Solving Vertical Pump Synchronous and Sub-synchronous Vibration Problems

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Presented by:

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Problems Analyzing Vertical Pumps

- Lack of knowledge of foundation properties
- Effects of piping and motor attachment stiffness
- Lineshaft balance, alignment, and bearing eccentricities
- Typically, there are a large number of natural frequencies within the first fundamental harmonics of running speed
- Field testing is invaluable when trying to characterize a problem

Analysis and Solution Methods

- Operational testing determines the natural excitation response of the pump
  - Steady operation is monitored to determine operating deflection shapes
  - Transient operation is monitored (particularly for variable speed machines) to determine problematic coincidences of excitation sources and natural frequencies
- Modal testing determines the natural frequencies of the structure and rotor
- Finite Element Analysis is calibrated to the installed field data and used to test practical fixes

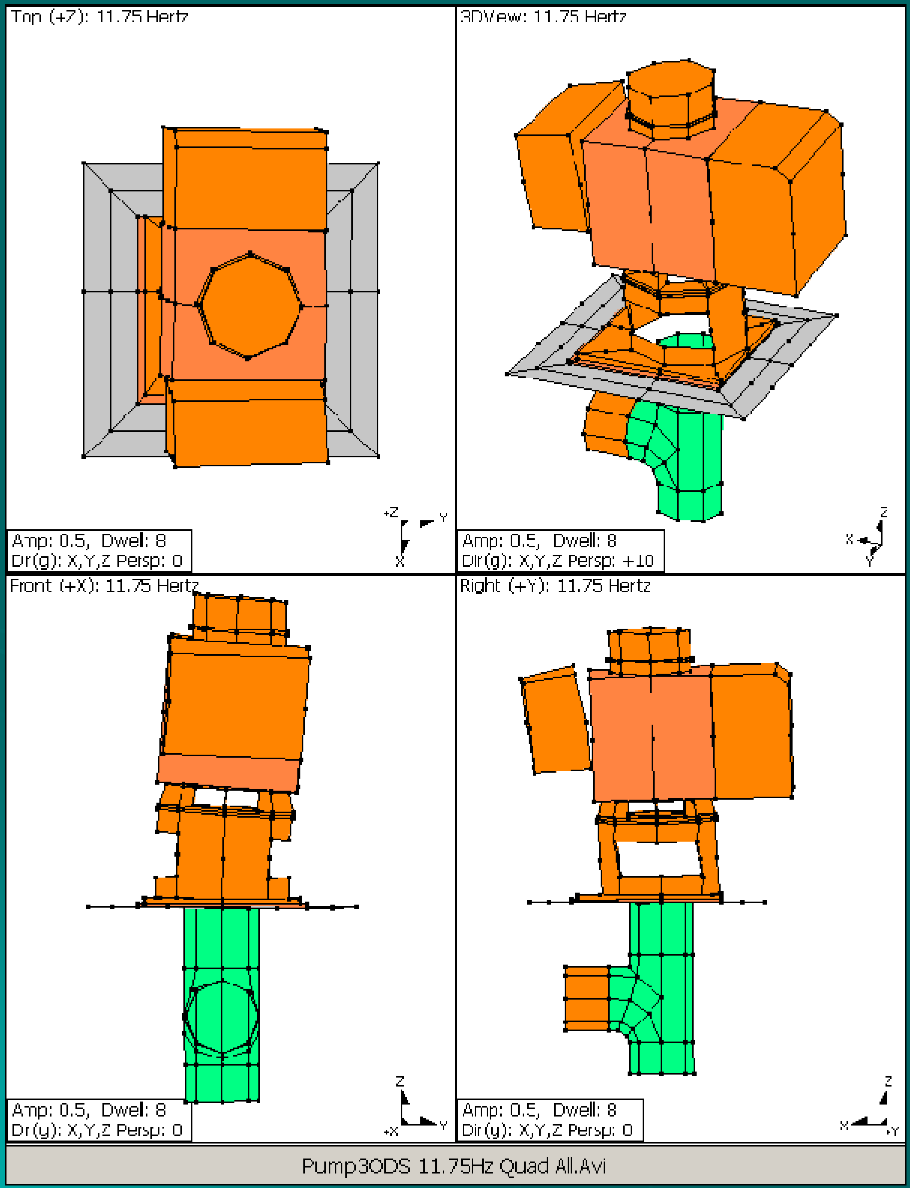
CASE 1

Synchronous Vibration due to Resonance with an Above Ground Mode

Problem Statement

- **Large vertical turbine pumps (2000+ hp) in raw water service**
- **The maximum vibration at the top of the motor was 9 mils pk-pk which exceeded the specification by a factor of 3**
- **Pumps were not accepted by the owner, and the OEM had significant financial penalties for delay of pump commissioning**
- **Preliminary testing by the OEM resulted in suspicion of a structural resonance and / or excessive flexibility of the building structure**
- **Vibration amplitudes exceeded the specification even when the pumps were not operating**

