STABILITY OF ROTATING MACHINE SUPPORTED BY ACTIVE MAGNETIC BEARINGS DURING BASE MOTION

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

[1]Université de Lyon, INSA-Lyon, LaMCoS UMR5259, LaMCoS
18-20 rue des Sciences, Bât J. d'Alembert, 69621 Villeurbanne Cedex, France
Email: clement.jarroux@insa-lyon.fr

[2]GE Oil & Gas Thermodyn
480 allée G. Eiffel, BP 119, 71203 Le Creusot Cedex, France

ABSTRACT

The study is devoted to rotor supported by Active Magnetic Bearings (AMBs) and subjected to base motion. The machine casing is considered rigid and able to move with 3 translations and the 3 rotations. The objective is to assess the suitability of machine supported by AMBs to withstand base motions for applications such as compressors on FPSO (Floating production storage and offloading). Experiments were performed of an academic test rig. The controller was an augmented PID similar to that used in industrial applications. At this stage, only harmonic motion is considered. Two levels of severity were applied. The results obtained in this configuration demonstrated the stability of the rotor-AMB system.

1 INTRODUCTION

Turbomachines manage the fluid-structures energy transfer, they have to be able to withstand severe environmental conditions. Consequently, a major focus of the research engaged by industrial and academic laboratories concerns their reliability in any circumstances. Most of the rotating machinery can be considered as on-board machines. Aircraft engines, automotive turbochargers or compressors fixed on an oil offshore-platform are notable examples. The base motion generates complex rotor dynamics in particular in the case of base rotations yielding parametric instabilities. At certain rotating frequencies of the support, combined with the natural frequencies of the rotor, instability zones emerge and depend on the amplitude of the rotation angle [1, 2]. The dynamic behaviour of on-board rotating machines should then be carefully analysed to improve the reliability and to maintain a maximal operability of the machines. On the other hand, Active Magnetic Beatings (AMBs) are more and more utilized in industrial applications for their several advantages (no wear due to friction, no oil system, compact space requirement). They are inherently unstable, therefore a feedback control is needed and the PID is the most implemented controller. Different studies focused on the control of rotors subject to base motion using magnetic forces. The sinusoidal base motion of a non-rotating mass mounted on magnetic bearings was experimentally and numerically analysed by [3]. Three PID controllers were tested and non-linear responses were found in the less damped controller. In [4], the transient dynamic behaviour of a rotor supported by homopolar permanent magnet bias magnetic bearings subjected to vertical shock was simulated. Rotor-to-stator contact was found. The feedforward control loop is often used to control base motion in parallel with a feedback control loop. This method was employed by [5] to reduce the harmonic translation motion of the base considering a rigid rotor supported by non-linear AMBs. Three controllers were tested in [6] and the H_∞ controller has the greatest effect in reducing the rotor response due to unbalance and horizontal shock of the base. This work is a part of a research program aim at the development of turbomachines mounted on AMB. Previous work demonstrated the effectiveness of the developed control strategies to have a reliable behaviour under several operating conditions [7]. In this work, experimental investigations are presented, the aim is to assess the effectiveness of the developed augmented PID to maintain the rotor operating under severe events. Only experimental results are presented. The experimental conditions will be presented first, then the results will be discussed and finally conclusions and perspectives will be dressed.

2 EXPERIMENTAL CONDITIONS

The experiments were performed using an academic test rig (Figure 1). It is a commercial product manufactured by SKF® and was delivered with a dedicated PID controller. The test rig is equipped with two identical AMB called NDE (Non Drive End) and DE (Drive End) bearings. Each bearing has a maximum static capability of 280N. The action lines are positioned in the configuration load between axes. They are powered in differential driving mode with a bias current of 1A. Current are provided in the range of 0-3A using PWM amplifiers. Two displacement sensors (variable reluctance probes) are integrated in the housing of each bearing and are non-colocalised with actuators. The Input/Output panel gives access to the displacements measured and enables entering current settings for the amplifiers. Each AMB has one back-up bearing with a clearance radius of 0.1mm. The shaft is composed of three parts bolted together. A central part (diameter: 25mm; length 344mm) with a decentred disc 120mm in diameter and 25mm long placed at two-thirds of the central part length from the DE side, together with two shaft ends (50mm of main diameter). The stack of laminated steel sheets is shrunk on each of these two shafts. The total rotor length is 645mm. The rotor mass is 6.5kg. The rotor is driven by a 500W electric motor with a maximum speed of 12,600rpm. Power transmission is provided by a flexible coupling. The operating speed range used in this work is 0 to 9,500rpm, which includes two first rigid modes. The speed of the rotor is monitored by using a speed sensor placed close to the motor.

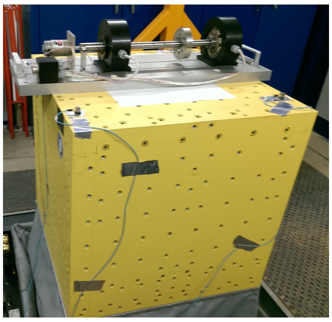

Figure 1. Experimental test rig.

