

Case Study of MHD Generator for Power Generation and High Speed Propulsion

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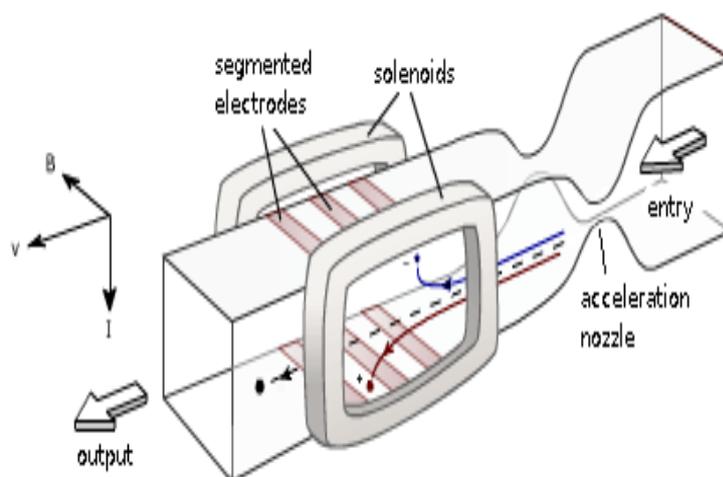
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Abstract: The main scope of the project is calculating the output power or the capacity of Eco-friendly Magneto Hydrodynamic Generator. Capacity of Thermal power station in India is compared with Eco-MHD. Modern society requires a variety of goods and services which require energy as the diversity of range of services increases so is the demand for energy. Electrical energy because of its versatility takes major share. About 75% of electrical energy is generated by thermal stations. Coal has to be transported to thermal stations located away from coalfields by railways and power has to be transmitted over large distances from pithead stations. These problems can be eliminated or reduced by converting coal into SNG (synthetic natural gas) at pithead and transporting the gas by pipe-grid to all thermal stations. The efficiency of power station can be increased by adopting combined cycle. Topping combined cycle by MHD generators failed to materialize Eco friendly Magneto hydrodynamic generator is now suggested for development as a topping addition for combined cycle to further improve the efficiency.

Keywords: MHD Generator, MHD aerodynes, High speed propulsion, sunspot modelling, Hypersonic vehicle

I. Introduction

The MHD (magneto hydrodynamic) generator transforms thermal energy and kinetic energy directly into electricity. MHD generators are different from traditional electric generators in that they operate at high temperatures without moving parts. MHD was developed because the hot exhaust gas of an MHD generator can heat the boilers of a steam power plant, increasing overall efficiency. MHD was developed as a topping cycle to increase the efficiency of electric generation, especially when burning coal or natural gas. MHD dynamos are the complement of MHD propulsor, which have been applied to pump liquid metals and in several experimental ship engines.[1]



MHD Generator

Faraday linear nozzle with segmented electrodes

Fig.1 MHD generator [7]

An MHD generator, like a conventional generator, relies on moving a conductor through a magnetic field to generate electric current. The MHD generator uses hot conductive plasma as the moving conductor. The mechanical dynamo, in contrast, uses the motion of mechanical devices to accomplish this. MHD generators are technically practical for fossil fuels, but have been overtaken by other, less expensive technologies, such as combined cycles in which a gas turbine's or molten carbonate fuel cell's exhaust heats steam to power a steam turbine. Natural MHD dynamos are an active area of research in plasma physics and are of great interest to the geophysics and astrophysics communities, since the magnetic fields of the earth and sun are produced by these natural dynamos.

The Lorentz Force Law describes the effects of a charged particle moving in a constant magnetic field. The simplest form of this law is given by the vector equation.

$$\mathbf{F} = Q \cdot (\mathbf{v} \times \mathbf{B})$$

Where,

- \mathbf{F} is the force acting on the particle.
- Q is the charge of the particle,
- \mathbf{v} is the velocity of the particle, and
- \mathbf{B} is the magnetic field.

The vector \mathbf{F} is perpendicular to both \mathbf{v} and \mathbf{B} according to the right hand rule.