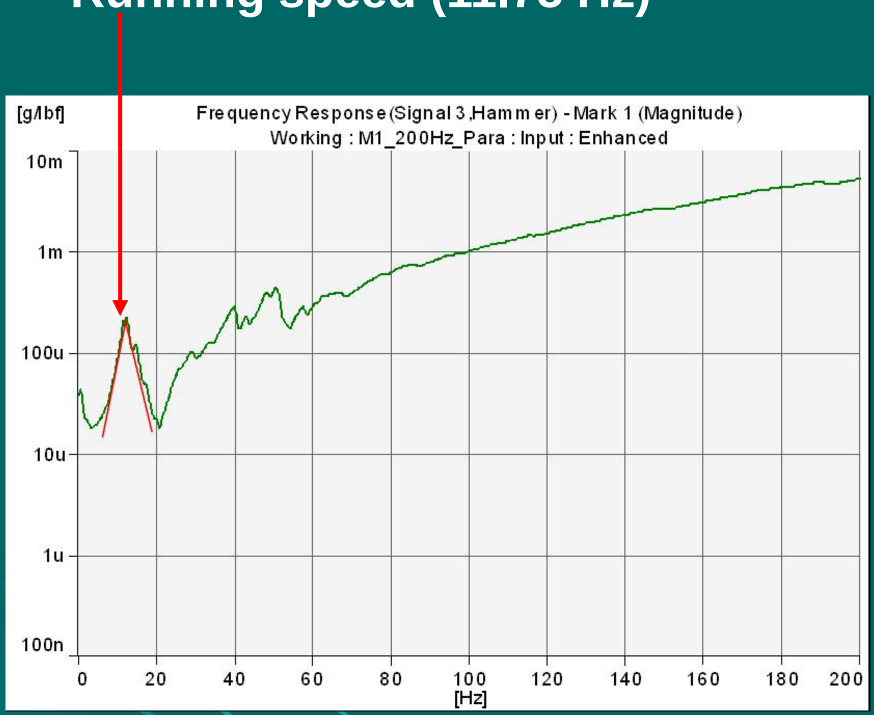
Operating Deflected Shape Animation at Running Speed



Pump #3 ODS at 11.75 Hz (705 CPM or 1X running speed)

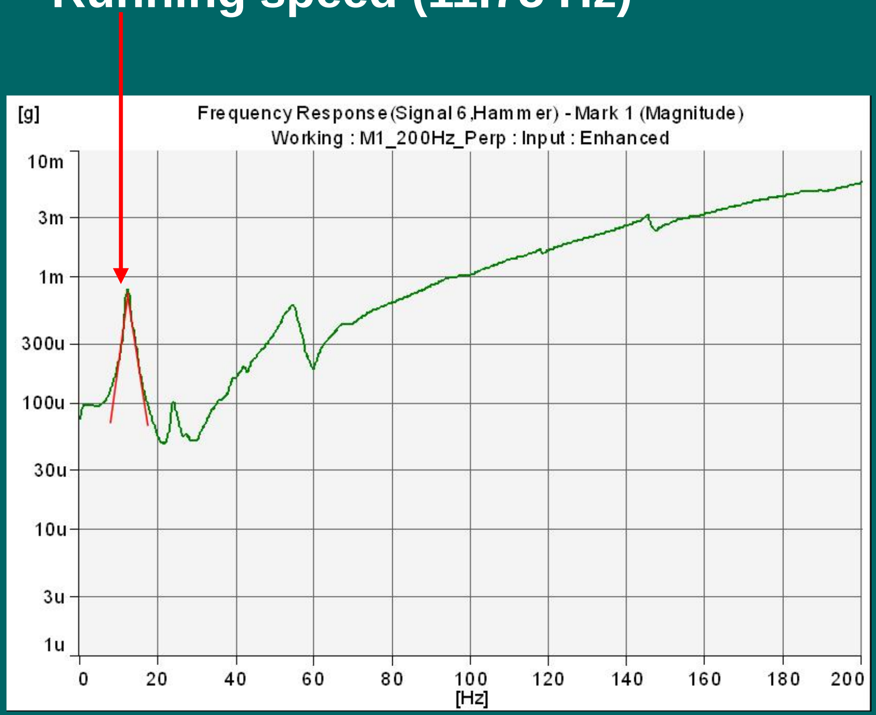
Impact Modal Response at top of Motor

Running speed (11.75 Hz)



1st above-ground bending parallel to the discharge piping at 11.38Hz

Running speed (11.75 Hz)

