



Flexware

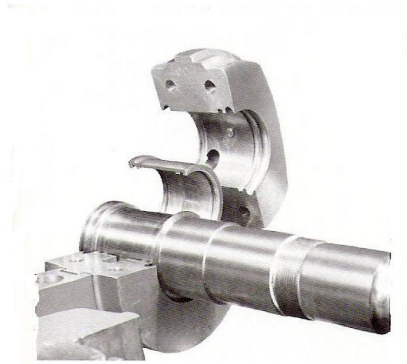
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Enhancing Rotor Stability

Whether instability of a rotor system is discovered by operation or by analysis, the best tool for correcting the situation is a rotor stability analysis program. Possible corrective measures can then be analyzed and the best possible solution can be selected. Some methods of improving stability are discussed in this article. As with any good design, it is always best to add some redundancy to assure stability as the equipment ages and the equipment degrades with time or otherwise as operating conditions change.

Root Cause

When solving any problem, it is best to first understand the root cause of the issue and specifically in this situation the underlying mechanisms of rotor instability.



The classic case is a liner bearing where the oil film supporting the rotating element builds oil pressure under the rotor lifting it in the bearing. As speed is increased, the oil pressure under the rotor builds and the shaft is lifted off the bearing surface. Continuing speed increase will lift the shaft higher and eventually go unstable.

The Instability Mechanism

In a hydrodynamic bearing, the rotating shaft rides on a wedge-shaped oil film and settles slightly off-center, so the shaft center orbits within the clearance as it spins. A portion of the oil film rotates with the shaft and acts like a fluid wedge that pushes the shaft sideways. This creates a **cross-coupled stiffness effect**: a radial displacement of the shaft produces a tangential force perpendicular to it, acting in the direction of rotation.

That tangential force is destabilizing because it continually pumps energy into the shaft's forward orbital motion rather than opposing it. Two conditions determine stability:

1. **Oil whirl** ($\sim 0.42\text{--}0.48 \times$ running speed): Below the first critical speed, the shaft orbits at slightly less than half of running speed. This sub-synchronous whirling happens because the average oil film velocity is just under half the journal surface speed, so the shaft gets carried along at roughly that rate. It's generally a mild, forced-vibration phenomenon.
2. **Oil whip**: Once running speed reaches roughly twice the first natural (critical) frequency, the oil whirl frequency coincides with that resonance and locks onto it. The shaft then whips violently at its natural frequency regardless of further speed increases — a self-excited, severe instability that can quickly destroy bearing surfaces through metal-to-metal contact and even cause damage to the compressor.

Key Factors

- **Light load / high speed** raises the eccentricity ratio problem: a lightly loaded journal floats near the bearing center where cross-coupling forces dominate
- **High Gas Density** increases the cross coupling forces in the labyrinth seals especially the balance piston or center seal.

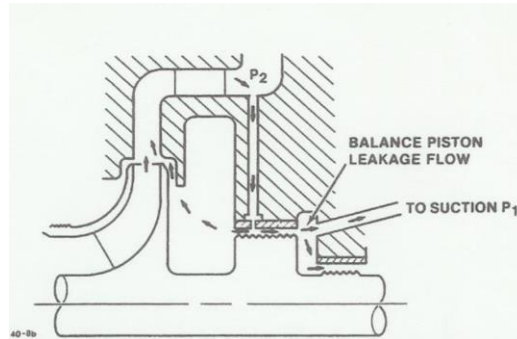
Common Fixes

Designers suppress the instability with tilting-pad bearings (the pads cannot support a circumferential oil wedge, eliminating cross-coupled stiffness), however, this is not always enough. If you already have tilt pad bearings, a modification to the clearance or pad curvature may do the trick.

While the tilt pad bearings cannot support the circumferential oil wedge, and thus cause instability, other elements in the compressor can, like all the internal labyrinth seals. The labyrinth seals can act like journal bearings and have a “gas” wedge that can cause instability similar to an oil liner bearing.

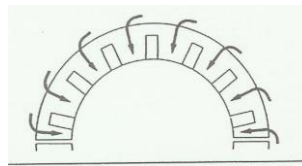
Since the instability is brought on by high speed, one way to enhance the stability of the rotor system is to reduce the circumferential velocity of the gas within the labyrinth seal.

The circumferential velocity in the labyrinth seal is a function of the rotating element as well as the circumferential velocity of the gas upstream of the seal, before entering the labyrinth. So, by adding a buffer to the labyrinth seal, the nominal circumferential velocity within the seal is reduced.

