Superconducting Electromagnetic Propulsion for Ships

(Magneto hydrodynamic propulsion)

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Abstract

The need for alternative propulsion systems has increased in the marine industry due to many factors some of which are discussed below. The continuous growth in trade between the countries has led to the need for effective, rapid & efficient transportation. This leads to a need for alternative propulsion systems with higher power output & greater flexibility. Increase in fuel prices is also one of the contributors for the necessity of developing alternative propulsion systems. The magneto hydrodynamic propulsion is one such alternate propulsion techniques.

Keywords

lorentz force; superconductivity; magnetohydrodynamic thrusters; cooling system; application

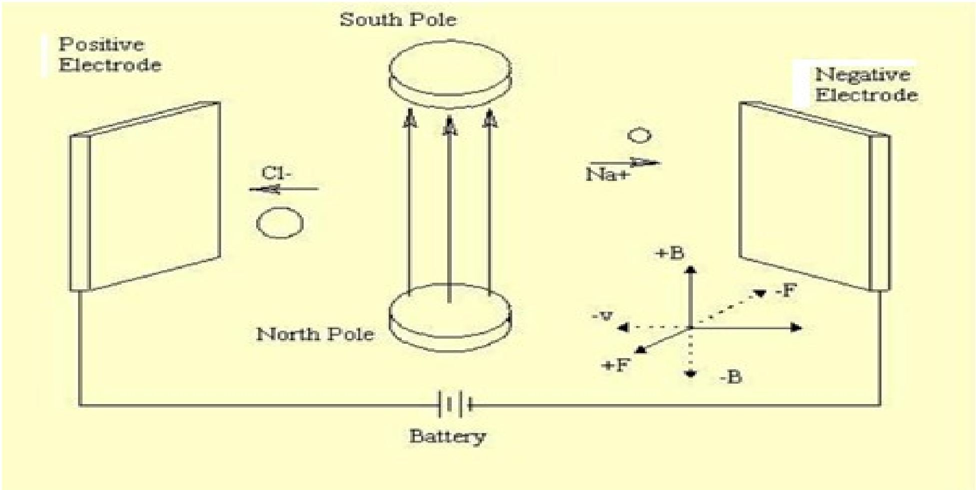
Introduction

The magneto hydrodynamic (MHD) thruster system for ships with superconducting electromagnets has been recognized for its potentially attractive performance. It does not need any rotating parts like conventional propellers or water jet propulsions, and therefore may be less affected by cavitation, which would be suitable propulsion means for high speed ships and for ships which specially require silent operation. It is considered that MHD thrusters can be designed with freedom for determining their configurations and size so that they could have high propulsive performance because shaftings are not required.

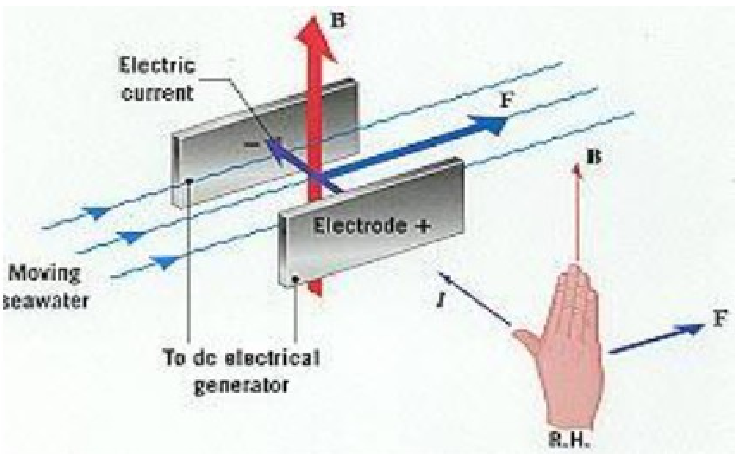
Japan, the United States, and perhaps the USSR, are racing to perfect this revolutionary type of propulsion for ships and submarines. In real life, scientists say MHD propulsion might find both military and civilian uses.

