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Excitation of Structural Resonance Due to a Bearing Failure

Robert A. Leishear

David B. Stefanko

Jerald D. Newton

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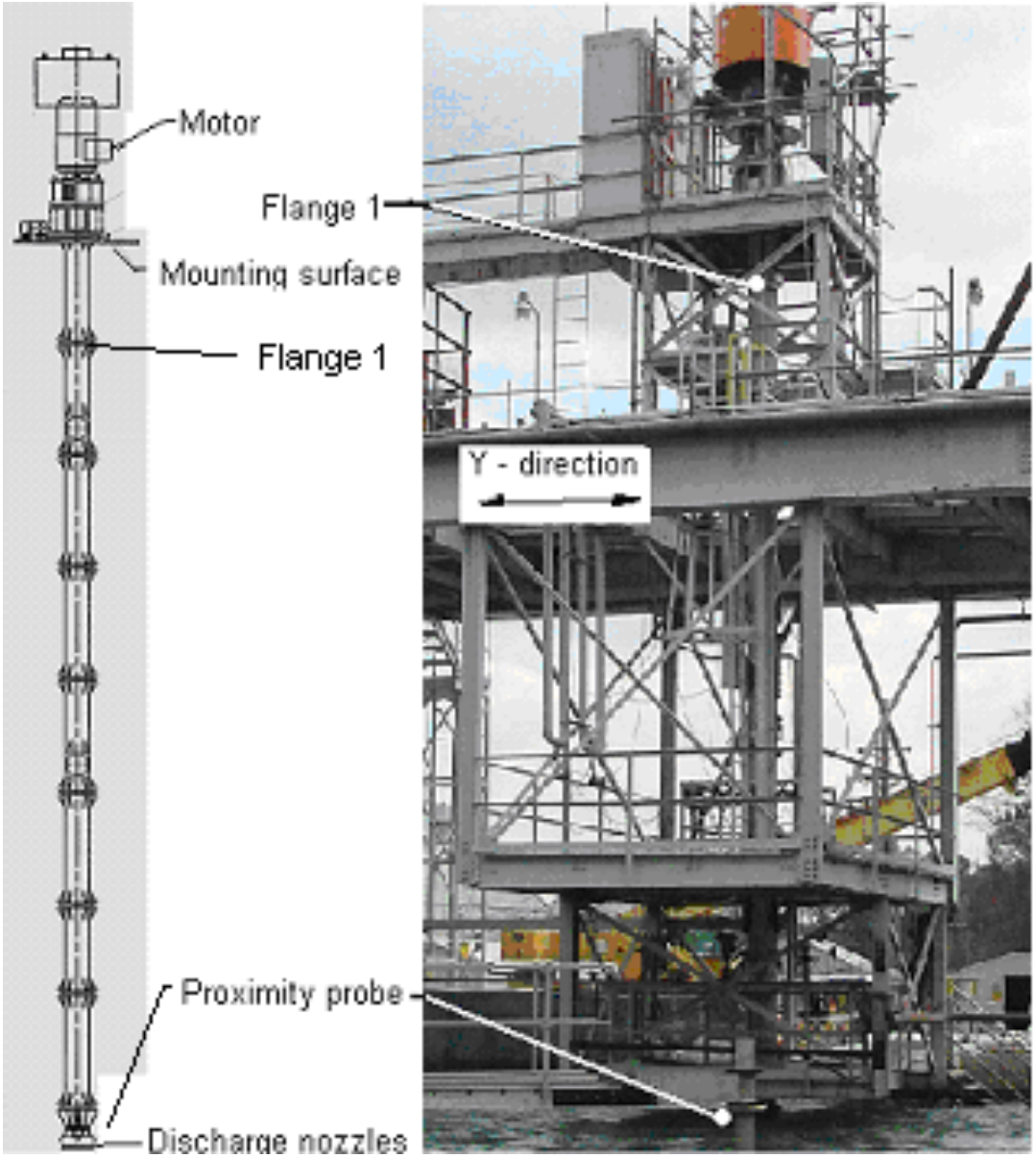
Introduction

- This paper relates system resonance to a detailed analysis of an incipient bearing failure for a 10,000 pound, 300 horsepower pump.
  - Imminent failure was prevented by recognizing and analyzing resonant equipment vibration.
  - To do so, vibration data for a pump installed in an operating nuclear facility was compared to vibration data from a pump at a test facility.
- This presentation includes: an equipment description; a description of the bearing failure; brief discussions of resonance and vibration monitoring techniques which are not detailed in the paper; and a discussion of the vibration analysis performed to prevent further damages expected to cost 2 million dollars.

Test Facility Vibration Data

- Vibration data was typically measured at numerous locations along the axis of the pump in both radial and axial directions.



