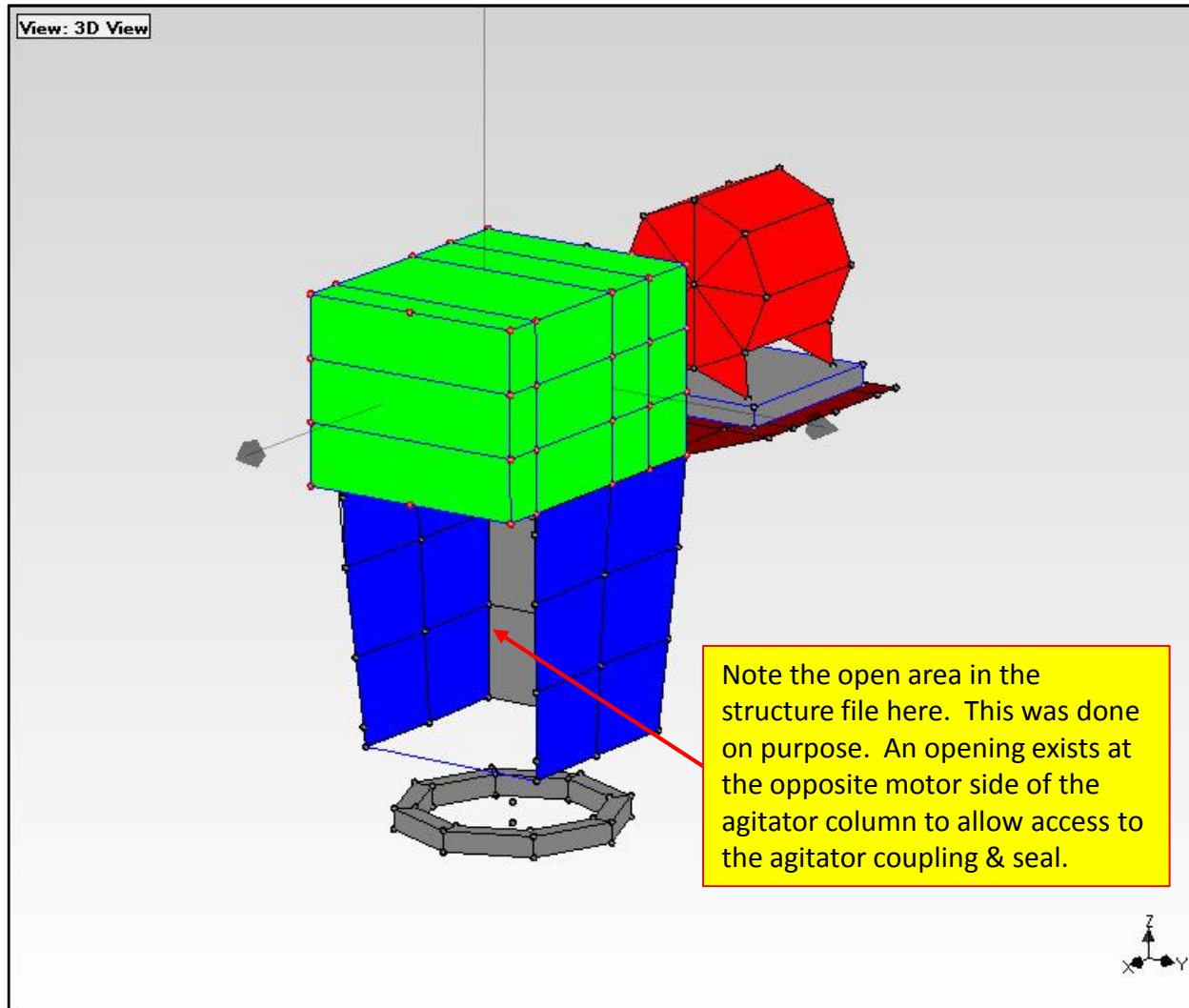
ODS ANALYSIS, VERTICAL AGITATOR, JULY 2012



OBSERVATIONS FROM ODS ANALYSIS

- 1) Twisting of agitator, gearbox & motor about the Z axis at the motor speed of ~ 1,787 rpm. See [video1](#), [video2](#).
- 2) Approximate center of twisting at or near where GIH is measured. See [video3](#).
- 3) Flexure (distortion) of the motor base particularly in the vertical direction at 2x motor speed. See [video4](#) & [video5](#).

ODS ANALYSIS, VERTICAL AGITATOR, JULY 2012



- The open area at the opposite motor end of the agitator column was there on purpose – to allow access to the agitator seal & coupling.
- A plastic door was in place to protect the agitator shaft, seal, coupling, etc from the elements and to comply with OSHA regulations.
- Note how due to this opening at the agitator column, the cross sectional area of our agitator column essentially resembles a channel and not a rectangular tube.
- The torsional stiffness of a rectangular tube is much greater than that of a channel of equal dimensions (higher geometric torsional stiffness).

RECOMMENDATIONS

Following the vibration & ODS analysis of the vertical agitator in July 2012, these recommendations were made:

- 1) Stiffen the agitator column by replacing the existing void with a bolted aluminum door at the opposite motor end of the agitator column. Use at least 8-ea bolts to secure this door to the column and incorporate handles to the door design to allow easy removal and installation by mechanics. **Move from a channel to a rectangular tube.**
- 2) Consider adding bracing under the motor base to eliminate deflection at 2x motor speed.

These findings & recommendations were communicated to both plant personnel and the agitator OEM. The OEM assigned a structural engineer to work with us and find a solution. The findings from our ODS, modal and vibration analysis of the agitator were used by the structural engineer to modify their existing model of the agitator and make the appropriate changes.

It is important to note that this vertical agitator was mounted on the top of a tank containing product at a chemical plant. Welding or drilling, etc onto the tank itself was not possible to maintain the integrity of the tank. Any structural modifications made to this vertical agitator could not involve either welding or drilling onto the tank. Also, the free, small motions of the tank could not be restricted by making hard structural connections between the agitator and nearby beams, struts, etc.

