PARAMETRIC ANALYSIS OF A RIGID ROTOR DROP ONTO TOUCHDOWN BEARINGS

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Abstract: Touch-Down Bearings (TDB) loads generated during a rotor drop event is analysed. When unexpected Active Magnetic Bearings (AMB) shut down occurs, the rotor drops onto TDB, providing a non-linear transient motion that can lead to unexpected responses. In this paper, the influences of TDB characteristics is assessed aiming at providing better drop characteristics in terms of loads.

Keywords: transient, non-linear dynamics, rotor dynamics, rotor drops, touch-down bearing

1 Introduction

Rotating machines supported by AMB lead to frictionless system and limit energy losses. However in some particular events AMB can shut down. The rotor, forced by gravity, drops onto its Touch-Down Bearings and can then affect their life time. This may lead to frequent changes of TDB, reducing the operability of the machine drastically. In this work, the influence of several parameters on the rotor dynamics during the drop event has been performed through time transient analysis. This work is a part of a research project on the prediction of the dynamic behavior of a rotor supported by AMB during critical events.

2 The rotor - TDB system

Several detailed TDB models exist in literature like in Cole et al. (2001) where each ball has two Degrees Of Freedom (DOF). In this paper, a classical 5 DOF TDB model (Sun (2006), Lee et al. (2012), Wilkes et al. (2014)) is used to describe the rotor drop after an AMB shut down. Indeed, sliding between the balls and races can be neglected when considering the whole rotor drop dynamics (Karkkainen et al. (2007)). Gelin (1991) concludes that mainly the rigid modes of the rotor are excited during a classical rotor drop. Under this assumption, the model is a rigid rotating mass. The control strategy is not included in the model, thus, AMB are considered having constant stiffness $k_{amb}$ and damping $c_{amb}$ coefficients at a constant rotating speed. The study concerns the situation where $k_{amb}$, $c_{amb}$ and the engine torque are nil see Figure 1. Therefore, the coast down rotor is subjected to unbalance forces, to the gravity along y-axis and to contact forces. When shaft-TDB contacts occur, the rotor decelerates while the TDB’s inner race accelerates due to high friction contact forces. Description of normal contact forces $f_{crd}$ in Figure 1 is always an issue and many types of contact law can be found in the literature. Here, a vibro-impact model is implemented based on Hunt et al. (1975), derived from the Hertz theory for inelastic collisions. This kind of model takes into account the energy losses inherent to the contact phenomenon through a non-linear damper. The tangential contact model is a Coulomb model smoothed with the arctangent law used in Duran (2014). The bearing restoring forces are implemented thanks to a quadratic law. Usually, TDB outer-races are separated from housings by Corrugated Ribbon Damper (CRD) limiting loads transmitted to the stator and providing damping to the overall system. As shown in Schmied et al. (1992), these components are of a great benefit for the rotor drop dynamics. Its restoring force $f_{crd}$, in Figure 1 is modeled as a cross-coupled elastic force in parallel with a damping force:

$$f_{crd} = -k_{crd} \begin{bmatrix} 1 \eta \sign(v_{or}) & -\eta \sign(v_{or}) \\ \eta \sign(v_{or}) & 1 \end{bmatrix} \begin{bmatrix} x_{or} \\ y_{or} \end{bmatrix} - c_{crd} \begin{bmatrix} 0 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{x}_{or} \\ \dot{y}_{or} \end{bmatrix}$$

(1)

$\eta$ being the cross-coupled coefficient, $v_{or}$ the whirling velocity of the outer race and the $\sign$ function is used as an arctangent law. Thus, the cross-coupled stiffness counteracts the whirl motion of the outer race. $f_{cor}$ is the contact force between the outer race and the housing and is modeled as the rotor to inner race normal contact force. This force appears when the CRD clearance in Figure 1 is consumed by the outer race normal displacement.
3 Influences of drop parameters

Once it drops, the rotor can develop several behaviors like pendulum oscillations \cite{Hawkins}, conical motions or backward whirl motions, which is the most dangerous for turbomachinery integrity. After transient motions composed with rebounds and shocks, two types of motion can appear: the Rocking Motion (RM), in Figure 2 and the Backward Whirl Motion (BWM), in Figure 3. In this analysis, distinction between "controllable" and "uncontrollable" parameter has been done. Most of uncontrollable parameters are not influent. However, the drop rotating speed has a great influence on Touch-Down Bearing load in case of BWM. Friction forces transfer energy from the spin speed of the rotor to its backward whirl motion increasing the centrifugal force. In controllable parameters, clearances are the most influent. Increasing rotor to inner race clearance increases the height of drop in RM case and increases rotor whirl radius in BWM. Both increase the TDB load. Increasing the Corrugated Ribbon Damper clearance has a great benefit for limiting the TDB loads. However, attention should be paid regarding to the maximum normal displacement of the rotor when it drops; possible rotor to seal contact could damage the turbomachinery.

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References