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BACKUP BEARING TESTING DEVICE FOR ACTIVE MAGNETIC BEARING

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Abstract: *Active magnetic bearings (AMBs) have various advantages over traditional bearings. Backup bearings are an essential part of AMB because they support the rotor while it is not operating and they prevent rotor-stator contact if failure occurs in the AMB. To investigate backup bearing behavior during rotor dropdown events a test rig without actual AMBs was built. Measurements with the test rig have strong correlation with the measurements of actual magnetic bearing system. This proves that the test rig with the pneumatic dropdown system is valid for backup bearing tests.*

Key words: dropdown test, overcritical rotor

1. INTRODUCTION

Active magnetic bearing (AMB) provides an attractive alternative to supporting rotating machinery because of its various advantages over traditional bearings. Main assets include a contact-free and thus frictionless shaft support and good energy efficiency, lubrication free use, high-speed operation, broad speed range and possibility to active vibration control [1].

An essential part of AMB is a mechanical backup bearing, which supports the rotor while the device is not in operation and prevents the electromagnet poles, electric motor stator and rotor from damaging in case of magnetic bearing system failure or bearing overload. Overload may be introduced by the rotor critical speed vibration. The principal design intent of the backup bearing is to ensure a secure deceleration of the rotor after a dropdown event due to failure of all the electrical backup systems. This deceleration may include passing through the natural frequencies of the system.

Conventional backup bearings are bushing-type or rolling element bearings with a fixed clearance between the rotor and the backup bearing. The clearance is usually half of the gap between the AMB and the rotor. Due to this clearance, the rotor, after the high rotating speed dropdown, is susceptible to fatal backward whirl induced by the friction between the rotor and the inner ring. The backward whirl can generate extremely large dynamic forces and thus lead to backup bearing, rotor and electric motor damage. [2]

Kärkkäinen et al. [3] simulated the effects of backup bearing misalignments on the rotors dynamics during the dropdown. Vertical and horizontal misalignments were studied separately and horizontal misalignment had more effect on the rotor behaviour.

Halminen et al. [4] demonstrated by simulation that misalignment of cageless backup bearings has an effect on the dropdown dynamics, and if the misalignment is large, the dropdown can lead to a significant damage being inflicted on the backup bearings and rotor.

Sun et al. [5] created a detailed backup bearing model including damping and spring dynamics. The simulation model included a flywheel attached to the shaft. The study showed that friction coefficients, damping factors and side loads have major impact to the performance of backup bearing and prevention of the whirl effect.

Wilkes et al. [6] showed that friction

between the journal and axial face of the backup bearing results in a force that pushes the rotor in the direction of rotation. This force results in synchronous whirl below a natural frequency of the rotor-stator system. The force is proportional to the friction between the axial face of the rotor and backup bearing. A simulation model was developed to simulate the nonlinear time-transient response of rotor on backup bearings.

Chengtao et al. [7] proposed a mechanism to achieve auto-elimination of the clearance in a backup bearing. An auto-eliminating clearance backup bearing device was shortened as ACABD. It used several tilting supports which were located around ball bearing. Particular mechanism was created to eliminate clearance between bearing inner ring and rotor. Damping effects were not involved in model and calculations. Kinematic and static analyses were carried out and ACABD was proved as suitable backup-bearing although more research is required.

In this study backup bearing test rig for high speed rotor dropdown event testing is introduced. The device itself contains no actual active magnetic bearing, because they are expensive. The test rig is easily configurable in terms of changing the backup bearings, using rotors of different natural frequencies, and varying the backup bearing locations. In addition initial backup bearing experiments are performed and the results are compared to previous researches and simulations for system validation.

2. METHODS

A test rig (Fig. 1) for backup bearing research was built. The test rig consists of a shaft, a belt drive system for rotating the rotor, a dropping device, backup bearings and their housings, and shaft position measuring instruments. The working principle is as follows:

1. The rotor is first accelerated to a desired speed with a belt drive system. The rotor is supported by the dropping device.
2. The belt drive is detached from the shaft and the dropping device releases the shaft.
3. Backup bearings catch the shaft after 250 µm drop.
4. The rotor center orbit is measured during the deceleration.

