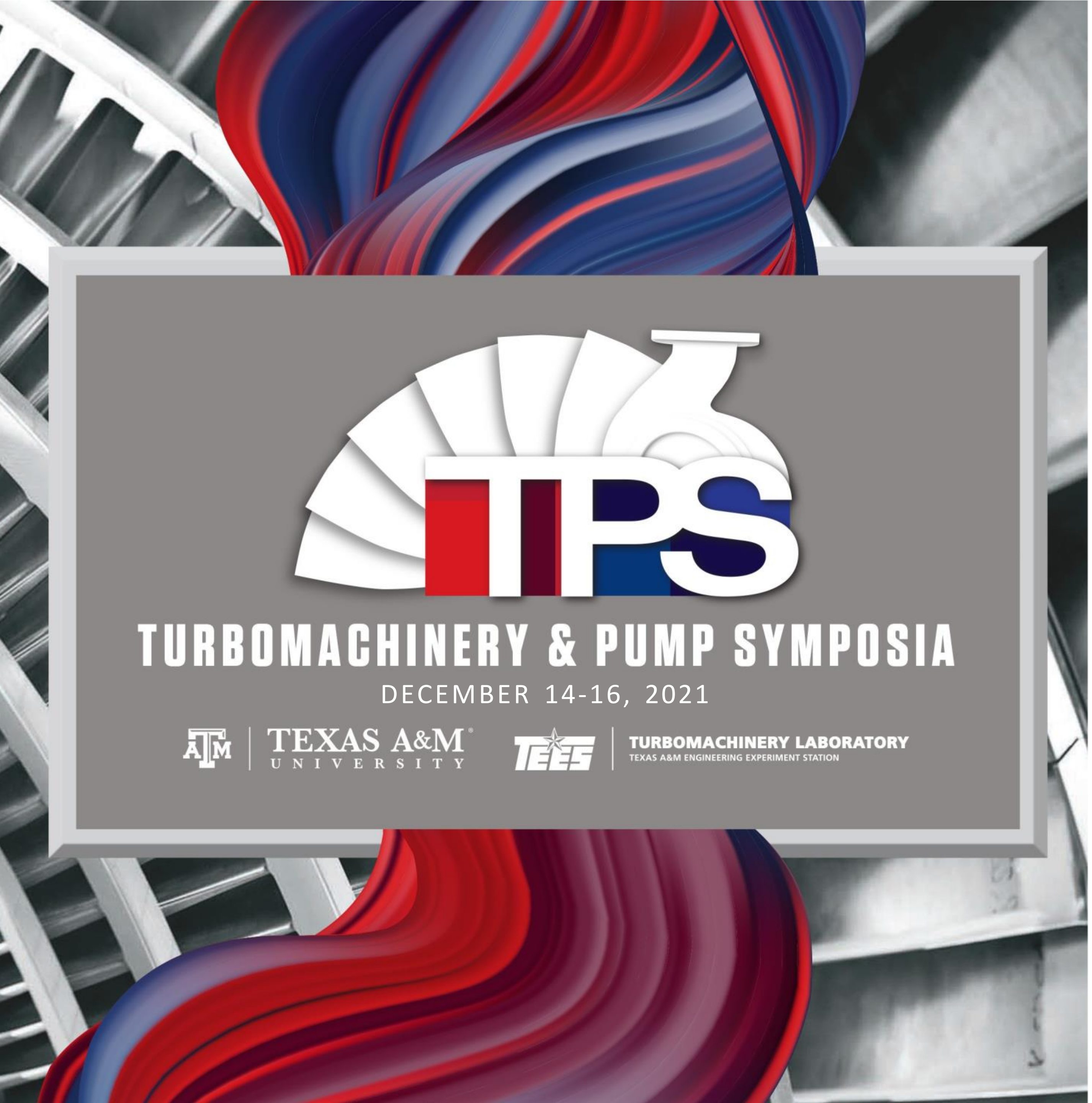


Accidental Excitation of Acoustic Resonances from Balance Holes on Rotating Disk: Noise Troubleshooting and Mitigation

Tommy Kerr, Ph.D.
Aaron Rimpel
Sarah Simons

Southwest Research Institute
San Antonio, TX

Presenter / Author Bios

Tommy Kerr has been a research engineer for Southwest Research Institute for a year and a half, and works on various projects in the turbomachinery field. He received his Ph.D. and Master's degree from the Turbomachinery Lab at Texas A&M under Dr. Adolfo Delgado and Dr. Dara Childs, respectively.

Aaron Rimpel is a Group Leader in the Rotating Machinery Dynamics Section of the Machinery Department at Southwest Research Institute in San Antonio, TX. He has over ten years of experience in mechanical system design, rotordynamics, and development of rigs for testing bearings and seals for conventional and oil-free machinery.

Sarah Simons is a Senior Research Scientist in the Fluid Machinery Systems Section at Southwest Research Institute. She has developed new state-of-the-art analyses and test devices from research performed in the fields of gas properties, acoustics, vibrations, and compressor operation. Ms. Simons has written and co-authored numerous papers, magazine articles, and 2 books on the subject of acoustics, pulsations, noise and vibration in compressors and pumps.

Problem Statement

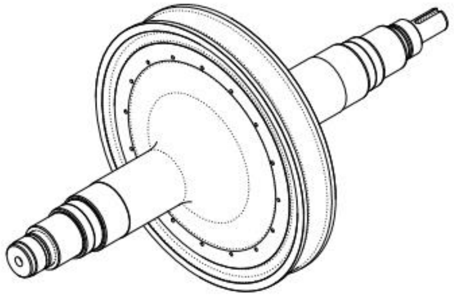
During commissioning of test rig - observed loud “squealing” noise at speeds above 3,000 rpm

- Greater than 105 dB
- High-pitch, range ~3 kHz

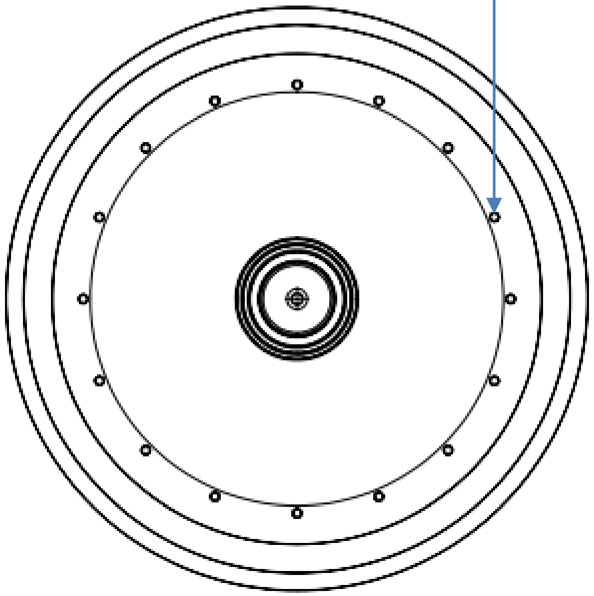
Need to identify and mitigate

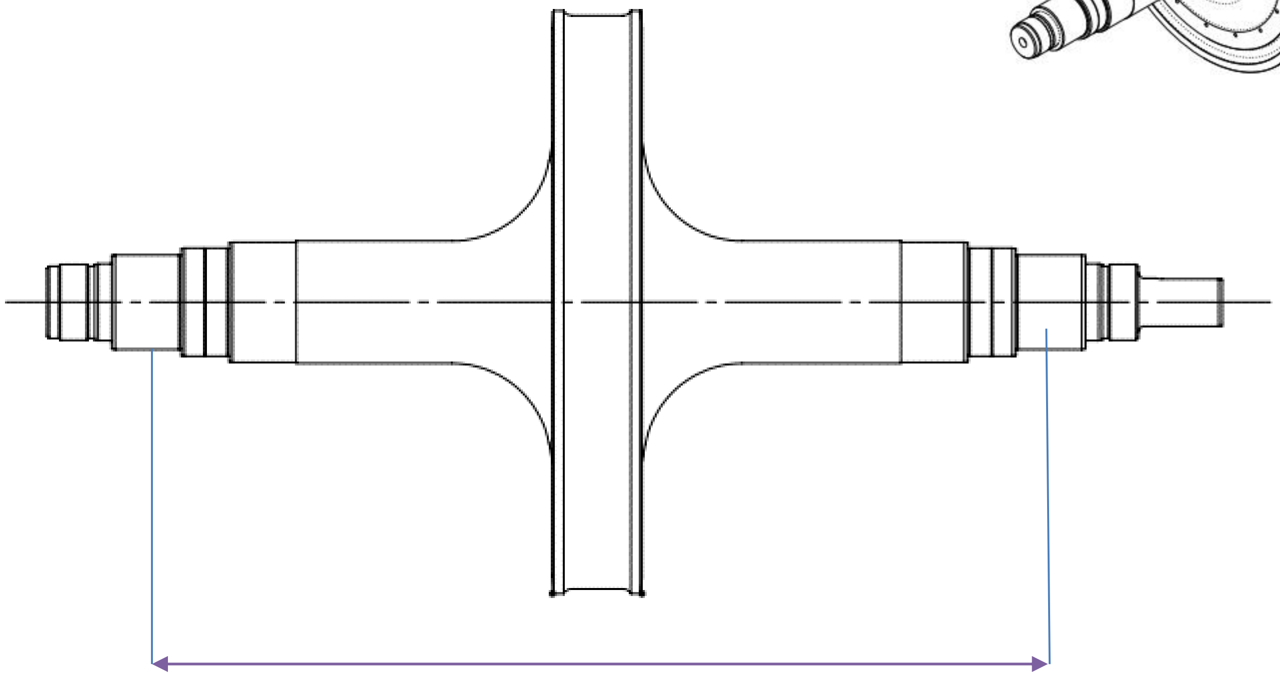
- Cause could indicate damage / future failure
- Noise masks other potential problems – listening is an important tool in test rig operation

