Research on High Efficiency Designs and Applications of Permanent Magnet Type Synchronous Machines

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【Out-line】

This thesis is a summary of the author's research/development and technological achievements (patented technology) on permanent magnet type synchronous machines (hereafter termed PMSM) at Yaskawa Electric Corporation since 1983, combined with three years of research contents of the doctoral program at the university. In this thesis, the focal point of increased efficiency research on armature winding methods, especially evaluations on increased efficiency design of the electromagnetic portion composed of fractional slot winding method and high energy magnets. Further, the achievements on this increased efficiency design evaluations will be explained with three representative load characteristics of the electric machines, “constant torque load characteristics”, “squared diminishing torque load characteristics”, and “constant output load characteristics” reflected on application development examples. At the end of this thesis, comparisons are made between line-starting type PMSM which was subject to the research during the three years of the doctoral program, magnet-less segment type switched reluctance motors, and the main subject of this thesis PMSM to evaluate the technological position of the PMSM among the rotary armatures. Hereafter, summary of each chapter will be described.

Chapter 1:

As the preface, the purpose, the background, and the issues regarding the PMSM research in order to proceed with the thesis will be described.

Chapter 2:

In this chapter, the PMSM optimal design procedure which constitutes the foundation of PMSM high efficiency designs throughout the thesis is evaluated. Motor constant (K_m) equation and torque equation are derived, performance goodness factor (hereafter called PGF) defined as motor constant density (K_m/Volume), and the optimum device physique (L_t/D_o) when the motor constant density is maximized with pole count as parameter are derived. At this time, the optimum device physique (L_t/D_o) with “maximum torque density” is also determined to compare both in order to clarify the differences of each evaluation approach. In this research, the evaluation results of the maximized motor constant density optimization designs are reflected on the practical application research described later.

Chapter 3:

In this chapter, the fundamental concept of fractional slot winding from the viewpoint of efficiency increase research is explained with the slot star diagram, and the issues and countermeasures regarding the applications are described. Also, the effects of irregular pitch winding of fractional slot winding which were evaluated throughout my enrollment period are described, and the effectiveness of the slot star diagram analytical method and uneven pitch winding method are described.

Chapter 4:

Hereafter, the technical evaluation results expanded over the PMSM applications are described. In this chapter, the evaluation contents of PMSM technology expanded on high thrust force and low torque ripple linear motors as the application example of the constant torque load characteristics are described. Especially with the high thrust force linear motors, contents of patent acquired attraction force canceling armature with directional electromagnetic steel plates of improved thrust characteristics are described. Furthermore, empirical results of torque ripple reductions of patent acquired cogging canceling designs are described.

Chapter 5:

In this chapter, as an application example of the squared diminishing torque load characteristics, the PMSM expanded over large wind mill generators is described. In this research, patent acquired “fractional slot winding method (1<q<3/2)" is used to improve total harmonic distortion (THD) of electro motive force combined with a matrix converter to be evaluated in order to perform a verification test on grid current THD characteristics. As the result, the initial goal clearing result is obtained.

Chapter 6:

In this chapter, as the application example of the constant torque load characteristics, the PMSM expanded over machine tool spindle motors is described. The research contents describe shortened machining times and improved machining capabilities of machine tools by applying the interior permanent magnet type synchronous motors with patent acquired switched winding control motor designs in place of induction motors on spindles.

Chapter 7:

In this chapter, positioning of PMSM discussed so far within the “AC motor electromagnetic structure matrix” described in this chapter is evaluated by comparing with self-starting PMSM with purpose of clearing IEC-3 and IEC-4 standards during the enrollment period, and segment type switched reluctance motor as magnet-less motor. As one of the conclusions, when evaluating the positioning of the PMSM, comparisons of “motor constant density” described in the chapter 2 of this thesis, “constant output index”, and “constant output index density” will be required.

Chapter 8:

Finally, the thesis is concluded by summarizing the entire thesis with the chapter 8. As such, the author has attempted to clarify the essence of the PMSM developed along the advancements of control technology and Nd-Fe-B characteristics improvements by comparing with various types of motors. As the result, the outcome of technological patent acquisitions developed in various research themes, and generation and proposals of AC motor structure matrix are described.