Principle of Operation

The basis for this advance is a tongue-twisting phenomenon known as magneto hydrodynamics, or MHD, in which magnetic fields are used to move water. Magneto hydrodynamics involves magnetic fields (magneto) and fluids (hydro) that conduct electricity and interact (dynamics). The phenomenon occurs naturally in the Earth's core, giving rise to the planet's magnetic field.



When a magnetic field and an electric field interact, a force called Lorentz Force is exerted on the charges present in between those fields. In other words the Lorentz force is the force experienced by a point charge moving along a conductor that is in a magnetic field; the force is at right angles to both the current and the magnetic field.



Lorentz Force is given by

$F = q[E+(v*B)]$

Where, q is the electric charge of the particle in coulombs

E is the electric field in volts per metre

V is the instantaneous velocity of the particle in metres per second

B is the magnetic field in tesla

The electric field is provided by two electrodes placed in the duct of the thruster. The magnetic field is created by superconducting magnetic coils. Superconductivity is a phenomenon of exactly zero resistance and expulsion of magnetic fields occurring in certain materials below a characteristic temperature. These superconducting wires can carry about 150 times the current of copper wires of the same dimension. Using superconducting coils a magnetic field of 15Tesla was tested in laboratory by Japan. Once set into motion, current will forever flow in a closed loop of a superconductor material - making it closest thing to perpetual motion in nature. Its electrical performance can further be increased by using nanotechnology.

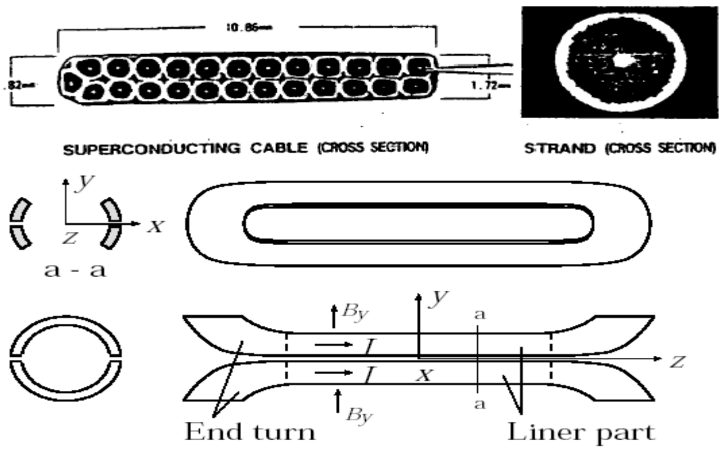


Fig. 4 Superconducting wire and coils (SHIMAMOTO et al.)

A MHD ship and its thruster system

A MHD ship has novel type thrusters which generate thrust force conducted by electromagnetic force. Lorentz Force is created in seawater by means of electromagnets and electrodes installed inside or outside a ship. Although its principle is simple, very strong electromagnetic force is necessary to gain effective thrust force because the electrical conductivity of seawater is very low. In the early 1960s, L.R.A.Doragh proposed to apply superconducting magnets to overcome this difficulty. After then, numerous studies have been continued for investigating on how to apply it to the ship's thruster system.

In 1991, a full scale experimental MHD ship "YAMATO-1" was built and a study was conducted to investigate feasibility for applying MHD thruster system to actual ships, which was motivated by the successful application of superconducting magnets to the MAGLEV (magnetic levitation) test train.

