Influence of the base motion on the dry-whip onset of an on-board rotor-journal bearing system

Yvon Briend*, Eric Chatelet *, Régis Dufour*, Marie-Ange Andrianoely*, Franck Legrand and Sophie Baudin**

**Univ Lyon, INSA-Lyon, CNRS UMR5259, LaMCoS, F-69621, France*

***Avnir Engineering, F-69621, France*

Summary: In this paper, the special class of on-board rotor undergoing rotor-stator contact is under investigation. In particular, a well-known and harmful contact instability, the dry-whip phenomenon, is addressed. The aim of the paper is to present original experiments evidencing this instability being triggered by a multi-axial shock translation from the rigid rotor base. Moreover, the influence of the base motion parameters, such as the shock amplitudes, directions and time instants, on the onset of dry-whip is investigated both numerically and experimentally.

Introduction

On-board rotors represent a very special class of rotors, which are subject to motions of their base that may induce high vibration levels. In practice, they can be encountered in a large variety of industrial fields such as energy, transports, defense, etc. In this context, these systems have recently raised a particular interest as highlighted by the literature [1-2]. Due to the base motions, contact is likely to occur between rotating and non-rotating parts. In some cases, these contacts can lead to harmful dynamic instabilities, such as the dry-whip phenomenon, threatening the structural integrity of the mechanical systems. The latter is characterized by a sudden change in the whirl that leads to backward whirl owing to the tangential friction contact forces, which causes high displacement amplitudes and frequencies. It can be triggered by a mass unbalance only or in combination with an external disturbance [3] such as a hammer impact or a base motion.
The evidencing of the dry-whip phenomenon as caused by base motion is relatively recent [4]. The aim of this paper is to emphasize the experimental and numerical outcomes of [4]. Moreover, the conditions of onset of the instability depending on the base motion parameters are investigated in more details.

Experimental and numerical investigations

The on-board rotor test rig (two disks mounted on a slender shaft) used in this context is modelled with Timoshenko beam elements and its mesh is sketched in Figure 1. It is equipped with two short fluid film bearings at Nodes 6 and 23 and with multiple contact rings. The ring at Node 15 is intended to be the first one to experience rotor-stator contacts and to be responsible for the dry-whip occurrence while the others are stator bores used rather for safety requirements.

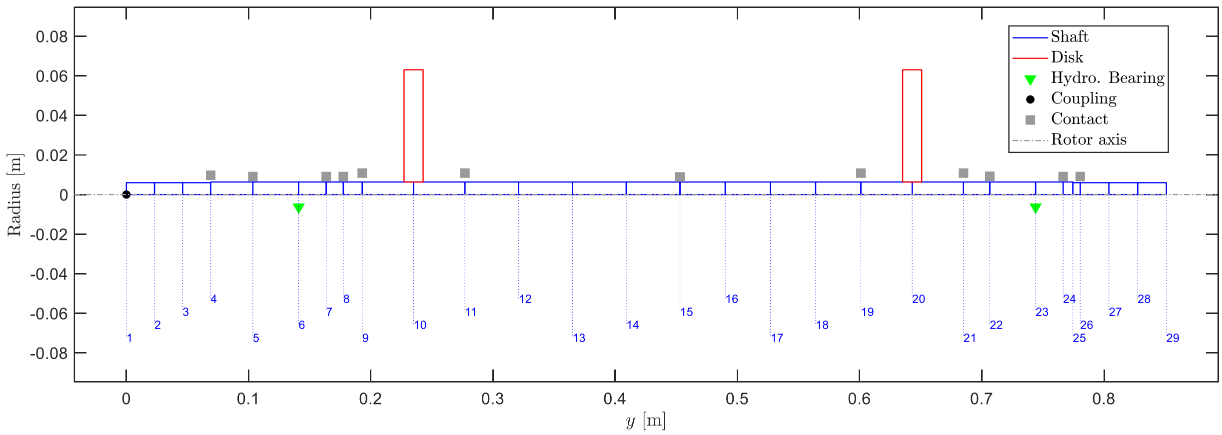


Figure 1: FE mesh of the on-board rotor-bearing system mounted on finite-length journal bearings and equipped with multiple contact rings

