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ABSTRACT

Effects of Fringing Magnetic Fields On MHD Seawater Thruster Performance

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Introduction

There are several loss mechanisms that influence the flow and electrical field characteristics of an MHD seawater thruster and hence its performance. Among those losses are the jet losses, ohmic losses, frictional losses, three-dimensional effects, and electrical end losses. Some of those loss mechanisms have been discussed before, together with the parameters affecting the thruster performance [1-3].

Thruster electrical end losses are caused by the fringing of the magnetic field near the ends of the electrodes, and by the nonuniformity of the current and electric fields across the thruster, particularly near the ends of the electrodes [4]. Therefore, the current density cannot be calculated from a simple one-dimensional relationship. Rather, a multi-dimensional solution of the electric fields should be performed. No simple expression can be written for the electrical end losses, because end effects depend on several parameters that include the thruster aspect ratio, load factor and the profile of the magnetic field in the fringe region away from the electrodes.

It has been shown by the authors in Reference [1] that for a typical operating conditions of an MHD thruster, the ideal electrical efficiency of the thruster, η_e ($= 1/K$, where K is the electric load factor) can drop by as much as 30 percentile points close to a load factor $K = 1$. As the load factor increases, ohmic losses (J^2/σ) become much larger, and the influence of electrical end losses gets smaller. In this case, even though the thruster efficiency decreases with the increase of the load factor, the computed thruster efficiency approaches the ideal value (1/K).

The purpose of this paper is to investigate the influence of fringing magnetic fields on the electrical end losses, the electric fields, and the thruster performance. The full text of the paper will include a detailed description of a two-dimensional MHD thruster model that couples the solutions of the electric fields and the flow fields. Also included will be the effects of electrode aspect ratio, load factor and the shape and location of the fringing magnetic field near the end of the electrode to determine the optimum shape for minimum end losses.

Results and Discussion

The coupled two-dimensional MHD model has been applied for an internal seawater thruster having a rectangular crossection with continuous electrodes. The electrical conductivity and mass density of the flow are taken to be 4.5 S/m and 1025 kg/m^3 respectively.

Electrical Model Validation

In order to establish confidence in the developed model, as a first case, the model was used to predict the resutls of Sutton's, et al [4] which were obtained from an exact analytical solution to an MHD pump. These results are for a frictionless flow and are shown in Figure 1. This figure presents the electrical efficiency of an MHD pump with varying amounts of magnetic field overhanging the electrode for two different aspect ratios (electrode length/thruster height) of $5/\pi$ and $10/\pi$ and for a load factor of 1.2. As can be seen in this figure there is very close agreement between the calculated model results and the exact analytical solution. These results were obtained using only a moderate size grid of 20 node points across the thruster and 300 node points along the thruster in the electrical calculation.

The results in Figure 1 indicate that the thruster efficiency increases with aspect ratio. However, the values of the efficiency are low compared to the ideal values corresponding to an electrical load factor K=1.2 ($\eta_{e,ideal} = 1/K$). The main reason for that is the small values of aspect ratios used in Sutton's cases, where the end losses comprise a significant part of the power produced over the short electrodes of the thruster.

Effect of Fringing Magnetic Fields

Parametric studies have been performed using the developed two-dimensional coupled MHD thruster model to investigate the effect of the shape and location of the fringing magnetic field near the end of the electrodes on the performance of the MHD thruster. Sample results are given here for the following operating parameters: thruster diameter = 0.5 m, electrode length = 5 m (aspect ratio = 10) and the total thruster length = 11 m. An inlet nozzle is assumed at the beginning of the thruster. The inlet flow velocity to the nozzle is taken to be 5 m/s. The applied voltage to the thruster is varied until the flow static pressure at the exit of the thruster is equal to that at the inlet of the nozzle.

The magnetic field is assumed constant over most (or all) of the electrode (B = 20 T) and is allowed to drop linearly to zero near the ends of the electrode.

Figure 2 shows the effect of the location of the fringing magnetic region on the thruster performance. The first case on Figure 2 corresponds to a magnetic field that starts at the beginning of the electrodes ($x_0/D = 0.0$). The other cases correspond to a gradual shift of the starting point away from the electrodes ($x_0/D = 0.5, 1, 2, 3$). The computed values of the thruster efficiency include frictional losses, as computed by the two-dimensional MHD thruster model, as well as the electrical end losses. Also included on Figure 2 are the values of the thruster efficiency, if electrical end losses are neglected. Figure 3 presents, in a graphical form the effect of the location of the fringing region on the thruster performance. The results indicate that the thruster efficiency suffers the most if the region of the fringing magnetic field is allowed to be over the electrode. Once the fringing magnetic field is outside the electrode, the thruster efficiency remains practically constant near its maximum value. This means there is no practical need for extending the magnetic field beyond the electrode region, particularly when the weight of the magnet is a big concern.