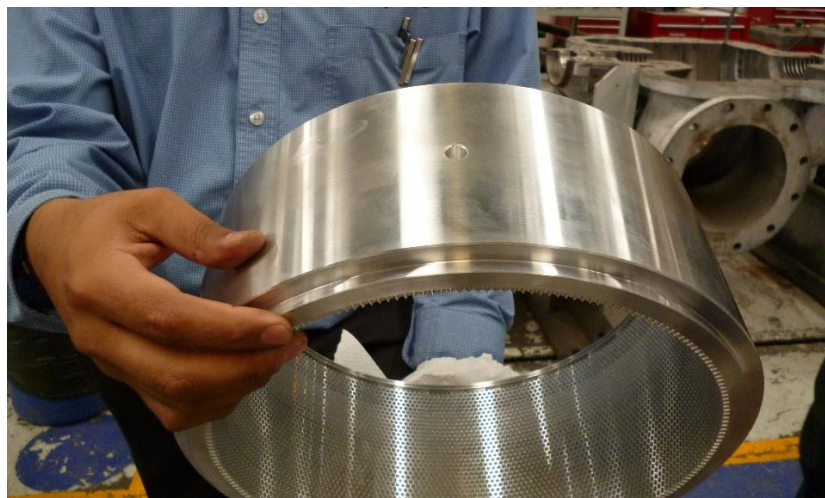


Buffered Balance Piston Seal

However, this may not always be practical to do, so another method is to add a dewhirl mechanism to the labyrinth seals in a compressor.



Dewhirl Mechanism for a Labyrinth Seal



Hole Pattern Seal

A hole pattern seal will not only limit the circumferential velocity of the gas in the seal, but also provide additional damping. The labyrinth teeth on the shaft drum must be removed so the seal can be adjacent to a smooth surface. Each hole in the hole pattern seal acts like a small shock absorber to enhance the stability of the bearing & seal rotor system.

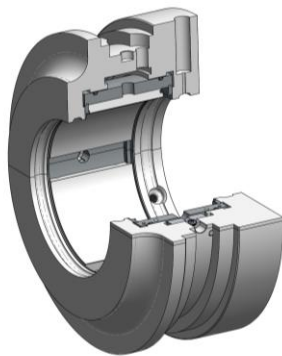
First Critical Speed

Since the instability, Oil Whip, locks on to the first critical speed, various modifications to increase the first critical speed like reducing the bearing centerline distance, increasing the shaft diameter or other measures like reducing coupling weight can help make a big difference. While this may at first seem like a monumental task, sometimes only very small changes like redesigning the journal bearing to reduce the bearing centerline distance by a small fraction can be all that is needed to turn an unstable compressor into a smooth running stable machine.

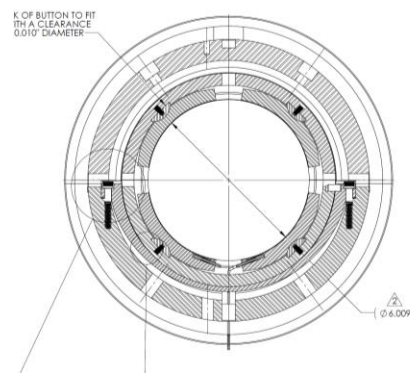
Ultimate Solution

The ultimate solution is a damper bearing where the tilt pad bearing is spring supported and the bearing is enclosed in an oil film to provide the needed additional damping to stabilize the system. The system is designed with a spring support to allow for some radial movement and an oil film to provide the system damping.

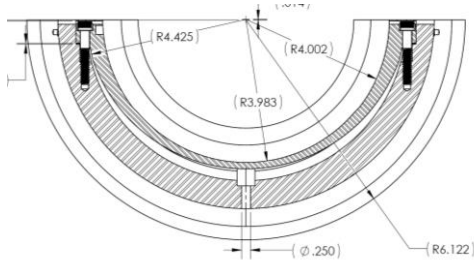
To visualize this, consider an ancient covered wagon with the axels mounted directly to the wagon frame with metal banded wooden spoked wheels. Now replace this with rubber tires and support them with springs and shock absorbers. This is the equivalent of what you do to your compressor when you modify your compressor with damper bearings.



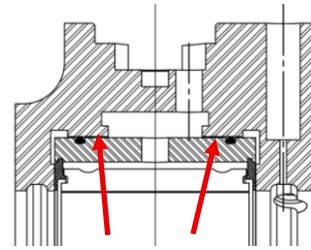
3D view of damper bearing mounted in bearing housing



Cross sectional view of damper bearing assembly mounted in the bearing housing.



Cross sectional view showing the arc spring bearing support.



Cross section view showing the oil film between the bearing cage ring and the bearing housing.

Summary

In summary enhance the stability by:

1. Convert to tilt pad bearings
2. Modify the bearing clearance and pad curvature
3. Reduce the bearing span
4. Add a buffer or swirl breaks to the labyrinth seals
5. Convert to honeycomb seals
6. Convert the labyrinth seals to hole pattern seals
7. Convert the bearings to damper bearings

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