PHOTO OF MODIFICATIONS TO VERTICAL AGITATOR



BEFORE DOOR MODIFICATIONS
(Plastic Door)



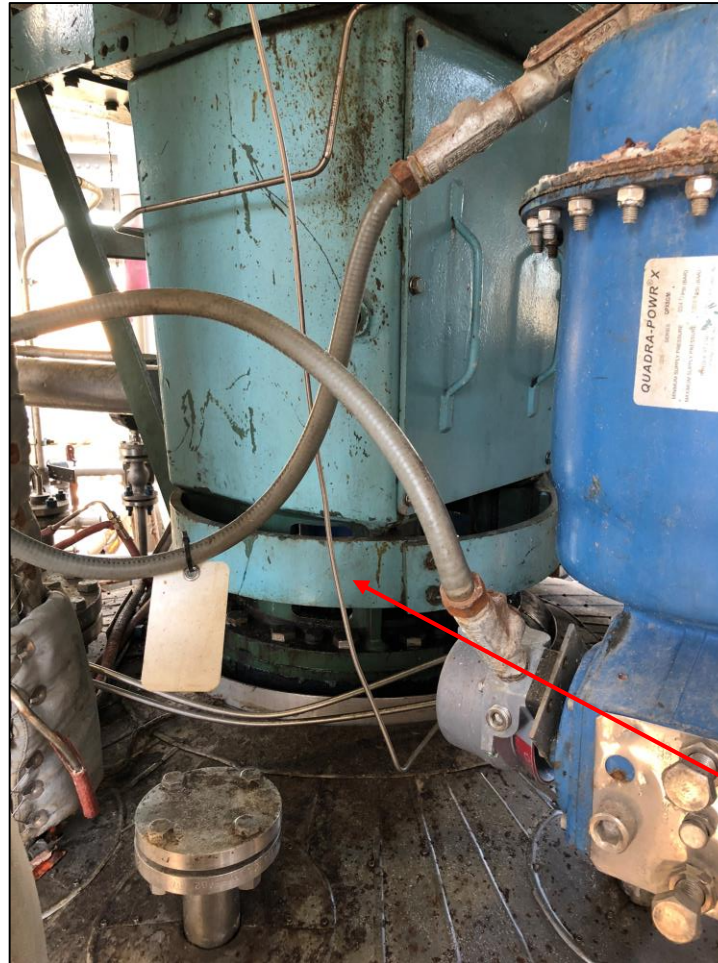
AFTER DOOR MODIFICATIONS
(Bolted Aluminum Door)



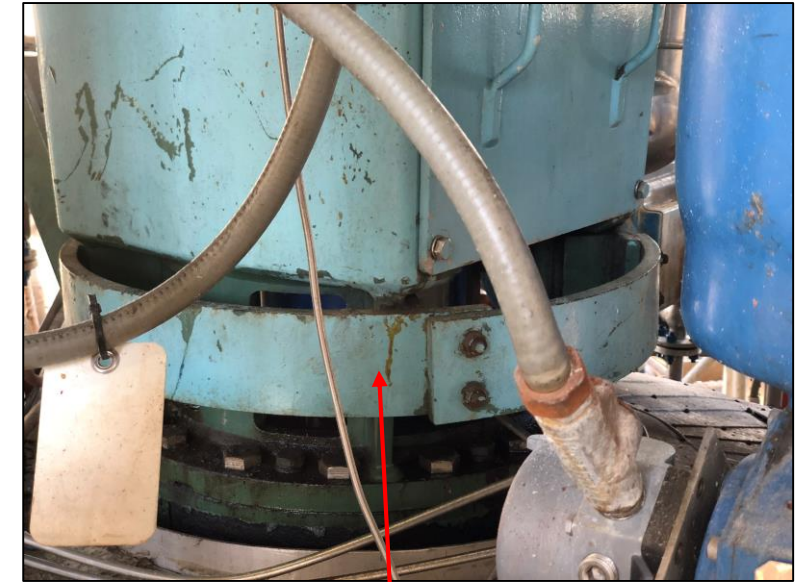
ADDITIONAL OEM MODIFICATIONS (COLLAR)



Note how the agitator column is supported by a bolted flange attached to the column via essentially 6-ea individual pieces of angle (not continuous).

