EXTERNAL DISTURBANCE REJECTION FOR COMPRESSORS ON ACTIVE MAGNETIC BEARINGS

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ABSTRACT

This paper presents the experimental results of a feedforward control strategy applied to a centrifugal compressor to reject disturbance coming from ground motion. The compressor is used for refrigeration tasks in public transport, it has a power of 30 kW with nominal speed of 51000 rpm and is levitated magnetically by means of cylindrical Active Magnetic Bearings (AMB). The proposed control strategy acts in combination with a classical decentralized control, it is implemented on a prototype of the compressor equipped with a substitute impeller without compression and is validated by means of acceleration tests simulating ground motion. The obtained results represents the basis for the future development of the proposed control strategy that will combined to an unbalance compensation action to minimize the effects of surge and stall of the compressor.

The paper illustrates the architecture of the machine, the control strategy and the experimental results conducted in laboratory environment and aiming to prove the validity of the proposed technique. According to the standards, the control is tested by shaking the system with an impulsive acceleration of the duration of 30ms and an amplitude of 5g. The obtained axial and radial displacement of the shaft are lower than 0.2mm.

1 INTRODUCTION

Compressors are widely adopted in several industrial processes like manufacturing, production lines and oil and gas industry. The main tasks requested to these machines are gas transportation and mixing, refrigeration and temperature control. In the last decades scientific research devoted many efforts to the development and the optimization of compressor technology aiming to improve reliability and performance. The current study is mainly focused on critical issues like stall and surge control and to the improvement of the efficiency of the machine. To this end, the adoption of active magnetic bearings (AMB) for the support of the compressor shaft witnessed a steady growth because of the intrinsic advantages of this technology: the absence of friction and fatigue issues, low maintenance allowing the installation in critical and harsh environments, the absence of contamination caused by lubricants and the possibility of tuning the suspension parameters by means of digital control [1][2].

When a compressor based on AMB is adopted for refrigeration tasks in mobile applications such as public transport, it is subjected to external disturbance coming from the ground that can generate heavy damage to the machine if the rotor comes in touch with the stator. It is important to find a control technique allowing the machine to work in safe condition without sacrificing the control devoted to the suspension of the shaft and permitting to minimize the clearance between the stator and the rotor to optimize the refrigeration efficiency [3][4]. In this paper a feedforward control acting in parallel to a classical decentralized control is adopted to reduce the axial and radial displacement of the shaft of a compressor with a nominal speed of 51000 rpm and a power of 30 kW used for refrigeration tasks in public transport. The proposed control technique is applied on a prototype of the compressor with an impeller mock up with the same inertial properties of the real one. The experimental validation is conducted with acceleration tests simulating ground motion. On the basis of this results, the strategy will be refined and used in combination with an unbalance compensation strategy to control surge and stall effects in real working conditions.

The architecture of the machine, the modelling and the control phases are exposed along with the experimental results conducted in laboratory environment aiming to prove the validity of the proposed technique. According to the standards, the control has been tested by shaking the system with an impulsive acceleration of the duration of 30ms and an amplitude of 5g. The reported experimental results show that maximum axial and radial displacement of the shaft are lower than 0.2mm.

2 ARCHITECTURE OF THE SYSTEM AND CONTROL DESIGN

The control strategy is tested on a prototype of the compressor supposed to be used for refrigeration and temperature control in public transport. Figure 1 reports the lateral cross section view of the machine. The shaft (17) is supported by means of cylindrical active magnetic bearings with two radial (4, 5, 12 and 13) and one axial actuator (11), the displacement is measured by five eddy current displacement sensors (1 and 3), an impeller mock up (14) is used in the place of the real one. An electronic control unit is responsible of the acquisition of displacement and current measurements and of the generation of the references for the power electronics adopted to drive the actuators.

The magnetic levitation is achieved with a standard decentralized control strategy based on two embedded control loops: the inner PI to control the current in the coils and the outer PID to control the position of the shaft. The rejection of the external disturbance is obtained by means of a feedforward control signal summed to the command of the external position controller as illustrated in Figure 2. The measured acceleration of the ground is filtered with an action that is equal to the inverse of the actuation dynamic.

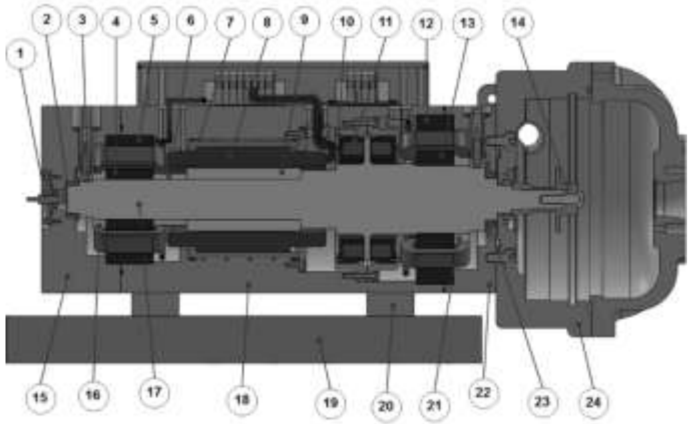

Figure 1. Lateral cross section view of the compressor. 1: Axial position sensor. 2: Lower landing bearing. 3: Radial position sensor. 5: Lower radial actuator, rotating part. 6: Lower radial actuator, static part. 7: Mechanical spacer. 8: Motor cooling system. 9: Electric motor, static part. 10: Electric motor, rotating part. 11: Axial bearing support. 12: Axial bearing. 13: Higher radial actuator, static part. 14: Higher radial actuator, rotating part. 15: Impeller mock-up. 16: Stator body, lower part. 17: Lower nut. 18: Shaft. 19: Stator body, central part. 20: Shaker slip table. 21: Compressor bracket (4 brackets in total). 22: Higher nut. 23: Stator body, higher part. 24: Higher landing bearing. 25: Volute.