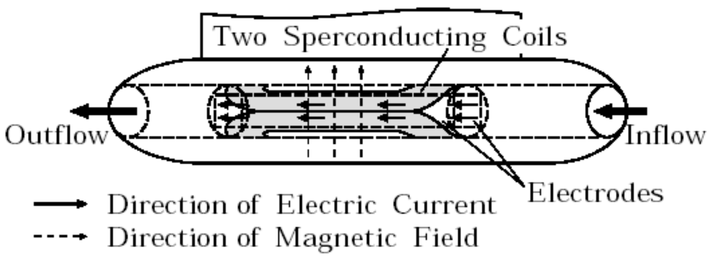
Concerning the application of the MHD propulsion to a ship, two kinds of basic configurations have been proposed to realize the superconducting thruster as the ship's propulsion system. One is the outer magnetic field system, and the other is the inner magnetic field system. In the case of the latter system, superconducting magnets are installed inside a ship's hull, which is suitable for shielding MHD field against surroundings. In the inner magnetic field system, superconducting coils cooled liquid helium and electrodes installed in a ship's hull form a electromagnetic field, in which seawater is led and accelerated by MHD force and generate thrust. Although this system is suitable for shielding the electromagnetic field as mentioned above, the flow resistance in a duct is slightly high, and its performance is very much influenced by the configuration and the shape of the thruster duct etc.

There are three different configurations of MHD thruster system namely

- The inner ducting
- The annular ducting
- The pod mount type

The Inner Ducting Type:

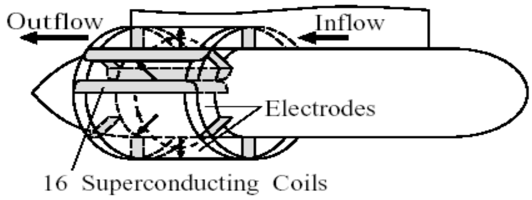
A thrust duct is installed in the lower hull of a SWATH, which accelerates seawater for generating thrust force. The ducting has a round type section, which are composed of a straight part, a nozzle, and a bell-mouth type inlet. The electrodes are installed in parallel at the mid-part of the duct. The superconducting coils with a saddle type shape are installed at both sides in the duct, which are cooled with liquid helium or liquid nitrogen (based on the type of superconducting material used) insulated with vacuum vessel.



(a) Inner ducting type

The Annular Ducting Type:

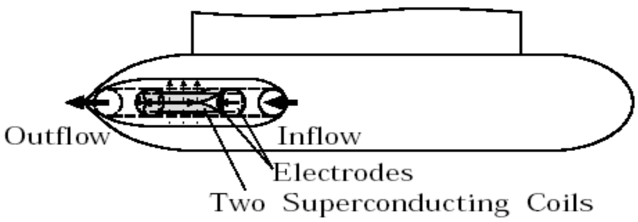
Superconducting magnets are composed of several segments which are installed surrounding the lower hull of the SWATH. The magnets and electrodes form an annular ducting surrounding the lower hull, which generates electromagnetic fields. Seawater is accelerated by the electromagnetic field generated in the annular spaces composed of the ring magnets and the ship's hull. The superconducting coils form a saddle type shape with double knuckles. The 16 elements of coils are arranged in a circle, which compose the superconducting magnets. The electrodes are installed with a distance, which generate the electromagnetic field together with the superconducting magnets.



(b) Annular ducting type

Pod Mount Type:

Two pods of thrusters are installed at both sides of the lower hull of a SWATH type ship. Their configuration is similar to that of inner ducting type thruster. The shape of the thruster surface is defined as a spheroidal form in the fore part and as a parabolic-revolution form in the aft part together with a parallel form in the mid-part.



(c) Pod mount type

In case of the inner ducting type thruster, a large volume of the electromagnetic field can be given although the long hydraulic duct (namely, higher hydraulic drag) is required; which results in higher propulsive efficiency. On the contrary, in the case of the annular ducting type the volume of the electromagnetic field is very limited, which subsequently increases the electric power. The pod mount system has a short hydraulic duct which causes lower drag and higher hydraulic efficiency. However, it also causes reduce in the volume of electromagnetic field, and subsequently electrical efficiency becomes lower. In order to improve the propulsive efficiency, it is necessary to increase the density of electromagnetic field, which has been limited by the today's level of superconducting technology being based on using NbTi (Niobium-Titanium) material.