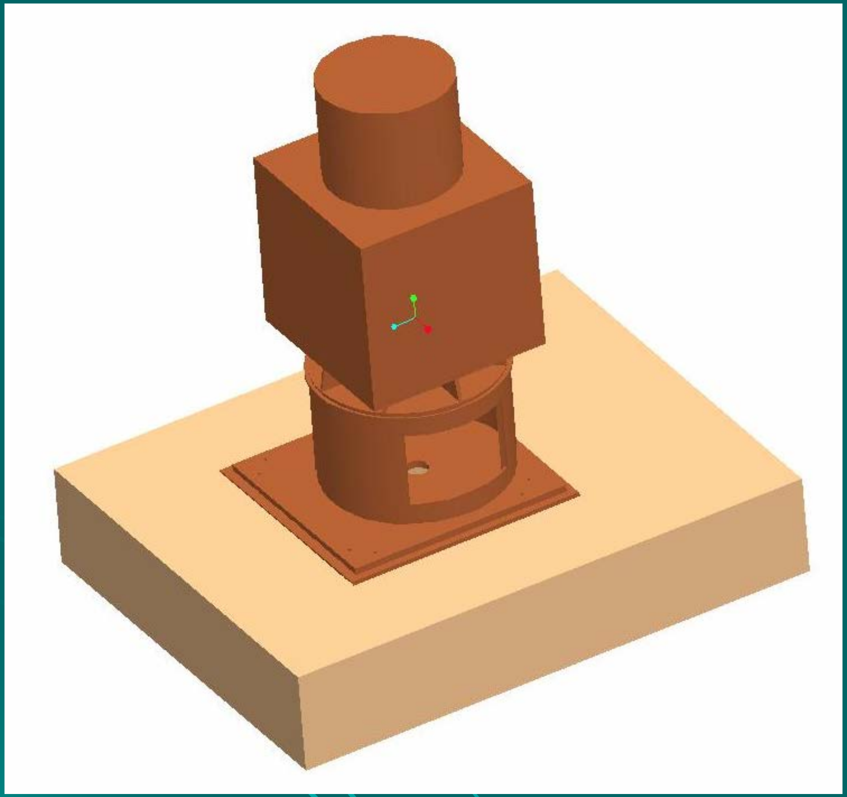


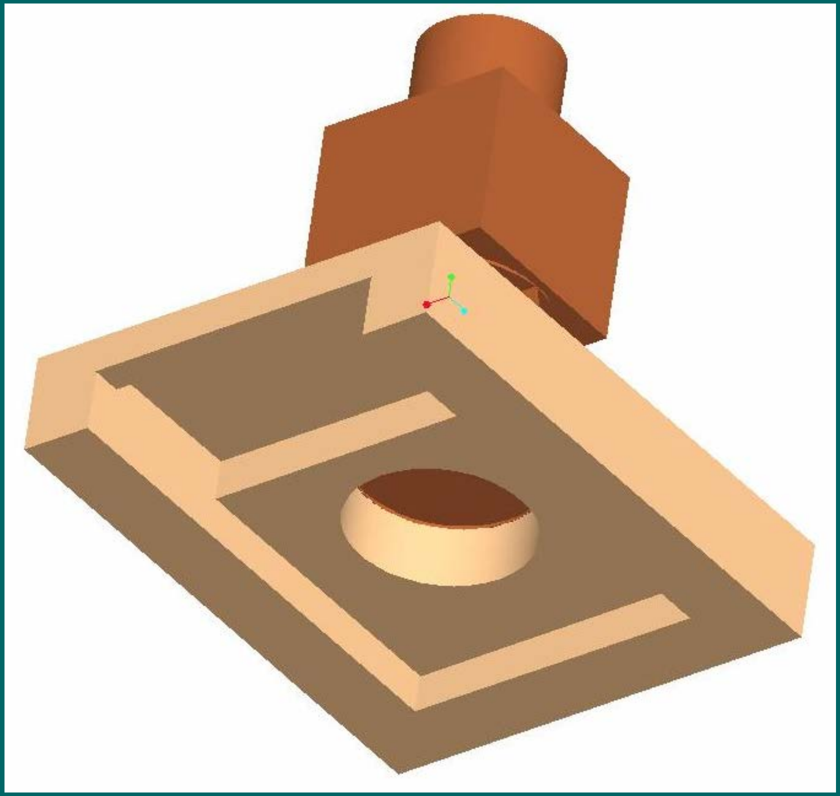
1st above-ground bending perpendicular to the discharge piping at 12.38Hz

Preliminary Recommendations

- Increase the stiffness of the motor stand