Test Rig Description



16 Balance Holes at approximately Ø14” circle

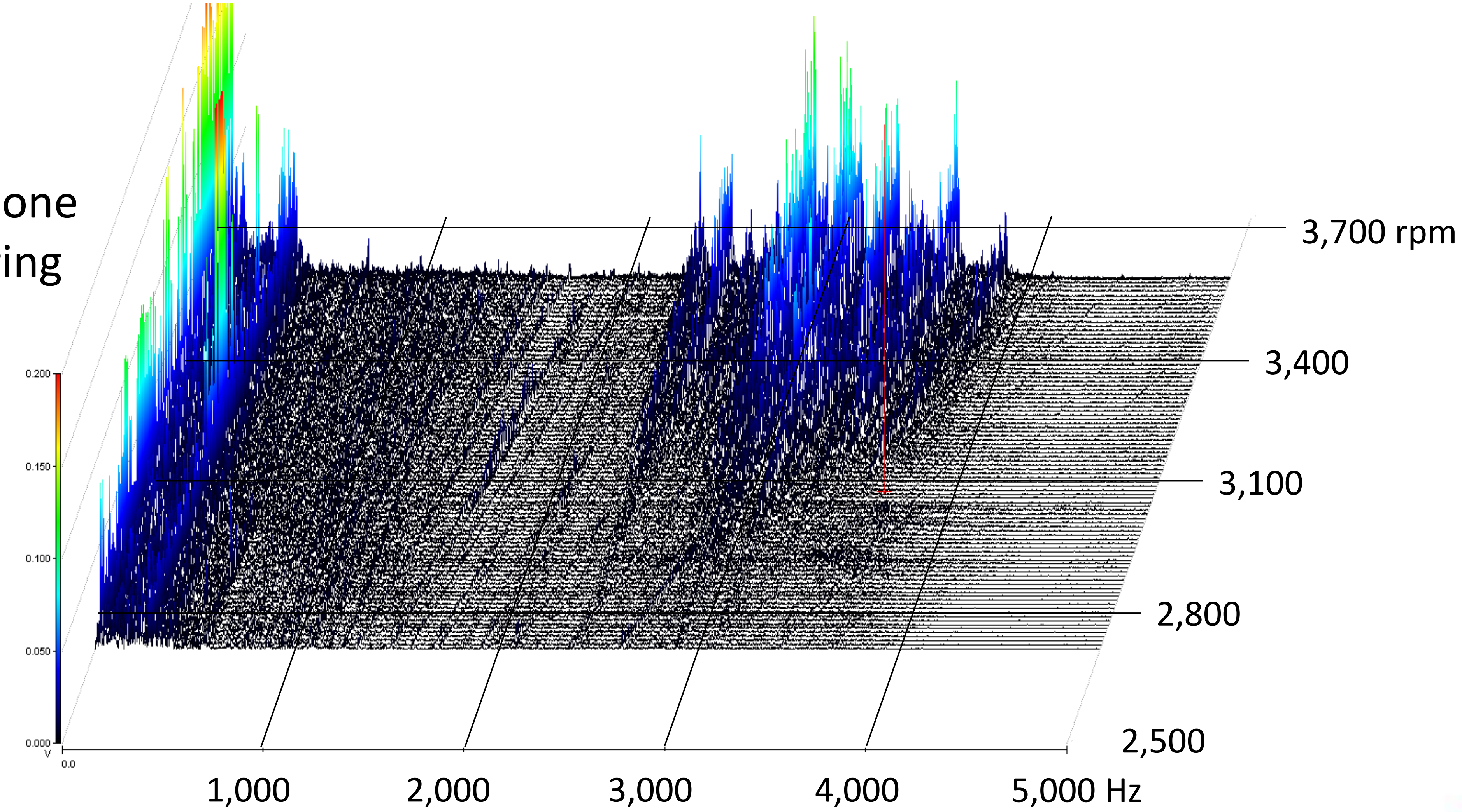




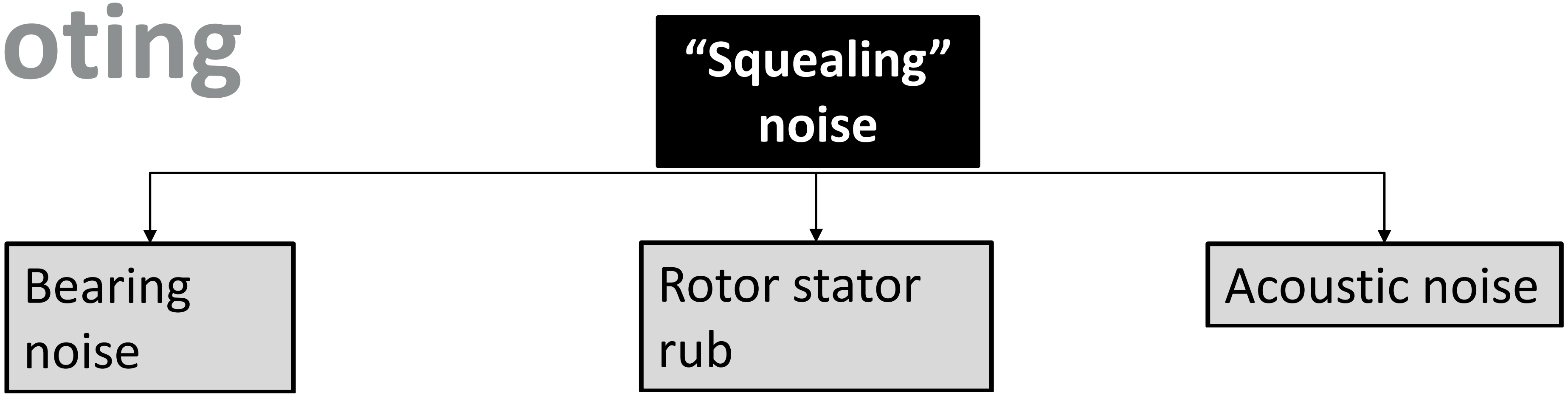
Ball Bearing Span Approximately: 36”