Electromagnetic Field in the system

The electromagnetic field utilized in MHD propulsion is created by superconducting coils. These superconducting electric coils are composed of NbTi wires. The configuration of this coil consists of a pair of the saddle type coils which generate unidirectional magnetic field. The parallel part of the coils contributes mainly the uniform strength of the magnetic field. For the MHD thruster system, the electrodes are placed with an adequate distance in the above magnetic field so that the Lorentz Force is generated for the required thrust. In addition to the above thrust force, the superconducting coil produces the force which expands the coil itself. In order to withstand the force, it is required to install ring type holding devices for coils.

Working

The simplest form of sea engine consists of two metal-plate electrodes mounted parallel to each other inside a rectangular chamber called a "cannula". An opening at each end of the cannula permits seawater to flow between the electrodes. The cannula is mounted between the poles of a powerful electromagnet, so that the magnetic field is concentrated on the water between them.

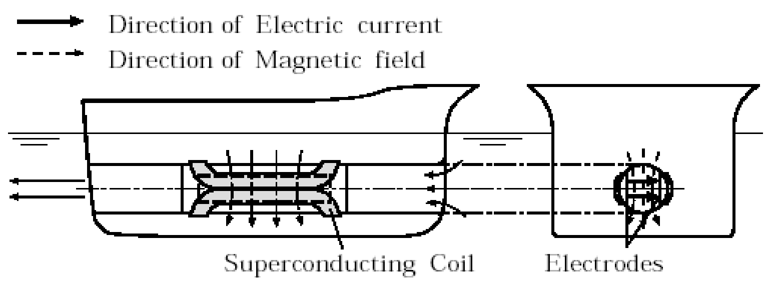


Fig. 1 Principle of the MHD thruster

When alternating current is applied to the two electrodes, large numbers of ions (sodium and chlorine atoms in sea water) are immediately attracted to the water between them. These ions attempt to move back and forth between the electrodes. Their individual magnetic fields (each ion is surrounded by its own tiny EM field) are repelled, however, by the powerful external magnetic field. The interaction of the magnetic field and the current produces a strong force on the water, moving it through the duct in the center of the magnet. Many of the ions are thus forced to move sideways, away from the electrodes. As they move along, they drag water molecules with them, causing the water to move out of the cannula. More seawater enters from the other opening, producing a continuous flow. If the polarity of the current is reversed, so is the direction of thrust.

Yamato 1:

Fig. Yamato 1

Yamato 1 is the first working prototype MHD ship completed by ocean policy research foundation, Japan in 1991. It was first successfully propelled in Kobe harbor in June 1992. It is propelled by two MHD thrusters that run without moving parts. Inside each thruster, the sea water flows into six identical tubes, arranged in a circle like a cluster of rocket engines. The ten inch diameter tubes are individually wrapped in saddle shaped superconducting magnetic coils made of niobium titanium alloy filaments packed into wires with copper cores and shells. Liquid helium cools the coils to -452.13 F, just a few degrees above absolute zero, keeping them in a superconducting state in which they have almost no resistance to conductivity. Electricity flowing through the coils generates powerful magnetic fields within the thruster tubes when an electric current is passed between a pair of electrodes inside each tube, sea water is forcefully ejected from the tubes, jetting the vessel forward. It can travel at 8 knots (15 km/hr) using a magnetic strength of 4 T.

