A theoretical-experimental study of backup bearings: The pinned vs ball bearing

The backup bearing is a mechanical component designed to improve the safety and reliability of Active Magnetic Bearings (AMBs). Rotors levitated by AMBs can be subjected to delevitation and consequently to impacts if a power loss happens because real-time active control is necessary to keep them running. When impacting on a stator surface, the rotor can develop a dangerous behavior caused by the friction force known as the full annular backward whirl. In this situation, the rotor will describe a trajectory around the surface of the bearing at a dominant superharmonic frequency and with large radial forces. Remaining in this condition, it may lead to permanent damage or total failure of the machine. This is why the backup bearing design has to be carefully planned and investigated as to whether it helps to protect the integrity of the machine. This PhD thesis provides a comprehensive study of two types of backup bearings, which are investigated experimentally and theoretically. The first type is a conventional ball bearing commonly used in industrial applications. The second is an unconventional bearing that, which contains pins inside the clearance for the rotor to impact on. The main objective of this work is to investigate the rotor-to-stator contact dynamics under certain conditions and to explore dynamical phenomena that emerge, so advantages and drawbacks can be stated based on a solid theoretical model validated experimentally. The mathematical model is discontinuous since the contact forces exist only if the rotor surpasses the boundaries defined by the type of backup bearing. The compliance models proposed by Lankarani and Hunt and Crossley (H&C) are employed to represent this interaction between the rotor and the backup bearing. As a matter of comparison, plots of shaft orbits, of contact force values in time and double-sided frequency spectra are given. The test rig consists of a horizontal rotor and is able to exchange backup bearings. Thanks to the force transducers, displacement sensors, and an encoder, one is able to characterize the lateral vibration of the rotor, the impact forces and to ascertain that the same conditions are met for each test run. The parameters of the test rig were determined accordingly, so the tests match with the mentioned theoretical analysis. The problem of crossing the resonance frequency is undertaken. In this case, the magnetic forces are weakly damped. It means that they are unable to withstand the occurrence of high orbits close to the resonance frequency. The pinned bearing is introduced and the pins are made of POM (polymer), whose contact characteristics are investigated. The different behaviors of the center of the shaft for the two types of backup bearings are analyzed. One concludes that the pinned bearing reduces the interval of impact by advancing the jump towards a safer contactless orbit while crossing the critical speed. The polymeric pins are softer than the rotor’s surface, so they wear from the impacts, saving the rotor. This is confirmed by a Finite-Element model of the contact case. For both types of bearings, the backward whirl could not be detected for the mentioned tests. Moreover, the H&C compliance model reproduced satisfactorily the changes in amplitude performed by the rotor and it is considered appropriate to represent both types of bearings for further investigation. Also, a full failure of the control and a rotor drop on the ball bearing as backup bearing is investigated by removing the magnetic forces. The nonlinear features of the dynamics of the rotor are assessed for different levels of unbalance. It has been shown that the proposed mechanical model for the rotor drop matches with the conducted experiments, as illustrated by the bifurcation diagrams, where three distinct behaviors are observed. The double-sided spectra demonstrate that higher unbalance values cause the rotor to perform a forward whirl trajectory.

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