International Journal of Offshore and Polar Engineering
Vol. 5, No. 2, June 1995 (ISSN 1053-5381)

Analytical and Experimental Studies of the Helical Magnetohydrodynamic Thruster Design

J. B. Gilbert II and T. F. Lin
Applied Research Laboratory, The Pennsylvania State University, State College, Pennsylvania, USA

ABSTRACT

This paper describes the results of analytical and experimental studies of a helical magnetohydrodynamic (MHD) seawater thruster using a 8-Tesla (T) solenoid magnet. The application of this work is in marine vehicle propulsion. Analytical models are developed to predict the performance of the helical MHD thruster in a closed-loop condition. The analytical results are compared with experimental data, and good agreement is obtained.

INTRODUCTION

The presence of salts allows seawater to conduct electricity by electrolytic ion exchange. Thus by passing an electric current through seawater in the presence of a magnetic field, a Lorentz (**J x B**) force will act to move the seawater in the direction normal to both the magnetic field and electric current (Fig. 1). This is the basis for MHD propulsion. Few mechanical moving parts are required with MHD propulsion. As a result, this type of propulsion may be acoustically attractive.

Recently there has been an increase of research and development in this field (Lin, 1992). An experimental MHD ship, Yamato-1, has been constructed in Japan (Motora et al., 1991). It uses two MHD thrusters, each capable of producing 4,000 N of thrust. Research in the United States includes experiments at Argonne National Laboratory (ANL) (Petrick et al., 1991), Naval Undersea Warfare Center-Newport (NUWC-N) (Meng et al., 1991), and Applied Research Laboratory of Penn State (Lin et al., 1992).

Analytical studies of seawater propulsion (Doss and Roy, 1991; Lin et al., 1991a) and seawater electrolysis, conductivity enhancements, and electrode studies (Lin, 1990; Gilbert et al., 1991) have been conducted. The experiments of ANL, NUWC-N and ARL Penn State use 6-, 3.2-, and 8-*T* magnets, respectively. Among them, the magnets for ANL and NUWC-N are superconducting dipoles, while the one for ARL Penn State is an electro-solenoid. The analytical studies did not consider the effects of electrolytic bubbles on the performance of the thrusters until later (Lin et al., 1991b), which showed that these effects are significant.

Taking advantage of the high-field characteristics of solenoid, both one- and two-loop cyclotron systems were investigated (Aumiller et al., 1993). In the cyclotron design, the magnetic field and electric current are applied axially and radially, respectively. As a result, the MHD flow is induced in the azimuthal direction, allowing an increased active length. Results from these studies showed that the two-loop system exhibits a higher efficiency than the single-loop. An obvious evolution from this approach is the utilization of the entire bore length of the solenoid via a helical configuration (Bashkatov, 1991). This paper reports the results of analytical and experimental studies based on an MHD helical thruster using an 8-T solenoid magnet at MIT's Francis Bitter National Magnet Laboratory (FBNML).

Received January 24, 1994: revised manuscript received by the editors November 4, 1994.
KEY WORDS: Magnetohydrodynamics, MHD, helix, two-phase flow, seawater, propulsion, Lorentz Force.

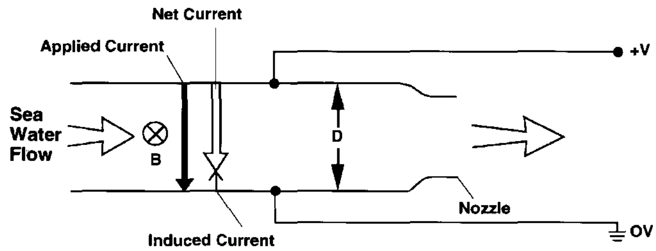

Fig. 1 Illustration of straight rectangular duct MHD channel

ANALYTICAL APPROACH

To optimize the geometry of the test section and to predict the performance of the thruster, analytical models were developed. They calculate the MHD-induced flow rate by equating the pressure rise in the thruster to the sum of all the hydraulic losses in the loop. In order to simplify the calculations and more accurately model the system, the MHD pumping region is divided into a variable number of segments where certain parameters vary as a function of location. This concept of segments is useful for the numerical finite-difference scheme, as discussed next.

Pressure Rise in MHD Pumping Region

According to the Lorentz Law, the force created by the thruster is:

$$\hat{F} = J \times B \tag{1}$$

where $\hat{F}$ = the resultant Lorentz Force vector per unit volume; J = the electric current density vector; and B = the magnetic field vector. Because the magnetic strength and electric current are functions of position in the magnet, the pressure rise is calculated for each segment. Therefore, the total pressure rise due to the MHD effect in the direction of flow is given by:

$$\Delta p_{MHD} = \frac{\cos\theta}{A_{flow}} \sum_{j=1}^{N} I_j B_j D \tag{2}$$