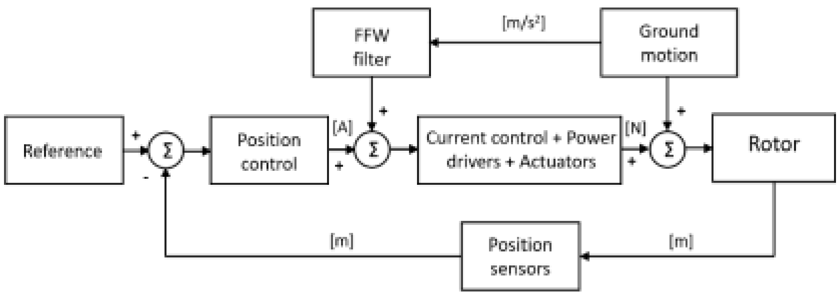

Figure 2. Control scheme.

3 EXPERIMENTAL RESULTS

The experimental tests are carried out to test the isolation from ground motion in operating conditions. The excitation is simulated by means of a shaker providing a profile of acceleration accordingly to the standards (Figure 3) where the peak A is equal to 5g and the duration in time is 30ms.

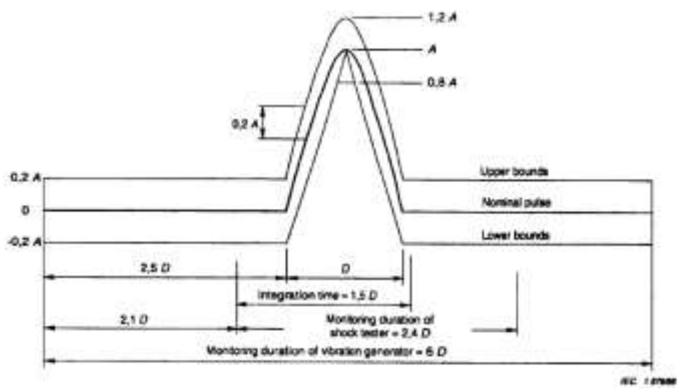

Figure 3. Acceleration profile.

Figure 4 shows the results obtained for the tests along axial (a) and radial direction at 0 rpm (b), 35000 rpm (c) and 51000 rpm (d). The maximum displacement is lower than 0.2 mm along both directions. The upper plots report the acceleration in g while lower plots show the displacement. Since acceleration of 5g when only PID control is running leads to the instability of the system, no plots are available when feedforward action is off.

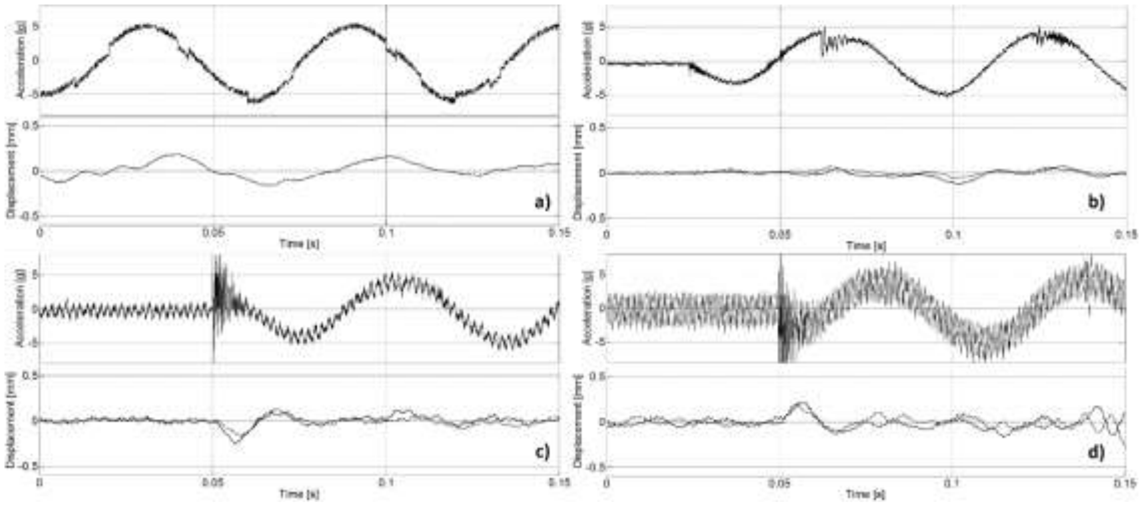

Figure 4. Experimental results. a) Axial direction at 51000 Rpm. b) Radial direction at 0 rpm. c) Radial direction at 35000 rpm. d) Radial direction at 51000 rpm. Solid line is x-axis and dashed line is y-axis in the lower plots of figures b), c) and d).

4 CONCLUDING REMARKS

A feedforward control technique has been presented to control ground motion on a compressor for refrigeration tasks in public transport. The control runs in parallel with a standard decentralized PID control devoted to magnetic suspension. The control architecture has been validated in the case of excitations coming from the ground when the machine is equipped with a substitute impeller without compression. Accelerations along longitudinal and transversal directions with a peak of 5g and a duration of 30ms have been provided with a shaker and the maximum recorded displacement are lower than 0.2mm. The obtained results represents the basis for the development of the control strategy that in the future will be used in combination with an unbalance compensation action to minimize the effects of surge and stall of the compressor in real working conditions.

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