PARAMETRIC ANALYSIS OF A RIGID ROTOR DROP ONTO TOUCHDOWN BEARINGS

C. Jarroux[1,2], R. Dufour[2], J. Mahfoud[2], B. Defoy[1] and T. Alban[1]

[1] Thermodyn, GE Oil and Gas, 71200 Le Creusot, France
[2] Université de Lyon, CNRS, INSA-Lyon, LaMCoS UMR5259, 69621 Villeurbanne, France
E-mail: *clement.jarroux@insa-lyon.fr*

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 TBD, 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_{crir} 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 tangentiel 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:

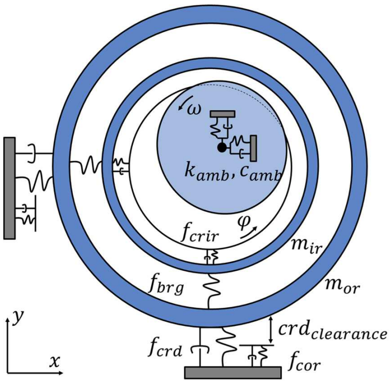

Figure 1: 5 DOF TDB model

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

η 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 (Hawkins et al. (2007)), 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 limitating 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.

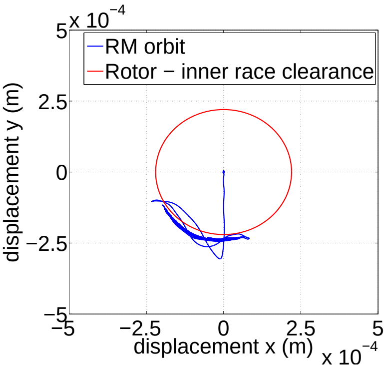

Figure 2: Rotor rocking motion orbit

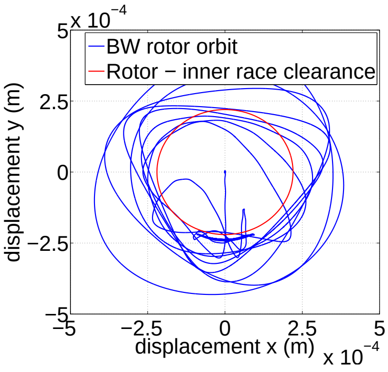

Figure 3: Rotor backward whirl motion orbit

Acknowledgements

This work is a part of Clément JARROUX PhD performed with the support of CIFRE funding N^0 *2013/1376. The authors are grateful to the ANRT National Agency.*

References

A. Gelin. Etude théorique et expérimentale des comportements dynamiques permanents et transitoires de rotors sur paliers magnétiques. PhD Thesis. INSA de Lyon. 1991.

A. Kärkkäinen, J. Sopanen, A. Mikkola. Dynamic simulation of a flexible rotor during drop on retainer bearings. Journal of Sound and Vibration. 2007.

C. Duran, L. Manin, M. A. Andrianoely, C. Bordegaray, F. Battle, R. Dufour. Effect of rotor-stator contact on the mass unbalance response. IFToMM International Conference on Rotor Dynamics. 2014.

G. Sun. Rotor drop and following thermal growth simulations using detailed auxiliary bearing and damper models. Journal of Sound and Vibration. 2005.

J. G. Lee, A. Palazzolo. Catcher Bearing Life Prediction Using a Rainflow Counting Approach. Journal of Tribology. 2012.

J. Schmied, J. C. Pradetto. Behaviour of a One Ton Rotor being dropped into Auxiliary bearings. International Symposium on Magnetic Bearing. 1992.

J. Wilkes, J. Moore, D. Ransom, G. Vannini. An improved catcher bearing model and an explanation of the forward whirl / whip phenomenon observed in AMB transient drop experiments. Journal of Engineering for Gas Turbines and Power. 2014.

K. H. Hunt, F. R. E. Crossley. Coefficient of Restitution Interpreted as Damping in Vibroimpact. Journal of Applied Mechanics. 1975.

L. Hawkins, M. N. Patrick, V. Vuong. Development and testing of the backup bearing system for an AMB energy storage flywheel. ASME Turbo Expo. 2007.

M. O. T. Cole, P. S. Keogh, C. R. Burrows. The dynamic behavior of a rolling element auxiliary bearing following rotor impact. Journal of Tribology. 2001.