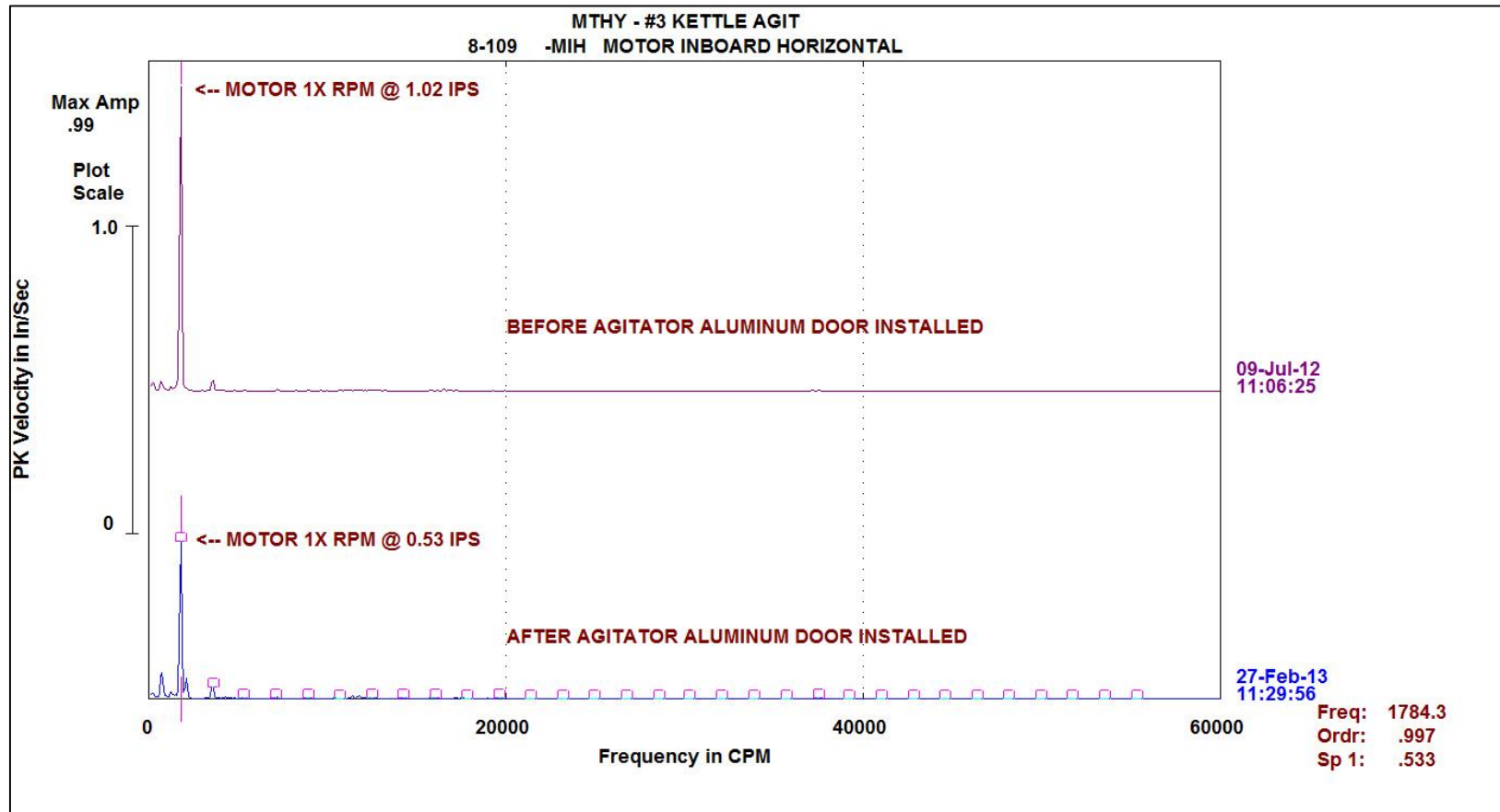


The addition of the bolted aluminum door and the bottom collar acted to increase the torsional stiffness of the agitator column.



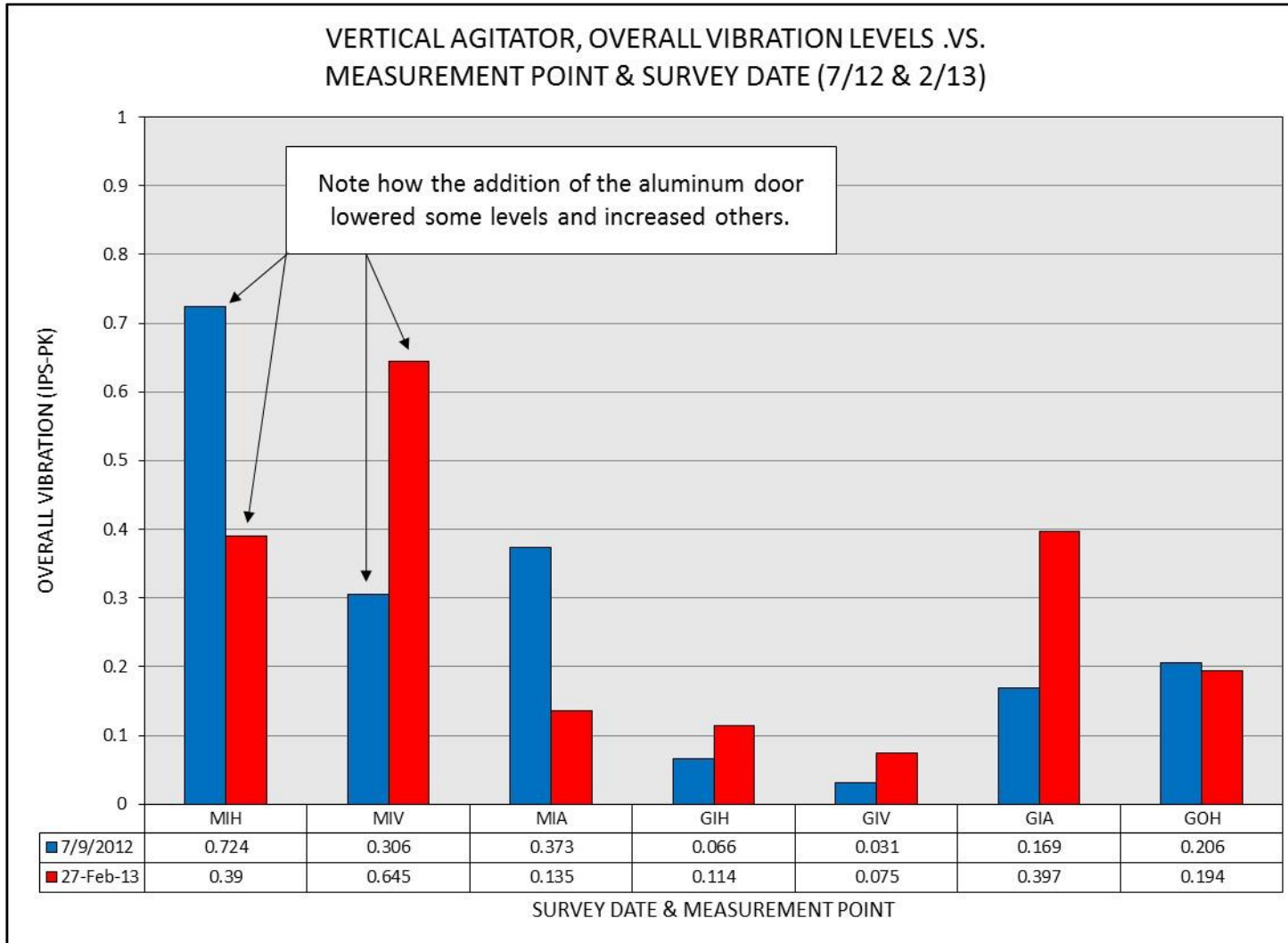
In addition to replacing the plastic door with an aluminum bolted door, the OEM decided to connect all six supporting angles together with a steel collar sized for this purpose. The collar was designed to bolt tightly to the existing angle.