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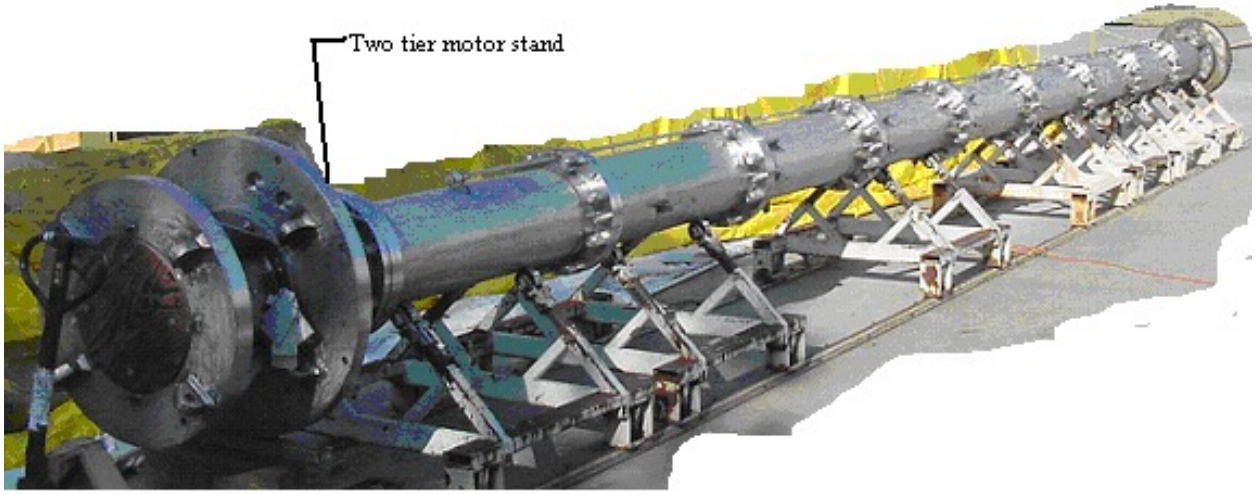
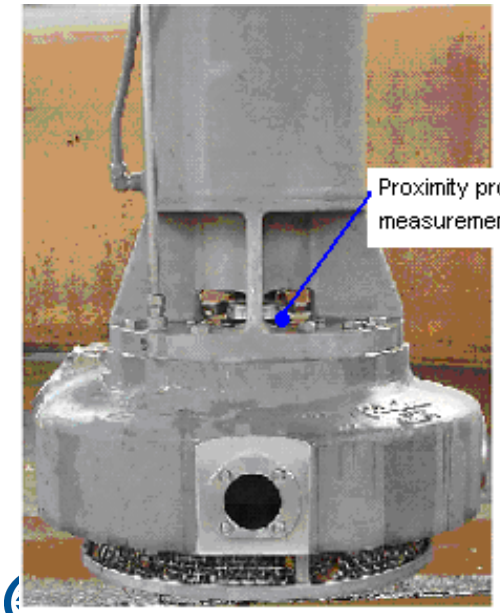
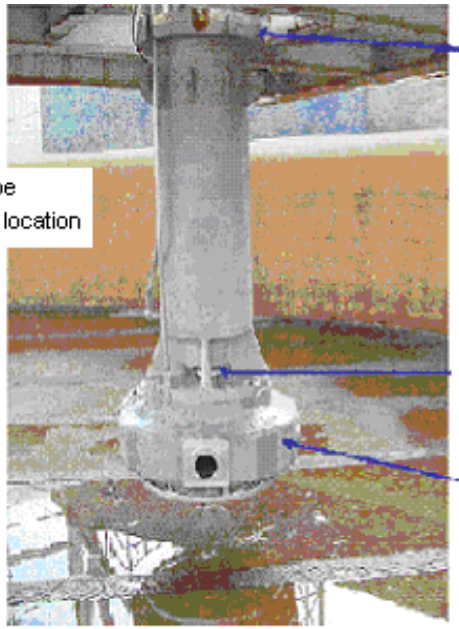
Vertical Pump Design