Figures 4 and 5 shows the current density fields for the two extreme cases $x_0/D = 0$, and 3 respectively. In these figures, the gray scale degradation of the current vectors gives some indication of the current density strength, although for presentation purposes the gray scale is not linear with current strength. For the first case (Figure 4) the ramp-up of the magnetic field is over the electrodes, which causes a large increase in the transverse current density at the ends of the electrodes. For the second case, where the magnetic field is extended far beyond the electrode region, current circulation occurs in that region. However, it seems that this has only a negligible effect on the thruster performance.

In the final paper, we will present results showing the effect on the thruster performance of electrode aspect ratio, load factor and the shape of the magnetic field in the fringing region.

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3. Doss, E.D., and Roy, G.D., "Flow Characteristics Inside MHD Seawater Thrusters," Journal of Propulsion and Power, Vol. 7, No. 4 pp. 635-641.

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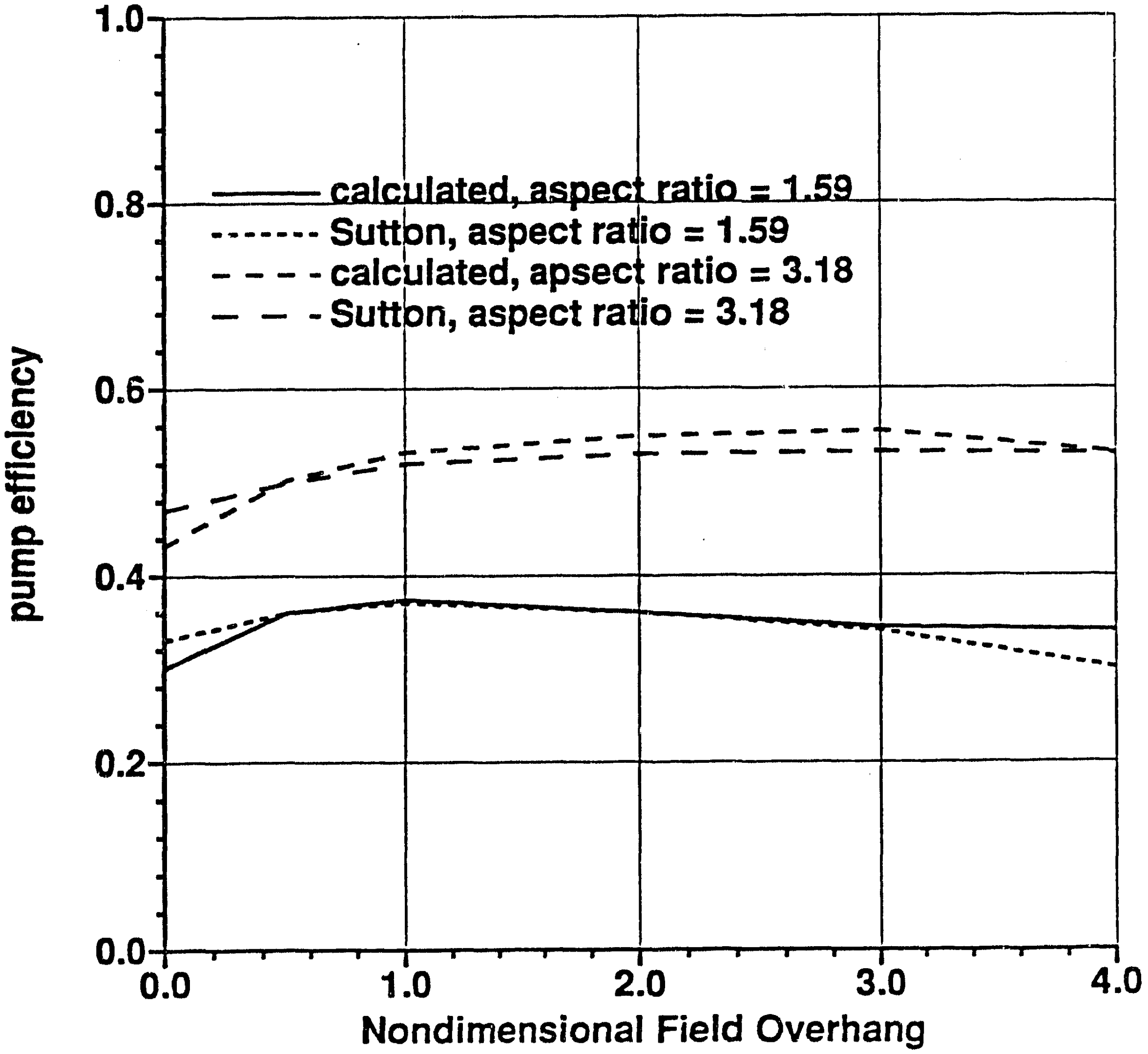
Figure 1. Comparison of Numerical and Analytic Solutions



