

Preface

Electrical machines and drive systems account for about 46 % of all global electricity consumption, resulting in about 6,040 Mt of CO₂ emissions. This is by far the largest portion of electricity use, easily outstripping lighting, which takes up to 19 % of the world's demand. Therefore, the energy efficiency of electrical drive systems is very important for the energy conservation, environment and sustainable development of the world.

Electrical drive systems are key components in many modern appliances, as well as industry equipment and systems. In order to achieve the best design objectives, such as high performance and low cost, various optimization methods have been developed for design optimization of electrical machines and drive systems. The traditional design optimization is at the component level, e.g. optimization of a motor design or the parameters of a control algorithm. However, modern appliances or systems demand that the drive systems be specifically designed and optimized to provide full support to their best functionalities with multiple performance indicators. For such applications, the authors developed an application-oriented multi-objective system-level design optimization method. Because of the complexity of drive system design that involves many disciplines, such as electromagnetics, materials, mechanical dynamics including structural, thermal, and vibrational analyses, power electronic convertors, and control algorithms, a multi-level optimization method was developed by the authors to improve the effectiveness of the optimization of electrical machines as well as drive systems.

On the other hand, the real quality of motors and drives in mass production highly depends on the available machinery technology and those unavoidable variations or uncertainties in the manufacturing process, assembly process and operation environment. The manufacturing precision and tolerances are two main issues in the manufacturing process, including mainly the variations of material characteristics, such as magnetization faults in terms of magnitude and magnetization direction for permanent magnets (PMs), and density and permeability of soft-magnetic-composite (SMC) stator cores manufactured by powder metallic moulding technology, and dimensional variations of parts of drive systems, such as

the rotor, stator, winding and PMs. The assembly process variations mainly include the lamination of silicon steel sheets and misalignments of stator, rotor and PMs. The operating uncertainties mainly include the load variations, changes of electrical and mechanical parameters, such as the changes of resistance and inductance due to the operational temperature rise, and fluctuations of drive voltage.

Limited by these variations in the practical machinery technology, an aggressively optimized design may be difficult for high-quality batch production and end up with high rejection rates. Similarly, variations in system parameters and operational conditions may also lead to sub-optimal performance, and in a severe case, even instability. To solve this type of problems, the methodology of Six-Sigma quality control can be adopted to develop a robust design optimization method to guarantee the high-quality batch production of drive systems.

Based on many years of research experience of the authors, this book aims to present efficient application-oriented, multi-disciplinary, multi-objective, and multi-level design optimization methods for advanced high-quality electrical drive systems. The multi-disciplinary analysis includes materials, electromagnetics, thermotics, mechanics, power electronics, applied mathematics, machinery technology, and quality control and management.

This book will benefit both researchers and engineers in the field of motor and drive design and manufacturing, thus enabling the effective development of the high-quality production of innovative, high-performance drive systems for challenging applications, such as green energy systems and electric vehicles.

This book consists of eight chapters, based on our several research projects, and covering the aspects of electrical machines, drive systems, high-quality mass production and application-oriented design optimization methods.

Like most books, this book starts with an introduction in Chap. 1 to provide an overview of application fields of electrical machines and drives as well as the state-of-art design optimization methods for electrical machines, drive systems and high-quality mass production.

Chapter 2 presents an overview of the design fundamentals of electrical machines and drive systems. Design analysis models in terms of different disciplines (domains) are investigated in this chapter, such as the analytical models or methods for electromagnetic and thermal analyses, magnetic circuit model for electromagnetic analysis, finite element model (FEM) for all electromagnetic, thermal and mechanical analyses, and field-oriented control and direct torque control algorithms for the control systems.

Chapter 3 reviews the popular optimization algorithms and approximate models used in the optimization of electrical machines as well as electromagnetic devices. Optimization algorithms include classical gradient-based algorithms and modern intelligent algorithms, such as genetic algorithms, differential evolution algorithm and multi-objective genetic algorithms. Approximate models include response surface model, radial basis function model and Kriging model.

Chapter 4 presents the design optimization methods for electrical machines in terms of different optimization situations, including low- and high-dimensional, single and multi-objectives and disciplines. Five new types of design optimization

methods are presented to improve the optimization efficiency of electrical machines, particularly those PM-SMC motors of complex structures. They are the sequential optimization method (SOM), multi-objective SOM, multi-level optimization method, multi-level genetic algorithm and multi-disciplinary optimization method.

Chapter 5 develops the system-level design optimization methods for electrical drive systems, including single- and multi-level optimization methods. Not only the steady-state performance parameters but also the dynamic motor performance parameters, such as output power, efficiency and speed overshoot are investigated at the same time.

Chapter 6 presents a robust approach based on the technique of Design for Six-Sigma for the robust design optimization of high-performance and high-quality electrical machines and drive systems for mass production. A multi-level optimization framework is presented.

Chapter 7 develops the application-oriented design optimization methods for electrical machines under deterministic and robust design approaches, respectively. Applications including home appliance and hybrid electric vehicles are investigated.

Chapter 8 concludes the book and proposes the future works for further research and development.

Four electrical machines and several benchmark test functions/problems are employed throughout the book to verify the efficiency of those proposed design optimization methods. Those machines are a PM-SMC transverse flux machine, a PM-SMC claw pole motor, a surface-mounted PM synchronous machine and a flux-switching PM machine. All the design optimization models including FEM and thermal network model are validated by experimental results. Therefore, the proposed methods and obtained optimal solutions are reliable.

This book can be used as a reference for designers and engineers working in the electrical industry and undergraduate and graduate students majoring in electrical engineering. Students majoring in automotive engineering and mechanical engineering may also find this book useful when dealing with vehicle motor and drive related design, optimization and control development.

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