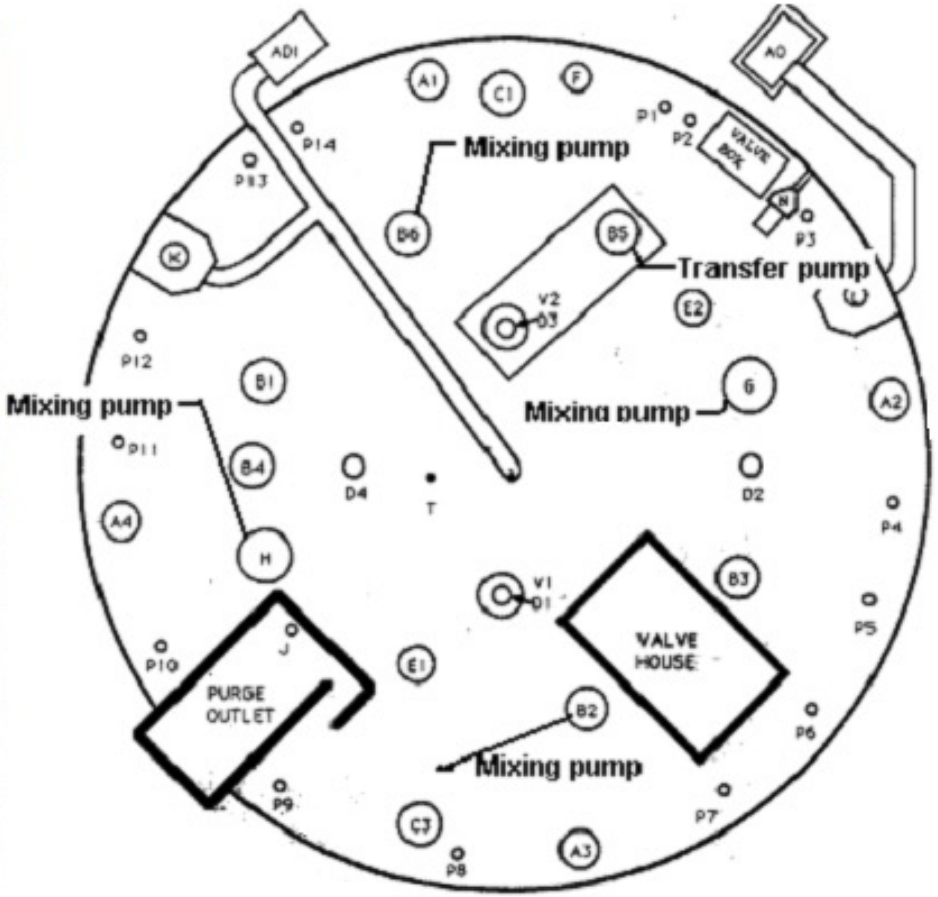


Pump Operation

- High velocity discharge jets are used to mix waste in 85 foot diameter by 30 foot high tanks.
- The tank at test facility is shown.

Pump installation on a tank

- Pump used to mix nuclear waste in a 1.3 million gallon tank .



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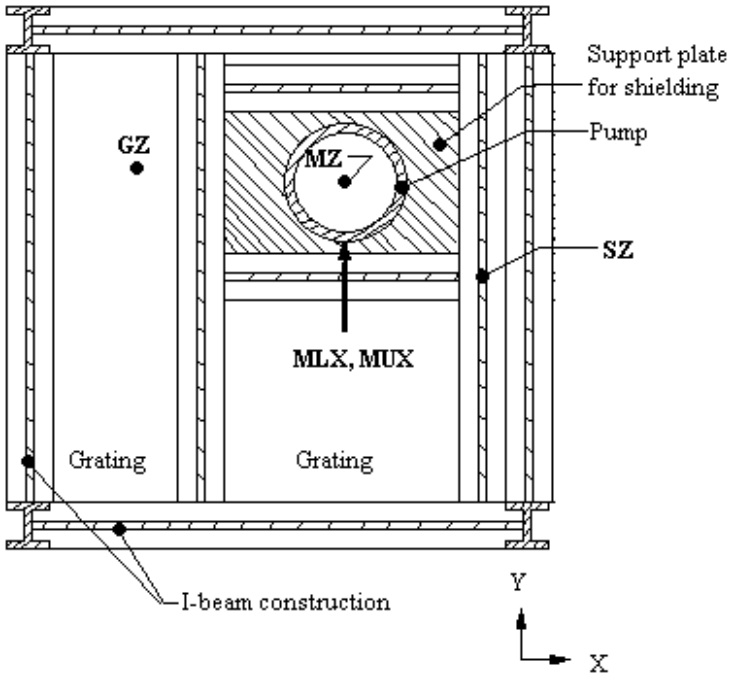
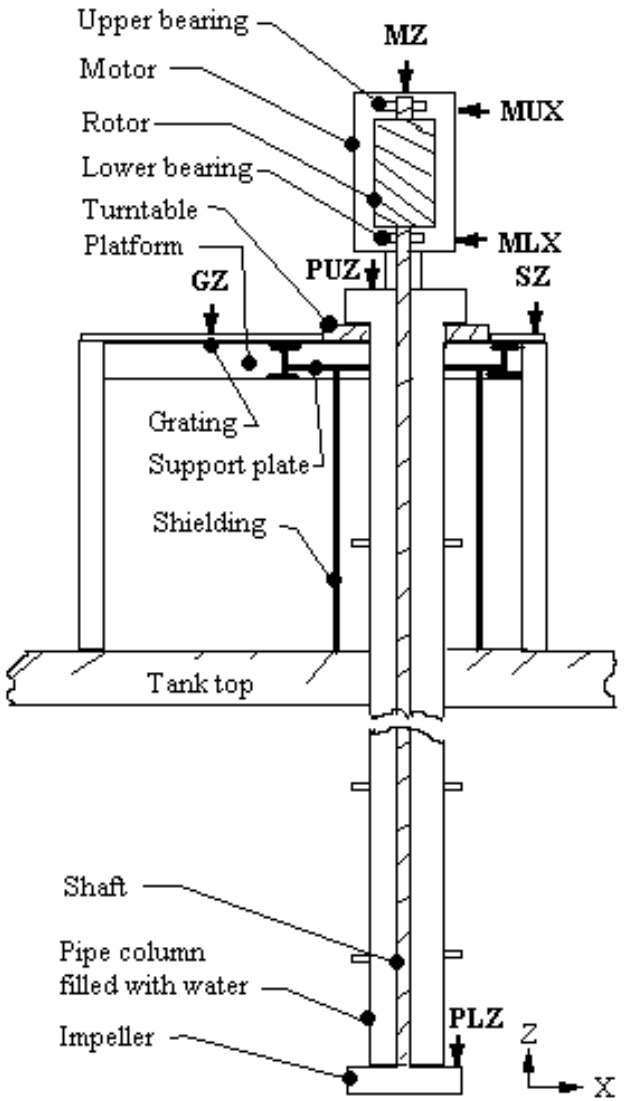
Nuclear Facility Vibration Data

