MAGNETO HYDRO DYNAMICS-PLASMA DYNAMIC (MHD) FOR POWER GENERATION AND HIGH SPEED PROPULSION

Vamsi Krishna. C, A. Sai Kumar
Department of Aeronautical Engineering,
MLR Institute of Technology, Hyderabad, India

ABSTRACT

The interaction of moving conducting fluids with electric and magnetic fields provides for a rich variety of phenomena associated with electro-fluid-mechanical energy conversion. Effects from such interactions can be observed in liquids, gases, two-phase mixtures, or plasmas. Numerous scientific and technical applications exist, such as heating and flow control in metals processing, power generation from two-phase mixtures or seeded high temperature gases, magnetic confinement of high-temperature plasmas even dynamos that create magnetic fields in planetary bodies. Several terms have been applied to the broad field of electromagnetic effects in conducting fluids, such as magneto fluid mechanics, magneto-gas-dynamics, and the more common one used here magneto hydrodynamics, or "MHD". The simplest example of an electrically conducting fluid is a liquid metal, for example, mercury or liquid sodium. However, the major use of MHD is in plasma physics. (Plasma is a hot, ionized gas containing free electrons and ions.) It is by no means obvious that plasmas can be regarded as fluids since the mean free paths for collisions between the electrons and ions are macroscopically long.

KEYWORDS*—Conducting Fluids, Electric, Magnetic Fields, Magneto Gas Dynamics, Plasma Physics.*

I. INTRODUCTION

Modern society is very much dependent on non-biological sources of energy mostly obtained by burning fossil fuels. In fact per capita consumption of energy is a reliable indicator of living conditions of an average citizen of any country. Every nation therefore is making strenuous efforts in increasing this factor. Most of the commercial energy is in the form of electrical energy as it is highly versatile and easily maneuverable. Latest figure for per-capita consumption of electrical energy in India is 360 units, which compares very badly with 6000 – 10,000 units of industrially advanced countries. India has to increase power generating capacity at a very rapid rate. About 75% of power is generated by thermal stations burning coal or lignite which are non-replenish able and polluting the environment. India's coal reserves are just 1% of the world's reserves, while its population is 16% of the global population. So increasing the generating capacity alone is not the right solution. Equal perhaps more stress has to be laid in increasing efficiency of power generation in increasing the energy productivity and accelerating the schemes to tap natural sources of energy, i.e., hydel, the sun, wind, tide, geothermal and Biomass.

II. MHD SCENARIO

The total installed capacity by March 1994 is 76,719 MW consisting of 54,347 MW thermal, 20,336 MW hydel and 2006 MW nuclear. So, thermal generating capacity is about 71%. Out of 323.5 billion units generated the sector wise generation is 247.8 billion units thermal, 70.35 billion units hydel and 5.4 billion units nuclear. Share of thermal power is 76.6%. In future also the share of thermal capacity and generation will hover around these figures. Hence any idea of improving the efficiency of thermal power generation deserves highest consideration.

Industrialization is not an unmixed blessing. Apart from generating disproportionate generation of incomes and accumulation of wealth it has brought environmental pollution which is increasing very rapidly so as to threaten the survival of biological systems including mankind. Manmade natural boundaries have no control over it. The pollution is caused by a 200 MW thermal station at Talcher in Orissa gives a sample of its growth. The station consumes 9000 tonnes of coal per day generating 3000 tonnes of ash. If only 15% of toxic metal from ash is leached out, which is a conservative estimate into the nearby Nandira the river will receive daily 208 kg of iron, 56 kg of zinc, 45 kg of copper, 5 kg of cadmium, 56 kg. of nickel, 4.6 kg of uranium, 16.5 kg of thorium, 60.6 kg of chromium and 11.2 kg of cobalt all in absorbable micron size.

The pollution content in ash, flue gasses, and water in the river Nandira in PPM is given below. The passage of this finely divided toxic metals into the living systems and finally into human system and damage to their health and well-being of mankind is a different subject but that has to be borne in mind in searching for solutions. With slight variation depending upon coal used every thermal station spews out pollutants more or less at the same level.