- Improve motor rotor residual unbalance
- Improve the connection of the motor junction box
- Increase the building floor stiffness

FEA Modal Analysis

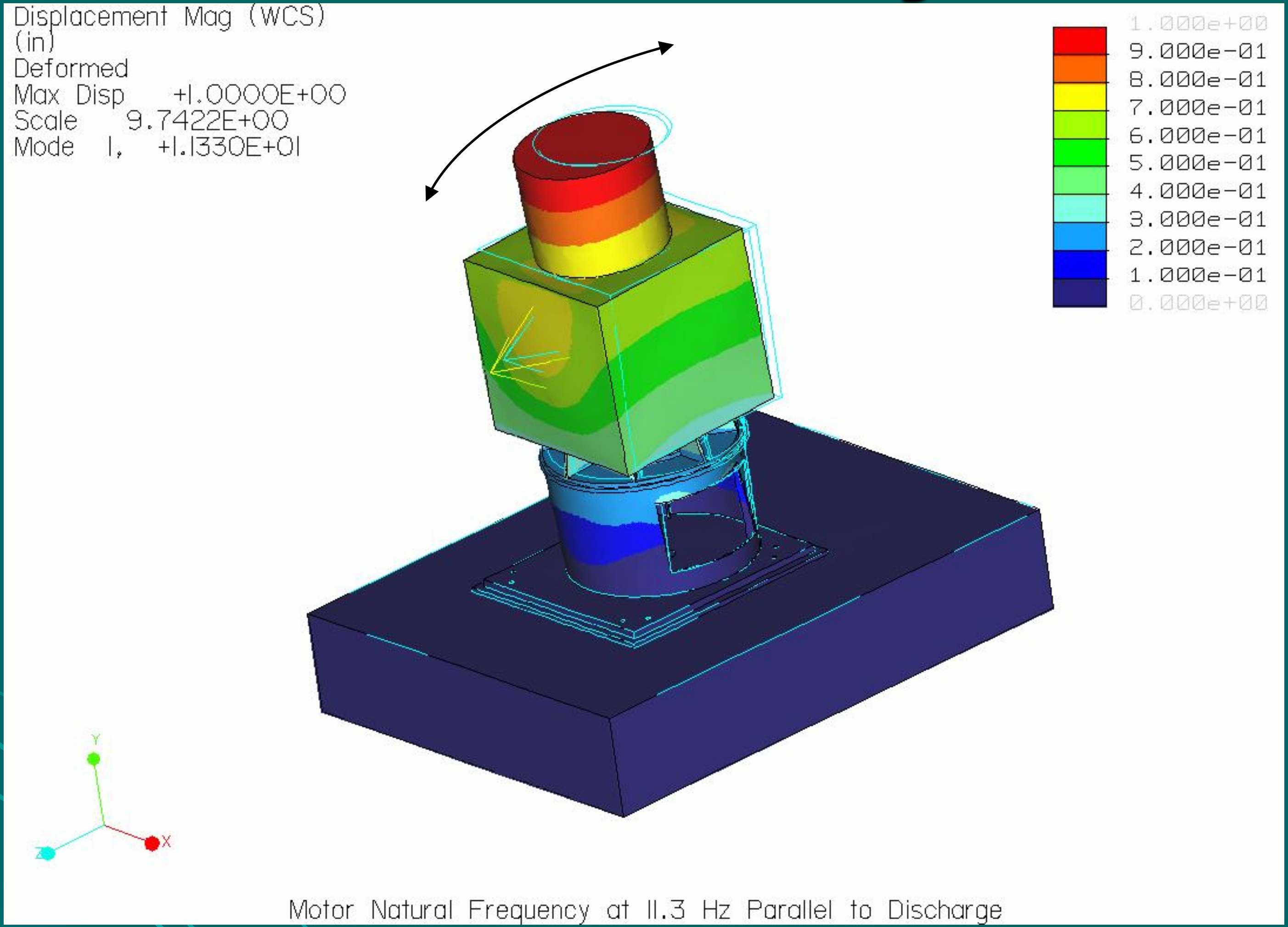




Detailed solids model of the pump

Junction box not shown (mass element)