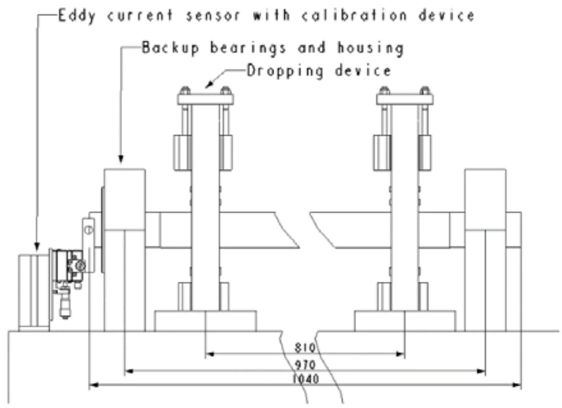

Fig. 1 Overview of the test rig build

2.1 Dropping Device

Magnetic bearings are imitated by two identical mechanical dropping devices (Fig.2). The shaft is accelerated by the belt drive system to a desired speed while supported by normal rolling element bearings which are assembled inside the housing. The housing is supported between two pneumatic cylinders. When the desired angular velocity for the shaft is achieved the housing and the shaft are released by pneumatic cylinders. A microcontroller is used to achieve fast and synchronized pneumatic valve opening. Pneumatic tube lengths were minimized to avoid unsynchronized operation of multiple pneumatic cylinders.

The synchronous operation of cylinders was verified by four accelerometers without the shaft assembled. The accelerometers were attached to each piston end and cylinders were actuated to down-stroke which means releasing the shaft. Measured accelerations were compared together and delay was added to cylinders that were faster.

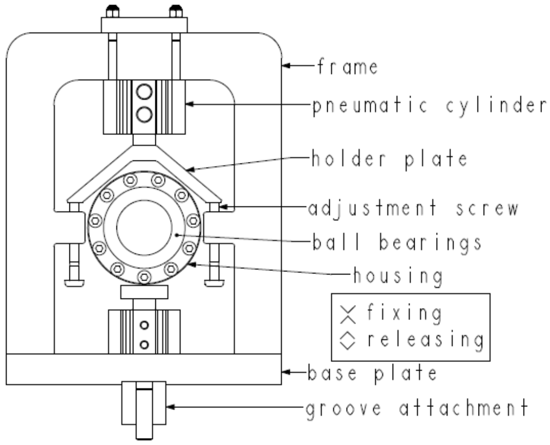

Fig. 2. Dropping device used for supporting the shaft during acceleration and releasing it to backup bearings.

In each dropping device, a pair of angular-contact ball bearings was chosen because of their suitability for high rotating speeds. The bearings were preloaded in screw-tightened housing units. Alignment of the bearings and the shaft was done vertically by adjustment screws against holder plate and horizontally by groove attachment.
It is shown that a rotating shaft will start to drop downwards if there aren't any natural frequencies present at the dropping speed [[3]]. The main boundary condition was to accelerate the lower pneumatic cylinder faster than the gravitational force accelerates the rotor. Upper cylinder was chosen greater in diameter to produce more force and to fix the shaft position specified by holder plates and adjustment screws. Respectively, the double-acting cylinders were chosen 32 mm and 40 mm in diameter. Directional valves, used for actuating the cylinders, were equipped with quick release valves lowering the pneumatic capacitance to improve the response time of the cylinders.

2.2 Backup Bearing Mounting

The mounting system of the backup bearings is presented in Figure 3. The backup bearings were located in both ends of the shaft. The guiding end of the backup bearing consisted of two angular contact ball bearings (SKF 7007 CDVGA /HCP4A). The guiding end supported the

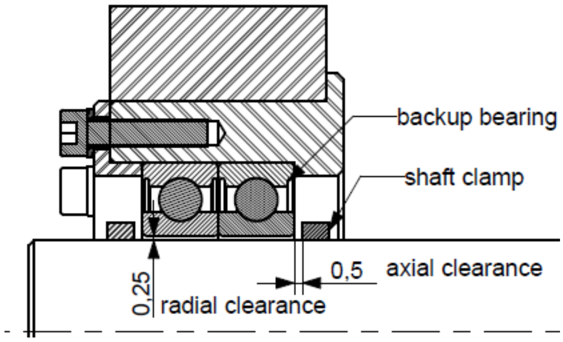

Fig. 3. Upper half (section) of the backup bearing mounting.

shaft after the dropdown in both radial and angular directions. The free end consisted of the same set of bearings as the guiding end, but without the shaft clamps. Thus the free-end bearings support the shaft only in radial direction. Clearances are listed on Table 1.

Description	Clearance (mm)
Guiding end radial	0.25
Guiding end axial	0.5
Free end radial	0.25

Table 1. Clearances between the shaft and backup bearings.

The lower bases were aligned carefully to be concentric relative to each other. The upper base was fastened to the lower base; this enables easier procedure for bearing changes without the need to align the housings again. Different sized bearings can be easily studied by changing the fitting and positioning sleeves.
Mounting was designed considerably stiff to avoid problems with mounting vibration and resonance. Moreover, sturdy mounting structure was considered to make the system more fail-safe.