High Frequency Squealing Noise Occurs Above 3,000 rpm

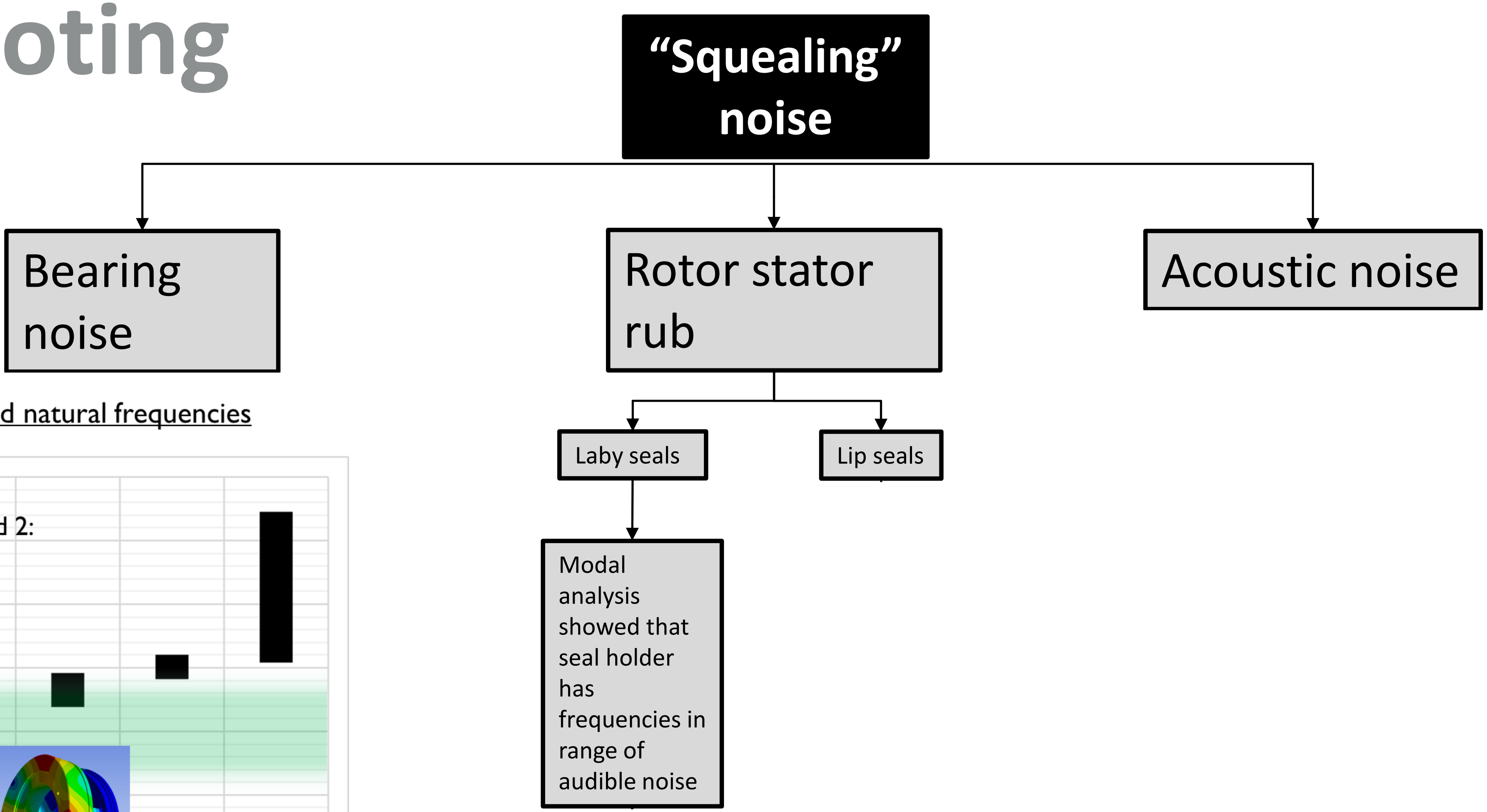
Microphone data during start-up



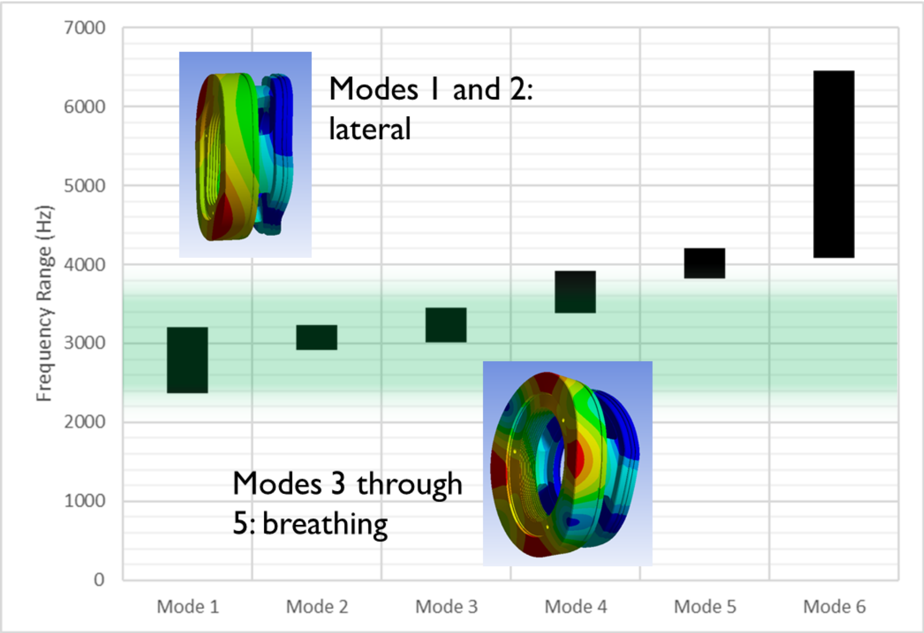
Troubleshooting



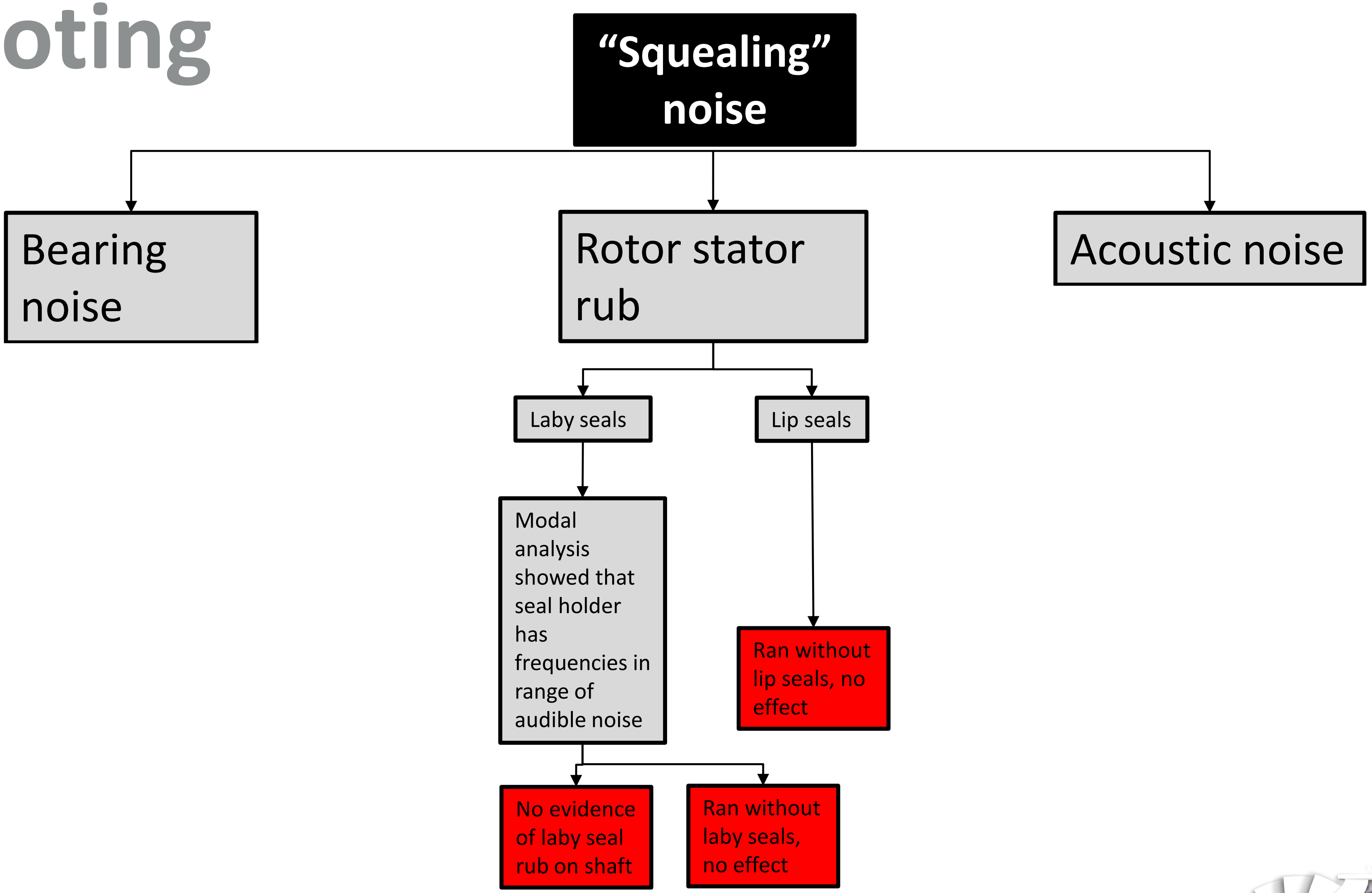
Troubleshooting



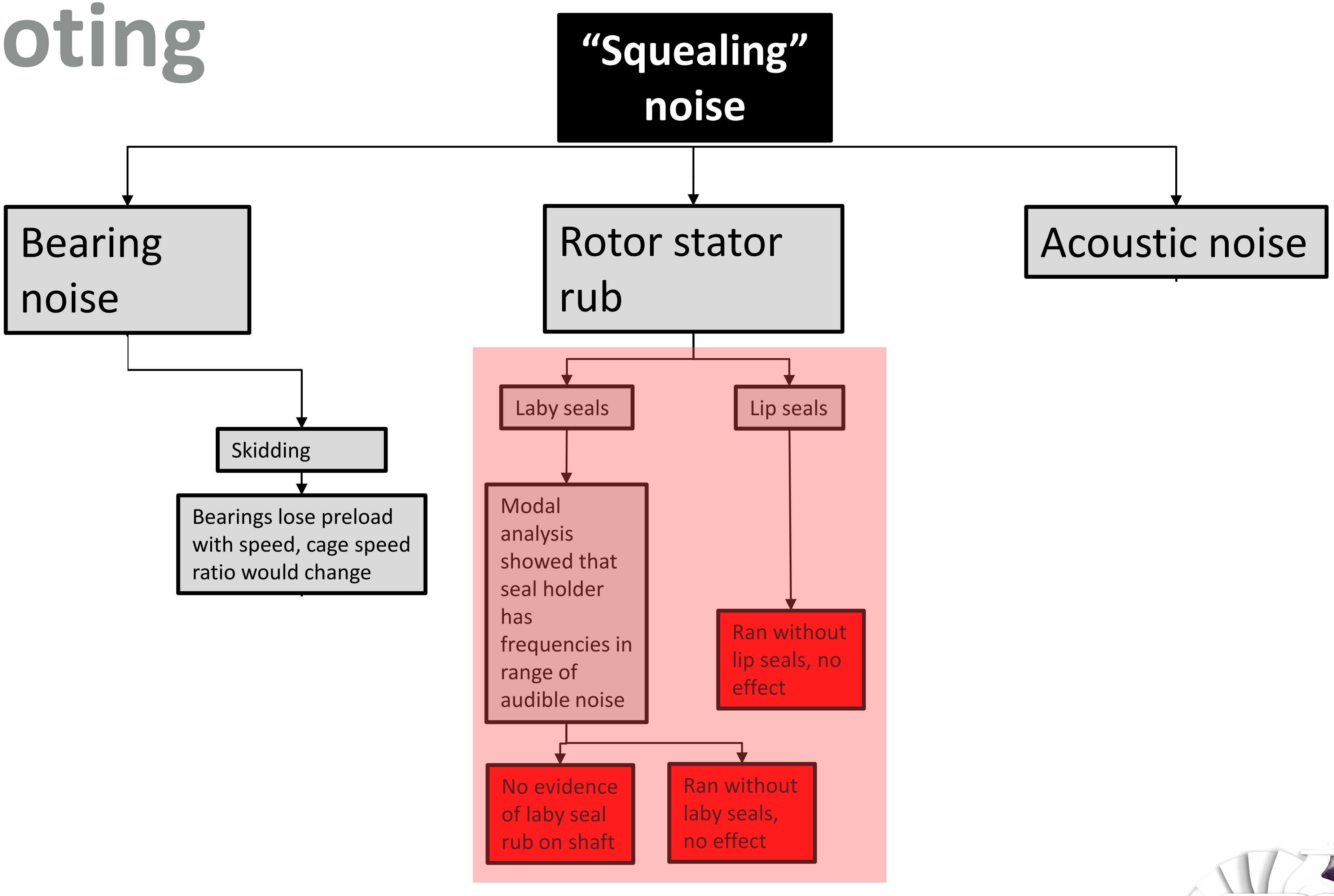
Ranges of predicted natural frequencies



Troubleshooting



Troubleshooting



Troubleshooting

“Squealing” noise

Bearing noise

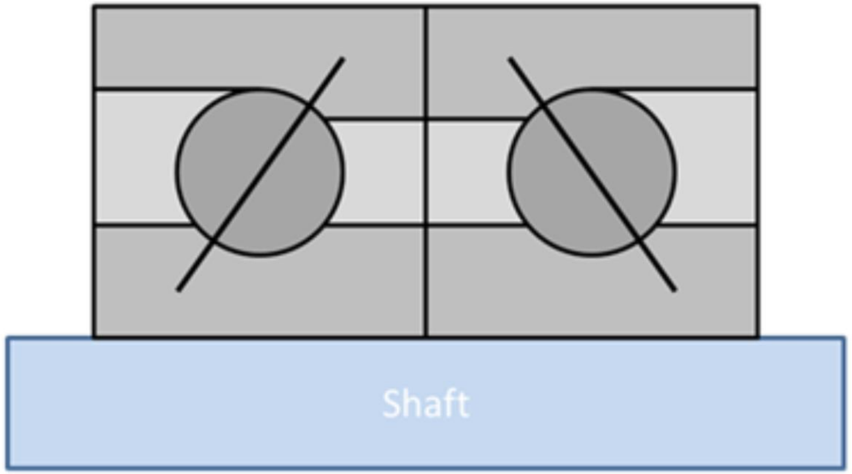
Skidding

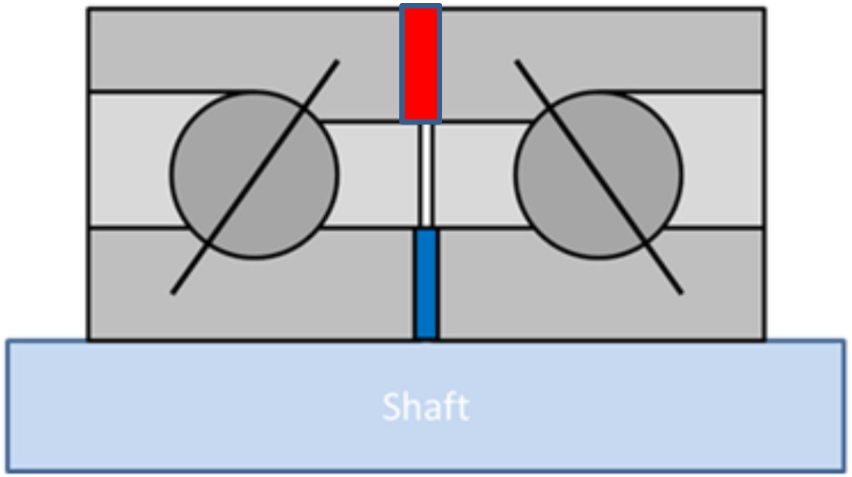
Bearings lose preload with speed, cage speed ratio would change

