Active Control of Rotor Vibration in an Electric Machine by Cascaded Optimal and Convergent Control Methods

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(Received 8 June 2011, provisionally accepted 13 October 2011, accepted 12 December 2011)

This paper presents a method for suppressing radial rotor vibrations in an electric machine by the means of active vibration control. The required control forces are generated by an electro-magnetic actuator implemented as extra windings in the stator slots of the machine. A generic modified optimal LQ-based controller cascaded with a convergent controller is introduced to tackle the problem. The test results obtained by the implementation of the designed control algorithms in a 30 kW squirrel-cage induction motor are presented. The results show that the proposed control strategy is capable of significant vibration suppression.

1. INTRODUCTION

Electric motors and drives are process components that are found practically in any industrial process. In electric drives, one of the major bottlenecks for efficiency is the width of the air-gap between the rotor and the stator. This gap is inversely proportional to the strength of the magnetic field in the air-gap, which again is directly related to the generated torque.[1] The minimum width of this gap is restricted by several safety margins as the rotor should not be allowed to collide with the stator in any possible scenario. One reason for an increase in this margin is the rotor vibration.

Another issue is the cost effectiveness. The major costs for electric drives, besides normal energy consumption, are due to the maintenance and upkeep, if the whole life cycle of the product is considered. A significant portion of maintenance costs is generated by the need to replace some of the process components before they are worn out. It is a generally known fact that vibration can cause severe wear and tear on the supportive structures of the machine.[2] In this particular case, the rotor bearings are subject to heavy vibration, resulting in shorter lifetime of the bearings thereof, and in the worst case, the whole machine. By suppressing the vibration, the forces causing the wear become lower, hence prolonging the lifetime of the machine, reducing the required maintenance effort, and increasing the overall efficiency of the motor.

Under the benefits stated above, it is reasonable to put some research effort in finding a reasonable and cost effective way of rotor vibration mitigation. Rotor vibration is typically caused by some mass unbalance or poor machinery, resulting in a bent or deformed shaft. In electric drives, the major radial vibration occurs at the driving speed of the motor. The traditional passive vibration damping and isolation methods are based on the dissipation of the vibration energy or the change of the natural frequency of the system.[3] In general, these methods are inadequate for tackling the problem, as it would require significant, and usually unrealistic changes in the structure of the rotor to make the desired change in its natural frequency; in essence, these changes would make the structure stiffer. This is especially true with very large machinery, where the size and weight of the motor is already an issue. Even in the cases where it is possible to make such changes, the operational frequency band of the motor would be severely limited —the motor must not be driven at the speeds that correspond to the natural frequencies of the rotor.

In this paper, an experimental study on the active control of radial rotor vibration at a single static frequency is presented. The required control forces are produced by an electromagnetic actuator implemented as additional stator-windings. The characteristics of this actuator and the evaluation of its usability for the given task are described in detail in a previous publication.[4] The focus of this paper is in the design and implementation of a controller that defines the required control action. The proposed controller is essentially a cascade implementation of two existing control methodologies. The first is an LQ-controller, which has many similarities with a method based on frequency-shaped cost functionals,[5] and the second is a convergent controller, which is essentially a frequency domain recursive controller.[6] The validity and the effectiveness of the resulting controller are proved in a testbed implementation. It is shown that by implementing the proposed controller, an electric motor can be driven at its critical speed for an arbitrary long time period —something that cannot be done at all