The test rig was mounted on a shaker that has 6 real-time pilots able to reproduce various combinations of solicitations along the 3 axes (translations and rotations) with a maximum mass of 450 kg in a range [0-250] Hz. Sine, random, shock excitations or replication of signals previously recorded and with a maximum acceleration of 10g, $\pm$ 50 mm in translations and $\pm$ 4 degrees in rotation. The rotor at rest was subject during 5 seconds to two cases of excitation: 0.3g at 20 Hz, and 1.1g at 20 Hz. Only the last case led to contact between the rotor and the touch-down bearings (TDB). The characteristics of an augmented PID were determined as a function of the dynamic behaviour and the number of modes included in the operating conditions. Also, the stiffness was chosen low and the damping was concentrated around system natural frequencies (Figure 2).

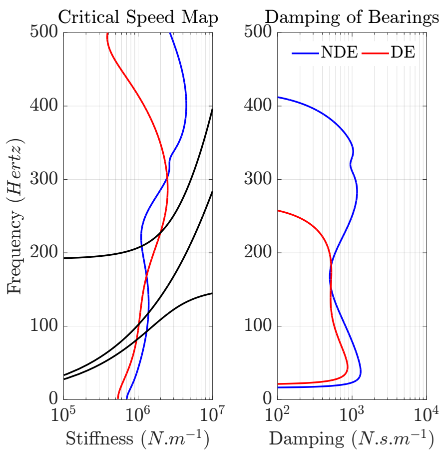

Figure 2. Controller damping and stiffness.

3 RESULTS

The displacements measured are presented in Figure 3. It can be noticed that the PID operated efficiently since the rotor was still controlled even after the contact with the TDB.

4 CONCLUDING REMARKS

The study was devoted to the assessment of the dynamic behaviour of a rotating machine under sever excitations. The aim was to check the ability of the developed control strategy to maintain

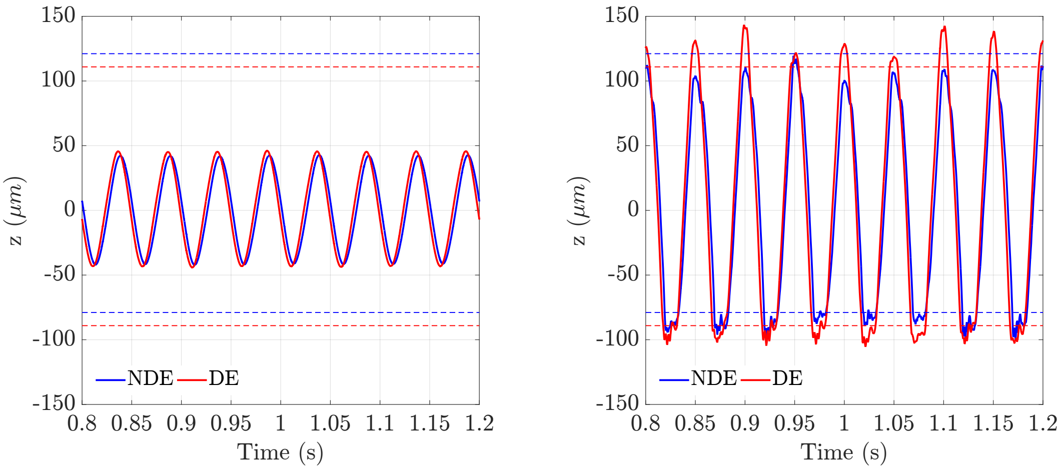

Figure 3. Displacement of the rotor subject to 0.3g (left) and to 1.1g (right).

the rotor in operation. In this paper only first results are presented, and it could be seen that the controller was able to maintain the rotor in operation.

5 ACKNOWLEDGMENTS

This work is supported by the CIFRE funding Nº 2013/1376 and uses an equipment of the Equipex PHARE (ANR-10-EQPX-43). The authors are grateful to the ANRT and ANR, two National Agencies.

REFERENCES

[1] M. Dakel, S. Baguet, and R. Dufour. Steady-state dynamic behavior of an on-board rotor under combined base motions. *Journal of Vibration and Control*, 20(15):2254–2287, 2014.

[2] Q. Han and F. Chu. Parametric instability of flexible rotor-bearing system under time-periodic base angular motions. *Applied Mathematical Modelling*, 39(15):4511–4522, 2015.

[3] M. E. Kasarda, J. Clements, A. L. Wicks, C. D. Hall, and R. G. Kirk. Effect of sinusoidal base motion on a magnetic bearing. In *IEEE International Conference on Control Applications.*, pages 144–149, 2000.

[4] L. A. Hawkins. Shock analysis for a homopolar, permanent magnet bias magnetic bearing system. (78712):V004T14A040, 1997. 10.1115/97-GT-230.

[5] Steven Marx and C. Nataraj. Suppression of base excitation of rotors on magnetic bearings. *International Journal of Rotating Machinery*, 2007:10, 2007.

[6] M. O. T. Cole, P. S. Keogh, and C. R. Burrows. Vibration control of a flexible rotor/magnetic bearing system subject to direct forcing and base motion disturbances. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, 212(7):535–546, 1998.

[7] B. Defoy, T. Alban, and J. Mahfoud. Energy cost assessment of a polar based controller applied to a flexible rotor supported by amb. *Mechanical Engineering Journal*, 2015.