Preface

Compressors are essential machines for a large number of modern manufacturing processes. Like the hearts pumping life to the production lines, compressors are vital to the operation of key industrial sectors, such as the petrochemical and the mining industries, which rely on compressors for critical tasks, ranging from temperature control to gas transportation and mixing. As a result, there have been continual efforts by the academic and industrial communities to improve the reliability and performance of such turbomachinery as new technologies become available. Active magnetic bearing (AMB) is one such enhancing technology that has been gaining strong momentum in recent years. Among other benefits, the low maintenance requirements and small parasitic energy losses have made these bearings highly desirable for high performance compressors, particularly those designed to operate in harsh or inaccessible environments. Additionally, with their ability to actively change the rotor-dynamic characteristics of the compressor by controlling the bearing parameters in real time, the AMBs can provide a smoother and more reliable operation of the compressor over a wider range of operating conditions.

Stability is a critical factor that limits the performance of compressors. The maximum mass flow output of a compression system is capped by choke, which is generally not a destabilizing phenomenon, and it is caused by the compressed medium reaching sonic conditions. At the opposite end, the minimum mass flow is limited by the compressor instabilities known as stall and surge. Stall is a localized phenomenon that can be observed in some compression systems, and it is sometimes accompanied by a sudden drop in the average compressor output flow. On the other hand, surge is a system-wide instability that is characterized by large amplitude oscillations in the output pressure and mass flow. These oscillations can cause extensive damage to the compressor casing and internal components due to high vibrational loads. They can even lead to a catastrophic mechanical failure of the compressor if they are not addressed properly. A conservative way of dealing with surge is to avoid it, by operating far away from the instability. A more efficient way is to implement an active method to stabilize surge and stall, so that the stable operating region of the compression system is extended, resulting in both higher productivity and safer operation.

Unfortunately, a majority of current compressors operate conservatively to avoid surge. In other words, many compressors trade the peak performance at the maximum pressure rise for the stability at the higher mass flow rates. The focus in surge avoidance is on guaranteeing the mechanical integrity of the machines and the safety of the work place by keeping a precautionary margin between the operating output flows and the known surge points. Additionally, a reset mechanism is built in the system that quickly releases the built-up pressure in the compressor if surge is detected by the different safety triggers. An active surge controller, on the other hand, stabilizes the compressor flow during the initiation of surge, effectively extending the operational range of the compressor with no loss in performance. The implementation of a control mechanism is much rarer in industrial applications than the surge avoidance strategies for several reasons. The main reason is that the modifications to compressors in the field required for the installation of a surge control mechanism are very often complicated and involve very specialized equipments. More importantly, there has not been an univocal experimental demonstration of the potential benefits that an effective surge controller could offer to an actual industrial-size compressor.

Recently, promising results have been presented in the literature on an active surge control scheme that modulates the impeller position to stabilize the flow in an AMB supported single stage centrifugal compressor. With the AMB acting as a high bandwidth actuator to regulate the displacement of the impeller, the compressor flow states can be restored to the equilibrium operating point during the early stages of the surge instability, when the amplitude of the limit cycle is relatively small. The main advantage of this active surge control scheme is that it can be easily implemented in existing AMB suspended compressors, generally with a simple modification in the control software.

The purpose of this book is to present the fundamentals on the integration of the AMBs for the suspension of the rotor in compressors, and how this relatively new bearing technology can be employed to actively control and potentially eliminate the compressor surge. The material presented here is intended to serve as a comprehensive reference in the areas of compressor surge control and AMB application in turbomachinery. For readers who are unfamiliar with compressors, rotor dynamics and magnetic bearings, brief introductions to these topics are presented in the earlier chapters of this book. A brief discussion on compressors and compressor instabilities is presented in Chap. 1, where the literature on the surge modeling and control is also reviewed. Chapter 2 contains a review of the basic theories and tools in the study of rotor dynamics. Chapter 3 presents a brief discussion on the operating principles of the AMBs and a summary of the potential benefits that come from the implementation of this bearing technology in compressors. Both Chaps. 2 and 3 are intended to be a self-contained reference for control engineers.

In order to develop the theory in a physical context, and to provide experimental validation of the theory developed throughout this book, an industrial-sized AMB suspended compressor system was designed, constructed and commissioned for the study of surge control. A thorough description of this compressor test rig is presented in Chap. 4. This description includes the integration of the AMBs to the compressor for rotor support and for surge control. The derivation of the dynamic models for both the AMB/rotor system and the compression system flow, along with their experimental validations, are presented in Chaps. 5 and 7. The experimental identification of the system dynamics included in these chapters will demonstrate that the assumptions made in the derivation of the mathematical models are sound. These models will serve as the basis on which the AMB levitation controller and the active surge controller are designed, in Chaps. 7 and 8, respectively.

In the design of the AMB levitation controller, performance and robustness specifications that are desirable for AMB suspended compressors are included in the discussion. In the design of the surge controller, the performance degradation of the surge controller due to dynamic limitations in the AMB system will be studied. For both controllers, the theoretical derivation is accompanied by the experimental data to show their effectiveness in industrial-size compressors.

Finally, it is important to note that this book is not intended to be reference material for general design and operation of compressors. There exists an extensive list of excellent references on the topics of compressor design and flow modeling. Instead, this book is intended to serve as a guide for the application of the AMB technology in turbomachinery, and to demonstrate the advantages that this rotor support system can provide in the stabilization of the compressor surge for a particular group of single stage centrifugal compressors. Since active magnetic bearings play a central role in the surge control method to be presented in the book, their theory and applications are extensively discussed. The stabilization of the compressor surge is mainly discussed from a control theory perspective.

This book builds on years of work invested by many engineers and scientists from the Rotating Machinery and Controls (ROMAC) Laboratory at the University of Virginia. The authors would like to acknowledge those who participated in the different stages of the research presented here. The derivation of the theoretical concept for the surge control strategy presented here, as well as the design and the initial preparation of the experimental setup, was executed in the early stages of this project by the team led by Professor Eric Maslen and Dr. Dorsa Sanadgol. The experience in industrial compressors brought by Kin Tien Lim and the advice of Professor Chris Goyne in experimental fluid dynamic testing came to be of great value during the construction and commissioning of the compressor test rig. Finally, the authors would also like to express their appreciation for the generous donations made by Kobe Steel Ltd., Kobe, Japan, and the constant support and funding by the ROMAC Laboratory and its industrial partners around the world.

Charlottesville, Virginia, USA

Se Young Yoon
Zongli Lin
Paul E. Allaire

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