Table: 1 Gases and Materials produced

Materials	Ash	Flue gases	Water in River Nandira
Iron	416	118	79
Zinc	112	36	-
Copper	90	145	39
Cadmium	10.2	8.5	39
Cobalt	21.3	3.5	46
Nickel	112.9	38.5	264
Uranium	9.2	6.4	-
Chromium	121.2	50	-
Thorium	32.9	16.5	-
Manganese	-	-	756

III. MHD POWER GENERATION

MHD Generation:- Second law of Thermodynamics sets a limit on the efficiency of conversion of heat into work or electrical energy obtained from that work. This limit is determined by the extreme limits of temperature of the working medium. If Ti and 12 are the maximum and minimum temperature in kelvin of the working medium then the efficiency limit is (1— 12/Ti). Stated otherwise a certain non-available fraction of heat defined by 12/Ti cannot be converted into work. Efforts are continuing in decreasing this factor, first by raising steam temperature and pressure and then by combining steam turbine with gas turbine. Taking the ambient temperature as 300K and the maximum temperature of steam as 500°C or 810K the non-availability factor is 300/810 = 0.37 and in the combined cycle taking the inlet gas temperature as 1300K the non-availability factor is 300/1300 = 0.23. If a method to utilise heat right from the temperature of furnace, say 2500K, is developed, then the non-availability factor will be 300/2500 = 0.12. Only direct conversion of heat energy into electrical, as MHD promised, is the only way of utilising heat directly when its temperature falls from 2500K to 1300K.

A. Equation Involved in MHD

The complete set of magneto hydrodynamic equations for a Newtonian, constant property fluid flow includes the Navier-Stokes equations of motion (*i.e.*, momentum equation), the equation of mass continuity, Maxwell’s equations, and Ohm’s Law. In differential form they constitute the following system of equations.

$$\rho\ (\partial u/\partial t + (u.\nabla)u = -\nabla p + j*b + \mu f \nabla^2 u + pg$$

$$\partial\rho/\partial t + \nabla.\ \rho u = 0$$

$$\nabla * E = -\partial B/\partial t$$

B. Determination of Plasma State

When the magnetic field is sheared, resistive reconnection of the magnetic lines can occur causing the appearance of magnetic “islands” in the magnetic topology. This phenomenon is very important in magnetic confinement devices (the island “short circuits” adjacent nested magnetic surfaces) and astrophysical phenomena such as solar flares etc.

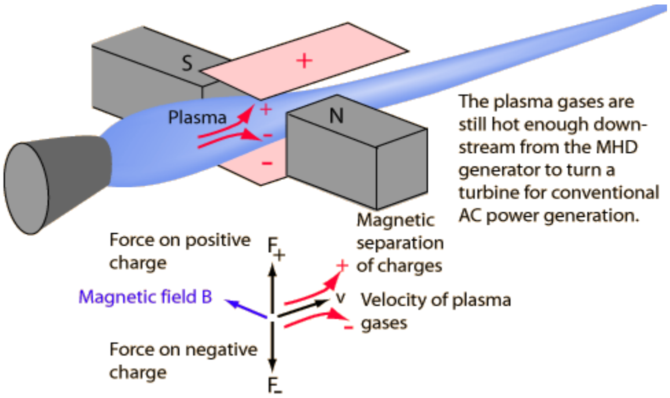

Fig 1. Plasma State Distribution and Flow

A key dimensionless parameter for ideal MHD is the plasma-beta It is the ratio of thermal to magnetic pressure Low beta means dynamics dominated by magnetic field, high beta means standard Euler dynamics most important parameter.