FOLLOW-UP VIBRATION DATA (MOTOR, HORIZONTAL)

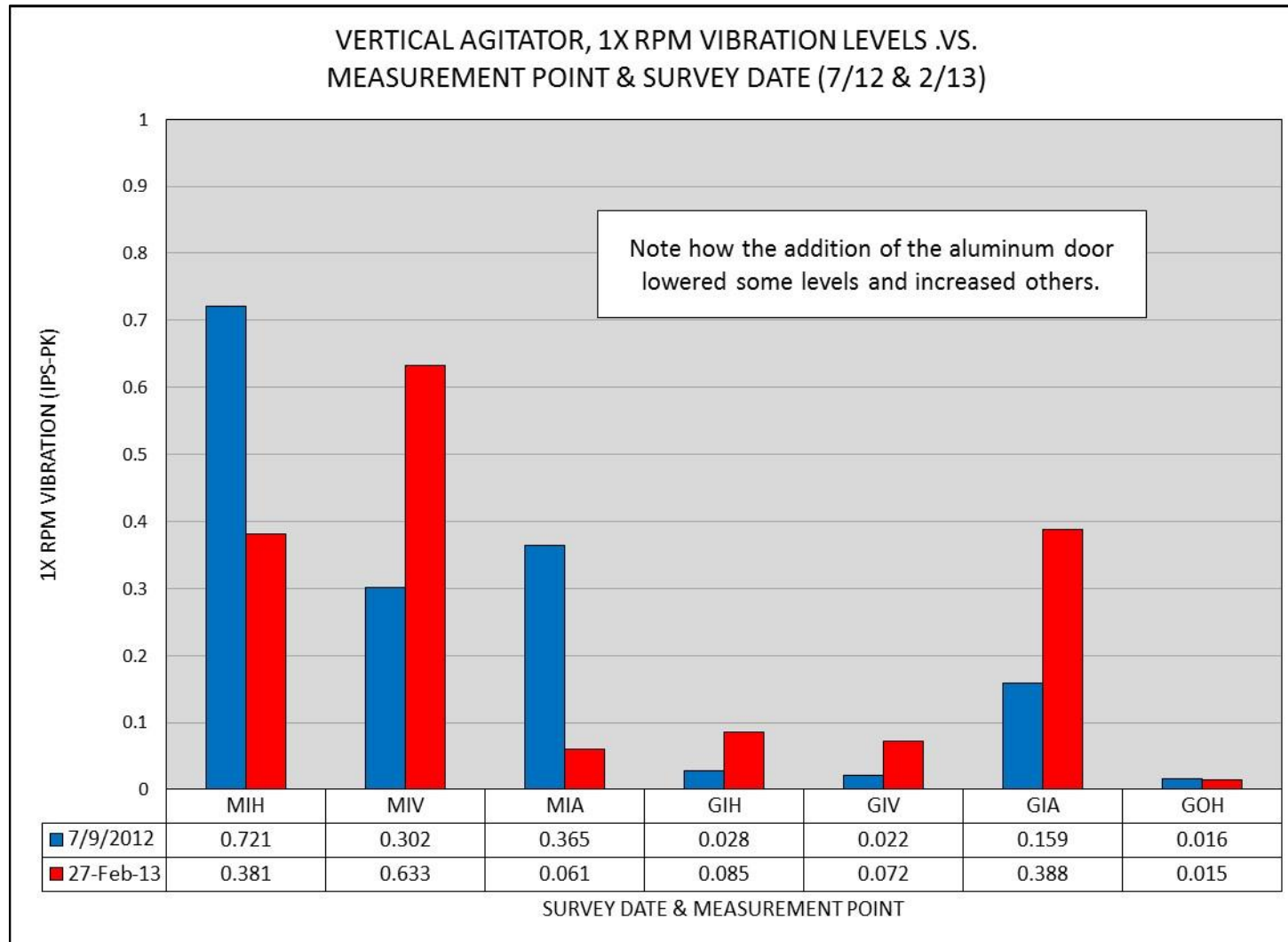


- The aluminum door was installed at the void on the backside of the agitator column and the collar installed near the agitator-tank flange.
- Follow-up vibration data after these modifications showed a 50% drop in vibration levels at the motor speed of ~ 1,784 rpm at the point of highest vibration (MIH).
- Unfortunately, all the recommendations from the July 2012 analysis were not yet completed, namely, the bracing of the motor base was not yet installed.

