

INVESTIGATIONS ON CURRENT TRANSITION IN MHD GENERATORS

by
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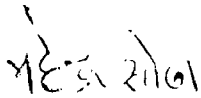
*A THESIS SUBMITTED
IN FULFILMENT OF THE REQUIREMENTS FOR
THE AWARD OF THE DEGREE OF
DOCTOR OF PHILOSOPHY*



**Department of Physics
INDIAN INSTITUTE OF TECHNOLOGY, DELHI
INDIA
SEPTEMBER, 1989**

CERTIFICATE

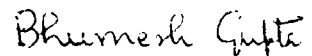
It is certified that the thesis entitled, "**Investigations on Current Transition in MHD Generators**" being submitted by **SATHEESH KUMAR A.** is worthy of consideration for the award of the degree of **Doctor of Philosophy** from Indian Institute of Technology, Delhi and is a record of the bona fide research work carried out by him under our guidance and supervision. The results contained in this thesis have not been submitted in part or full to any other University or Institute for the award of any degree or diploma.



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ACKNOWLEDGEMENTS

I express my deep sense of gratitude to Prof. M.S.Sodha, Prof. D.P.Tewari and Dr. Bhumesh Gupta for their invaluable guidance, affectionate encouragement, profound enthusiasm and painstaking efforts during the course of this work.

I am highly grateful to Dr. Avinash Chandra, Dr. B.K.Sawhney and Dr. R.P.Dahiya for the stimulating discussions and for their contributions too to my education in MHD research.

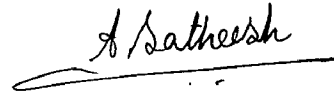
I am extremely thank^{ful} to Dr. A.Ganguli for the fruitful discussions and valuable suggestions, as well as for his keen interest in my work. My thanks are also due to Dr. D.Subba Rao, Dr. G.Umesh, Dr. Y.S.Satya and Dr. R.P.Sharma for their interest in my research work.

It gives me great pleasure to express thanks and to acknowledge my stimulating and highly useful association with Mr. Suram Singh Verma. I also wish to thank my colleagues Mr. Rakesh Panwar and Mr. U.K.Singh and all the members of the Plasma and MHD groups.

I wish to express my gratitude to Dr. Ram Chandra and Dr. Phull (NPL) for their friendly cooperation and help.

Thanks are also due to my friends, especially, Mr. V. Sajeev, Mr. K.C. Harikumar and Lt. Arun K. Varghese, who helped me during the critical stages of my work. Special thanks are due to Mr. Dinesh Bhardwaj for his elegant and painstaking typing of the thesis.

Finally, I express my extreme sense of gratitude to my parents, brothers and sisters and all other relatives who have provided me with abundant affection, love and the necessary moral support for the completion of this work.

A handwritten signature in cursive script that reads "A. Satheesh". The signature is written in black ink and is positioned above a horizontal line.

(A. Satheesh Kumar)

SUMMARY

This thesis presents the investigations on current transport through the cathode boundary layers of slagging (coal-fired), as well as, non-slagging (using hydrocarbon gases as working fluid) channels of MHD generators. In MHD generator channels, current transition occurs from a diffuse mode to an arc mode at large current densities, which are of practical interest. Arcing causes enhanced erosion of the electrodes due to local heating in the arc-spots and hence, leads to a decrease in the electrode life-time, which is one of the most serious problems in open cycle MHD generators. Therefore, a better understanding of the current transport mechanism and the determination of the critical values for the transition, of the parameters involved, become extremely helpful in predicting the mode of current transport through the boundary layers in MHD generator channels.

Studies have been made, considering both the thermal boundary layer and the cathode electrostatic sheath caused by the difference in electron and ion mobilities. An analytical prediction has been made for the critical values of potential drop and current density for the cathode electrostatic sheath breakdown based on the assumption that a constant electric field is required for the breakdown of the sheath. Thermionic emission of electrons from the seed deposited cathode has been taken into consideration in the analysis. The predicted values have been found to compare well with the experimental data.

The Breakdown of the cathode electrostatic sheath can be caused by the occurrence of electrothermal instabilities in the narrow and cold electrode boundary layers. A stability analysis has been carried out for the onset of instability at the electrode surface and the critical values of current density and electric field have been obtained. The analysis has also been able to predict the work function (ϕ) of the seed deposited electrode surface, as a function of the electrode temperature. The value of ϕ was found to vary from 1.59 eV to 1.93 eV for an electrode temperature variation from 850°K to 1100°K.