Increased preload with shim, no effect

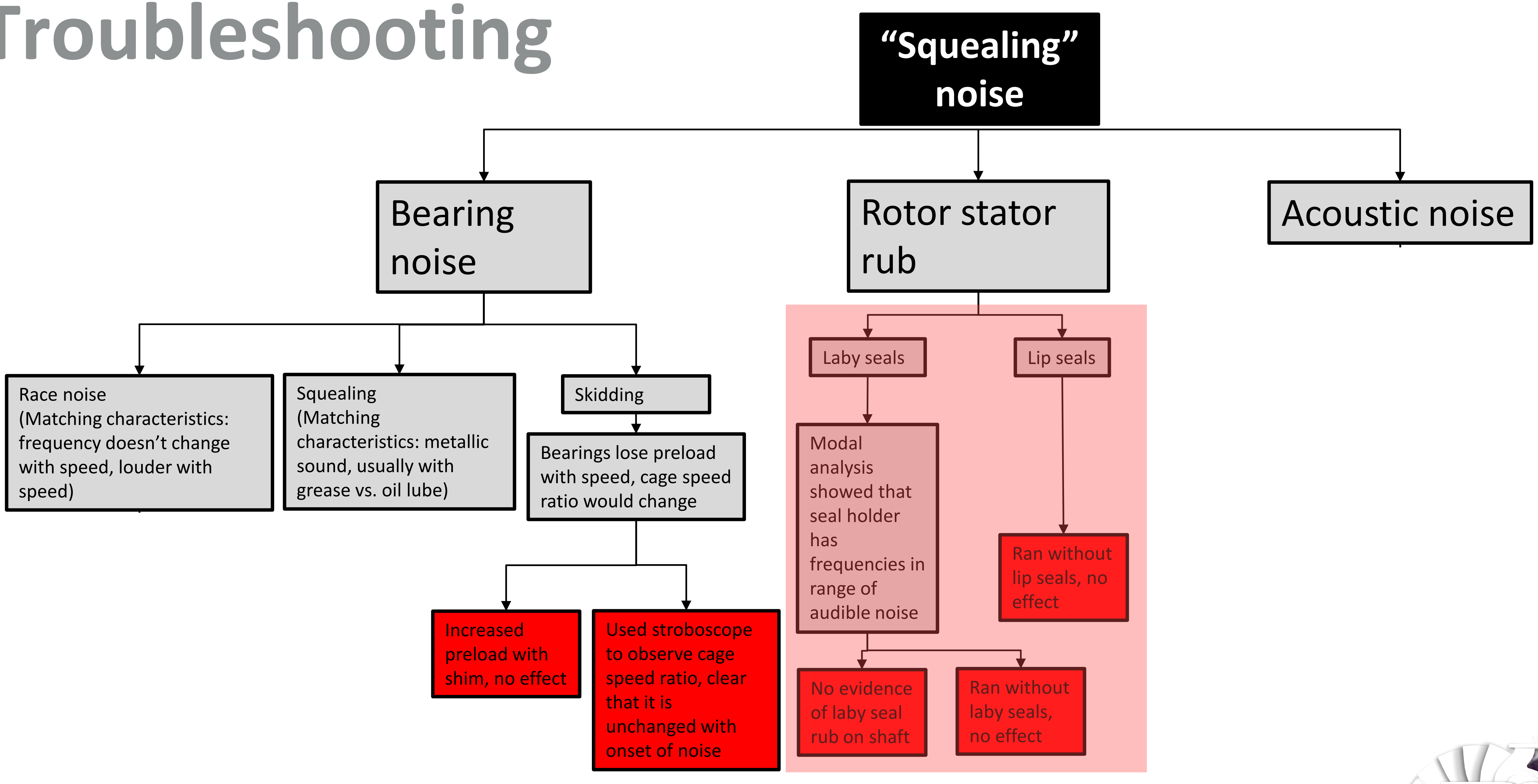
Used stroboscope to observe cage speed ratio, clear that it is unchanged with onset of noise

ustic noise





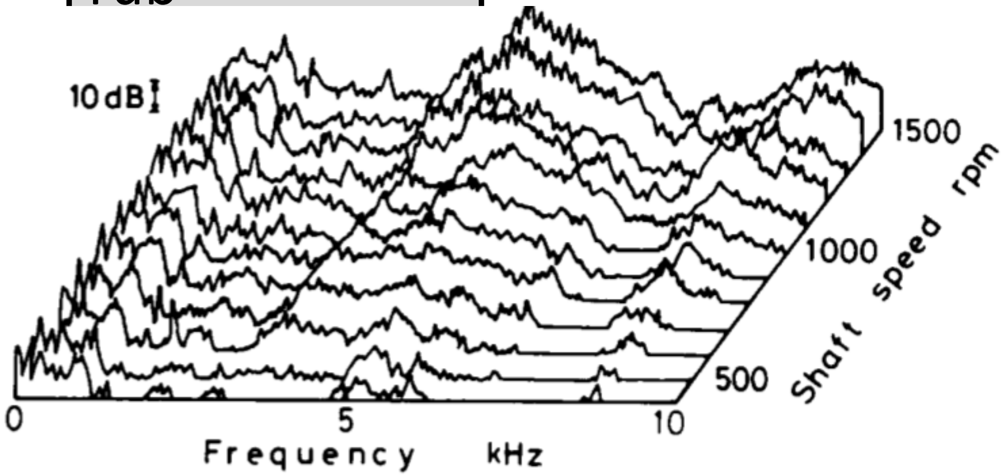
Troubleshooting



Troubleshooting

"Squealing" noise

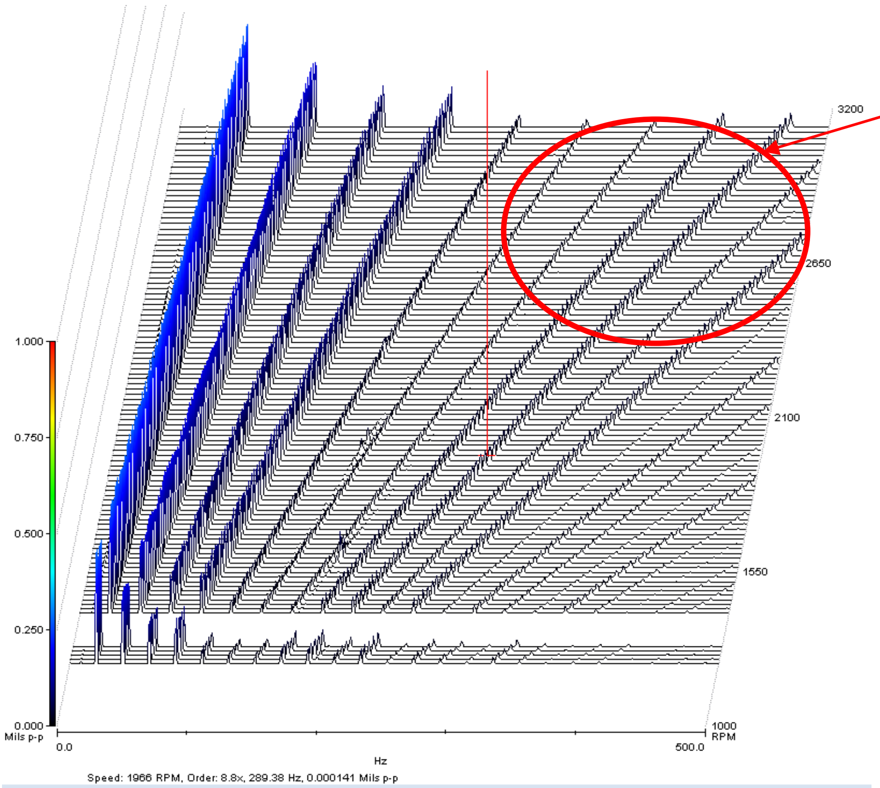
- Bearing noise
  - Race noise (Matching characteristics: frequency doesn't change with speed, louder with speed)
    - Lubrication
      - Worse with low viscosity
    - Geometry
      - Poor housing fit, non-circularity can contribute
  - Squealing (Matching characteristics: metallic sound, usually with grease vs. oil lube)
  - Skidding
    - Bearings lose preload with speed, cage speed ratio would change
      - Increased preload with shim, no effect
      - Used stroboscope to observe cage speed ratio, clear that it is unchanged with onset of noise
- Rotor stator rub
  - range of
  - rub on shaft
  - no effect
- Acoustic noise