- In the facility, vibrations can only be measured near the motor, since the pump is inside the tank.





Initial Data / Problem Definition

- Increased noise levels were observed by operators at an installed pump on a waste tank.
- Vibration levels were well below typically accepted values of 0.2 inches / second.
- According to established standards, the pump vibrations were acceptable.
- Further investigation was warranted.

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Bearing Damage Found After Motor Replacement

- The race was cut to disassemble the bearing for inspection.
- The bearing cage was broken, the balls were dented and spalled, and the race was scored.

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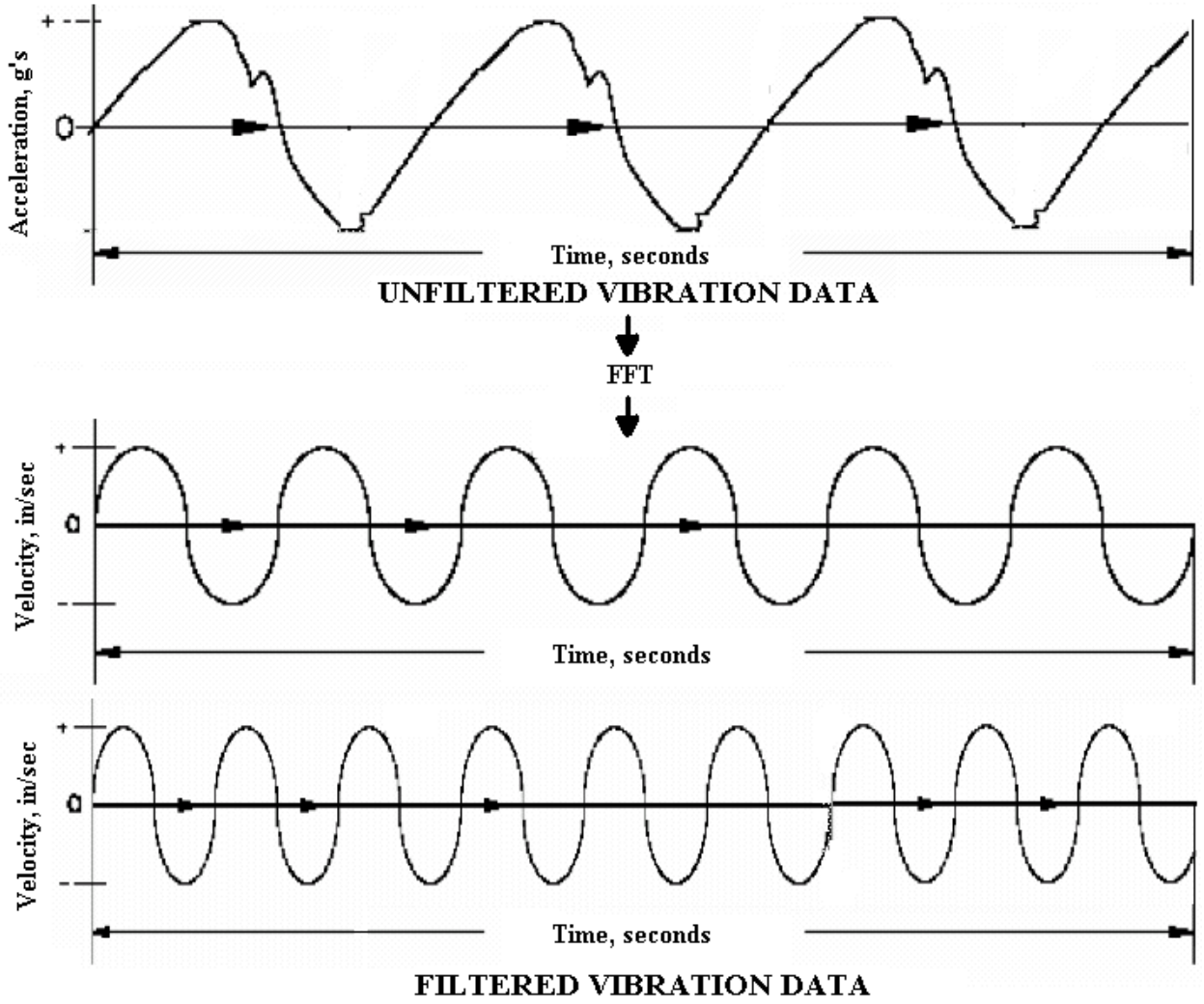
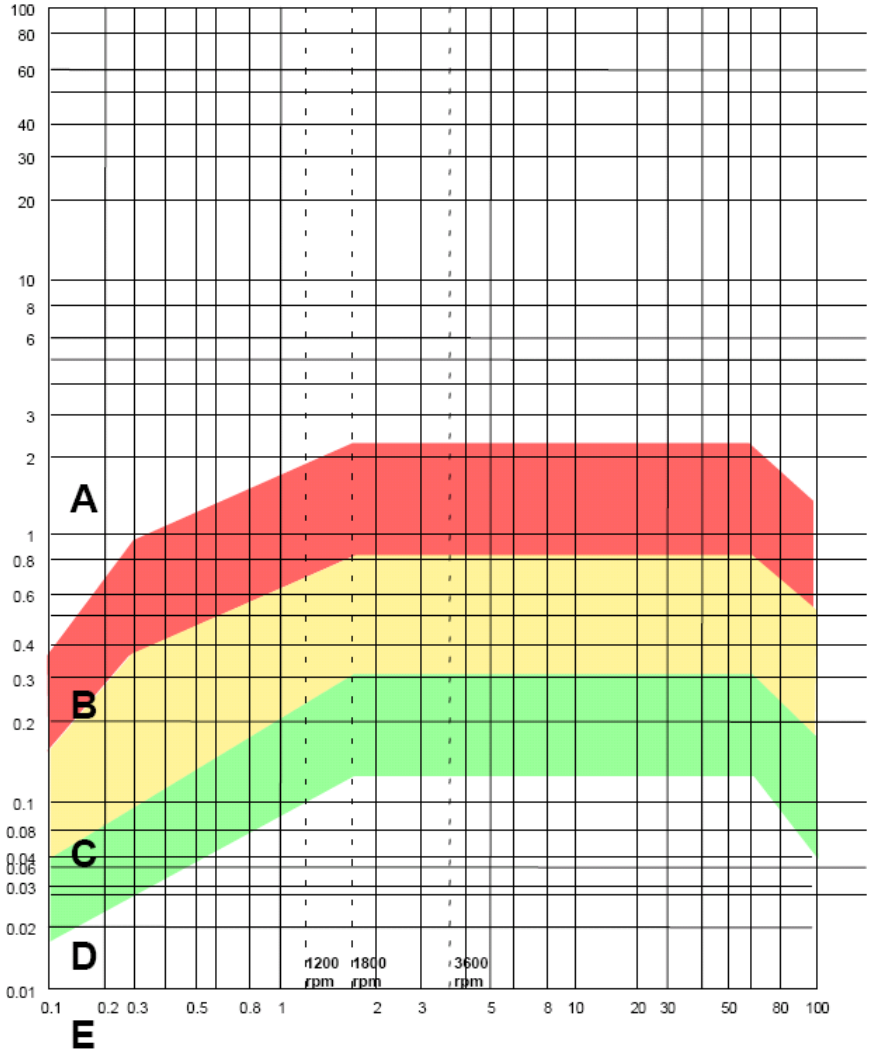
Vibration Monitoring Techniques