FEA Modal Analysis

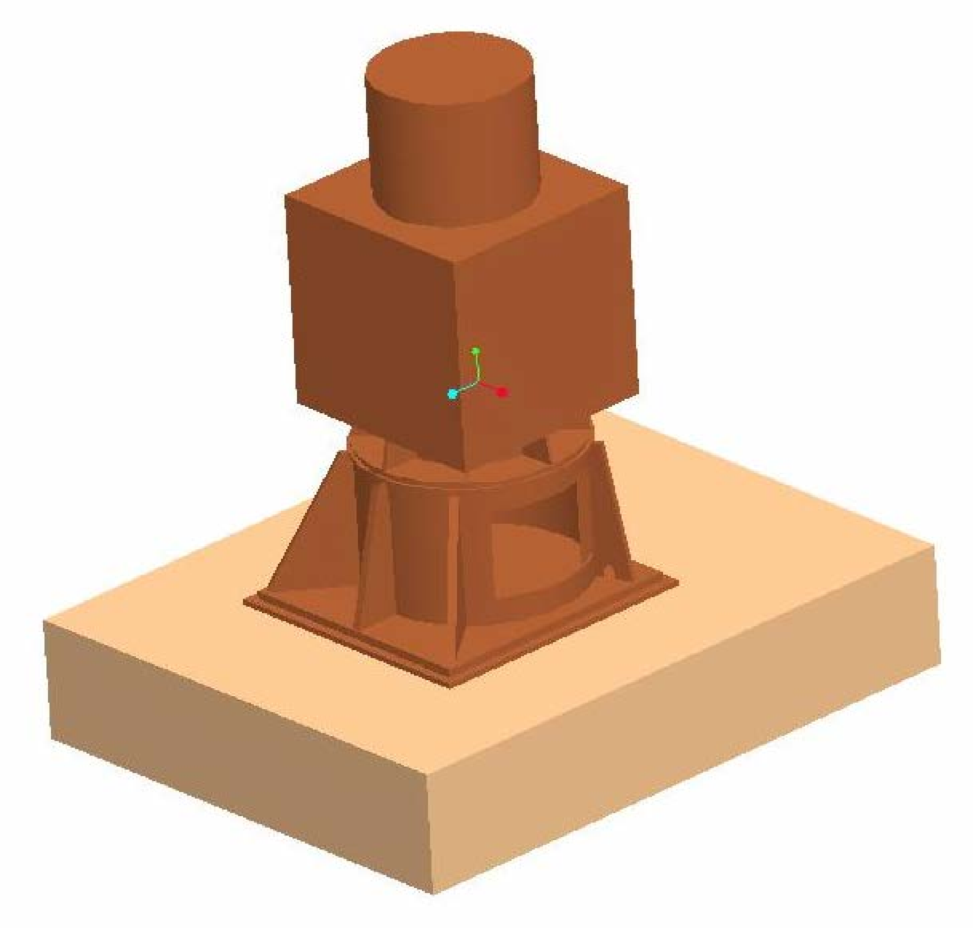


1st above-ground bending parallel to the discharge piping at 11.3 Hz

Calibrated FEA model for original pump

Junction box shown as mass element

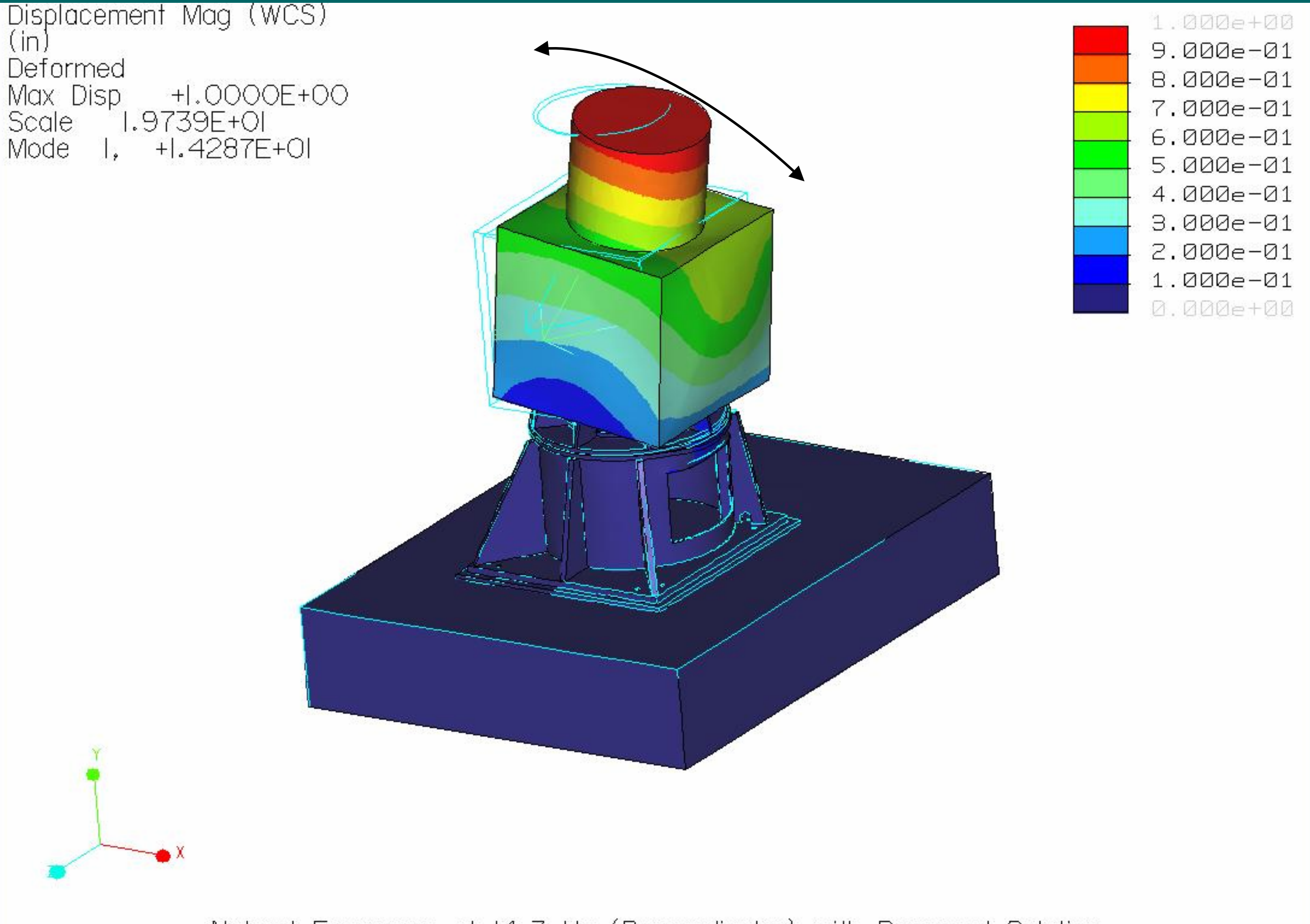
FEA Modal Analysis



Proposed modification of the motor stand

Junction box not shown (mass element)

FEA Modal Analysis



Natural Frequency at 14.3 Hz (Perpendicular) with Proposed Solution

1st above-ground bending perpendicular to the discharge piping at 14.3 Hz

Predicted structural natural frequency

Junction box shown as mass element

Summary

- Vibration was being amplified by a structural natural frequency of the pump
- Modification of the motor stand resulted in the predicted shift in the structural natural frequencies and the desired 15% separation
- De-tuning of the structural natural frequencies resulted in a reduction of the vibration from 9.0 mils pk-pk to 3.0 mils pk-pk
- Vibration increased to 4.5 mils pk-pk due to unequal thermal expansion of the motor rotor
- Improving the motor residual imbalance resulted in a vibration amplitude of 1.5 mils pk-pk which did not increase with time