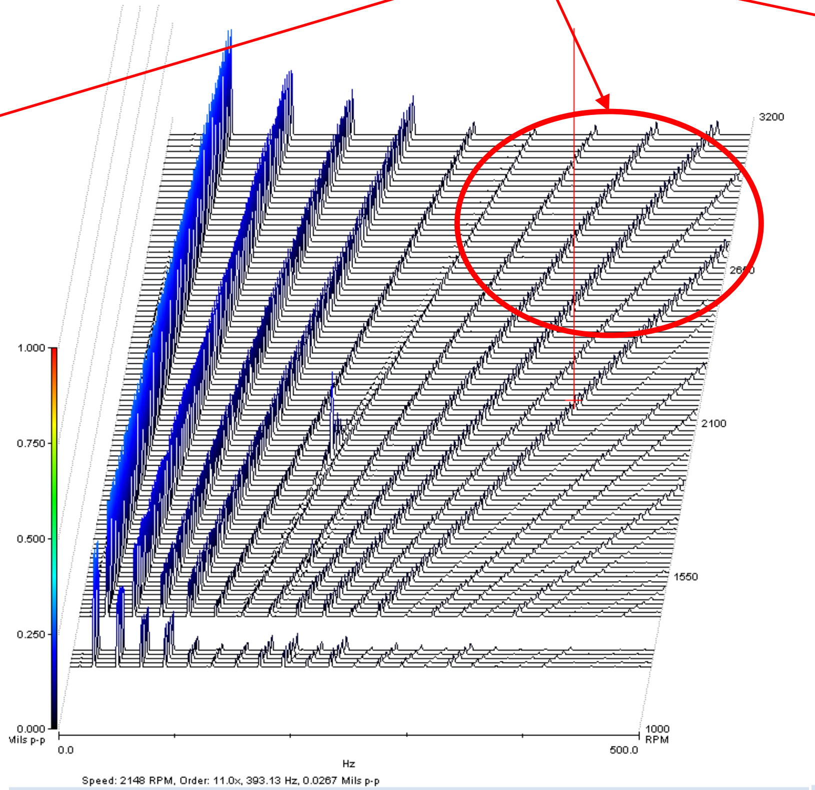
Noise Amplitude for "Squealing bearing" where spin speed excited natural frequency of a single roller. [1]

Vibration Data Doesn't Show Bearing Issues

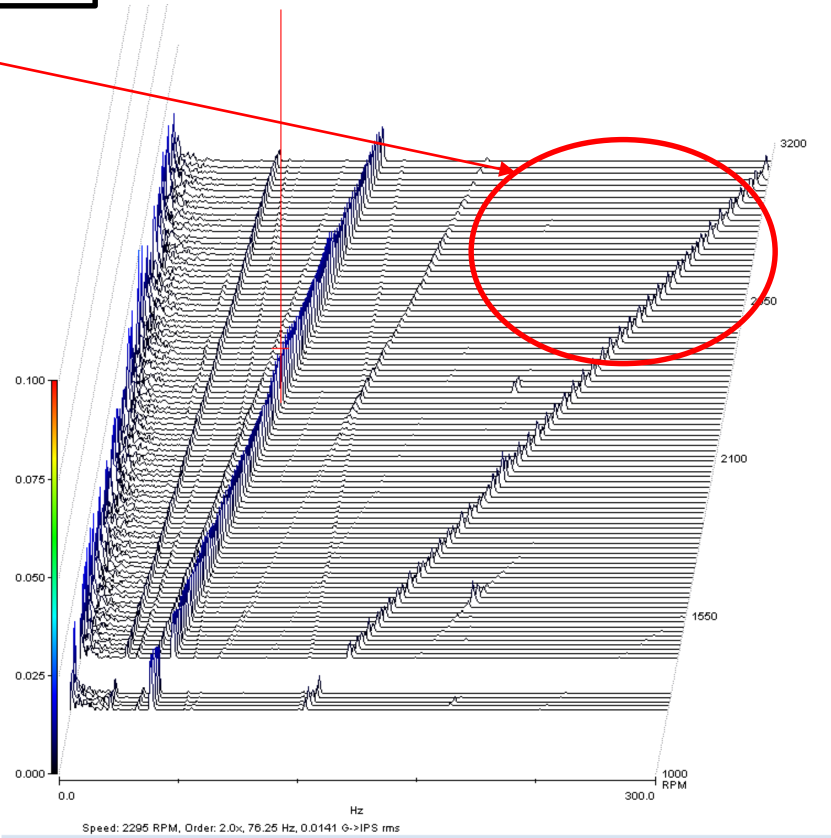
No vibration occurs in frequency range where sound is occurring