- Commercially available equipment used to measure accelerations, which were converted to velocities



Vibration Acceptance Standards

- Commercially recommended standards are available.
- Vibration velocity is generally considered to be equivalent for different size equipment.
- Trending importance is recognized by vibration analysts, since the graphic approach is not always reliable.



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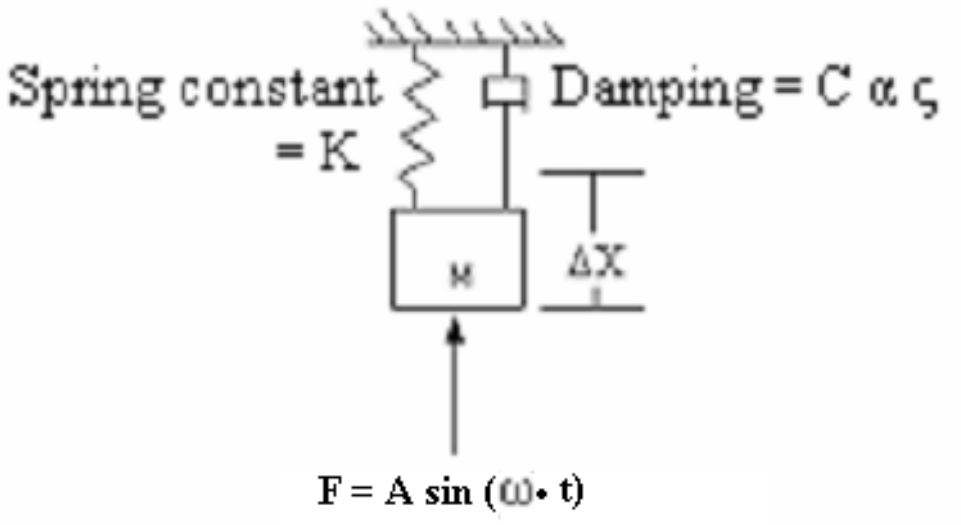
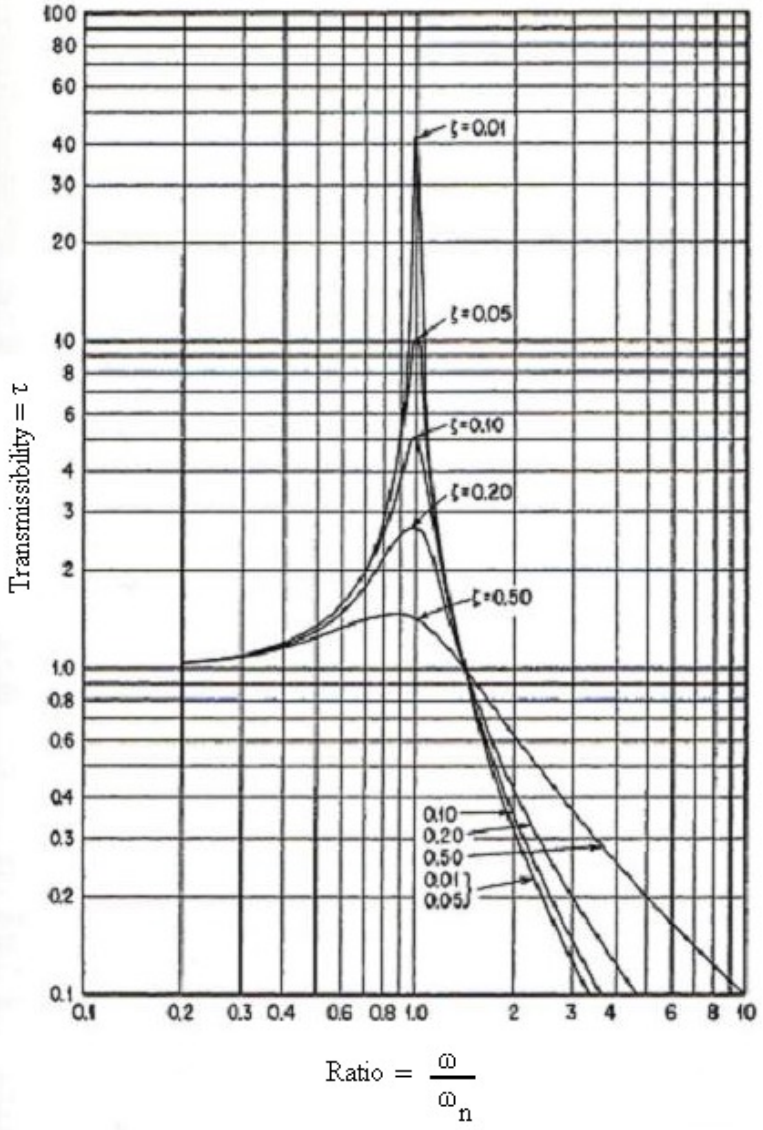
Resonance of Rotating Equipment

- In rotating equipment, resonance is achieved as the equipment vibration frequency, ω, approaches the natural frequencies of the equipment, ω_n.
  - Equipment frequency, ω, is proportional to the rotational speed of the motor , $\omega = 2 \cdot \pi \cdot f = 2 \cdot \pi \cdot rpm / 60$.
  - Natural frequencies ω_n, are the vibration modes inherent in any structure or its components.
- A SDOF system provides an approximation for the system response of rotating equipment.
- The SDOF model is developed from the equations of motion for a simple spring mass damper system



Relationship Between Transmissibility and Frequency

- Solving the equations of motion, the transmissibility can be defined as the maximum, dynamic system response divided by the static response due to a slowly applied force, F.
  - If ω is small the system acts as if a static load is harmonically applied.
  - If ω is large, the system has a negligible response to an applied force.
  - If ω = ω_n, the system response is significantly greater than would be expected from a static load.

