

THE FINITE ELEMENT METHOD APPLIED
TO ROTATING ELECTRICAL MACHINES

BY

PER BERGET

JANUARY 1978

THE UNIVERSITY OF TRONDHEIM
THE NORWEGIAN INSTITUTE OF TECHNOLOGY
ELECTRICAL ENGINEERING DEPARTMENT
POWER SECTION
TRONDHEIM, NORWAY

THE FINITE ELEMENT METHOD APPLIED
TO ROTATING ELECTRICAL MACHINES

CONTENTS

	Page
PREFACE	III
SUMMARY	V
1 INTRODUCTION	1
2 BASIC THEORY	4
2.1 Equations and Methods	4
2.1.1 Analytical methods	6
2.1.2 Numerical methods	10
2.2 The Finite Element Method	14
2.2.1 The finite element method in its basic form	14
2.2.2 Time varying magnetic fields	21
2.2.3 Electrical connections of elements	27
2.2.4 I^2R losses	34
2.2.5 Sinusoidal magnetic fields	36
2.2.6 Boundary conditions	40
2.2.7 Bandwidth	50
2.2.8 Adaption of the element method to rotating electric machines	55
2.2.9 Torque calculations and rotor motion	62
3 COMPUTER PROGRAMS	70
3.1 Program Structure	70
3.2 Comparison between Real and Complex Calculations	87

4	APPLICATIONS	89
4.1	Additional Losses in Asynchronous Machines	89
4.2	Synchronous Machine Damper Bar Analysis	92
4.2.1	General considerations	92
4.2.2	Voltage between damper winding rings	94
4.2.3	Sample calculation	98
4.2.4	Results of the calculations	101
4.2.5	Discussion of results	108
	Diagrams of results:	
	Damper bar currents - unloaded	118
	Damper bar currents - rated load	121
	Oscillations at transient load	127
	Air gap flux density	129
	Torque curves	132
5	CONCLUSION	133

APPENDIX

A1. Solution of the integral

$$I = \iint_{\Delta} (a_{\ell} + b_{\ell}x + c_{\ell}y) (a_m + b_mx + c_my) dx dy \quad 137$$

REFERENCES	148
------------	-----