In a first study case, the rotor rotates at a fixed speed of rotation of 1700 rpm and two mass unbalances of 2.37 10^{-3} kg with a 57.0 10^{-3} m gyration radius are screwed on each disk at 0° and 20°. After reaching the steady-state response, a multi-axial base motion composed of two synchronous transverse shocks (pre- and post- 10 ms pulse of 15 m/s²) is imposed suddenly and briefly in order to trigger the dry-whip. The measured response in terms of the full spectrogram of the Node 16 transverse displacements is shown in Figure 2. The whirl transition from forward at ~28 Hz (1700 rpm) to backward at ~-170 Hz is clearly identified when the shock is performed near t=2.55 s. Meanwhile, critical vibration levels are also highlighted, until t=~6 s where the instability suddenly vanished because of the motor-shaft coupling failure and the damping effects.

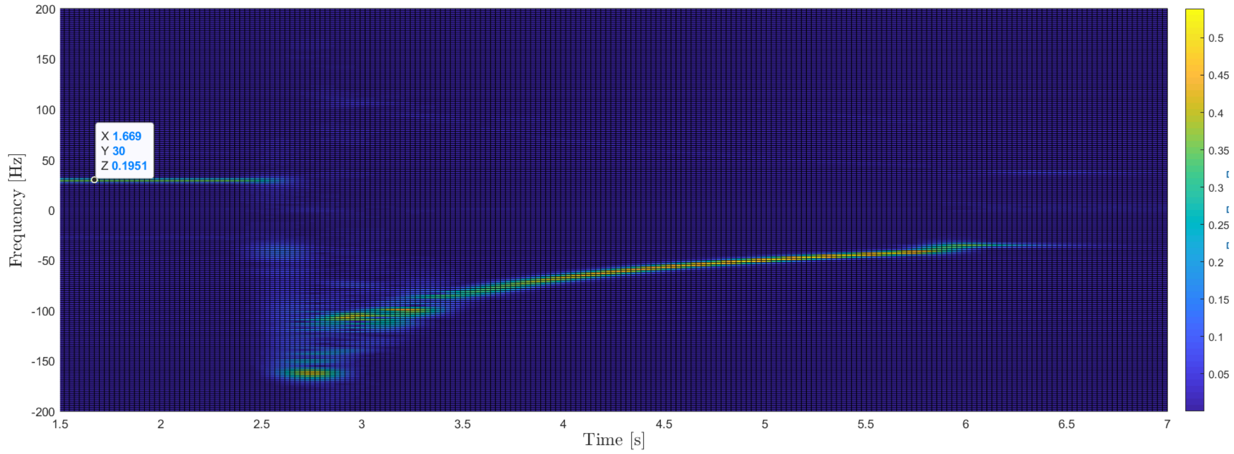
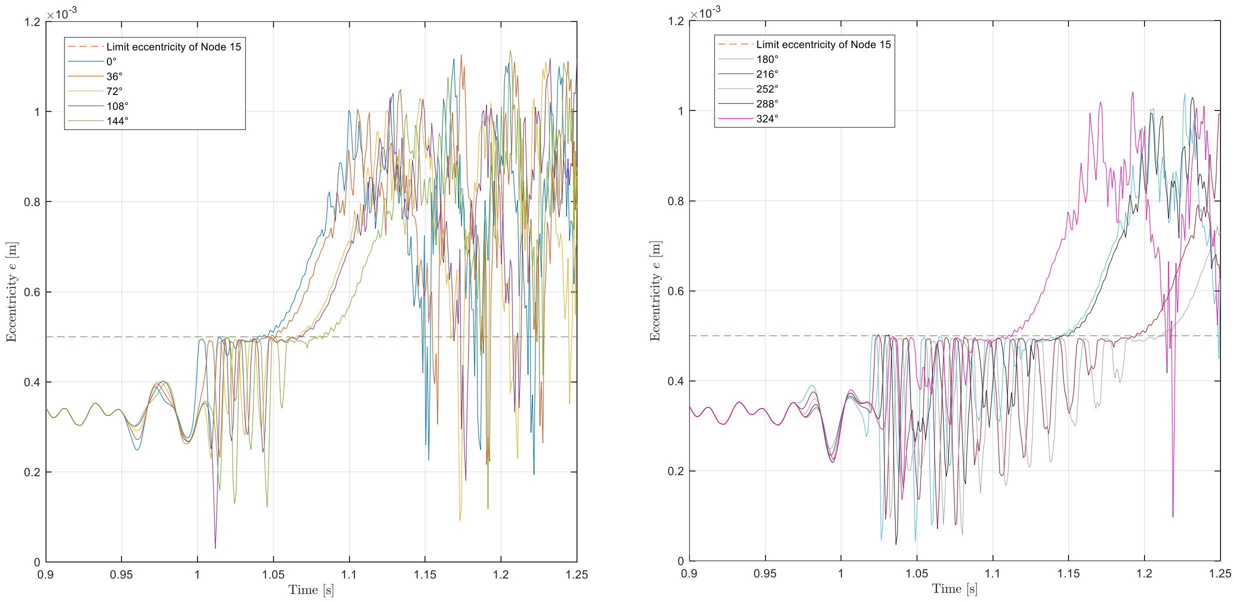