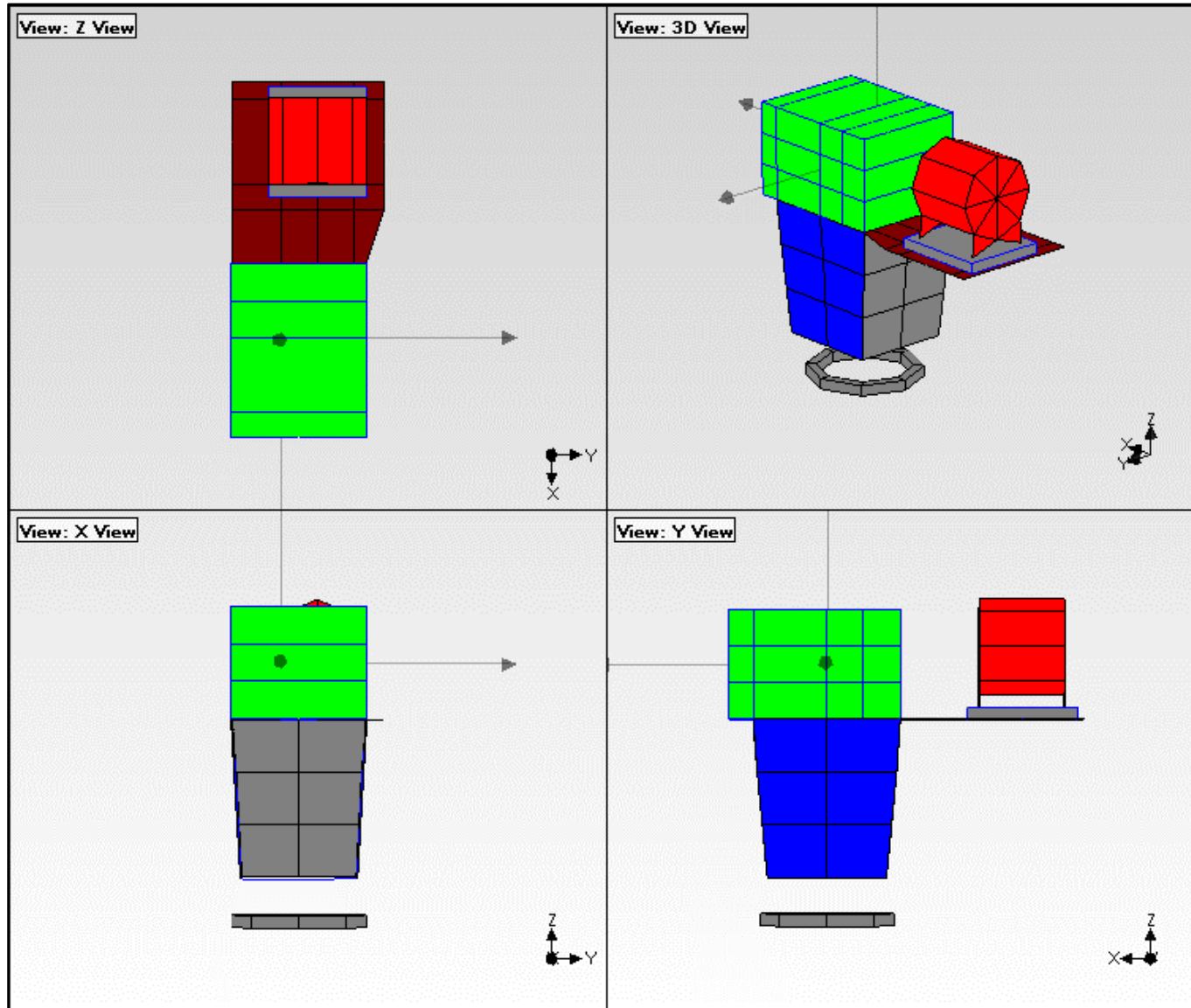
FOLLOW-UP VIBRATION DATA – OA PROFILE PLOT



FOLLOW-UP VIBRATION DATA – 1X RPM PROFILE PLOT



FOLLOW-UP ODS ANALYSIS, VERTICAL AGITATOR, MARCH 2013



OBSERVATIONS FROM ODS ANALYSIS

- 1) Dominant motion at 1x motor speed is vertical flexing of motor & motor base particularly at the outboard, left corner of the motor base. See [video6](#), [video7](#), [video8](#) & [video9](#).
- 2) Compared to the July 2012 ODS of this machine, comparatively little twisting motion of entire agitator column (the new door and collar helped with this problem). Compare [video3 \(7/12\)](#) to [video10 \(3/13\)](#).
- 3) Flexure (distortion) of the motor base particularly in the vertical direction at 2x motor speed. See [video11](#) & [video12](#).

RECOMMENDATIONS (MARCH 2013)

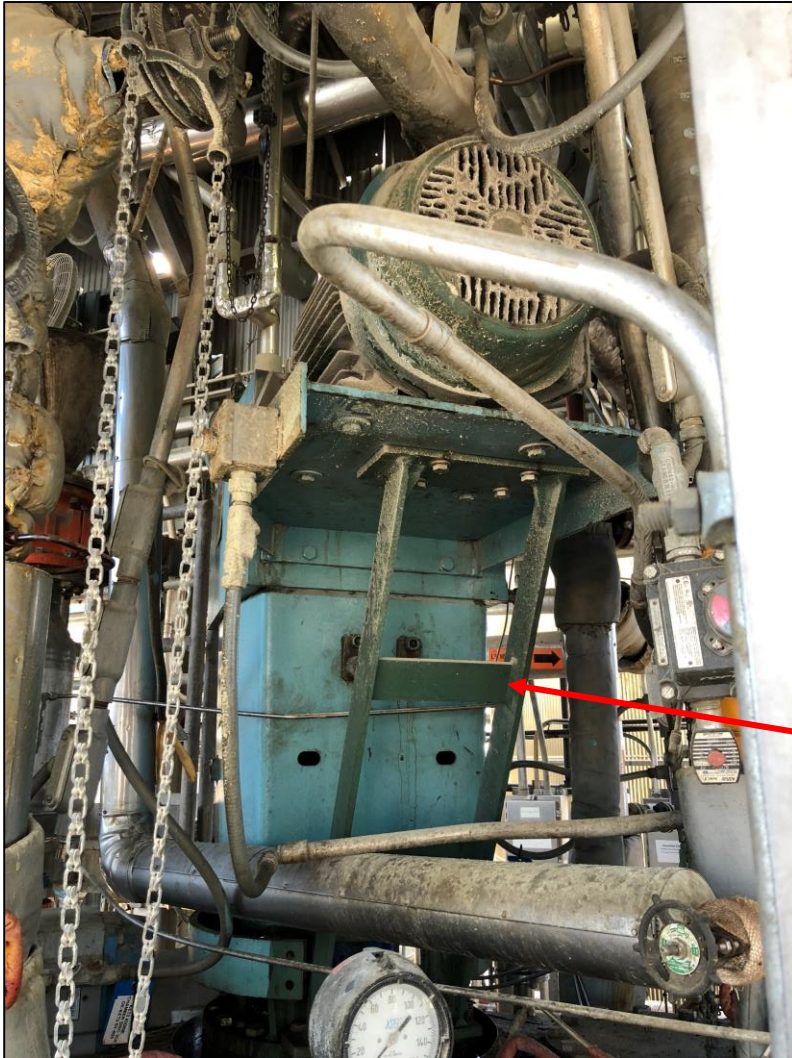
Following the vibration & ODS analysis of the vertical agitator in March 2013, the prior recommendation was restated to plant personnel and the agitator OEM:

- 1) Add bracing under the motor base to eliminate deflection at 1x & 2x motor speed. For maximum effect, ensure this new bracing supports the motor base at or near its outboard end.