$$\beta=2\mu_o P/B^2$$

$$\beta\propto c_s{}^2/\upsilon_a{}^2$$

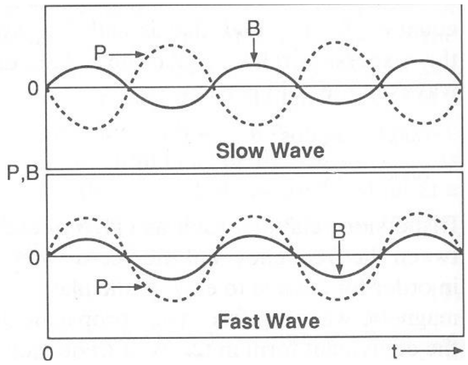

Fig 2. Pressure Perturbations

This is a simple measure of the relative importance of the gas and magnetic forces.

$$\beta= p_{gas}/\, p_{mag}$$

If β>> 1 Gas Dominates and If β<< 1 Magnetic field dominates.

IV. MHD WAVES

All the wave forms in MHD are by restoring forces. Sound waves are produced by compression. Magneto acoustic waves produced from Gas, Magnetic Pressure, ad Magnetic Tension.

Basic assumption of MHD: changes of electric field slow displacement current neglected in Ampere-Maxwell law.

$$1/c^2\partial \mathbf{E}/\partial t\approx 0$$

The simplest wave mode of propagating in a Fluid is sound wave. The sound wave is a propagating pressure perturbation whose ***k*** is normal to the pressure front. In Plasma state magnetic field do not affect particle motion along B→ sound wave can propagate in plasma with k||B

