A MATHEMATICAL MODEL OF A DC MACHINE

By

Ning Chuang, B.E.(Hons), MIEAust, CPEng

School of Engineering

Submitted in fulfillment of the requirements for the degree of

Master of Engineering Science (Research)

UNIVERSITY
OF TASMANIA

2004

Statement of Originality

I declare that this thesis presents my own original work and contains no material which has been accepted for a degree or diploma by any university or other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material previously published or written by another person, except where due acknowledgement is made in the text of the thesis.

……

Ning Chuang
October 2004

Statement on Authority of Access

This thesis may be made available for loan and limited copying in accordance with the *Copyright Act* 1968.

…….

Ning Chuang
October 2004
School of Engineering
University of Tasmania, TAS 7005
Australia

ABSTRACT

This research aims to determine how a mathematical model may predict the effects of a shorted and/or opened armature coil on a d-c machine. A mathematical model and a simulating computer were developed for a particular 0.375 kW d-c machine under both healthy and faulty conditions.

The model was based on the coupled-coil theory, with a set of first order differential equations that were solved in the time domain. New techniques for measuring inductances on a particular d-c machine were implemented in order to acquire data for development of a simulation. The research found that measurements of armature current waveform, including commutator ripple, agreed quite well with the simulated waveform.

Acknowledgement

During my extremely busy but unforgettable period of study for this research, I have received lots of help and support. I wish to take this opportunity to give my thanks to the following organisations and individuals.

Firstly, I would like to thank the Head and the Deputy Head of the School of Engineering, Professor Frank Bullen and Dr Greg Walker, for their support in my research, so that I could complete this work in such a short time.

Secondly, my sincere thanks should be given to my research supervisor, Dr Richard Langman, and my primary supervisor, Dr Tim Gale. I would like to thank them for their understanding, support and very kind help during the difficult time of my studies. Sometimes I kept them very busy with many issues regarding my work and its progress. I have enjoyed working with Richard in the Power Laboratory in solving some difficult problems with the machine. I also received lots of encouragement and suggestions from Tim. I am so glad that I was able to develop a very close friendship with my supervisors, so that my research project could be kept on the right track to meet the tight deadline.

I would also like to thank Dr Martin Ringrose and Associate Professor Michael Negnevisky, for helping and supporting me while I was learning MATLAB/SIMULINK. I very much appreciate the opportunity that enabled me to start using SIMULINK when I was working for Martin last year.

I also would like to thank a number of the technical support staff in the school, Steve Avery, John McCulloch, Glenn Mayhew, Bernard Chenery, Russell Twining and David Benda. Their help with my research has been very much appreciated.

I wish to give special thanks to a retired lecturer in the School of Engineering, my former university supervisor, Bob Wherrett who has given me support and assistance every time I was faced with various problems.

I am also grateful for Dr Sam Ho's kindness in allowing me to have a copy of the reference papers from his research in 1999. I would also like to thank Prof. Dieter Filbert in Germany for sending me a copy of his published papers.

In the School other postgraduates Andrew Barton, Simon Locke, Andrew Greenhill, Warwick Gillespie, Alan Henderson, Tzuu Bin Ng, Phi Anh Phan, Patrick Burke and Mark Lim have given me varied help and moral support. I often had conversations with them, sharing our research experiences or trying to solve technical problems. I would like to extend them my appreciation.

At the beginning of my research, Hydro Tasmania's Peter Fluckiger helped me by translating a paper in German, and TAFE teacher Rosalind Goodsell translated a French paper. These two papers were very useful to my research, and their many hours' work on technical translations relating to electrical machines has been much appreciated. Here also, my thanks should go to them.

While I was working on MATLAB/SIMULINK, I received assistance from the Applications Engineer from Ceanet, David Willingham, in relation to problems with my model. It may have taken longer to get my model working, without his valuable help, and I would like to thank him as well.