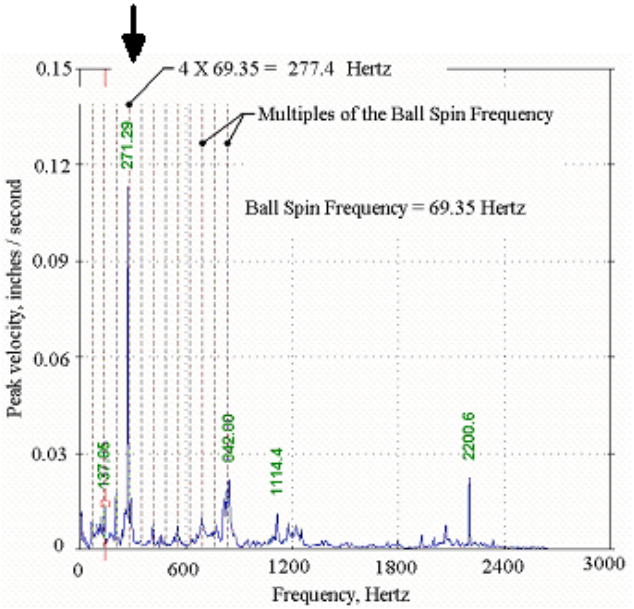


Vibration Analysis Results

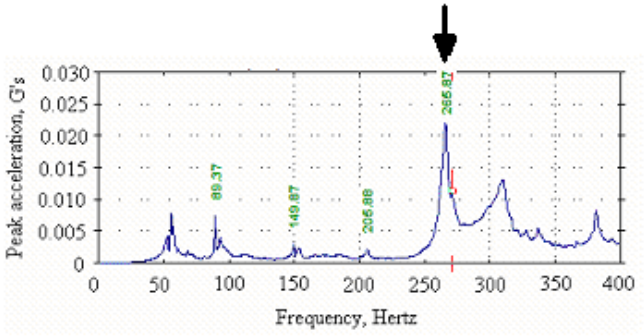
- Minor vibrations at the bearing were transmitted to the pump, which were in turn were transmitted to the mounting platform , and then rattled the grating .
- The natural frequencies of the ball bearings, the pump, and the platform were nearly coincident, or resonant.
- Accordingly, the platform grating vibrated in response to the coupled resonances and vibrated at the random frequencies of the grating.
  - Noise was generated at the random frequencies of the grating.
  - The noise level increased to a point where conversations could not be heard within 40 feet of the pump.

Vibration Data

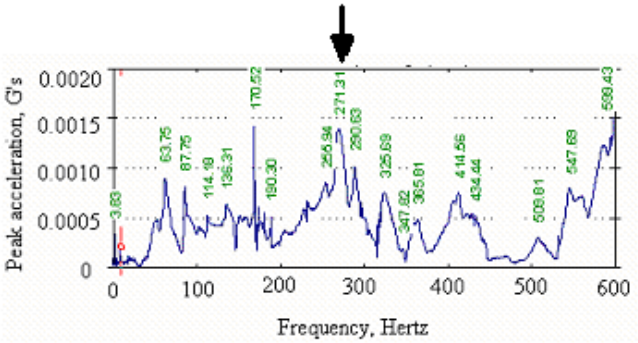
- The bearings, the platform, and the pump had nearly coincident, resonant vibrations at 271 Hz.
- Grating vibrations were random as the grating impacted the I-beams resulting from the I-beam vibration.
- Note that the maximum vibrations are ≈ 0.1 inches / second at the bearing.
- This vibration magnitude is < 0.2 inches / second per typical acceptance criteria.



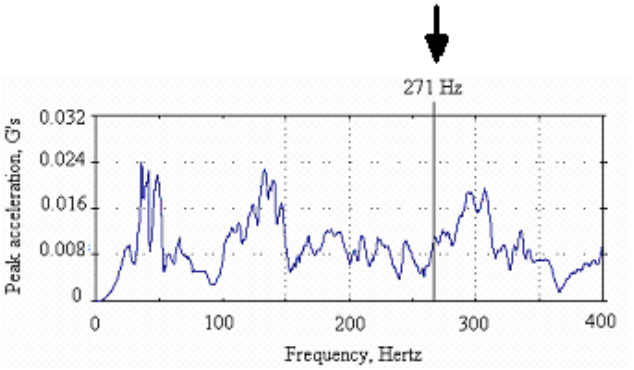
Ball bearing frequency



Platform frequency



Axial pump frequency



Grating frequencies

Deflection Due to Force Magnification

- The measured force from the pump will be tripled when it is transmitted to the platform.
- The pump displacement due to the bearing was calculated from the measured acceleration, such that