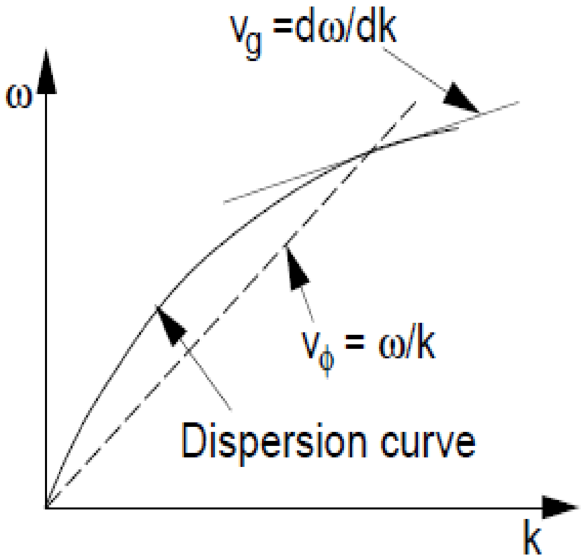

Fig 3. Dispersion Curve

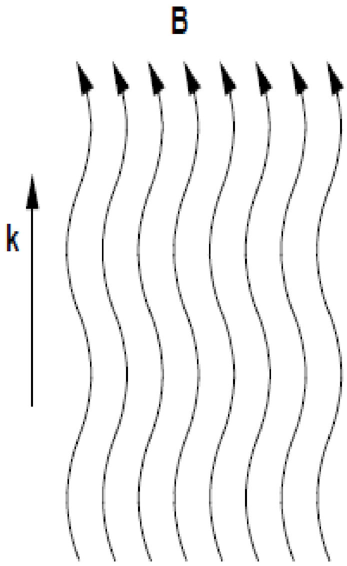

Fig 4. Torsional Alfen waves

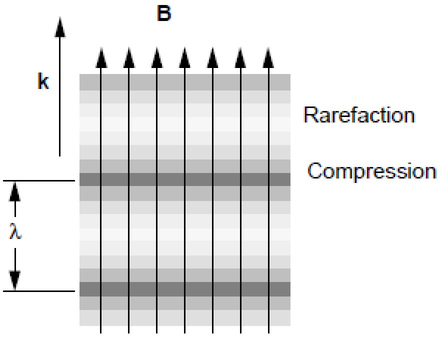

Fig 5. Longitudinal Sound waves

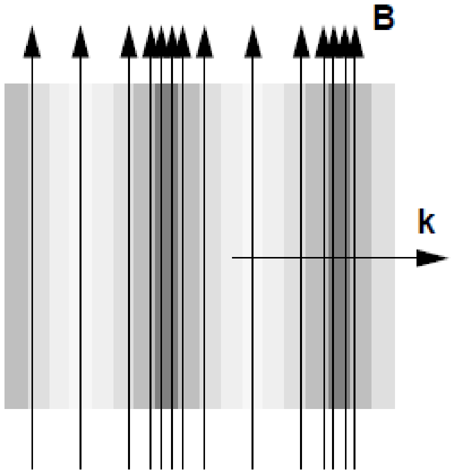

Fig 6. Magneto Acoustic Wave

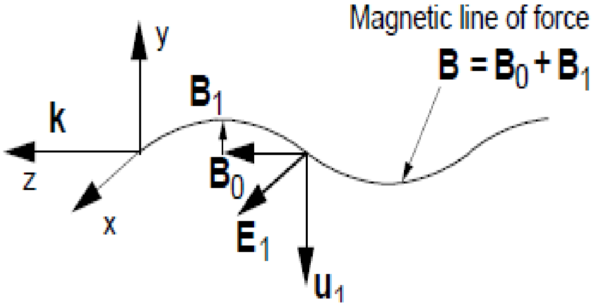

Fig 7. Magnetic Line of Force

V. MHD PROPULSION

The results of this study suggest that, within a typical submarine's size and geometric constraints, a magnetic flux density of between 8 and 10 T results in an optimum propulsive efficiency. The hydraulic efficiency is increased by minimizing exit velocity U_N with a diffuser. The magnetic coils are of "Racetrack Toroid" configuration. The" Saddle" magnet configuration is competitive if a cluster of smaller propulsors is used. The "Solenoid" configuration results in a complex flow path through a MHD thruster and relatively high magnetic fringe field in all directions. The "Racetrack Toroid" configuration allows for segmentation of the thruster and simple flow path for the sea water.
A number of experimental methods of spacecraft propulsion are based on magnetohydrodynamic principles. In these the working fluid is usually plasma or a thin cloud of ions. Some of the techniques include various kinds of ion thruster, the magnetoplasmadynamic thruster, and the variable specific impulse magnetoplasma rocket. There are two main types of MPD thrusters, applied-field and self-field. Applied-field thrusters have magnetic rings surrounding the exhaust chamber to produce the magnetic field, while self-field thrusters have a cathode extending through the middle of the chamber. Applied fields are necessary at lower power levels, where self-field configurations are too weak. Various propellants such as xenon, neon, argon, hydrogen, hydrazine, and lithium have been used, with lithium generally being the best performer.

MPD thrusters could produce extremely high specific impulses (I_{sp}) with an exhaust velocity of up to and beyond 110,000 m/s, triple the value of current xenon-based ion thrusters, and about 20 times better than liquid rockets. MPD technology also has the potential for thrust levels of up to 200 newtons (N) (45 lb_F), by far the highest for any form of electric propulsion, and nearly as high as many interplanetary chemical rockets. This would allow use of electric propulsion on missions which require quick delta-v maneuvers (such as capturing into orbit around another planet), but with many times greater fuel efficiency. Hall Effect thrusters accelerate ions with the use of an electric potential maintained between a cylindrical anode and negatively charged plasma that forms the cathode. The bulk of the propellant (typically xenon gas) is introduced near the anode, where it becomes ionized, and the ions are attracted towards the cathode, they accelerate towards and through it, picking up electrons as they leave to neutralize the beam and leave the thruster at high velocity.

The anode is at one end of a cylindrical tube, and in the center is a spike that is wound to produce a radial magnetic field between it and the surrounding tube. The ions are largely unaffected by the magnetic field, since they are too massive. However, the electrons produced near the end of the spike to create the cathode are far more affected and are trapped by the magnetic field, and held in place by their attraction to the anode. Some of the electrons spiral down towards the anode, circulating around the spike in a Hall current. When they reach the anode they impact the uncharged propellant and cause it to be ionized, before finally reaching the anode and closing the circuit. Magnetoplasmadynamic (MPD) thrusters and lithium Lorentz force accelerator (LiLFA) thrusters use roughly the same idea with the LiLFA thruster building off of the MPD thruster. Hydrogen, argon, ammonia and nitrogen gas can be used as propellant. In a certain configuration, the ambient gas in Low Earth Orbit (LEO) can be used as a propellant.