Horizontal Displacement

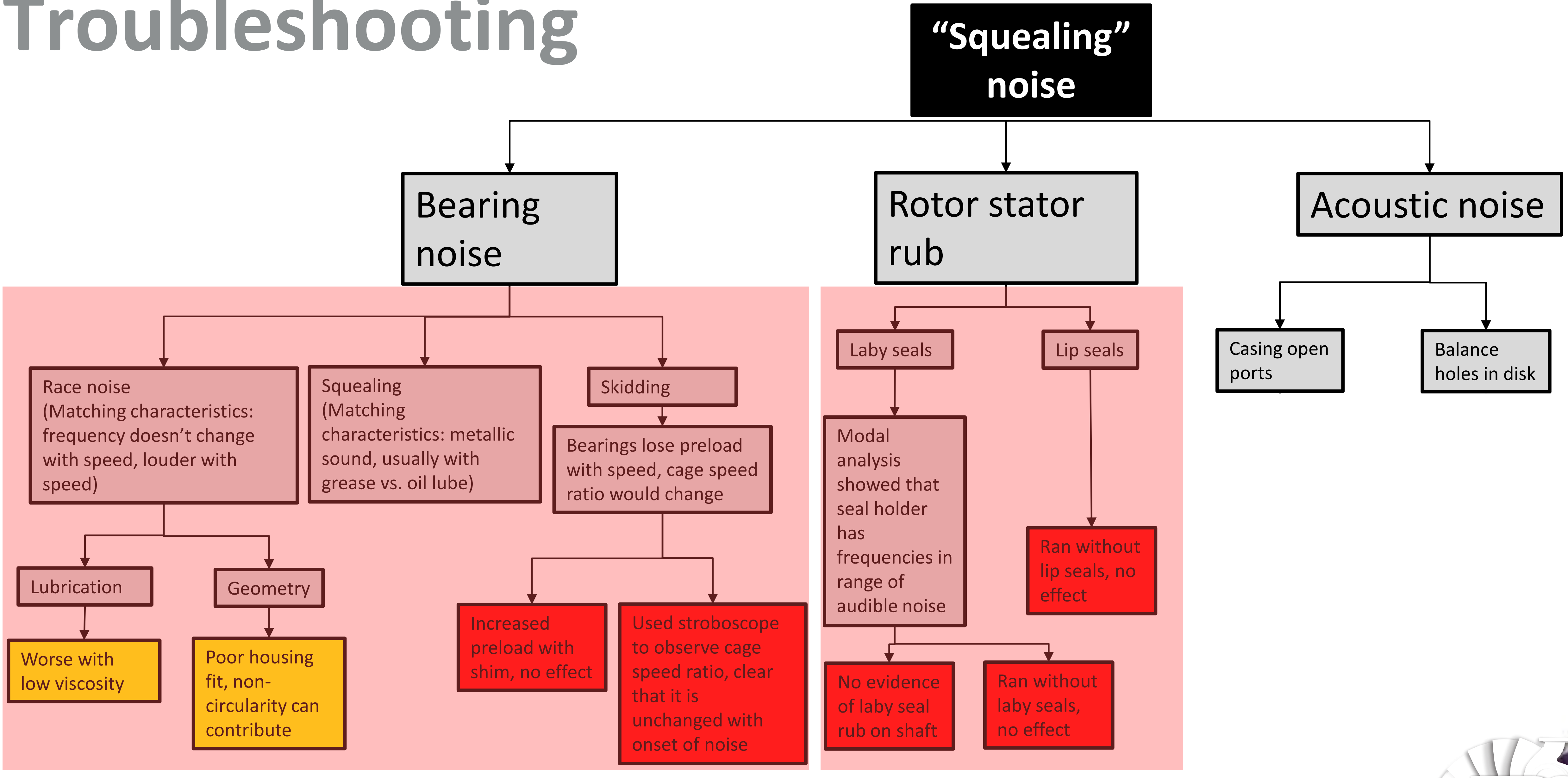


Vertical Displacement

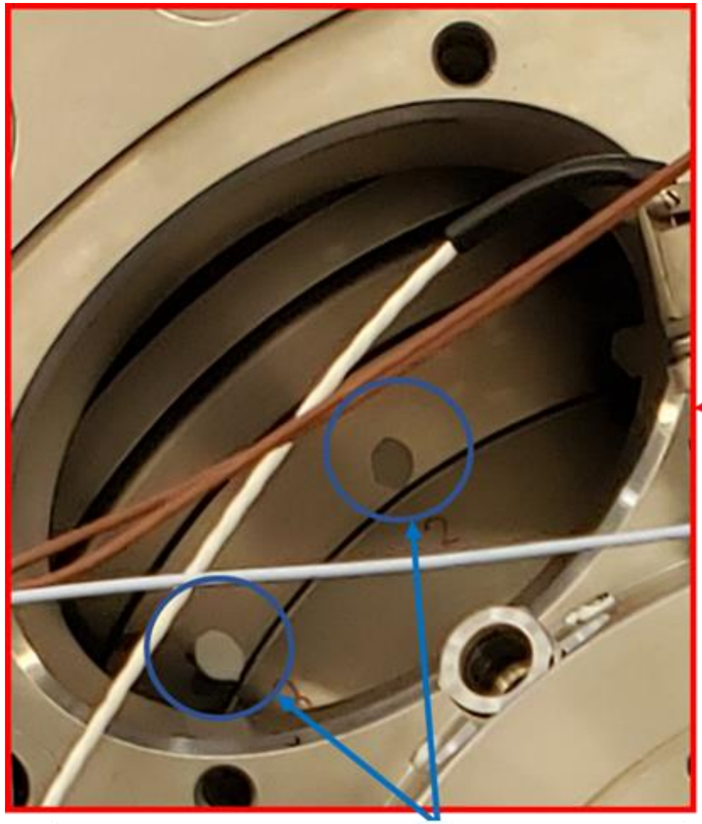


Housing Acceleration

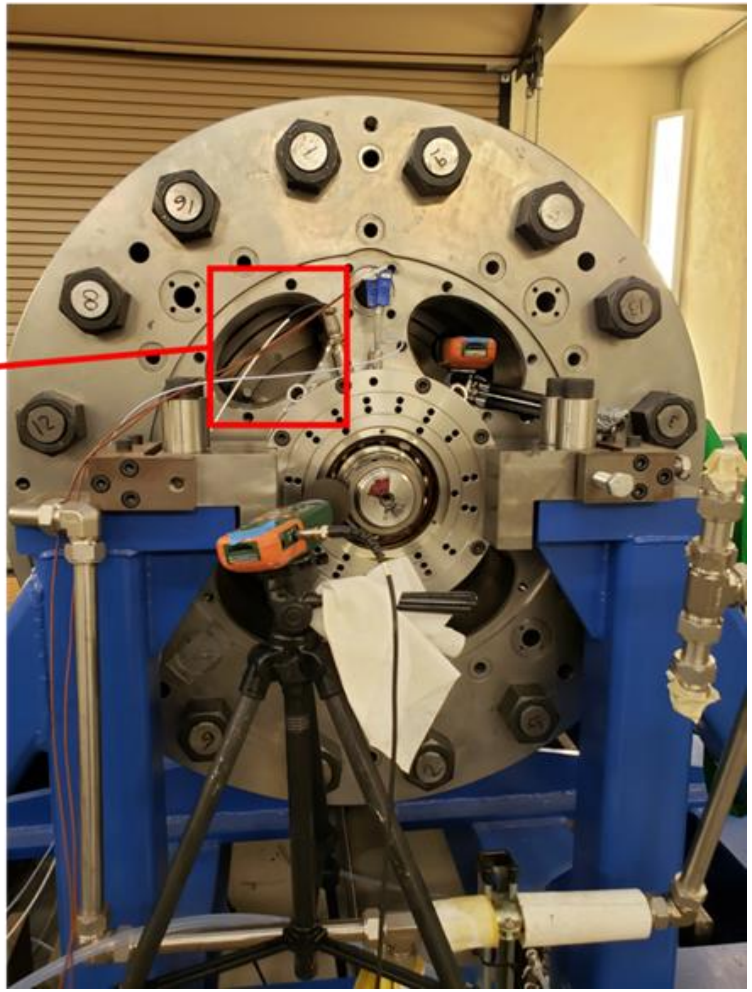
Troubleshooting



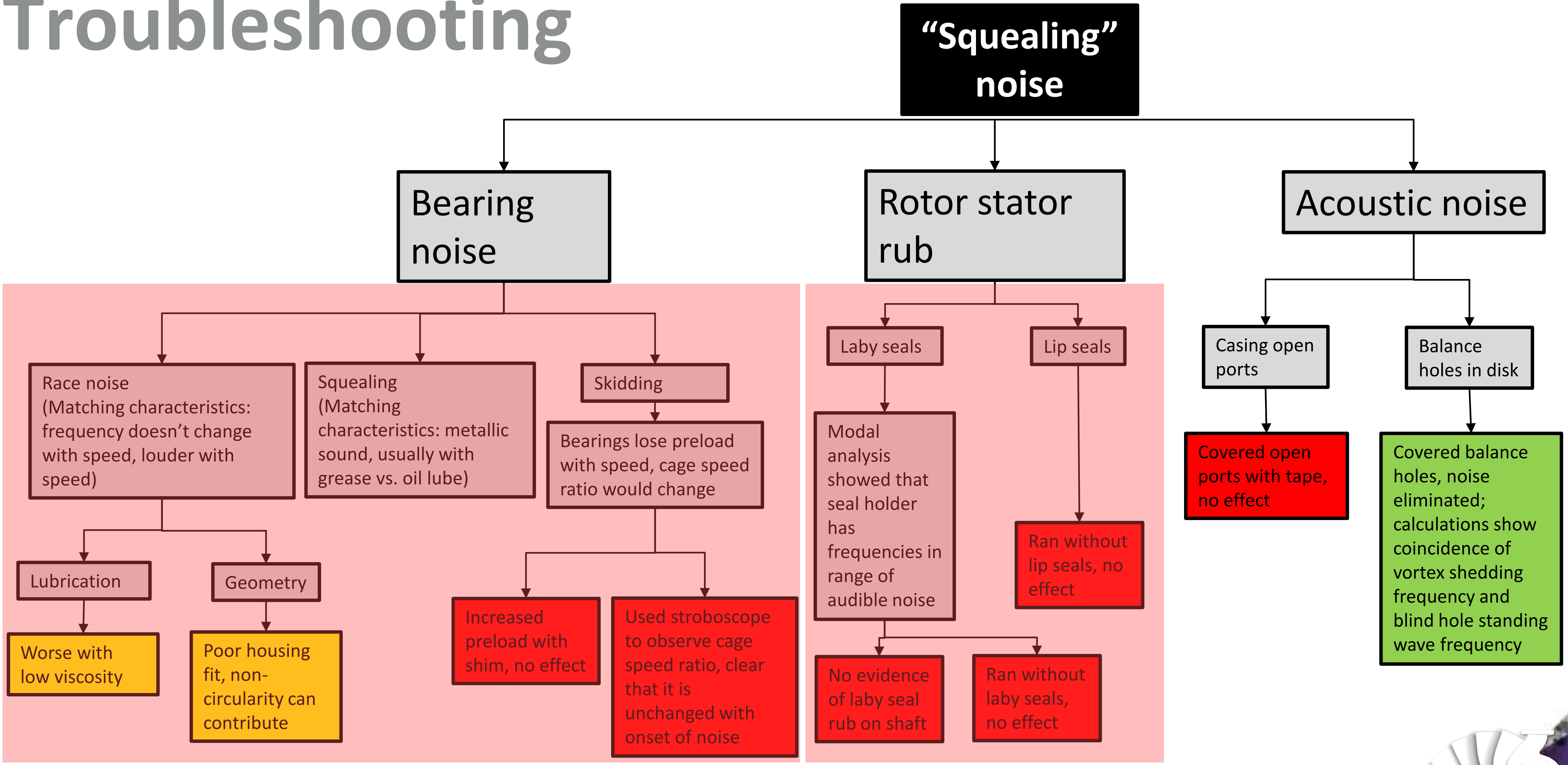
Covering Balancing Holes Leads to Remedy of Noise Problem



Threaded Balance Holes



Troubleshooting



Flow Across Cavities Creates Periodic Vortex-Shedding

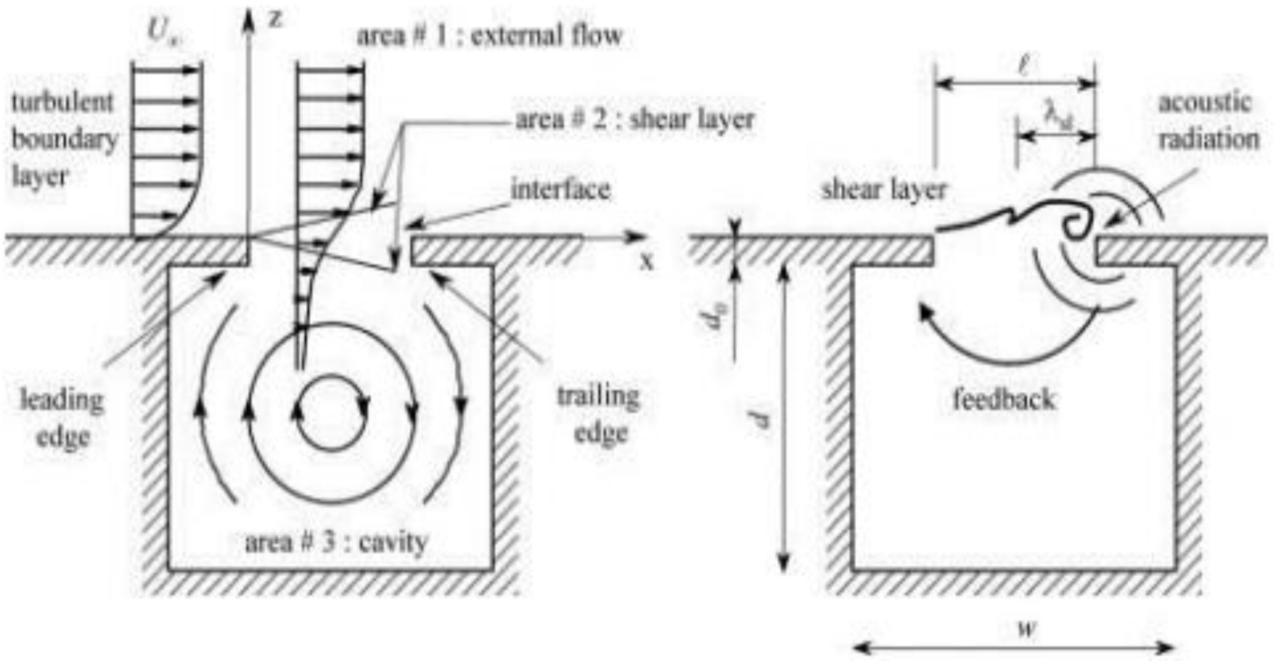


Illustration of Flow Acoustic Resonance Due to Vortex-Shedding of the Free Shear Layer of the Flow Over an Open Cavity [2]