2.3 Sensors and Data Acquisition

All the measurements were non-tactile because of the high shaft surface velocity and irregular dropdown event. Averaging of the results was considered impossible since there are no two similar dropdown events.

The speed of the shaft was measured with a photoelectric sensor and a piece of reflective tape attached to the shaft.
The shaft position was measured after dropdown in x and y directions (vertical and horizontal) with eddy current sensors (Microepsilon S1 sensors with DT3010-M signal conditioning electronics) in free end of the shaft. Eddy current sensors were chosen because of their capability to high measuring speed and relatively good precision. Since eddy current sensors are strongly application specific (materials, surface finish and environment), they were calibrated in their actual measuring position against a micrometer. The data was transmitted to computer with a data acquisition card (National Instruments NI-USB 6215), which was programmed with LabVIEW.

3. RESULTS

The ability of dropping device actuators to simultaneous movement was measured. Rotor center orbit during dropdown events was measured and analysed.

3.1 Dropdown actuator verification

The simultaneous movement of the four pneumatic cylinders during the rotor drop-down was measured with accelerometers attached to the cylinders. The timing of the cylinders was tuned with a microcontroller. The values of accelerations are shown in Figure 4.
Fig. 4 shows that the timing of the four cylinders could be tuned so that the movement was almost simultaneous. The difference between the start of the first and the last cylinder movement was in range of 1 ms. The results show that the pneumatic actuators could be used for simulating magnetic bearing immediate failure on both ends. The microcontroller based timing tuning allows also the dropping device utilization to simulate non-simultaneous magnetic bearing failures.

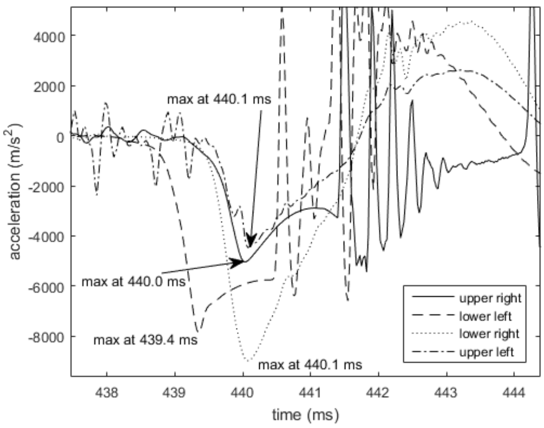

Fig. 4. Cylinder movements concurrence in the dropdown event.

3.2 Dropdown events

Dropdown experiments were performed at initial speeds of 4700, 5700, 15100 and 18900 rpm. All the tests were conducted with same backup bearings. The rotor center point orbits during the dropdown events at those speeds are shown in Figs 5, 6, 7 and 8. Initially the shaft rotated within a limited range around the coordinate system origin. Increased shaft center position ranges were observed with higher speeds. After releasing the shaft, it dropped downwards and contacted the backup bearing. After the contact the rotor decelerated to the bottom of the backup bearing due to the circumferential damping.

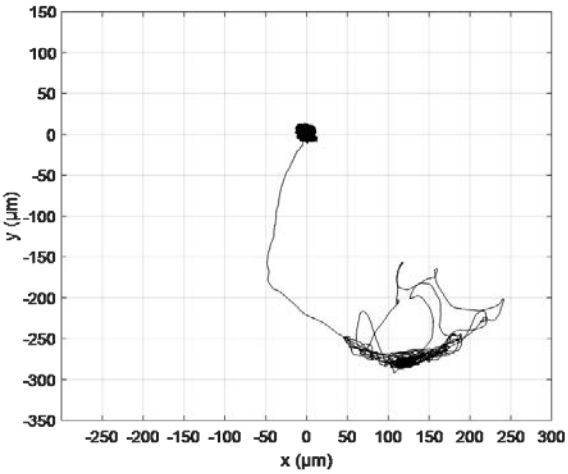

Fig. 5. Rotor center point movement at 4700 rpm dropdown.