Bracing was designed & fabricated for the agitator by the OEM and installed in the Fall of 2014 during a scheduled outage. Follow-up vibration data were collected on the agitator after start-up.

Bracing was installed between the agitator column and the motor base. No connections were possible between the tank itself or nearby structure and the motor base.

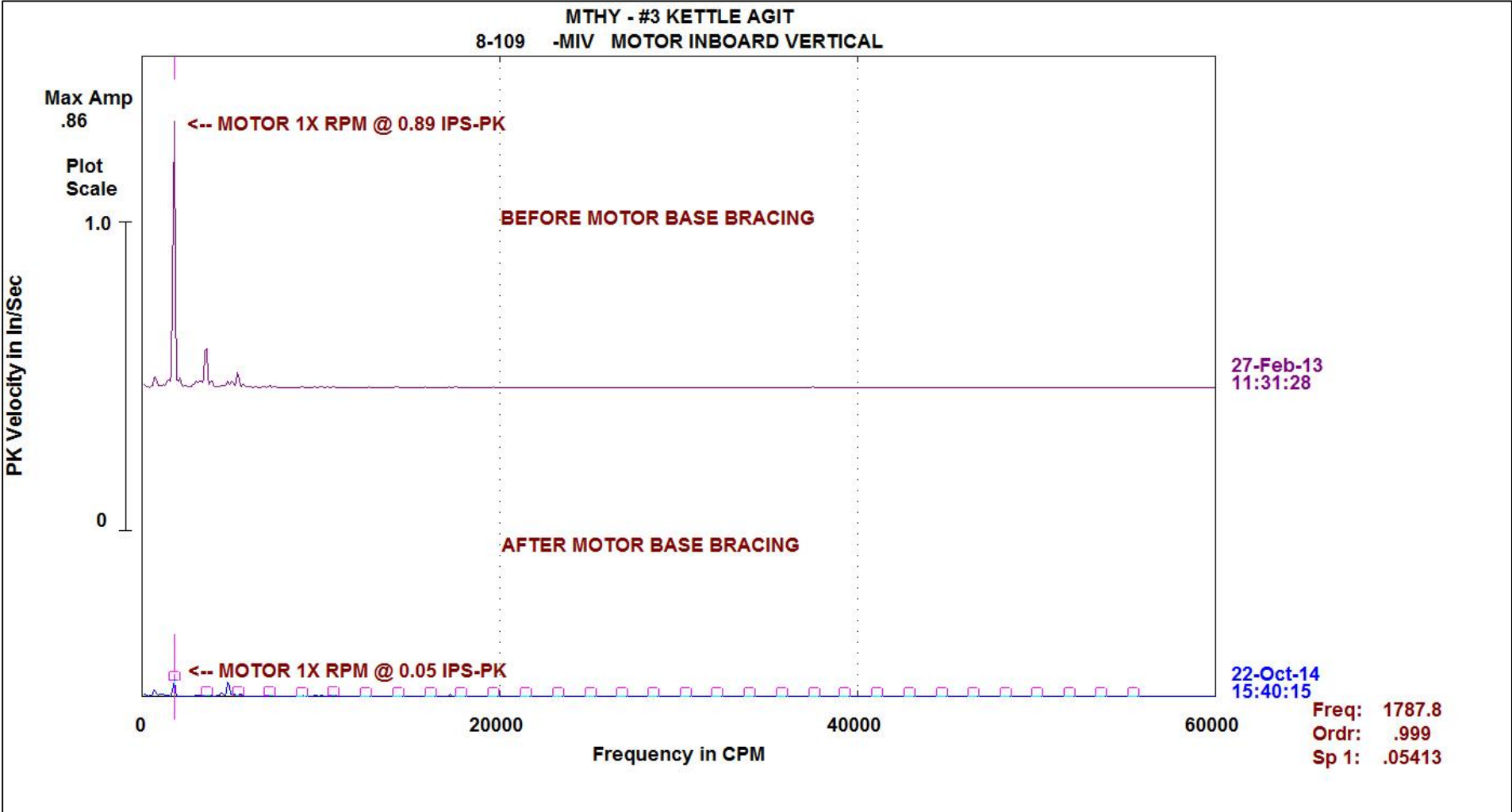
PHOTO OF MOTOR BRACING



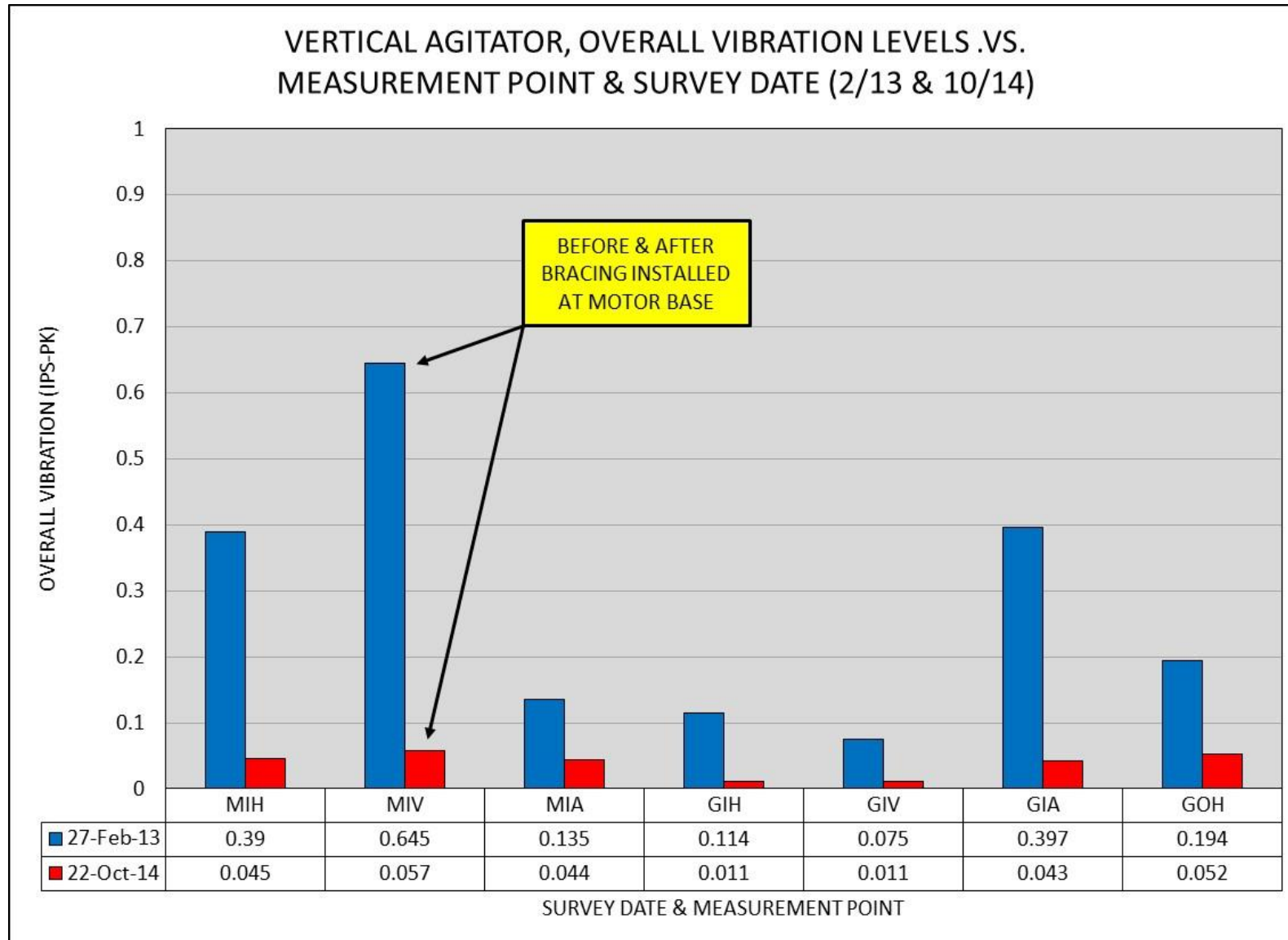
- The motor brace was installed and follow-up vibration measurements were made.
- The follow-up vibration data showed a significant drop in vibration levels and acceptable levels across the entire machine.

MOTOR BRACE

FOLLOW-UP VIBRATION DATA – MOTOR, VERTICAL (MIV)