Figure 2: Full spectrogram of the measured Node 16 orbit of the test rig subject to mass unbalance and to pre- and –post pulse from the base

Then, the instant of the shock is varied numerically in order to impact the contact ring at different rotation angles and to assess if this may favor or inhibit the dry-whip triggering. To this aim, ten values of time instants, equally distributed between 0° and 360° (0° and 360° corresponding to t=2.55 s and t=2.55s + T, respectively, with T the mass unbalance period), are performed. The results are presented in Figure 3. It is noticed that for all instants, the dry-whip is triggered, however, it is more delayed and many rebounds are found for instants near 216°. This result can be assigned to the variation of the angle of contact and to the radial velocity of impact that change with the shock instant.



(a) (b)

Figure 3: Numerical eccentricities of Node 16 of the test rig subject to mass unbalance and to a base transverse shock translation at t=0,95s with different time instants equivalent to (a) [0°-144°] and to (b) [180°-324°]

Acknowledgments

The authors are indebted to the French National Research Agency (Funder ID: 10.13039/501100001665) (ANR) for its financial support within the framework of the LaBCoM-SME AdViTAM, ANR-16-LCV1-0006 and Equipex PHARE 10-EQPX-0043.

References

[1] Soni, T., Dutt, J. K., & Das, A. S. (2019). Parametric stability analysis of active magnetic bearing supported rotor system with a novel control law subject to periodic base motion. *IEEE Transactions on Industrial Electronics*, *67*(2), 1160-1170.

[2] Su, Y., Gu, Y., Keogh, P. S., Yu, S., & Ren, G. (2021). Nonlinear dynamic simulation and parametric analysis of a rotor-AMB-TDB system experiencing strong base shock excitations. *Mechanism and Machine Theory*, *155*, 104071.

[3] Jiang, J. Determination of the global responses characteristics of a piecewise smooth dynamical system with contact. *Nonlinear Dyn* **57,** 351–361 (2009)

[4] Briend, Y., Chatelet, E., Dufour, R., Andrianoely, M. A., Legrand, F., Sousa Jr, M. S., Steffen Jr, V. and Baudin, S. (2021). Dry-whip phenomenon in on-board rotordynamics: Modeling and experimentation. *Journal of Sound and Vibration*, *513*, 116398.