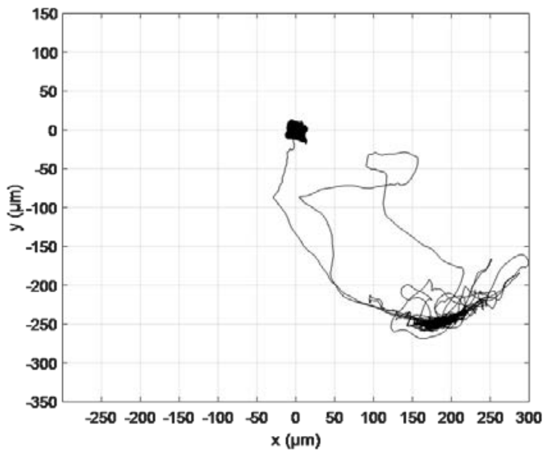

Fig. 6. Rotor center point movement at 5700 rpm dropdown.

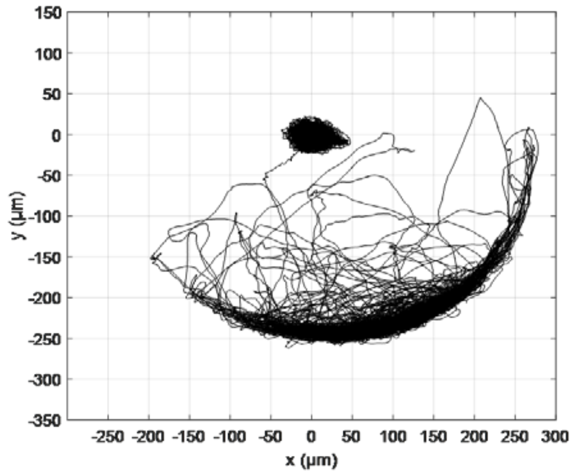

Fig. 7. Rotor center point movement at 15100 rpm dropdown.

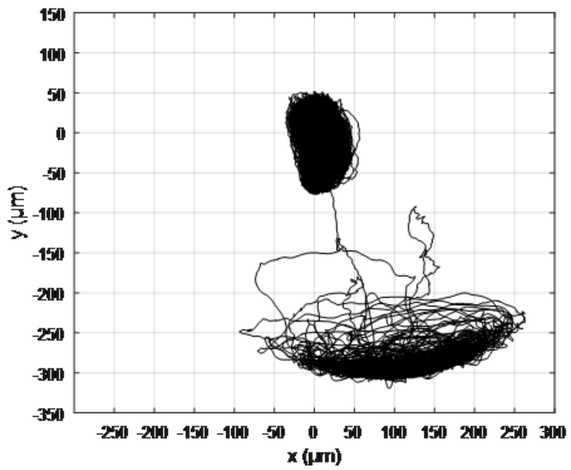

Fig. 8. Rotor center point movement at 18900 rpm dropdown.

However, Figures 5 and 6 show that the shaft was misaligned approximately by 0.1…0.2 mm to the left from the backup bearing center. In the higher speed experiments the alignment was corrected (Fig. 7 and 8). In measurements at 15100 rpm and 18900 rpm the rotor speed passes its natural frequency, while accelerating and decelerating. The rotor natural frequency was estimated to be between 12000 and 13000 rpm.

No slip was observed between locating plates and accelerating bearing housings. Neither rotor touching the backup bearings during the acceleration was observed.

The test rig speed performance was validated by accelerating the shaft to a speed of 28300 rpm. The results correspond to real magnetic bearing dropdown events [2, 8]. Orbits of the test device dropdown events were similar as in measured AMB tests.

4. DISCUSSION

The data collected from measurements with the test rig introduced in this paper, corresponds to the results with actual active magnetic bearings. The pneumatic dropdown event actuation in both ends was measured to be simultaneous within an acceptable variation.

Ball bearings are used instead of magnetic which leads to different kind of physics. Magnetic bearing systems have inductance that could cause damping in real magnetic bearing system dropdown events. This possible damping effect is not incorporated in dropping effect as it would only compensate the whirl effect.

Increased shaft position ranges at higher speeds prior to dropdown were considered to be caused by vibration. The phenomenon may also be associated with the belt drive detachment from the rotor right before the dropdown.

The rotor positioning back to the acceleration position after each dropdown was limited to approximately 0.1 mm. This caused a need to align the system again before each run. The reason was considered to be the poor stiffness of the dropping device alignment screws.

In the future more rotor position measuring sensors should be included to the test rig to achieve more accurate and valuable results. Also the positioning accuracy of the dropping device shall be improved.

Future research should include researching different kind of backup bearings and the effect of their properties to the shaft behavior. Clearances could be made smaller to study their effect to the dropdown event. Also damping elements around the bearings should be included in those considerations. Moreover, a clearance eliminating device could be developed.

In conclusion, this research suggests that the test rig with the pneumatic dropdown system is valid for backup bearing tests. The device is easily configurable for testing various different backup bearings, backup bearing positions and rotors. The device offers also a suitable platform for future research.

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