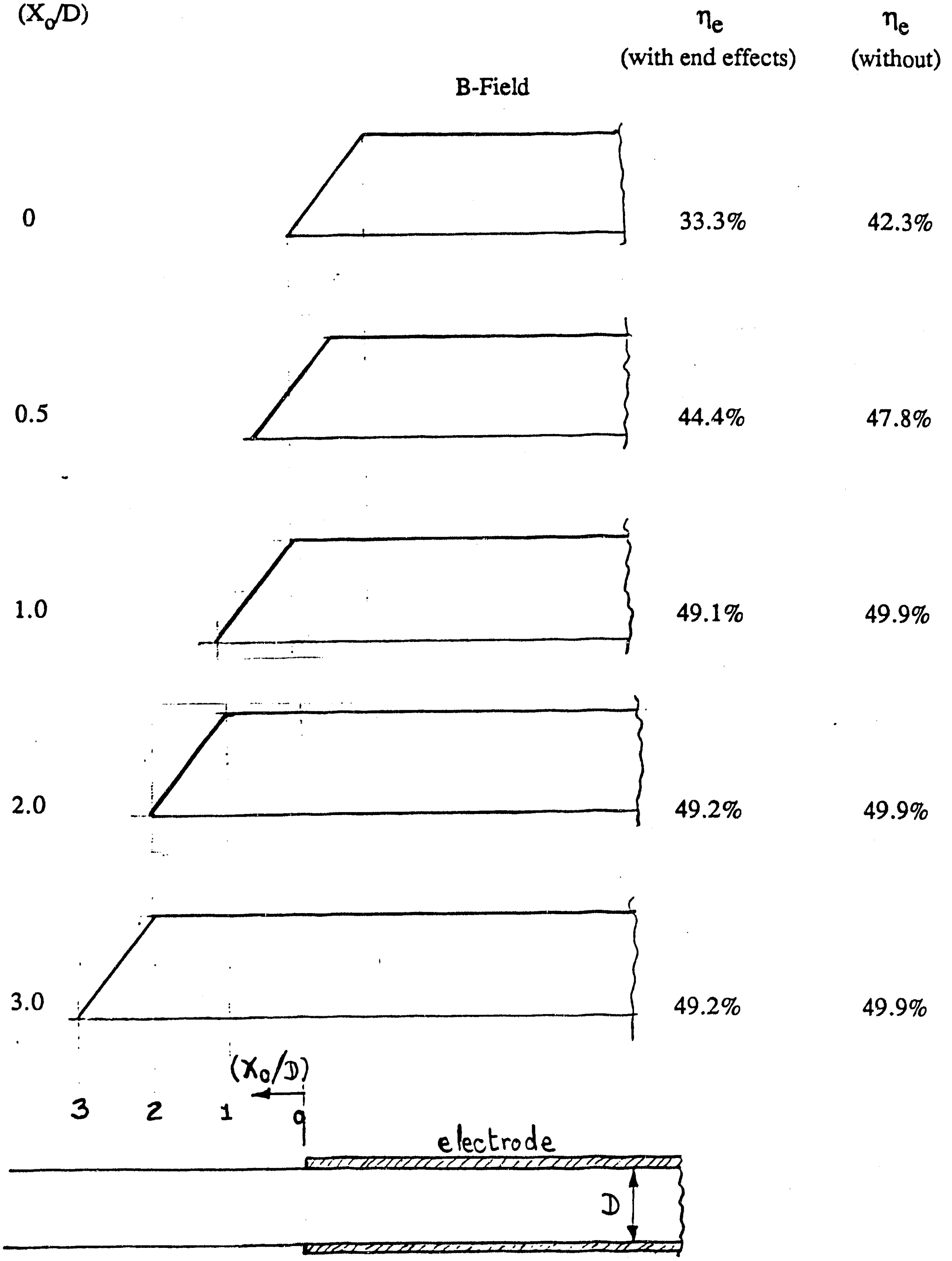


Fig. 2 Effect of Fringing Magnetic Field on Thruster Efficiency

Figure 3. Effect of Position