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REAL MACHINE EFFECTS IN THE MHD INDUCTION GENERATOR*

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Abstract

The MHD induction generator has been proposed for use in liquid metal power generation systems[1,2,3] using a condensing ejector[4] or other form of liquid acceleration.[5] In this paper real machine effects in the induction generator are analyzed to determine the conditions under which this machine may be successfully utilized in a liquid metal power system. Both land based and space vehicle applications are considered. Attention is confined to the case of flat, linear geometry and a channel of constant cross-sectional area. Extension to other situations, such as the variable area generator in which dynamic head is utilized in the energy conversion process, is presently under consideration. The terminal properties, power-flow relations, and steady-state performance characteristics are determined for a machine of finite length with a viscous, incompressible fluid, and implications of the results obtained are discussed for several examples.

The theory for the infinite-length machine with a constant fluid velocity has been previously presented.[6] The extension of this theory to cover both symmetric and antisymmetric exciting currents shows that the power densities in the antisymmetric case may be many orders of magnitude less than with symmetric excitation, and that antisymmetric excitation is accordingly not acceptable for power generation.

The inclusion of fluid viscosity in the theory changes the velocity profile and the power flow, besides adding viscous loss. Laminar flow solutions are obtained using an approximate set of equations. For a narrow channel in which the magnetic field is constant across the channel, a Hartmann velocity profile is obtained with an effective Hartmann number based on the rms magnetic field. Viscosity increases the mechanical power required to drive the flow due to circulating currents and viscous loss without changing the electrical output power of the generator. For large variations in the magnetic field across the channel, numerical solutions are required. The power flow is drastically altered from the constant velocity case, since the boundary regions determine the behavior, to the extent that generator operation with an acceptable efficiency is not possible.

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The fluid flow in a practical MHD generator will be turbulent. Little is known about turbulent MHD flows with either d-c or a-c magnetic fields, yet both the velocity profile and the viscous loss are required for the design of a generator. Approximate results can be obtained using boundary layer theory until experimental data becomes available. The analysis is applicable to channel flows with either d-c or a-c magnetic fields provided the magnetic field is constant across the channel. For laminar flow it yields an approximation to the Hartmann profile. For turbulent flow the analysis gives both a velocity profile to use in studying the power flow and a friction factor. The friction factor lies between the ordinary hydraulic value[7] and the results of Harris[8] for MHD turbulent flows, as it should since Harris includes both viscous losses and circulating-current losses in his definition. The friction factor does not give the correct viscous power loss for MHD flows, but is high by about a factor of two.

The finite-length generator is considered by an analysis similar to that of Sudan.[9] The equations for the coil impedance and power flow are obtained and interpreted, and numerical results are presented. The principal effect if the machine is more than about two wavelengths long is to reduce the power level without much change in the electrical efficiency, while for a shorter machine generator operation is impossible. The minimum length increases with decreasing magnetic Reynolds number and decreasing magnitude of the fluid slip relative to the traveling magnetic field.

Based on the previous theory, the range of machine parameters for acceptable performance is determined. Preliminary calculations are given for several examples of MHD induction generators operated on liquid-metal flows. It is concluded that overall efficiencies in the range of 70 to 85 per cent can be attained in practical high-power generators, but that it may not be possible to achieve the lower efficiency limit at power levels below about one megawatt.

References

1. D. G. Elliott, Two-Fluid Magnetohydrodynamic Cycle for Nuclear-Electric Power Conversion, ARS Journal, 32, 924, 1962.
2. G. A. Brown, K. S. Lee, W. D. Jackson, and M. H. Reid, MHD Power Generation with Liquid Metals, Proceedings of Fifth Symposium on the Engineering Aspects of Magnetohydrodynamics, M. I. T., Cambridge, Massachusetts April, 1964.
3. L. L. Prem and W. E. Parkins, A New Method of MHD Power Conversion Employing a Fluid Metal, International Symposium on Magnetohydrodynamic Electrical Power Generation, Paris, July, 1964.

4. G. A. Brown and K. S. Lee, A Liquid Metal MHD Power Generation Cycle Using a Condensing Ejector, International Symposium on Magnetohydrodynamic Electrical Power Generation, Paris, July, 1964.

5. M. Petrick and K. Y. Lee, Performance Characteristics of a Liquid Metal MHD Generator, International Symposium on Magnetohydrodynamic Electrical Power Generation, Paris, July, 1964.

6. W. D. Jackson, E. S. Pierson, and R. P. Porter, Design Considerations for MHD Induction Generators, International Symposium on Magnetohydrodynamic Electrical Power Generation, Paris, July, 1964.

7. L. F. Moddy, Friction Factors for Pipe Flow, Trans. Amer. Soc. Mech. Engs., 66, 671, 1944.

8. L. P. Harris, Hydromagnetic Channel Flows, John Wiley and Sons, Inc., New York, 1960.

9. R. N. Sudan, Interaction of a Conducting Fluid Stream with a Traveling Wave of Magnetic Field of Finite Extension, J. Appl. Phys., 34, 641, 1963.