Table 2. Experiment operating/test conditions.

Location	*M*	*T* (K)	*p* (MPa)	*u* (m/s)	*A* (cm2)
Pre-ionizer	0.3	291	0.186	301	17.3
Test section	1	225	0.097	883	8.7

The gas first enters the main chamber where it is ionized into plasma by the electric field between the anode and the cathode. This plasma then conducts electricity between the anode and the cathode. This new current creates a magnetic field around the cathode, which crosses with the electric field, thereby accelerating the plasma due to the Lorentz Force. The LiLFA thruster uses the same general idea as the MPD thruster, except for two main differences. The first difference is that the LiLFA uses lithium vapor, which has the advantage of being able to be stored as a solid. The other difference is that the cathode is replaced by multiple smaller cathode rods packed into a hollow cathode tube. The cathode in the MPD thruster is easily corroded due to constant contact with the plasma. In the LiLFA thruster the lithium vapor is injected into the hollow cathode and is not ionized to its plasma form/corrode the cathode rods until it exits the tube. The plasma is then accelerated using the same Lorentz Force.A magnetohydrodynamic drive or MHD propulsor is a method for propelling seagoing vessels using only electric and magnetic fields with no moving parts, using magnetohydrodynamics. The working principle involves electrification of the propellant (gas or water) which can then be directed by a magnetic field, pushing the vehicle in the opposite direction.

RESULTS AND DISCUSSION

The resulting system specific mass predictions are shown in figure 7 as functions of net output power and radiator temperature. A radiator temperature of ≈600 K provides the minimum specific mass for all net output power levels. In order to clarify why the minimum specific mass is achieved at the radiation temperature of ≈600 K, mass fractions of major components are shown in figure 8 for radiation cooler temperatures of 400, 600, and 800 K. When radiator temperature increases, radiation area becomes smaller to release waste heat, and as a result the specific mass of the radiator is also reduced, as shown in figure 8. At the same time, however, a larger MHD generator and a larger superconducting magnet are required to provide the same net electrical output power because total plant efficiency declines with increasing cooler temperature. As shown in figure 8, the mass fraction of the MHD generator and magnet at a radiation temperature of 800 K is 36.4 percent, which is twice as large as the mass fraction when at a radiation temperature of 600 K. On the other hand, the mass of the radiator itself is large and accounts for >50 percent of the total system mass at a radiator temperature of 300 K. These results in an increase of specific mass compared with the 600 K case.

If an appropriate radiator temperature (≈600 K) is chosen, the specific mass decreases with increasing net electric output power, as can be seen in figure 7. The expected result is a system specific mass of ≈3 kg/kWe at 1 MWe, 2–3 kg/kWe at 2 MWe, and <2 kg/kWe for >3 MWe. These values are in general agreement with the results reported in reference 8. The present NFR/CCMHD power generation system could provide both a higher plant efficiency and a much lower specific mass for multimegawatt electrical power levels in comparison with other energy conversion systems.

CONCLUSION

A multi-mega watt class NFR powered CCMHD space power plant cycle using a He/Xe working gas has been studied. This included a detailed system analysis and the formation of a comprehensive research and technology plan.

The major conclusions of the system analysis are as follows:

- A MHD nuclear space power generation system, which does not rely on the use of condensable alkali-metal seed, was proposed. The total plant efficiency was expected to be 55.2 percent, including pre-ionization power.
- Three compressor stages were sufficient from a plant efficiency perspective.
- Regenerator efficiency affected the total plant efficiency; if removed, plant efficiency declined from 55 to 28 percent for the full regenerating case.
- Total plant efficiency depended significantly on radiation cooler temperature. The radiator temperature also had a strong influence on power plant specific mass.
- Minimum system specific mass occurred at a radiation cooler temperature of ≈600 K.
- System specific mass was estimated to be ≈3 kg/kWe for a net electrical output power of 1 MWe, 2–3 kg/kWe at 2 MWe, and ≈2 kg/kWe at >3 MWe.