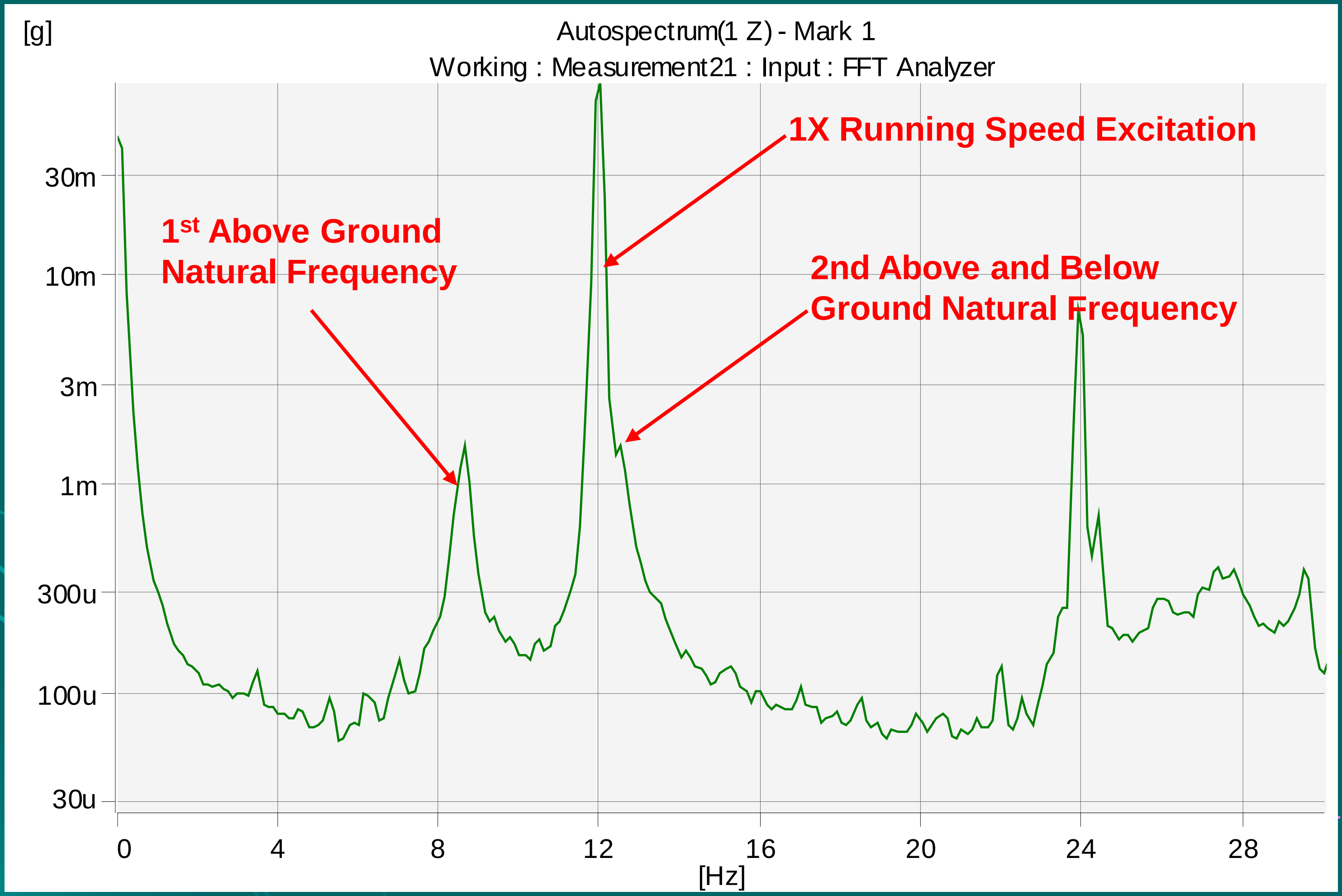
CASE 2

Excessive Synchronous Vibration due to Resonance with a Combined Above and Below Ground Mode

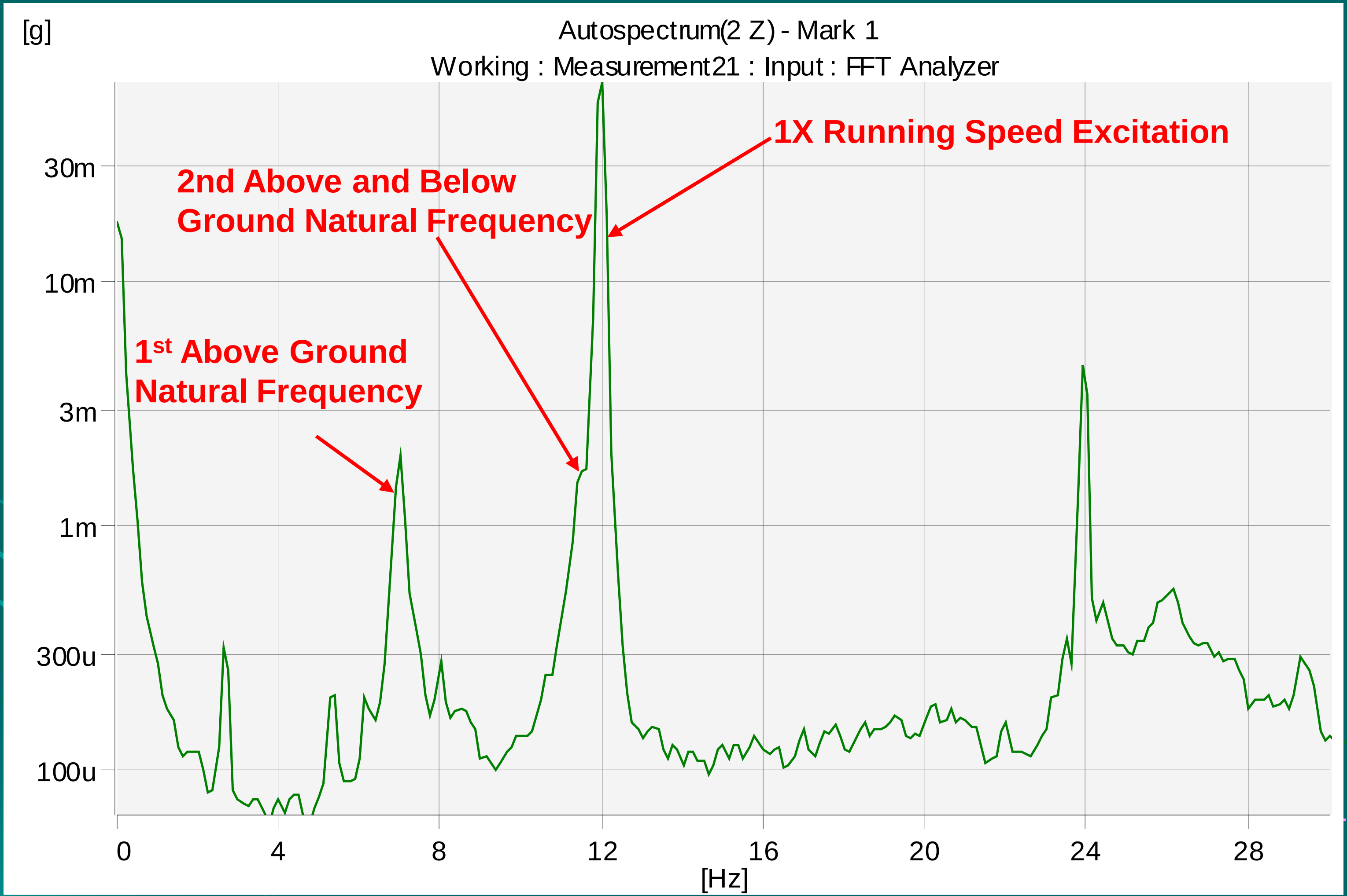
Problem Statement

- Circulating water pumps (1200 hp) installed at a new cogeneration plant in the Midwest
- Vibration levels measured on the motor were as high as 1.1 in/s RMS which exceeded specification and put commissioning of the plant in jeopardy
- Plant personnel had placed large steel plates on top of several of the motors which were successful in reducing vibrations on several of the pumps, but not on others