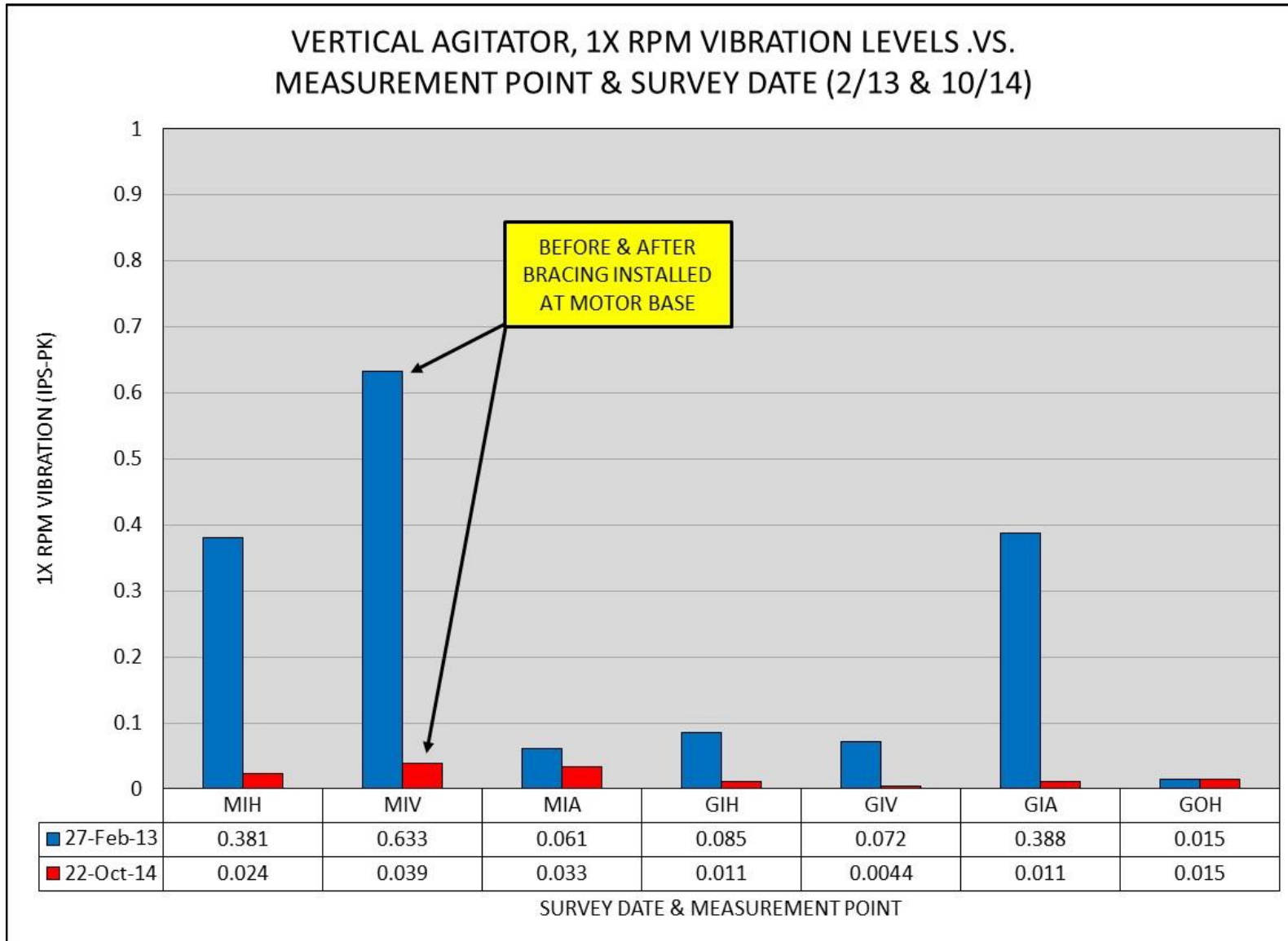


FOLLOW-UP VIBRATION DATA – OA PROFILE PLOT

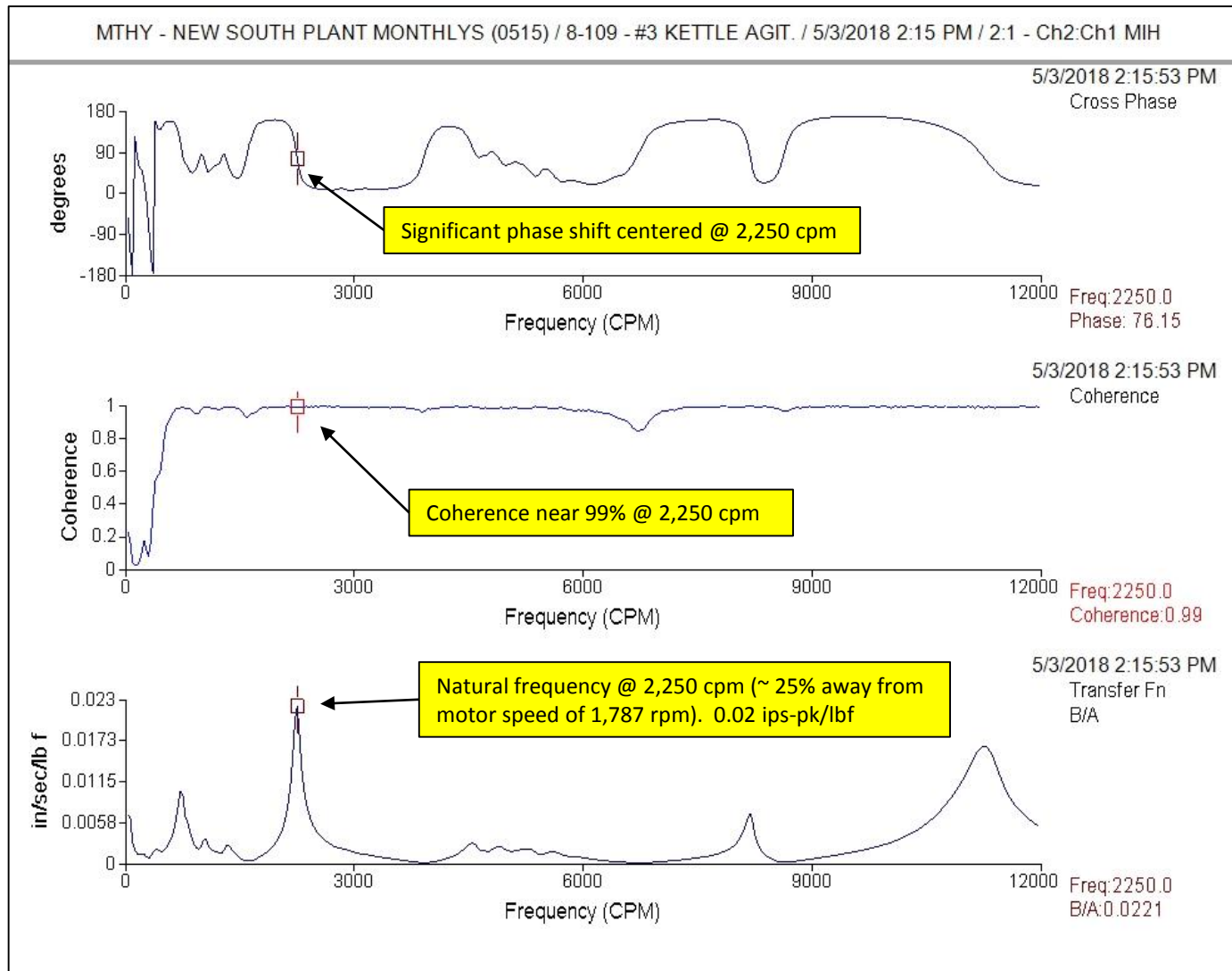


- All measurements across the entire machine are now < 0.10 ips-pk (excellent).

FOLLOW-UP VIBRATION DATA – 1X RPM PROFILE PLOT



FOLLOW-UP IMPACT TESTING AT MOTOR INBOARD HORIZONTAL (MIH)



- Follow-up impact testing was performed at the vertical agitator after all repairs and modifications were complete.
- The plot at left shows the results from impact testing at the motor, inboard, horizontal point (MIH).
- Note the high peak at 2,250 cpm at bottom associated with high coherence at the middle plot and a significant phase shift at the top plot.
- All the modifications to the agitator mentioned earlier have moved our natural frequency from 1,613 cpm to 2,250 cpm.
- Not only did we move the natural frequency from 11% to 25% away from 1x rpm, we also doubled our effective dynamic stiffness at resonance from 0.04 ips/lbf to 0.02 ips/lbf.

CONCLUSION

- It is a very good thing to know the **shape** of a machine's vibration and not only its frequency.
- Vibration at 1x motor speed in this case could have easily been mistaken by some as a coupling or alignment problem or perhaps unbalance within the motor, coupling, or keyway. Understanding the **shape** of the vibration pointed to an entirely different cause - resonance of the agitator column and motor base.
- Raising the stiffness of a structure in the twisting or torsional direction might involve closing up any voids that might exist along a structure or another way to think of it is **look at moving your structure's cross sectional area from a channel towards a tube**.
- Connecting individual columns (angle) together into a continuous circular tube (collar) was an additional move towards higher torsional stiffness.