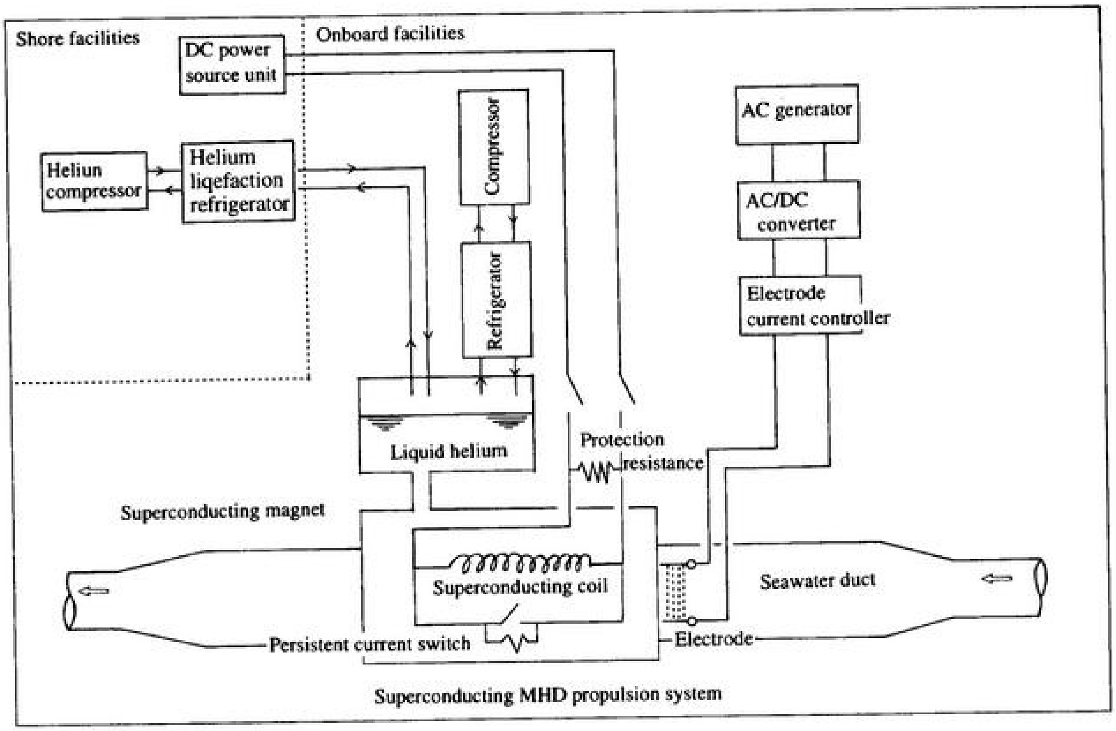


Fig. 3 Outline Diagram of Propulsion System "YAMATO 1"

High temperature superconductors can also be used. In such a case liquid nitrogen is used as coolant instead of liquid helium. Research on using high temperature superconductors is being carried out.

Advantages

- No moving parts (rid of lubrication problems)
- No sound and vibration.
- A small electromagnetic force would be acting over a large area, rather than a large physical force acting over a very small area, as with a propeller.
- More maneuverable than a conventionally propelled craft.
- High-energy production rate to unit weight.
- It can be used wherever silent operation is necessary (Navy Applications).

Challenges Faced:

- The crew's proximity to magnetic fields inside the sub is a problem. It can be solved by placing the field coil slightly aft and the crew well forward, with an iron shield between.
- In coastal rivers or fresh water MHD ship moves at one third its original speed.

Conclusion:

It will be most crucial whether the MHD propulsion will be applied commercially. There are several issues associated with MHD propulsion in application; they are thruster performance, electrical discharge and availability of superconducting magnet with high field and light weight. Because the efficiency bears a relation to magnetic flux density, so the most important factor is the magnet technology. Many scientists believe that the technology with the greatest expectations in the 21st century is the superconductivity. The pace of progress is rapid today. For example, according to the Tohoku university,1996, new design with newly developed superconducting wire of $Cu\text{-}Al_2O_3/Nb_3Sn$ to replace the conventional design with $Cu\text{-housing}/Nb_3Sn$ for a 15 Tesla magnet, the magnet will be reduced by about 43% of weight and by about 38% of volume. Days are not far when with the use of Superconductivity we may find MHD propulsion system being used on large scale for naval as well as merchant ships. This is possible only with the advancement in the field of superconductivity.

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