Typical Vibration Spectrum – Perpendicular to Discharge



Typical Vibration Spectrum – Parallel to Discharge



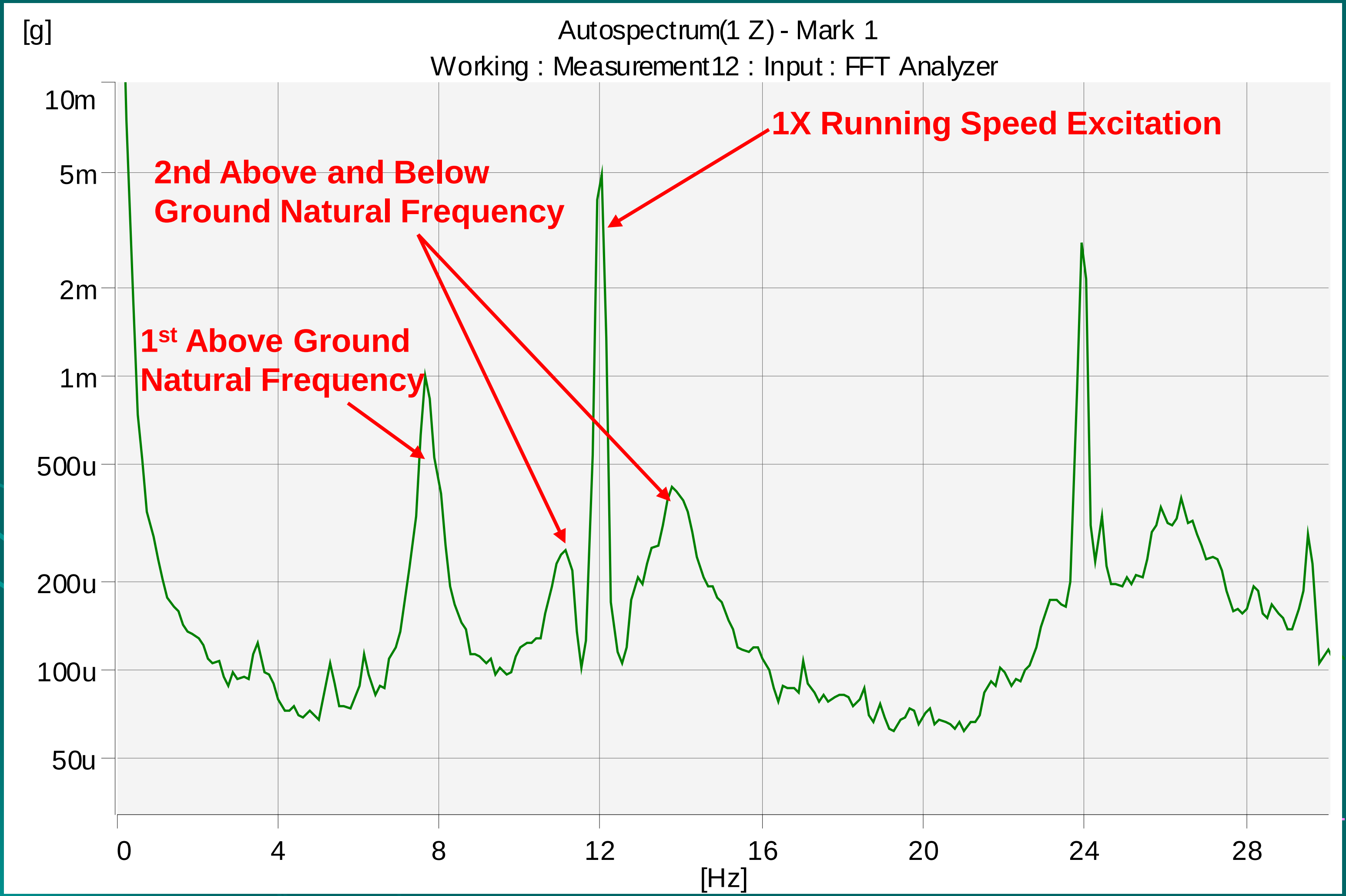
Preliminary Conclusions

- Vibration was being amplified by a structural natural frequency of the pump
- The problematic vibration mode had the top of the motor and the bottom of the pump moving in-phase with each other
- Due to differences in construction, the natural frequencies varied slightly from pump to pump
- Weights on top of the motor acted as “tuned-absorbers” for some pumps
- The flexibility of the conduit box similarly resulted in “tuned-absorber” effect

