Nonlinear dynamics of an accelerating rotor supported on self-acting air journal bearings

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Abstract. Self-acting air bearings are used in several high-speed micro-turbomachines, where frequent acceleration/deceleration of the rotor is common. The whirl amplitude of the rotor must be kept within tolerable limits for safe operations of the system. This research presents, for the very first time, the dynamics of an accelerating rotor supported on self-acting air journal bearings. Due to the rotor unbalance, the dynamics between the translational and spin coordinates get nonlinearly coupled. The work utilizes these coupled equations to plan appropriate acceleration schedules to limit the whirl amplitude and frequency as low as possible. Based on the research, it is found that in the presence of rotor unbalance, the acceleration should be scheduled in at least three regimes: the first with the maximum torque, the second with the minimum torque, and the last with an intermediate torque.

Introduction

With the rise in demand for eco-friendly, high-speed and extreme-temperature micro-turbomachinery, self-acting air bearings are evolving to replace traditional oil/grease-lubricated bearings. The rotors supported on self-acting air journal bearings typically operate at very high rotational speeds in the order of 10^4 to 10^5 rpm. In this process, frequent acceleration to/retardation from such high speeds is prevalent [1,2]. During this phase, the rotors experience high-amplitude whirling, which is undesirable from a safety point of view. The present research presents the non-linear dynamic response of an accelerating rotor supported on self-acting air bearings and proposes suitable acceleration schedules to keep the whirling amplitude and frequency as low as possible. From the point-of-view of mathematical simulations, it is observed that the highly nonlinear rotordynamics of rotors supported on self-acting gas bearings cannot be predicted accurately by considering only the two translational degrees of freedom to build the equations of motions of the rotor. Moreover, the spin direction dynamics are often not considered in this process because it makes the equations of motions highly nonlinear and coupled in all directions. Therefore, the inclusion of spin direction dynamics along with the translational and tilting dynamics to form the equations of motions is essential, particularly for very high-speed rotors, usually supported by self-acting air bearings [2]. Therefore, in the present study, the generic form of equations of motions for a rigid rotor with a non-central disc supported on two self-acting air bearings considering five degrees of freedom (two translations, two tiltings and one rotational degree of freedom) are being proposed. The transient compressible lubrication equation and the equations of motion of the rotor are simultaneously solved to compute the dynamic response of the rotor during the acceleration phase. The mathematical simulations have shown that the driving torque significantly affects the rotordynamic response during the acceleration phase of the rotor. Based on the analysis, the acceleration scheduling is implemented by varying the driving torque at different phases of the acceleration to contain the whirl amplitude and its frequency as low as possible. <*TEPUCS: Trace of the Equilibrium Positions Under Constant Speed* >

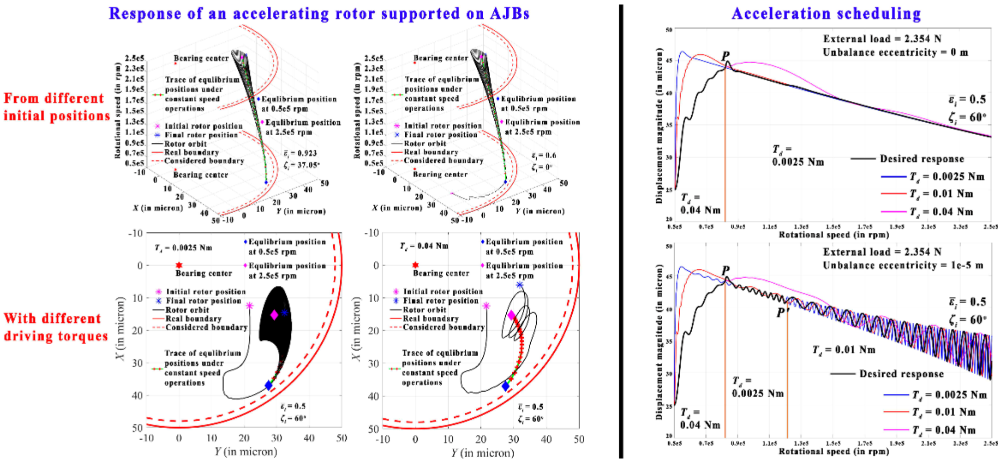

Figure 1: Response of acceleration rotor supported on self-acting air journal bearings and execution of acceleration scheduling

Results and discussion

The core findings are as follows: i) During the initial acceleration, the rotor center moves towards the *TEPUCS* line and later revolves about this line. ii) During the periodic phase, the frequency of whirling reduces with the rise in the external driving torque. iii) During the acceleration, as the rotor approaches the *TEPUCS* line, higher driving torque results in minimum rotor response, whereas the response increases after crossing this line. iv) There should be at least three acceleration schedules to contain whirl response.

References

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