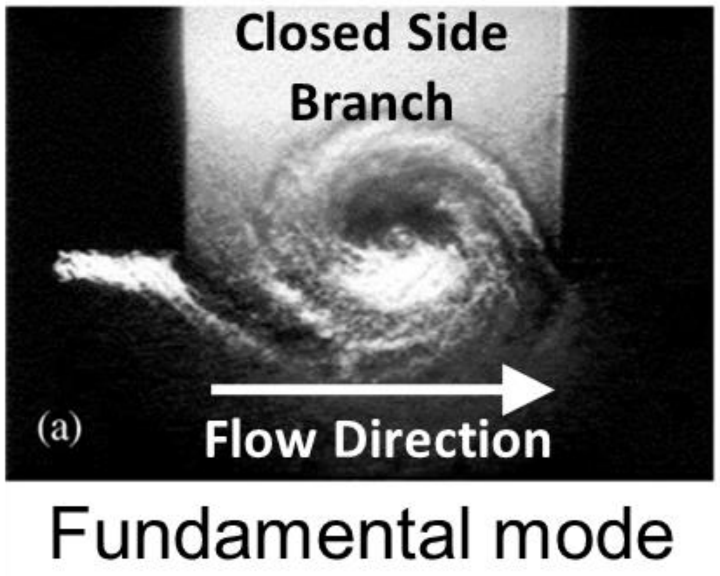
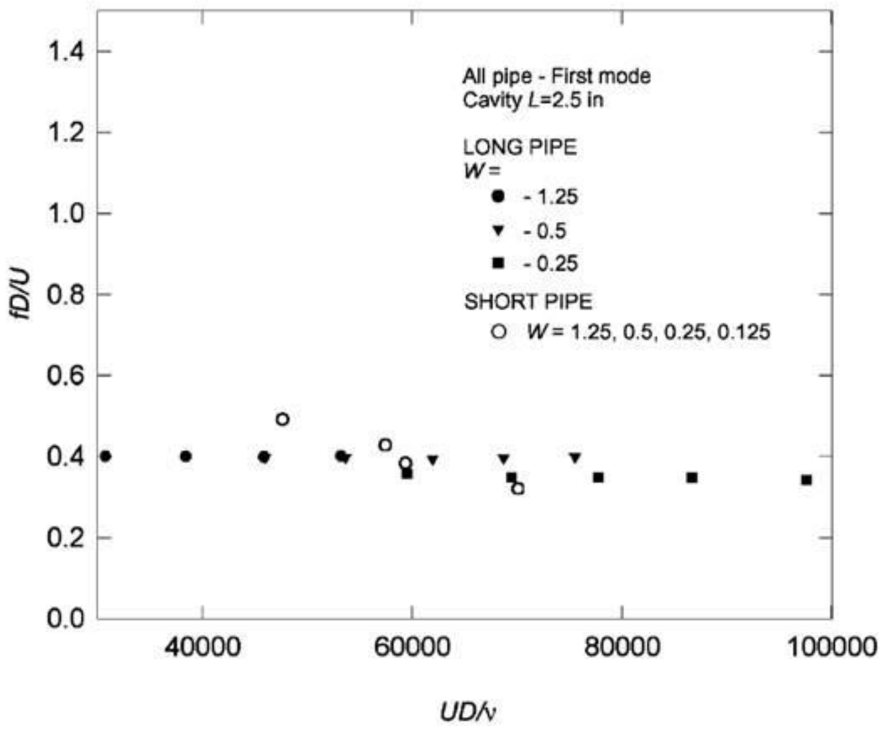


Image of Vortex in Water [3]

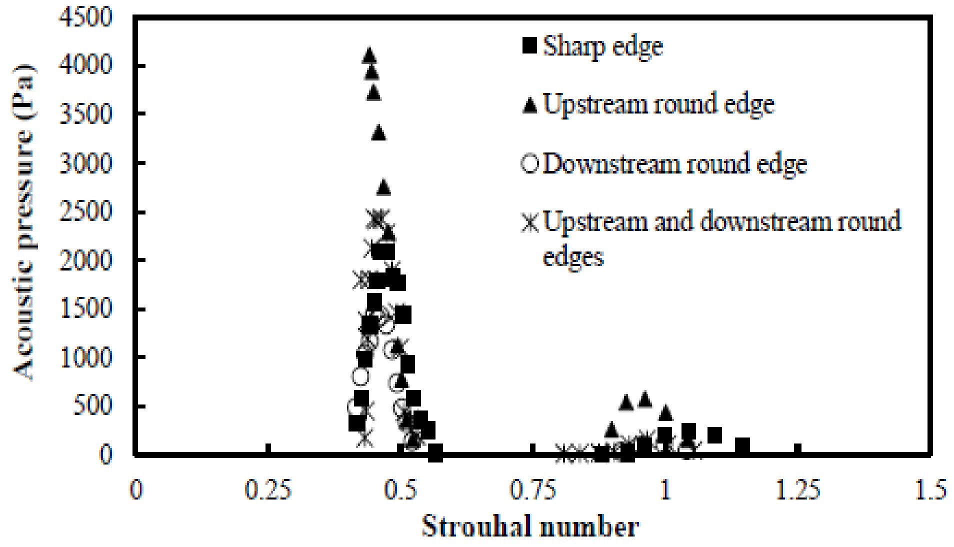
Strouhal Number Evaluation

$$St = \frac{fL}{U'}$$

Good agreement was found in literature that a St=0.4 was appropriate for this geometry



St Number Associated with Flow Over a Cavity with Varying Diameters Over Range of Re Numbers [4]



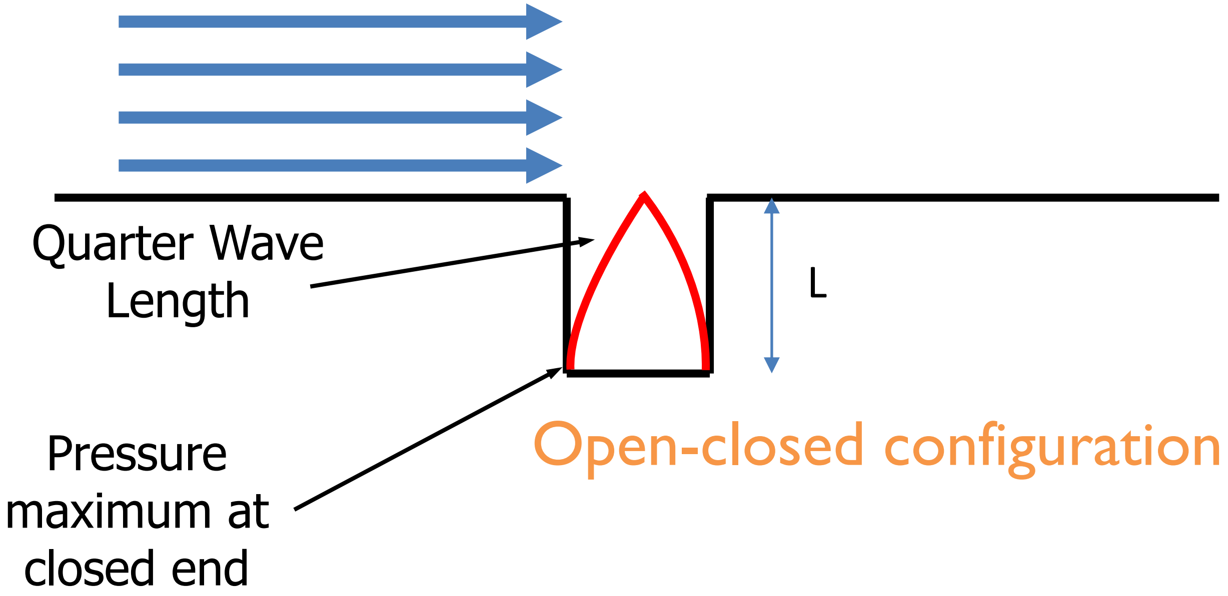
Strouhal Numbers Associated with Excitation of a Shallow Cavity as a Function of Different Edge Geometries [5]