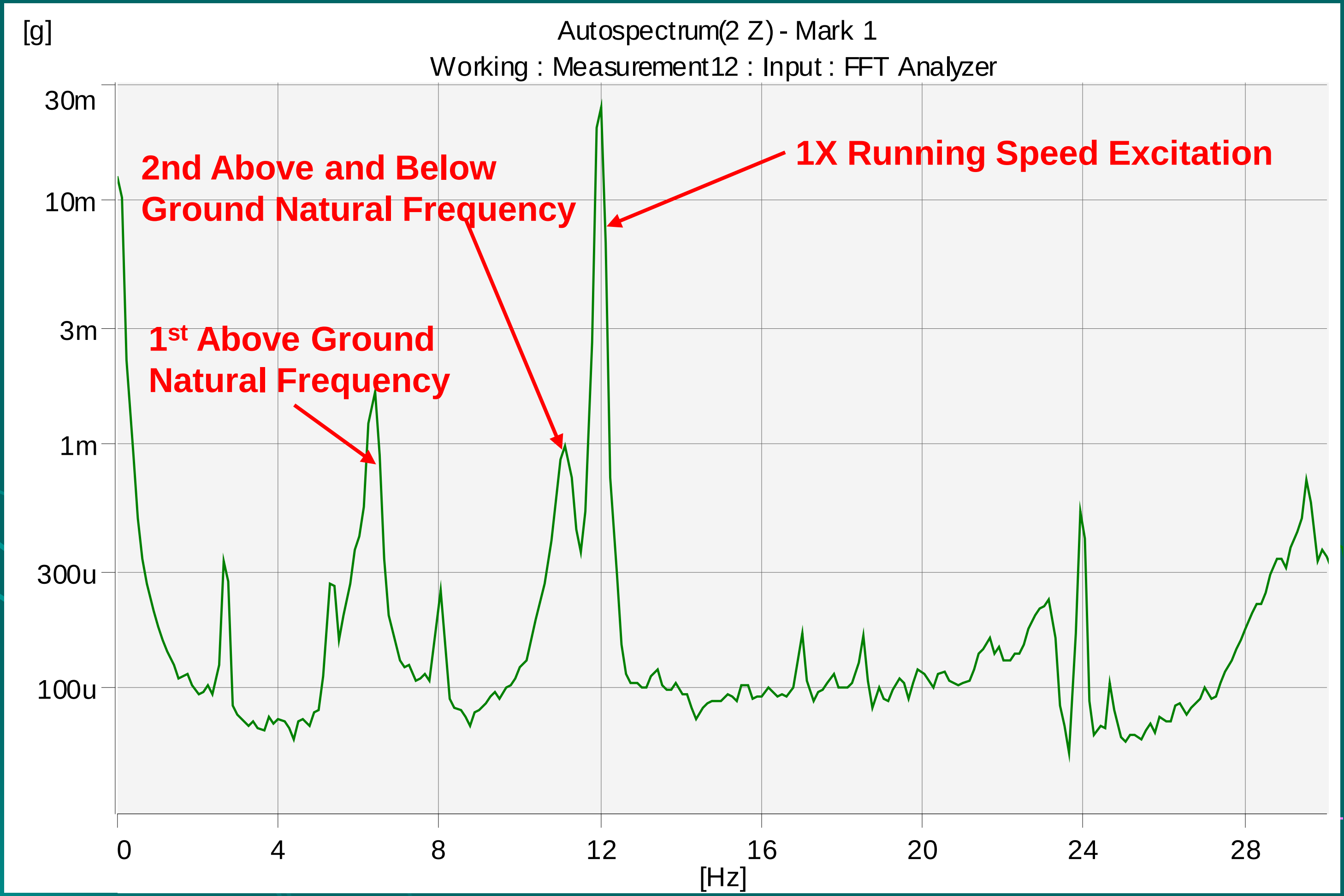
Finite Element Analysis

- A finite element model was calibrated to match the test results
- Initial analysis predicted that more than 4,000 lbm of material needed to be added at the top of the motor to de-tune the natural frequency
- A more significant effect was predicted by adding mass to the bottom of the pump (suction bell)
- Recommendations varied from pump to pump, but all included added mass to both the suction bell and the top of the motor

Vibration Spectrum - Perpendicular to Discharge with Added Weight



Vibration Spectrum - Parallel to Discharge with Added Weight



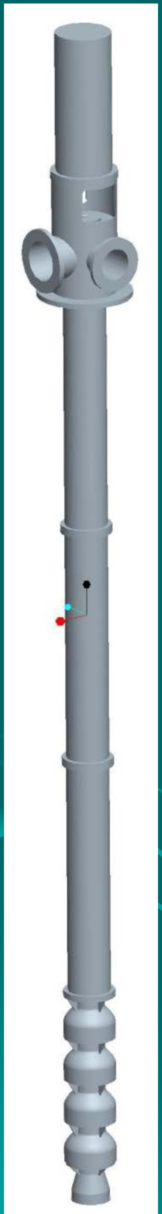
Summary

- Vibration was being excited by a structural natural frequency which had combined above and below ground motion
- Adding mass only to the top of the motor would not have been sufficient to de-tune the below ground natural frequency
- With mass added to the top of the motor and to the suction bell, the vibration levels were reduced from 1.1 in/s RMS to below 0.28 in/s RMS and within the specification limits
- Stiffening of the junction box connection was recommended to reduce the chance of fatigue failure in the future

CASE 3

Sub-synchronous Vibration due to Rotor and Bearing Rub

Problem Statement



- Vertical turbine pumps in service offloading petroleum products from a tanker
- High synchronous and sub-synchronous (½X) vibrations
- High temperatures were measured on the lineshaft bearings
- Product lubricated fiber reinforced Teflon bearings were used
- Concern over potential for heat or sparking in the bearings that could result in an explosion of the cargo

Findings

- Strong sub-synchronous vibration was measured with probes on column pipe and shafting at exactly ½X running speed
- Inspection of the bearings discovered non-friable grit impregnating the relatively soft bearing material
- Investigation found that a new type of grit was used to clean the hull of the vessel
  - New grit was not sharp and friable
  - Residual grit in the hull after cleaning passed through the bearings

Conclusions

- Exact ½X running speed excitation is indicative of mechanical rubbing
- High bearing temperatures are also consistent with rubbing in the bearings
- Initial rubbing resulted in heat generation in bearings which expanded thermally
  - Coefficient of thermal expansion of Teflon is greater than that of surrounding steel, so the bearings reduced their clearance around the shaft and made the situation worse

Solution

- Short term solution was to change back to the original blast grit and to improve the procedure for cleaning residual grit
- The long term conservative solution selected by the tanker company was to change out the pumps and install submersible pumps which did not have lineshaft bearings
- Alternatives
  - Changing bearing material
  - Installing enclosing tubes to keep bearings isolated

Conclusions

Conclusions

- Synchronous vibration problems are typically due to poor balance and / or inadequate alignment
- After balance and alignment have been addressed in vertical turbine pumps, the excitation of the structural natural frequencies are the most common source of problems
- A combination of vibration testing and finite element analysis has proven to be valuable in diagnosing synchronous vibration problems and determining practical solutions
- Rubbing in bearings and seals typically results in a sub-synchronous vibration component at exactly ½X running speed

Conclusions

- **Rotordynamic instability can result in a sub-synchronous vibration component between 40% and 49% of running speed. Cases of rotordynamic instability have been experienced in vertical turbine pumps, but it is rare.**
- **Hydraulic problems such as suction recirculation can also result in sub-synchronous vibration**

Recommendations

- **Testing combined with analysis are excellent tools when good engineering judgment and experience have not been successful in diagnosing and fixing vibration problems in vertical pumps**

Thank you

Any Questions?