초전도 자석을 이용한 전자유체(MHD) 추진

Magnetohydrodynamic Ship Propulsion with Superconduction Magnets

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Abstract

The feasibility of magnetohydrodynamic (MHD) Ship propulsion using superconduction magnets is reviewed in light of recent advances in high-temperature superconducting.
The propulsion using a screw propeller in the noise reduction has it's own limitation.
The epochal noiseless MHD propulsion method which does not have this disadvantage is studying nowadays.
The subject of a marine MHD as propulsion has been examined before and was found to be interesting because of relatively low magnetic flux densities.
It is demonstrated that the MHD propulsion is technically interesting with high magnetic flux density.
The development of large-scale magnets using the high-temperature superconductors now under development could make it practical to construct submersibles for high-speed and silent operation.

Key words : magneto hydrodynamics ; Superconducting magnets ; high temperature superconductor.

1. INRRODUCTION

It has long been the dream of the naval engineer to build faster ships, and recently to this has been added the desire to go fast quietly. It has been clear for some time now that these two desires cannot be met simultaneously with the marine propeller.

Electromagnetic propulsion of ships or submarines may be realized by sending an electric current through the sea water in the presence of applied transverse magnetic field.

The concept of MHD Ship propulsion was proposed by W.A.Rice(1) in 1961 as a similar idea of MHD pumps used for liquid metal. During 1960s, investigations into MHD Ship propulsion were conducted mainly in the U.S.A..

Theoretical as well as experimental research works on superconducting electromagnetic propulsion have been done by saji et al.2), Doragh3), Way4), Way et al.5), etc., attracting public attention. Based on the experience of saji et al., Japan Foundation for Ship Building Advancemect(JAFSA) set up, in 1985, a committee chaired by Yohei Sasakawa (president;JAFSA) to promote an extensive research and development project aiming to construct a prototype experimental ship of about 150 tons which is capable of carrying all necessary apparatus on board and runs with electromagnetic force. Total budget of the project is about $40 millions subsidized by the Japan Shipbuilding Industry Foundation (Chairman : Ryoichi Sasakawa).

2. Modeling and scaling relations

A wire or other electrical conductor placed in a magnetic field experiences a force perpendicular of electrical current.

If theelectrical current flows through an incompressible fluid, such as seawater, then the Lorentz force exerts a pressure on the seawater, which may be used to drive a MHD pump-jet. The force per unit volume acting on the seawater is given by

$$F\nu = J * B \qquad (1)$$

Where J is the current density and B is the magnetic induction.

A simple pump-jet with uniform magnetic fields and current distributions is shown in Fig. 1. The configuration adopted here is a simplified version of the MHD thrusters adopted by Doragh and Hummert for their studies.

The approximations are made to facilitate the development of simple scaling relations and do not affect the conclusions.

For the pump-jet shown in Fig.1, the pressure generated by the Lorentz force is given by

$$\Delta P = \overrightarrow{F\nu} \cdot \overrightarrow{L} \qquad (2)$$

Where L is the length of the electrodes. The increase in velocity due to this pressure head can be calculated from the relation for the conservation of energy as expressed by Bernoulli's equation :

$$\Delta P = \frac{\rho}{2} (\nu^2_{out} - \nu^2_{in}) \qquad (3)$$

Where ρ is the density, ν_{in} is the inlet speed or speed of the vessel, and ν_{out} is the speed of the jet.

For incompressible fluids, the speeds of the inlet and outlet also are related by the flow rate

3. Parameters for a model submersible.

Values of the drag for a model submersible with a diameter of 10 m and an assumed drag coefficient of 0.05 are plotted in Fig.4 as a function of the speed in knots(top scale) or the speed squared in meters per second (bottom scale).

The values for the drag and equivalent values for the thrust required to maintain constant speed were calculated from Eqs.(17)-(19).

The drag value calculated by Phillips, Doragh, and Hummert correspond to values for the drag coefficient C_D of 0.05,0.05, and 0.13, respectively.

We adopt a value of $C_D = 0.05$ for this study following Doragh, who considered a large number of factors in arriving at his estimate.

The output power required to drive the model vessel at constant speed also is plotted in Fig.4 as a function of the speed.

The power levels are approximately the same as those given by Doragh, but are significantly lower than Hummert's values discussed above.

Values for the electrical efficiency η_E and the total efficiency η_T for the model vessel described in Fig.4 are given in Fig.5 as a function of the speed in knots for several values of the magnetic induction B.

The figure shows that values for the total efficiency in excess of 60% are possible for speeds up to 70 knots, provided that magnetic fields of 10 T could be sustained over the required volumes. The corresponding speed for 60% efficiency is 29 knots for a 5 T field. The efficiencies presented in Fig. 5 demonstrate the importance of developing practical magnet systems in the range 5 - 10 T in order for MHD propulsion to be feasible for vessels on this scale. However, lower fields could be feasible for larger-scale vessels, as in Figs.2 and 3.

The importance of developing large-scale magnet systems with field strengths > 5 T is illustrated in Fig.6. The cross-hatched regions represent the range in parameters for magnetic induction and speed-to -length ratio that were adopted by Doragh and Humment in their studies.

Also shown in Fig.6 is the curve for an electrical efficiency of 50%, as calculated from Eq.(12), with a jet rato $r = 1.5$.

The electrolysis of seawater with consequent generation of hydrogen and chlorine gases was addressed by Phillips, Doragh, and Hummert. All of the authors concede that the generation of gases and erosion of electrodes ard detrimental side-effects to MHD propulsion, but do not consider either to be a factor limiting feasibility. Magnetic signature may also be a concern, but proper magnet design and shielding could minimize the problem.

Higher current densities, of the order $10^9 A/m^2$ or greater, at fields of the order of 10 T, will be required for MHD propulsion to become practical for high-speed vessels.

Structural containment strengths scale as B^2 ; hence, these high-field magnet systems will require a substantial support structure. If we assume that the support structure is equal in weight to the magnet, then the propulsion system for a 2000-ton submersible would weigh 100 tons.

4. Conclusions

MHD propulsion systems have potential advantages for submarines, which could lead to revolutionary advances in marine propulsion.

Perhaps the most significant of these features is the potential for quiet and efficient operation at speeds that would not be possible with conventional propeller-driven vessels.

The scaling reactions for MHD pump-jets indicate that the efficiency of MHD propulsion units scales inversely with the ratio of speed to pump length ; therfore, such units become more efficient for larger vessels.

Electrical efficiencies of 80% or more are possible at speeds of the order of 60 knots for pump-jets 100 m in length with magnetic field strengths of 10 T.

Scaling arguments based on the magnetic Reynold's number or diffusion velocities for the magnetic field indicate that the conductivity of seawater may not very large scale vessels.

The actual dependence of the efficiencies on the size, speed, and conductivity is beyond the scope of this study and would require more extensive calculations of the MHD equations for specific geometries with consideration of the finite diffusion velocity of the magnetic field through the conducting medium.

In order for MHD propulsion systems to become feasible, it will be necessary to develop practical magnet materials and systems capable of producing fields in the range of 5-10 T over volumes of the order of 100 m^3.

The recent discovery of new classes of superconducting materials with critical temperatures well above liquid nitrogen temperatures could lead to revolutionary advances in large-scale electrical machinery and magnet systems.

Realization of this potential will depend on the development of commercial superconducting wires with current densities of the order of 10^8 A/m^2 and larger.

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