I also need to pass my thanks to the Science Librarians of the University, Chris Evans and Sandy von Allmen, for their very kind help when I was searching my references for this research. It was very hard to find appropriate references in this field, but I found most of them with Chris's and Sandy's help.

I would like to thank SEMF drafter David Belanich for helping me to learn AutoCAD, so that I could draw my many circuit diagrams in CAD within a short time.

Finally, my thanks should be given to my loved dog, Smudge, even though he could not directly help me in my research. But I always found a solution for the problems in my complicated model when I was out walking with Smudge, so I thought he should also be included in these acknowledgements.

Contents

Contents 1

Chapter 1 Introduction 4
1.1 Background of the research 4
1.2 Summary of this research project 4

Chapter 2 Literature review 6
2.1 Perspective on failure in d-c machines 6
2.2 Condition monitoring techniques for d-c machines 8
2.3 Initial studies on d-c machines 10
2.4 The effect of commutation on d-c machines 15
2.5 Technical methods of measuring machine parameters 20
2.6 Mathematical modelling techniques for d-c machines 20
2.7 Summary of literature review 25

Chapter 3 Equivalent circuits of the Davey machine 27
3.1 Basic Principles of modeling a d-c machine 27
3.2 7-coil and 5-coil equivalent circuits 29
3.3 Analysis of commutation during one revolution 32

Chapter 4 Measurement of inductances on the Davey machine 35
4.1 The need for a d-c inductance measurement 35
4.2 The d-c method of measuring inductance 35
4.3 Modifications of the basic DCIB method for measuring the self-inductance of armature sub-coils 39
4.4 Measuring other self-inductance on the machine 41
4.5 Measuring mutual inductance on the machine 43
4.6 Field current required for the Davey machine 47
4.7 Conclusion 47

Chapter 5 A mathematical model 50
5.1 Establishment of armature voltage equations 50
5.2 Preliminary model design techniques 58

5.3 Varying brush resistance programming in the model 58
5.4 Connection schemes 64
5.5 Implementation of the model in MATLAB 67
5.6 Conclusion of the model 69

Chapter 6 Experimental results 70
6.1 Load testing on the Davey machine 70
6.2 Armature and field current waveforms comparison 70
6.3 Problem solving and sensitivity analysis 75
6.4 Analysis and assessment on model's performance 77

Chapter 7 An armature shorted coil model 79
7.1 Armature winding with one shorted coil 79
7.2 The shorted coil position after 22.5^0 rotation 84
7.3 Implementation of the one shorted coil model for 22.5^0 of rotor movement 85
7.4 Model's outputs for the shorted coil machine 89
7.5 Test results on the Davey machine with shorted coil 91

Chapter 8 Conclusion of this research and further discussion 93
8.1 Overall review of the research work 93
8.2 Measuring inductance method using a d-c source 93
8.3 A model of the healthy Davey machine 93
8.4 A model of the faulty Davey machine with one shorted coil 94
8.5 Working with models in MATLAB/SIMULINK 94
8.6 Recommendations and future directions 95

References 96

Appendix A Measurements of armature inductance using an a-c source 103
A. 1 Measurement errors in the a-c method 103
A. 2 Saturated and unsaturated inductance data 106

Appendix B-1 A model of the healthy Davey machine 107
Appendix B-2 A model of the rotor position selector for the Davey machine 108

Appendix B-3 A model of the 7-coil circuit for the healthy Davey machine..... 109
Appendix B-4 A model of the 5-coil circuit for the healthy Davey machine..... 110

Appendix C-1 A model of the Davey machine with one shorted coil..... 111
Appendix C-2 A model of the 8-coil circuit for the Davey machine with SC 112
Appendix C-3 A model of the 6-coil circuit for the Davey machine with SC 113
Appendix D-1 Data for the model of the healthy Davey machine.....114
Appendix D-2 Data for the model of the healthy Davey machine.....115