STEADY-STATE BEHAVIOUR OF A MULTIPHASE CHOPPER-FED SEPARATELY EXCITED D.C. MOTOR

by

P.M. SREEKUMARAN NAMBISAN

ELECTRICAL ENGINEERING DEPARTMENT

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TO

THE MEMORY OF

MY

BELOVED FATHER

CERTIFICATE

This is to certify that the thesis entitled "STEADY-STATE BEHAVIOUR OF A MULTIPHASE CHOPPER-FED SEPARATELY EXCITED D.C. MOTOR," submitted by Shri P.M. Sreekumaran Nambisan to the INDIAN INSTITUTE OF TECHNOLOGY, DELHI , for the award of the degree of DOCTOR OF PHILOSOPHY is a record of bonafide research work carried out by him. Shri P.M. Sreekumaran Nambisan has worked under my guidance and supervision for the submission of this thesis, which to my knowledge has reached the requisite standard.

The thesis or any part thereof, has not been submitted to any other University or Institution for the award of any Degree or Diploma.

CMBhatia

Dr. C.M. Bhatia,
Department of Electrical Engineering,
Indian Institute of Technology,Delhi,
New Delhi-110016

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PMSreekumar

- P.M.Sreekumaran Nambisan

SUMMARY

Many limitations of the pulsed-power-fed D.C. motors have been reported time-to-time by Rajagopalan [1], Ewing [2], Robinson [3] and Franklin [7,8]. However, Bhatia et. al.,[5,6] vividly accounted for various losses in the thyristor-fed machines and also suggested the remedies to reduce these losses. Some of these limitations as reported by various authors [2-8] are summarised as under;

i) increased copper and iron losses resulting from the high ripple content in the armature current,

ii) increased commutation difficulties,

iii) increased sparking at the commutator surface and higher noise level.

iv) reduction and phase shifting of the interpole-flux due to the pulsating armature-reaction flux leading to the role of the interpoles to be detrimental to the machine torque-speed characteristics, and

v) increased source current ripple and the source losses.

To combat the above mentioned problems, the design engineers have suggested new design techniques [3,7,8] such as use of full-length laminated interpoles, laminated yoke, reduced number of turns per armature coil, increased number of commutator segments and the use of special grade materials for the magnetic field frame. Although some of these design considerations have been made use of [3] along with suitable filters, the machine performance with sparkless commutation still could not

match with that obtained from the D.C. mains supply. It is therefore thought that these new design suggestion is likely to offset the simple construction features making the machine costlier, without achieving the performance in line with the D.C. mains supply. The use of appropriate filters to improve the performance of the machines under pulsed-power-supply have also been suggested by some authors [4,5]. Bhatia et.al. [5] have reported the successful attempt in obtaining the normal (constant speed) torque-speed characteristics of the single-phase chopper-fed separately excited D.C. motor using suitable filter circuits. However, problems of increase in the weight of the converter, sluggish system-response and higher reactive current are some of the factors which limit the use of high values of the filtering elements. A more attractive proposition is therefore to use the time-shared parallel connected pulsed-power circuits. Arockiasamy et al [10] reported in detail the improved machine performances by the use of multiphase choppers recommending its use against the filter circuits. Ohno [11] and Reimers [26] have also recommended the use of multiphase chopper circuits for the D.C. motor control. Thus, the research work reported in this thesis has been persued both theoretically as well as experimentally on these lines.

The research work reported in this thesis is divided into three parts namely;

i) analytical investigations
ii) developmental work, and
iii) experimental investigations.

These are organised in six main chapters, in addition to the chapters on Introduction and Conclusions. Chapters 2-5, deal with the various analytical investigations, whereas Chapters 6 and 7 cover the other two parts of the research work. These chapters are organised as under:

Chapter-2 gives a general information regarding various types of chopper circuits e.g., their classifications, commutation process, approach for the analysis of the circuit etc. A detailed analysis of an impulse - commutated chopper, which constitutes various phases of the multiphase chopper circuit to be discussed in the subsequent chapters, is also presented. In addition, the limitations of a single-phase chopper circuit and some remedies to overcome these are also discussed.