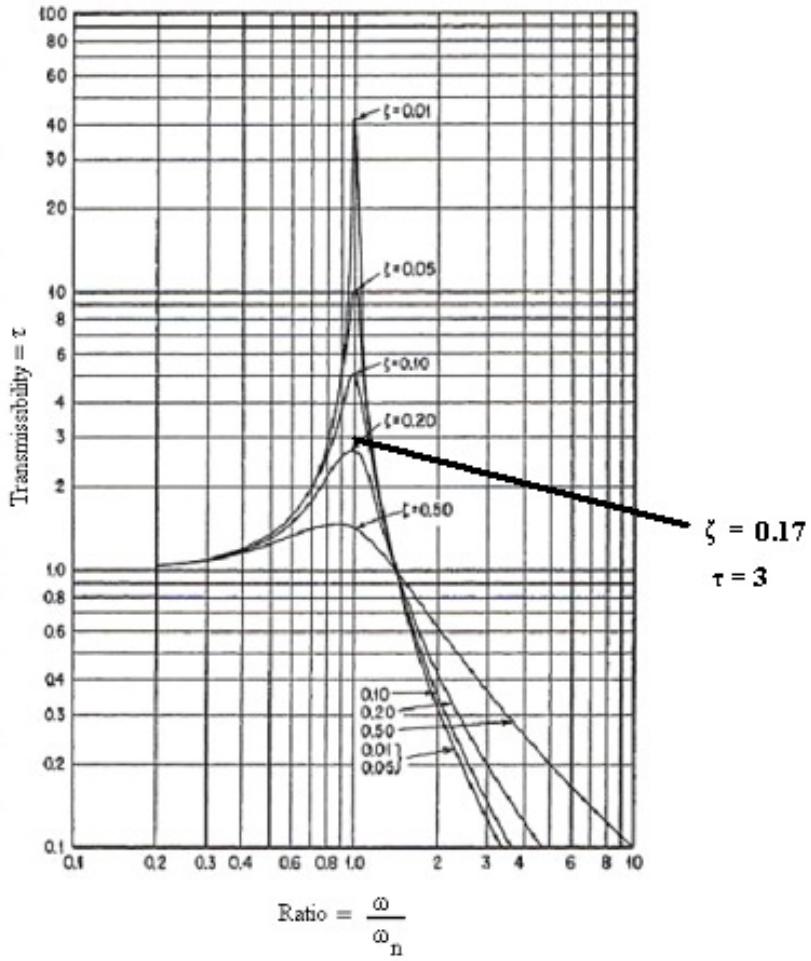
$$D_{pump} = 0.039\_inches\_peak\_to\_peak$$

- The beam deflection is then

$$D_{beam} = \tau \cdot D = 3 \cdot 0.039 = 0.120\_inches\_peak\_to\_peak$$

- and the deflection of the bearing due to spalling is approximately 1/80 inch

$$D_{bearing} = D/\tau = 0.039/3 = 0.013\_inches\_peak\_to\_peak$$



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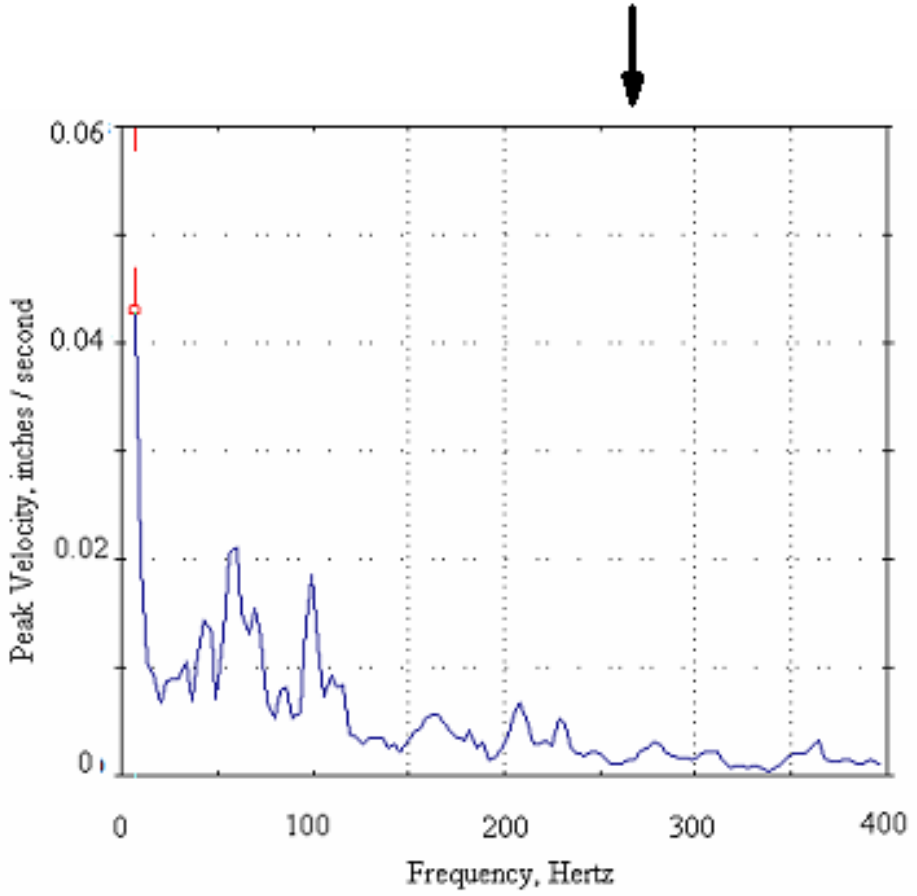
Vibrations After Motor Replacement

- Negligible vibration at the 271 Hz ball spin frequency.
- Bearing vibrations had increased by a factor of 30 since installation, and periodic vibration monitoring, or trending, may have found the failure earlier.



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Conclusions

- Vibration acceptance criteria may be used for guidance on rotating equipment.
- Vibration acceptance criteria can be misleading, and vibration trending to assess equipment degradation is preferred to acceptance criteria.
- Although resonance is a familiar term, this paper provides the first well documented case to quantify the relationship between resonance and incipient machinery bearing failures.
- An understanding of structural resonance can prevent further equipment damage in operating facilities.