of Magnetic Field Ramp-up on Thruster Efficiency

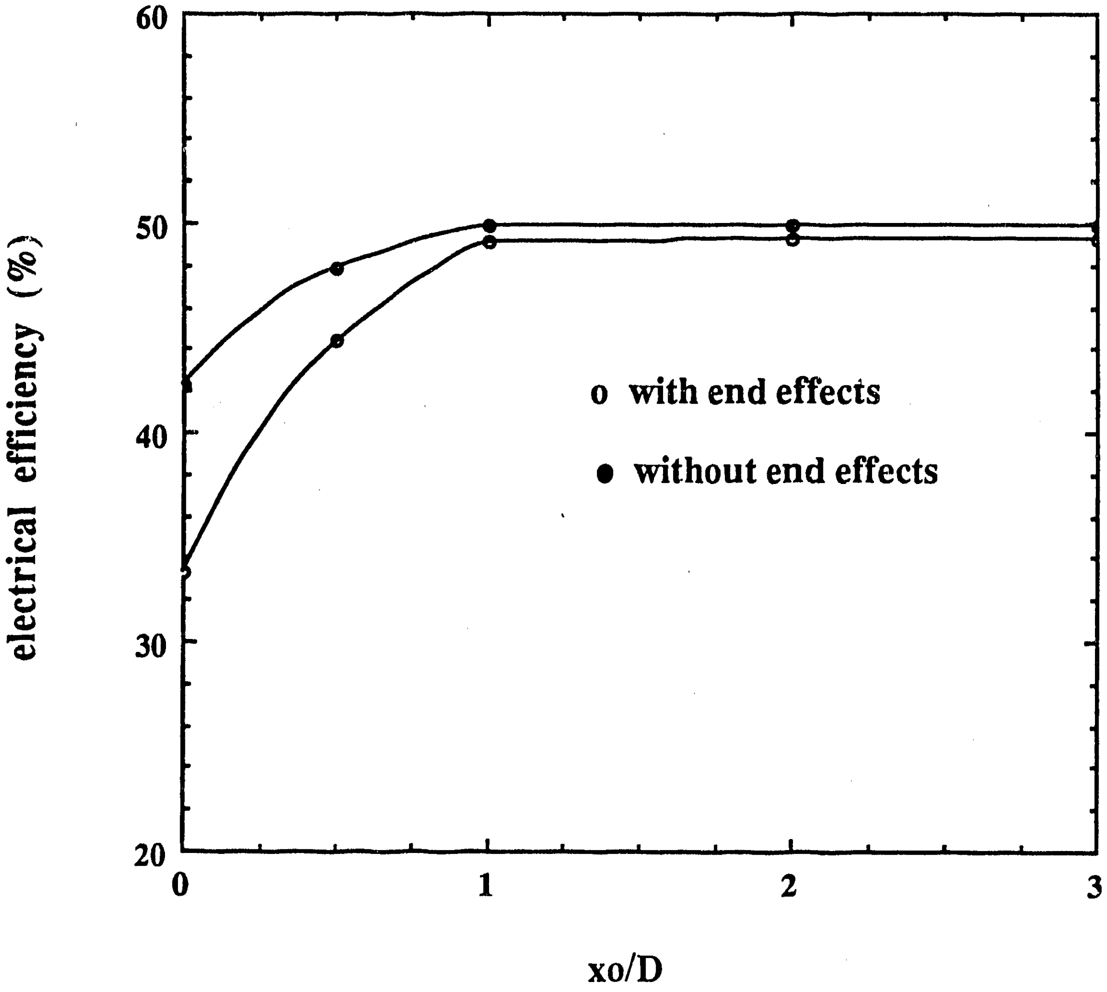
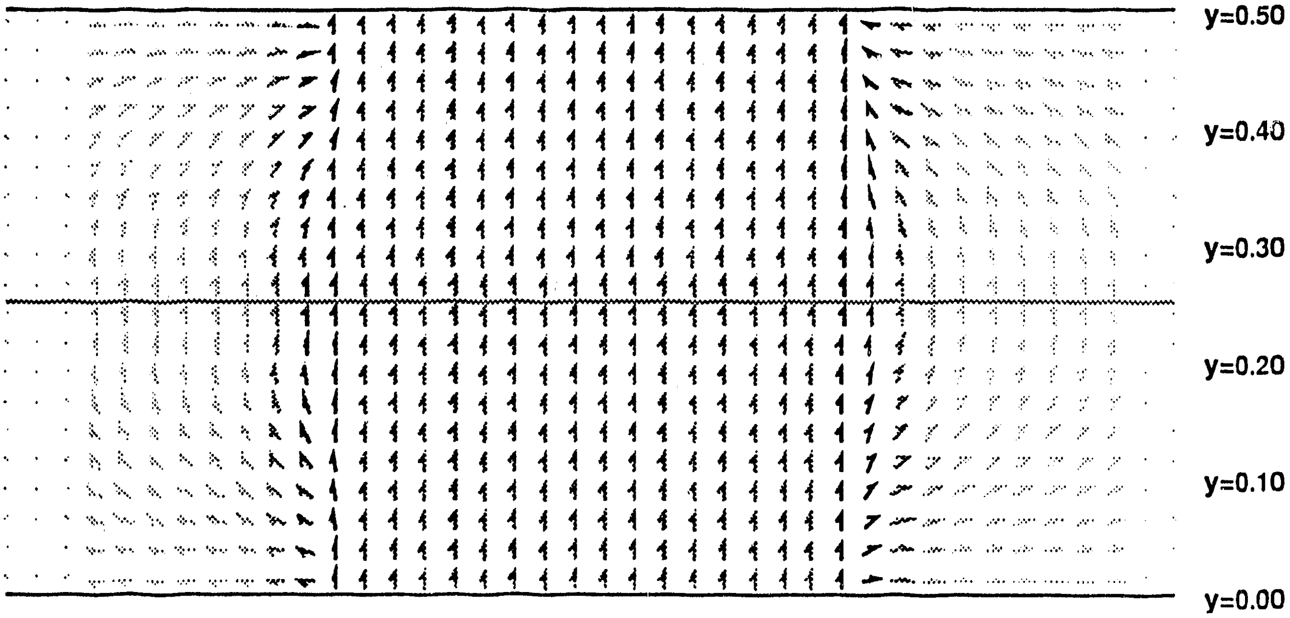