In Chapter-3, a generalised analysis for the multiphase chopper-fed separately excited D.C. motor has been presented, taking into account the continuous current mode of operation. These generalised expressions enable quick determination of the load current, load voltage, phase current, source current and the free-wheeling diode current waveforms during any part of the chopping period of the multiphase chopper consisting of any number of phases, and operating with any value of mark/space ratio. Since this analysis is complete in all respects, it is an improvement over the analyses reportes so far [10, 15, 26]. The application of the generalised analysis is illustrated by obtaining the analytical expressions for the load voltage and various current waveforms in a four-phase chopper-circuit. The torque-speed characteristics of the chopper-fed separately excited D.C. motor are also predicted in this chapter.

Chapter-4 deals with the discontinuous current mode of operation. In a multiphase chopper circuit of m-phases, either both the load and phase currents or the phase current alone can become discontinuous depending upon the value of the circuit inductance and the mark/space ratio. Analytical expressions are developed for various current and voltage waveforms under the two cases of discontinuous current mode of operation mentioned as above. The analysis of a three-phase chopper-motor circuit with discontinuous armature current is also presented, so as to establish the validity of the generalised analytical expressions developed for the discontinuous load current mode of operation. Further, in this chapter, expression for the minimum value of the series inductance to make the load current continuous in a multiphase chopper circuit is also developed.

Chapter-5 pertains to the analytical investigations made on determining the per-unit ripple content in the load current, and also the values and the weights of the smoothing reactors. The steady-state analysis is developed for the per-unit ripple content in the load current for the given chopping frequency, considering different parameters such as the value of smoothing reactor, the average load current and the mark/space ratio.

Based on the same peak per-unit ripple and the same average load current, the values and weights of smoothing reactors in a multiphase chopper circuit and the single-phase chopper circuit are compared. The ratio of the weights of smoothing reactors in the two cases, namely the multiphase and the single-phase circuits is also studied taking the chopper operating frequency as the variable parameter.

In Chapter-6, the power circuit and the digital trigger-circuit for the four-phase chopper are designed and developed. Based on the size of the smoothing reactor designed in Chapter-5 the per-unit ripple contents in the output as well as source currents and the operating torque-speed characteristics are measured for three cases of chopper-motor combinations, namely the single-phase, the two phase and the four-phase circuits. The characteristics mentioned as above are also measured at different values of the mark/space ratio and for different values of the smoothing reactors to bring out vividly the effects of these on the machine performance. All these results are presented in this chapter and comparison among various cases are brought out. The predicted torque-speed characteristics and per-unit ripple contents in the load currents are compared with the measured values.

To study the effect of the pulsating interpole-flux on the torque-speed characteristics of the multiphase chopper-fed separately excited D.C. motor, the characteristics are measured with the interpole windings normally connected in the circuit and also when these windings are open circuited. Measurements are made for different values of the mark/space ratio and with different values of smoothing reactors and comparison of the torque-speed characteristics under different operating conditions is presented in this chapter.

Chapter-7 deals with the microprocessor implementation of the trigger circuit for the open-loop control of the four-phase chopper. Design of both the hardware and software are presented in this chapter, along with all other performance characteristics of the machine, as well as of the chopper reported in the preceding chapter. These characteristics obtained using the microprocessor based trigger-circuit are compared with those obtained with digital control circuit in order to confirm the successful implementation of the microprocessor control of the four-phase chopper.

In the concluding chapter, Chapter-8, the conclusions arrived at, from the various analytical and experimental investigations are presented. Some suggestions for the future lines of research work are also made in this chapter.

It is hoped that these conclusions and suggestions reported in this thesis may be helpful to the application engineers.

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