REFERENCES

[1] Bateman. 1978. MHD Instabilities, Cambridge Mass.: MIT Press.
[2] Boyd, T. J. M. & Sanderson. 1969. Plasma Dynamics, London: Nelson.
[3] Jeffrey, A. & Taniuti, T. 1966. Magnetohydrodynamic Stability and Thermonuclear Confinement, New York: Academic Press.
[4] Magneto Hydrodynamics Propulsion, A.Sherman, Space Science Laboratory.
[5] MHD Power Generation- A Technology of Future by Dr. B.Ramana ,BARC, Vol 26 Jan **1977**
[6] Camac, M. "Plasma Propulsion of Spacecraft", Astronautics Vol. 4, October **1959**
[7] Demetriades, **S.** T. "Plasma Propulsion **-** Part **r',** Astronautics Vol. **7,** March **1962**
[8] Gourdine, M. **C.** "Recent Advances in Magnetohydrodynamic Propulsion" ARS Journ. **31, 1670 (1961).**
[9] Sutton, **G.** W. and "Magnetohydrodynamic Power and Propulsion" Gloersen, P. published in Magnetohydrodynamics. Proceedings of the Fourth Biennial Gas Dynamics Symposium, edited **by** A.B. Cambel, T.P. Anderson, M.M. Slawsky, Northwestern University Press, **1961.**
[10] Grundy, R. F., Magnetohydrodynamic Energy For Electric Power Generation, (Noyes Data Corporation, Park nidge,NJ,1978) pp. 2-10
[11] Way, Stewart, Electromagnetic Propulsion For Cargo Submarines, Journal of Hydronauti.,s, Vol. 2, NO. 2, pp. 49-57, April 1968
[12] Taussig, R., A Foreign Technology Assessment Of Superconductor Technology Applied To MHD Ship Propulsion, Spectra Technology, Inc., STI #1705.01, December 1988
[13] Coombe, R. A., Magnetohydrodynamic Generation Of Electrical Power, (Chapman and Hall, London, 1964)pp.34-52.
[14] NASA MHD on Space Propulsion, R.J Litchford, N. Harada Marshal Space Station
[15] Litchford, R.J.; Bitteker, L.J.; and Jones, J.E.: "Prospects For Nuclear Electric Propulsion Using Closed-Cycle Magnetohydrodynamic Energy Conversion," *NASA/TP—2001–211274*, 2001.
[16] Knight, T.; and Anghaie, S.: "Estimation of Specific Mass for Multimegawatt NEP Systems Based on Vapor Core Reactors with MHD Power," *Space Technology and Applications International Forum (STAIF) 2004*, AIP Proceedings 699, pp. 379–387, 2004.
[17] Harada, N.; Kien, L.C.; and Tashiro, T.: "Closed Cycle MHD Generator using He/Xe Working Plasma," AIAA Paper, 2002–2144, *Proceedings of the 14th International Conference on MHD Power Generation and High Temperature Technologies*, pp. 163–171, 2002.

BIOGRAPHY:

Author: 1

Mr. Vamsi Krishna .C completed Bachelors in Aeronautical Engineering and pursuing Masters in Thermal Engineering. Mr. Vamsi has published conference papers and journals on Aerospace and Propulsion. He is working as Assistant Professor in MLR Institute of Technology. He is currently working on Smart Materials for Aerospace Applications under sponsored project by MHRD in India.

Author: 2

Mr. Sai Kumar. A completed his Bachelors in Aeronautical Engineering and pursuing his Masters in Aerospace Engineering. Mr. Sai Kumar has carried out several project and published large number of papers in various journals.