At high current densities, the requirement of current continuity from the gas to the electrodes, necessitates the formation of a constricted (or arc) discharge at the walls of an MHD generator channel. The electrothermal instabilities which cause the cathode sheath breakdown, can arise either at the electrode plasma interface or at the electrostatic sheath-edge, which occurs when a high current density is forced through the cool gas dynamic boundary layer near the electrode. A perturbation analysis has been carried out to study this gas phase constriction. However, the values of the critical current densities and potential drops required for this sheath-edge breakdown came out to be much less than that required for the breakdown occurring near the electrode surface. Therefore, it is predicted that the perturbation which occur at the sheath-edge at low potential differences will only lead to fluctuations in the

observable parameters. These fluctuations get stabilized as the potential difference increases and the current transport remains uniform till the critical values for breakdown from the electrode surface are reached.

In coal-fired generators, the presence of the slag layer on the electrodes significantly influences the current transport in the near-electrode regions. Electrothermal instabilities can cause the breakdown of both the slag layer, as well as, the plasma electrostatic sheath. The stability analyses carried out separately for the slag layer and the plasma sheath, have been able to predict the mode of current transport through both the layers and also the region of initiation of breakdown. It has been found that for cathode temperatures below 1000°K , the slag layer breakdown should always occur since the critical current density for this breakdown is less than the thermionic emission current density from the slag surface (which is always at a high value). This breakdown may cause the formation of holes in the slag layer. At cathode temperatures above 1000°K , the slag layer electrical conductivity becomes quite high resulting in very high critical current density values for breakdown. Hence, it is possible to have a diffused current transport through the slag layer at very high electrode temperatures, irrespective of whether it is arcing or not in the plasma layer. This can explain the disappearance of arc spots observed in experiments at electrode temperatures above 1400°K .

Finally, this thesis contains a study of the arcs formed in the near-electrode regions of slagging channels in coal-fired MHD generators. A model for the arc, which includes an arc column, spreading region and a diffusion region have been considered. The arc dimensions (diameter of the arc column, arc height etc.) and the arc characteristics obtained have been found to compare very well with the experimental data. Arc size is found to decrease with increasing electrode temperature but increases with increasing arc current. It was found that increasing the plasma core current density increases the current per arc spot as well as, the dimensions of the spot. It was also observed that the boundary layer thickness strongly influenced the arc characteristics. An increase in boundary layer thickness leads to large increase in the values of arc current and dimensions of the arc which are in conformity with earlier investigation on arc made elsewhere.

A brief summary highlighting the original contributions and the new results

The work presented in this thesis describes the phenomena of the breakdown of the cathode electrostatic sheath and the transition of the current transport from a diffuse mode to an arc mode, and also gives a model for arcs burning at the cathode having a slag layer present at the surface. A theoretical study of the cathode electrostatic sheath, including the effects of electrode insertion¹, revealed for the first time, that the insertion of the electrodes not only produced higher current densities but also reduced the cathode potential drop for the breakdown of the sheath. Further, it was found that the increased thermionic emission from the cathode surface resulted in obtaining higher current densities in the diffuse mode but the total potential drop in the channel also showed an increase.

A stability analysis, which took into account, for the first time, the effects of thermionic emission from the cathode surface, was carried out to study the occurrence of electrothermal instabilities leading to the breakdown of cathode electrostatic sheath². With the help of the stability analysis, it was possible, for the first time, to obtain the value of the work function of the composite electrode surface as a function of the electrode surface temperature and also, to predict the predominant crystallographic orientation of the surface. The perturbation analysis carried out in the presence of a slag layer³, not only predicts the region of initiation of the electrothermal instability but also, gives an explanation for

the transition from a constricted discharge to a diffused discharge, in the slag layer, and the disappearance of arc spots, which have been observed experimentally. This study also suggests an explanation for the appearance of holes on the slag surface.

A stability analysis carried out to study the occurrence of electrothermal instabilities at the electrostatic sheath-edge⁴, shows that the occurrence of such an instability at the sheath-edge is possible only at very low cathode potential drops. Further, this instability at the sheath-edge cannot cause the transition to arc mode, but only causes temporary fluctuations in the values of observable parameters.

Finally, a model for arcs burning at the cathode, having a slag layer present at the surface⁵, has been presented. This makes it possible to have an estimate of the values of the arc parameters, for arcs occurring in the channels of coal-fired MHD Generators, which are of much practical importance.

The work has resulted in the following publications which have been referred to above.

1. J. Phys. D. 21, 590 (1988) Chapter II.
2. J. Appl. Phys. 66, 1690 (1989) Chapter II.
3. J. Phys. D. 23, 509 (1990), Chapter IV.
4. Electrothermal Instability in MHD Generators, Communicated (1990) Chapter III.
5. An Arc Model for Slag Coated Electrodes, Communicated (1990) Chapter V.

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