TANTA UNIVERSITY
FACULTY OF ENGINEERING
DEPARTMENT OF ELECTRICAL POWER
AND MACHINES

DESIGN AND ANALYSIS OF A TWO PHASE SWITCHED RELUCTANCE MOTOR

A Thesis Submitted by

Eng. Waleed Abd-Allah Ibrahim Afifi
B. Sc. In Electrical Power & Machines, May 2000

For the Award of the Degree of Master of Science
In

"Electrical Power and Machines"

Supervisors

Prof. Dr. Mohamed A. EL-Khazendar

Professor of Electrical Machines &
Former Dean of the Faculty of Engineering, Tanta University

Prof. Dr. Mahmoud M. Khater

Professor of Power Electronics,
Faculty of Engineering, Menoufiya University, Shebin El-Kom

2008

Acknowledgement

I wish to express my most sincere gratitude and appreciation to Professor Dr. *Mohamed El-Khazendar* and a deep gratitude and a warm thank to Professor Dr. *Mahmoud Khater* for his encouragement, constant support, and valuable guidance towards completion of this thesis. I also, convey my acknowledgement with special thanks to all staff members of the department of electrical power and machines faculty of engineering in Tanta University and Menoufiya University for their assistance and useful discussions. I wish to dedicate this work to my parents, sister, my wife, and honey daughter (*Salma*).

Eng. / Waleed A. Afifi

CONTENTS

LIST OF FIGURES

SYMBOLS

A	Magnetic vector potential
a	Cross section area
B	Flux density
C	Stator core width
Cr	Commutation ratio
D	Stator inner diameter
D_o	stator outer diameter
D_r	Rotor outer diameter
d_{sh}	Shaft diameter
e	Back emf
g	Air gap length
g_i	Inter polar air gap length
H	The magnetic field intensity
I_{dc}	Dc link current
i	Phase current
J	Current density
Je	Excitation current density
k	Phase number
L	Inductance
L_a	Axial core length
L_{min}	Minimum inductance
L_{max}	Maximum inductance
N_r	Number of rotor poles
N_s	Number of stator poles
n	Speed of rotating motor
p	Number of stator poles per phase
P_d	Developed power
P_{cu}	Copper losses
P_{in}	Input power
P_m	Mechanical power
P_{mag}	Magnetic power
pw	Pulse width
q	Number of phases
R	Phase resistance

S	The element area
T	Torque
T_{av}	Average torque
T_{ph}	Number of turns per phase
t	Time
V	Supply voltage
V_k	The phase voltage
W_{co}	Coenergy
β_r	Rotor pole arc
β_s	Stator pole arc
ψ	Flux linkage
θ	Rotor position angle
θ_{ext}	Extinguish angle
θ_{off}	Turn off angle
θ_{on}	Trigger angle
τ_r	Rotor pole pitch
τ_s	Stator pole pitch
ϕ	Magnetic flux
ω_m	Rotor speed
δ	Step angle

Summary

This thesis investigates and compares the operating performance of the two phase switched reluctance motor with four different rotor designs having different air gap geometries. An analysis for the magnetic circuit is introduced and a two-dimensional finite element procedure to predict the nonlinear flux linkage characteristics for different rotor designs. These characteristic curves are obtained numerically at different rotor angles and different current levels for the four designs under consideration and they are used to predict the static torque characteristics for these designs. A computer simulation procedure is devised to determine the operating performances for the four motor designs based on the predicted flux linkage and static torque characteristics. A comparison is held from the point of view of the torque developed at different speeds, motor efficiency and torque per ampere productivity of the different designs. The two-stepped air gap design proved the superiority over other configurations.

ABSTRACT

The 4/2 pole, 2-phase configuration of switched reluctance motors is characterized by its simple motor construction and simple power electronic circuit topology. This motor is known with different air gap geometries to enhance its starting performance. This thesis investigates the operating performance of this motor type with four different rotor designs having different air gap geometries. These configurations are the regular air gap design, the one step air gap design, the two steps air gap design and the tapered air gap design. A common frame size and similar number of turns per phase are considered for the four different designs. A numerical approach utilizing finite element magnetic circuit analysis method to predict the flux linkage and static torque characteristics for different rotor designs is carried-out. A nonlinear mathematical model is developed for the 4/2 pole, 2-phase SRM and implemented in a series of computer simulation programs based on the data obtained from finite element analysis to predict the operating performance of the four different motor designs. A comparative study is held between the four different designs under investigation from the point of view of torque production, current drawn from the dc mains, torque per ampere capability, and motor efficiency.

The thesis consists of six chapters, list of references and an Arabic summary.

The **first chapter**, introduces an introduction about SRMs. It contains their construction, different configurations and principle of operation. It introduces also their advantages, disadvantages and applications. A literature review for the different topics covered recently by research is also

included. This chapter ends with introducing the main objectives of the present thesis.

In **chapter two**, different motor designs under consideration are introduced. Different methods for determining flux linkage characteristics are discussed. Finite element method for magnetic circuit analysis is introduced and implemented for analyzing the different motor designs under consideration. A sample of flux linkage distributions for all designs is presented along with the flux linkage characteristics as a function of both armature current and rotor position angle. The static torque characteristics are also predicted and presented.

Chapter three is devoted to mathematical modeling and simulation of the SRM designs under consideration. It firstly introduces the principle of energy conversion within an SRM, and then introduces the different approaches for the analysis of SRMs. These approaches are discussed in details and then implemented in a computer simulation program to predict the motor operating performances.

Chapter four presents a comparative study between different motor designs under consideration based on the results obtained from the simulation program. In this chapter torque-speed, current-speed, torque/current-speed and efficiency characteristic curves for different designs are presented and compared. These characteristics are obtained at different duty ratios for motor excitation pulses. A comparison is held from the point of view of the torque developed at different speeds, motor efficiency and torque per ampere productivity of the different designs.

Chapter five introduces an experimental study for the present theses. In this chapter the construction steps of the experimental motor, power converter, position sensors and gate drivers are presented. A sample of experimental results is presented along with the corresponding simulation results.

Chapter six introduces the main conclusions drawn from the present from the present thesis. Some points are also proposed for future research as an extension for this work.

A list of the relevant references is included at the end of the thesis.

Chapter 1

((Introduction))