Figure 4.

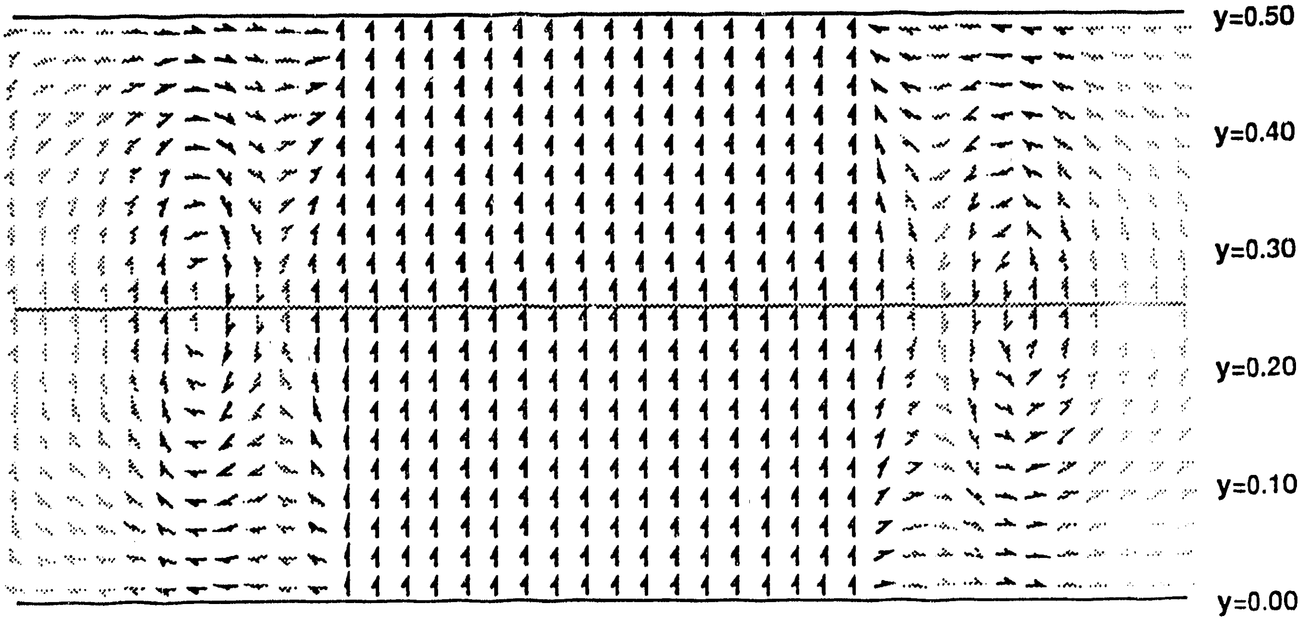
current plot - MHD2D electrical code



($x_0/D = 0$)

Figure 5.

current plot - MHD2D electrical code



($x_0/D = 3$)

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