Imbalance Response of a Rotor Supported on Gas Foil Bearings

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Introduction

Gas Foil Bearings (GFBs) are a proven alternative to rolling element bearings to support rotating machinery operating at high speeds. Unlike rolling element bearings, GFBs eliminate the need for lubrication, have no DN limit, and are capable of withstanding high temperature operation. Drawbacks include limited load capacity, minimal damping, and until recently, absence of reliable prediction methods.

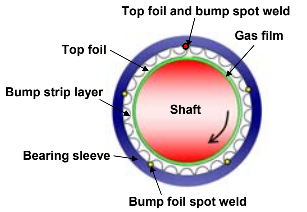


Fig 1. Schematic view of test gas foil bearings

The research objective is to measure and analyze the effect of imbalance masses on the rotordynamic response of a test rotor supported by GFBs. All data is collected during rotor coast down tests from 25 krpm. The bearings are supplied with pressurized air at 34.5 kPa (5 psi).

Test Apparatus

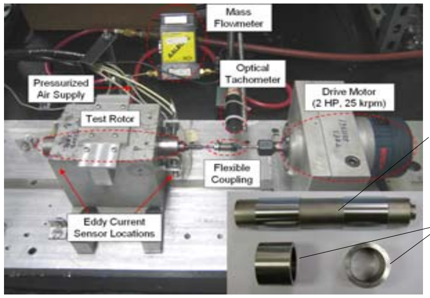
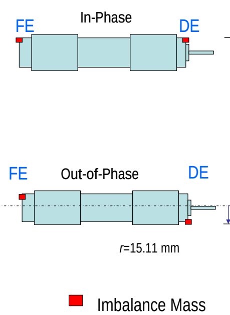


Fig 2. Photograph of GFB test rig. Inset shows rotor and test bearings

2.2 lb hollow test rotor made of AISI 4140 Steel. Chrome coating on journal surface to reduce wear.

Test foil bearings with spray-on Emralon® 333 coating to reduce friction during start up/shut down.

Imbalances: location and magnitudes



	Imbalance mass (m)		Imbalance displacement (u)	
	Drive End	Free End	Drive End	Free End
Test 1	60 mg (0°)	60 mg (0°)	1.4 µm	2.5 µm
Test 2	110 mg (0°)	110 mg (0°)	2.5 µm	4.6 µm
Test 3	160 mg (0°)	160 mg (0°)	3.7 µm	6.7 µm
Test 4	188 mg (0°)	188 mg (0°)	4.3 µm	7.9 µm
Test 5	240 mg (0°)	240 mg (0°)	5.5 µm	10.1 µm
Test 6	282 mg (0°)	282 mg (0°)	6.5 µm	11.8 µm
Test 7	334 mg (0°)	334 mg (0°)	7.7 µm	14.0 µm
Test 8	366 mg (0°)	366 mg (0°)	8.4 µm	15.3 µm
Test 9	400 mg (0°)	400 mg (0°)	9.2 µm	16.8 µm

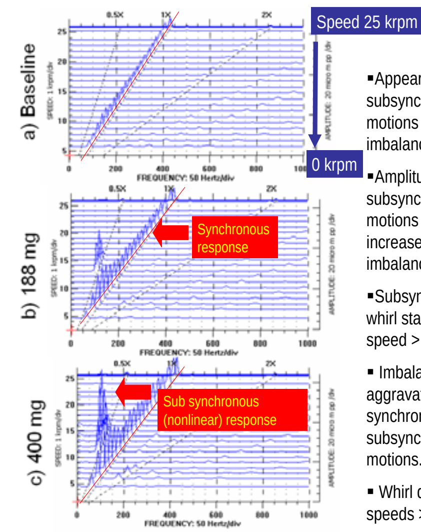
$$u_i = \frac{m \times r}{M_i}, \; _{i=DE,FE}$$

M_{DE} & M_{FE} are fractions of rotor weight/*g* acting on each bearin, equal to 0.66 kg and 0.36 kg, respectively

All masses calibrated within ± 2 mg

Test Results

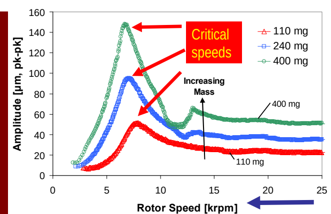
Cascade Analysis



- Appearance of subsynchronous motions with 188 mg imbalance mass
- Amplitude of subsynchronous motions (0.5X) increases with imbalance mass
- Subsynchronous whirl starts at shaft speed > critical speed.
- Imbalance aggravates both synchronous and subsynchronous motions.
- Whirl disappears at speeds > ~18 krpm

Fig 3. Cascades of rotor motions for (a) baseline condition, (b) 188 mg imbalance, and (c) 400 mg imbalance. Rotor free end, vertical plane. Horizontal axis: frequency, Vertical axis: rotor speed

Synchronous Response



- Increase in synchronous amplitude for increasing imbalance.
- Imbalance reduces system critical speed.
- Sharper peak for large imbalance evidences a decrease in bearing damping

Fig 4. Amplitude (pk-pk) of synchronous (1X) rotor response for increasing imbalances. Rotor free end, vertical plane. Baseline subtracted

While crossing critical speed, faster drop in phase angle denotes less damping (as imbalance increases)

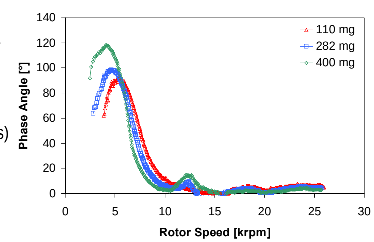
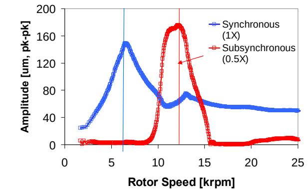


Fig 5. Phase angle of synchronous (1X) rotor response for increasing imbalances. Rotor free end, vertical plane. Baseline subtracted

Test Results Cont.

Subsynchronous Response



A high imbalance induces, for shaft speeds above the critical speed, subsynchronous motions with amplitudes surpassing the amplitude of synchronous response. Whirl disappears at speeds > 15 krpm.

Fig 6. Amplitudes (pk-pk) of synchronous & subsynchronous whirl motions 400 mg imbalance. Rotor free end, vertical plane. Baseline subtracted

Ratio of subsynchronous whirl frequency to shaft speed (WFR) is nearly 0.50. Whirl with largest amplitude at shaft speed = ~ 2 x critical speed

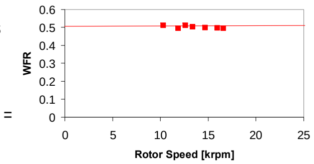
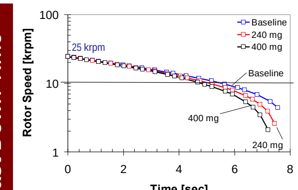


Fig 7. Subsynchronous frequency whirl ratio versus rotor speed. Response at rotor free end, vertical plane.

Coast Down Time



Rotor coast down time to rest decreases with an increasing imbalance mass. Earlier rotor touchdown with rubbing (dry friction) of rotor on its bearings.

Fig 8. Rotor speed during coast down versus time for increasing imbalance masses

Future Work

- Identify fully nonlinearities in rotor responses at drive end and other motion plane (horizontal).
- Conduct tests to measure rotordynamic response due to out-of-phase imbalance conditions.
- Analyze motions in frequency domain to determine effect of imbalance on the onset, persistence and severity of subsynchronous whirl motions.
- Understand disappearance of whirl at highest shaft speeds is also of interest.

Acknowledgements

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