Acoustic Natural Frequency of Cavity

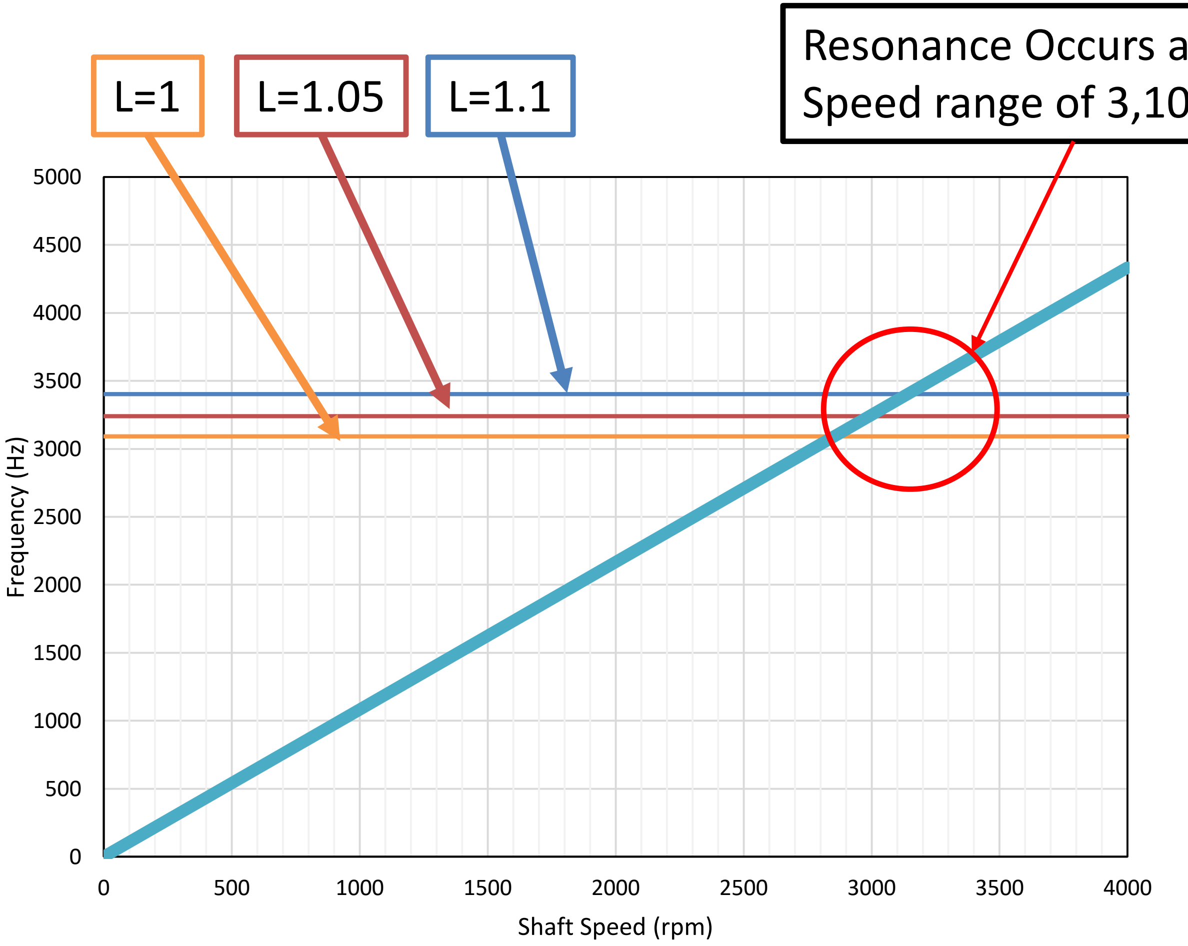
$$f = (2n-1)\frac{c}{4L}$$

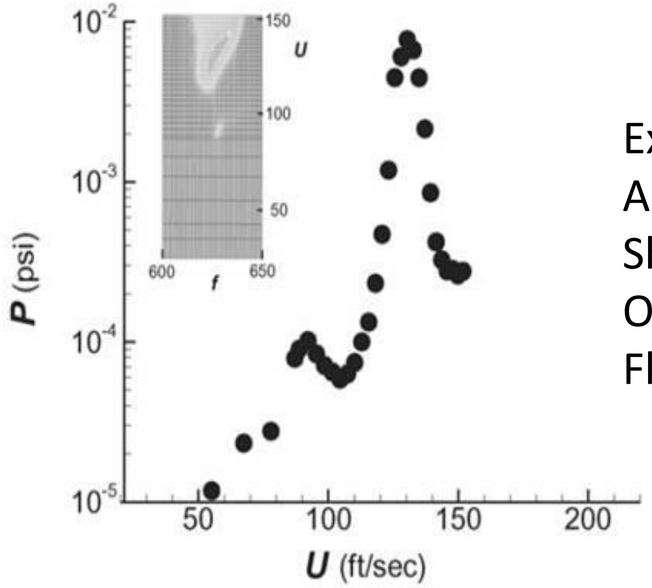
f = Response frequency
c = Speed of sound (13,400 in/s)
L = Acoustic length of pipe span
n = **1**,2,3,…(1)

When cavity depth (L) varied between 0.95-1.05-inches - Acoustic natural frequency of the cavity predicted to be between **3100-3400 Hz**.



Resonance Occurs when Excitation Locks onto Acoustic Natural Frequency

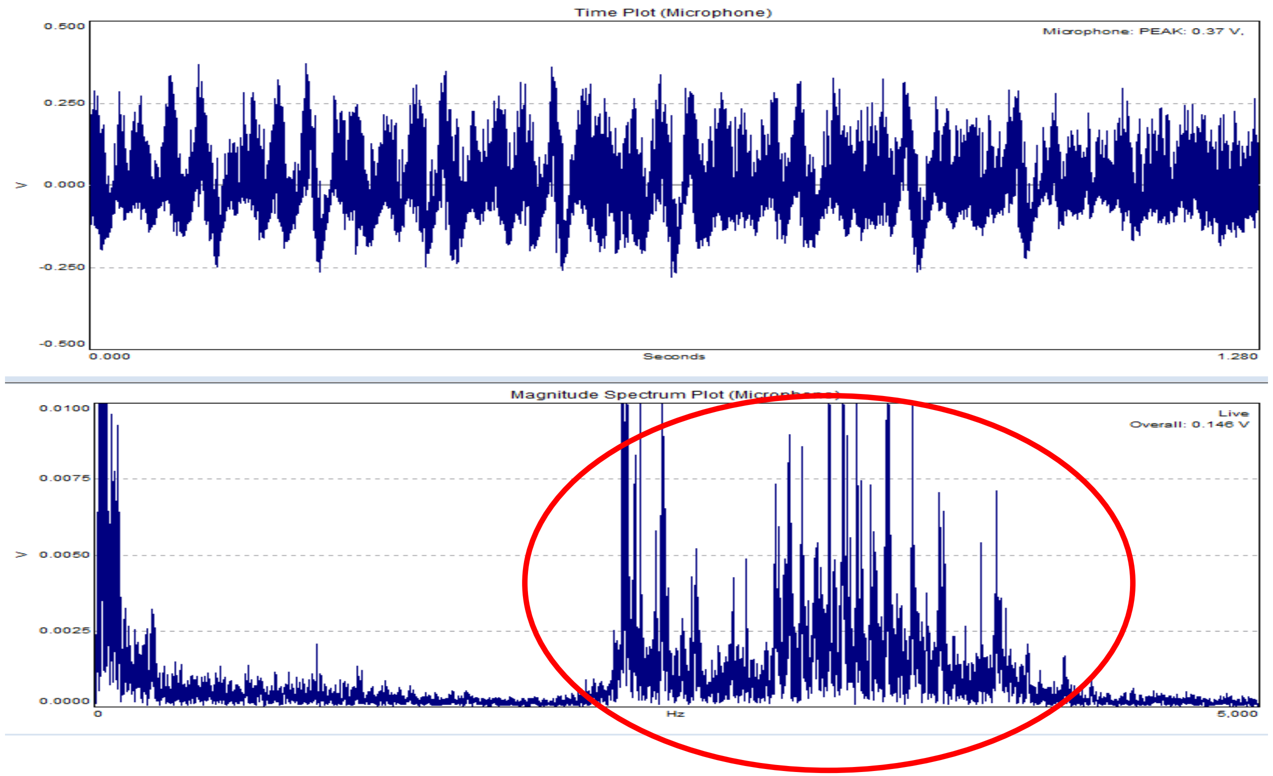




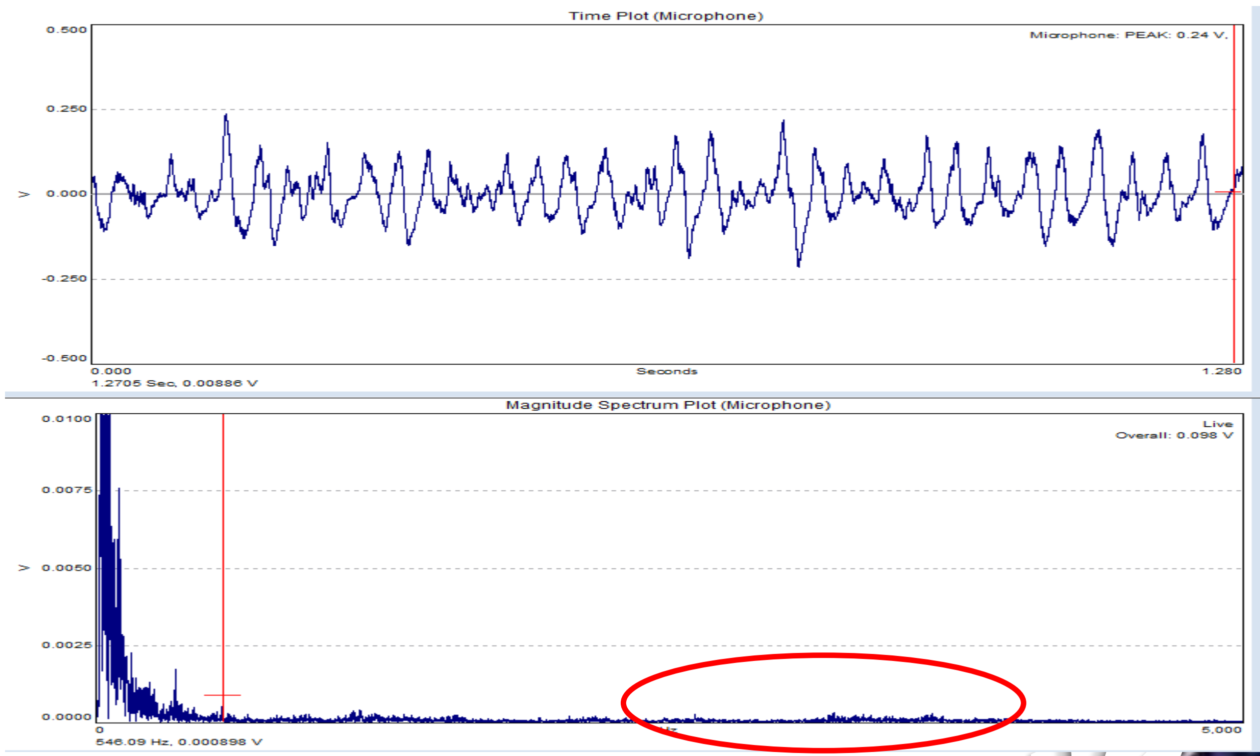
Example of Pressure Peak Associated with Vortex-Shedding Resonance when Operating Over a Range of Flow Velocities [5]

Microphone Data Shows Nearly Complete Noise Elimination

WithOUT Taped Balance Holes



With Taped Balance Holes



Solutions and Conclusions

Possible Solutions Considered:

- Increase the balance hole diameter
  - Most appropriate at the design phase of project
- Fill balance holes with equally weighted set-screws to change fundamental hole depth—most likely implemented solution

Conclusions:

- Noise is a universal problem
- Balance holes exist on most machinery - troubleshooting methodology with calculations that match sound frequency
- To the authors knowledge, no evidence of this occurring on any other machine reported in the literature
- Closed machinery vs open test rig
  - This noise could be occurring in a lot of closed machinery
- Do the easy things 1st
- Trust vibration data

References

[1] Motionindustries.com/knowledgelinks/bearings/strange-bearing-noise-inside-your-electric-motor/

[2] Mikio NAKAI, Masayuki YOKOI, Masaru INOUE, Keizo KAWAKAMI, Squealing of Cylindrical Roller Bearing, JSME international journal. Ser. 3, Vibration, control engineering, engineering for industry, 1991, 34 2008/02/18, Print ISSN 0914-8825

[3] Ver., I. and Beranek, L., *Noise and Vibration Control Engineering*, Second Edition, John Wiley & Sons, Inc., 2006.

[4] Mohamy, A. and Hassan, M., 2016, “Effect of Impingement Edge Geometry on the Acoustic Resonance Excitation and Strouhal Numbers in a Ducted Shallow Cavity,” Wind and Structures, Vol. 23(2), 91-107.

[5] Rossiter, J.E., 1964, “Wind-Tunnel Experiments on the Flow Over Rectangular Cavities at Subsonic and Transonic Speeds, *Aero. Res. Council* R&M, No. 3438.

[6] S. Dequand, S.J. Hulshoff, A. Hirschberg, “Self-sustained oscillations in a closed side branch system”, Journal of Sound and Vibration, Volume 265, Issue 2, 2003, Pages 359-386.

[7] Rockwell, D., Lin, J., Oshkai, P., Reiss, M., Pollack, M., 2003, “Shallow Cavity Flow Tone Experiments: Onset of Locked-On States,” Journal of Fluids and Structures 17: 381-414.