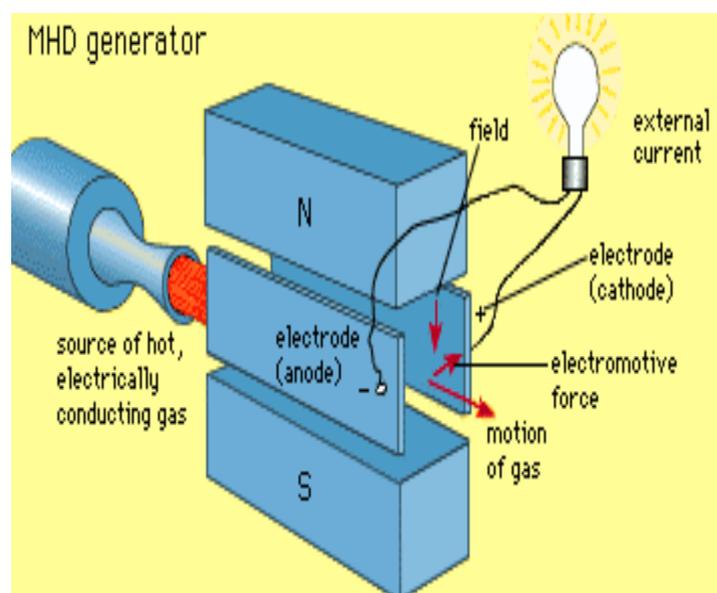


Figure-2 MHD generator producing electricity [1]

II. Power Generation

Typically, for a large scale power station to approach the operational efficiency of computer models, steps must be taken to increase the electrical conductivity of the conductive substance. The heating of a gas to its plasma state or the addition of other easily ionisable substances like the salts of alkali metals can accomplish this increase. In practice, a number of issues must be considered in the implementation of an MHD generator: generator efficiency, economics, and toxic by products. These issues are affected by the choice of one of the three MHD generator designs: the Faraday generator, the Hall generator, and the disc generator.

It has been sixty years since various methods have been investigated in view of lowering heat transfer to high-speed Flying bodies. Hypersonic magnetized plasmas have been initially studied for space capsules equipped with Electromagnetic shields, around which air is naturally ionized due to subsequent heat behind shock waves, Later Work focused on detaching shock waves from leading edges of blunt bodies with upstream non-magnetized Plasma "air-spike" acting like a protective cushion for the materials. Ionization is then obtained through many means, including applying high voltage discharges, high frequency electromagnetic waves or lasers. Moreover, the modification of gas-dynamic through microwave radiation heats up the plasma and modifies the local value of the sound velocity, which attenuates the recompression behind a soft shock wave. But none of these methods really acts on the flow to truly impose one way or another to it.

A first category of plasma-aerodynamic devices actively acting upon the flow uses electro hydrodynamics. Those EHD accelerators are generally known as plasma actuators. They use properties of electric fields only (par electric body force, DC ion mobility drift or RF peristaltic waves) to carry the ions and the neutral gas through Lorentzian collisions upon a thin layer. Peristaltic EHD devices can theoretically

accelerate air in the boundary layer up to Mach 1.0 (neglecting heating and viscous effects which lower the real effect). But magneto hydrodynamics, involving both applied electric and magnetic fields combined into Lorentz forces $J \times B$, is preferred to control airflows up to hypersonic regimes.

Next-generation aircrafts of a new kind are described which, if supplied by a powerful energy source, could flight silently at high Mach numbers in dense air without shock wave nor turbulence, fully driven by MHD force fields controlling the flow around their whole body. In relation with such devices, original solutions to classical problems raised by plasma instabilities in the presence of powerful magnetic fields are proposed.

Among applications of MHD converters described in this paper: wave drag and wake turbulence cancellation, flow laminarization, engine inlet control, combination of accelerators and generators into MHD-bypass systems, HV plasma protection of leading edges, electromagnetic braking for atmospheric re-entry. The association of all these techniques leads to a unique device combining a space launcher, a plane and an atmospheric re-entry capsule into one fully reusable vehicle taking-off and landing on its own steam, successor of conventional rockets.

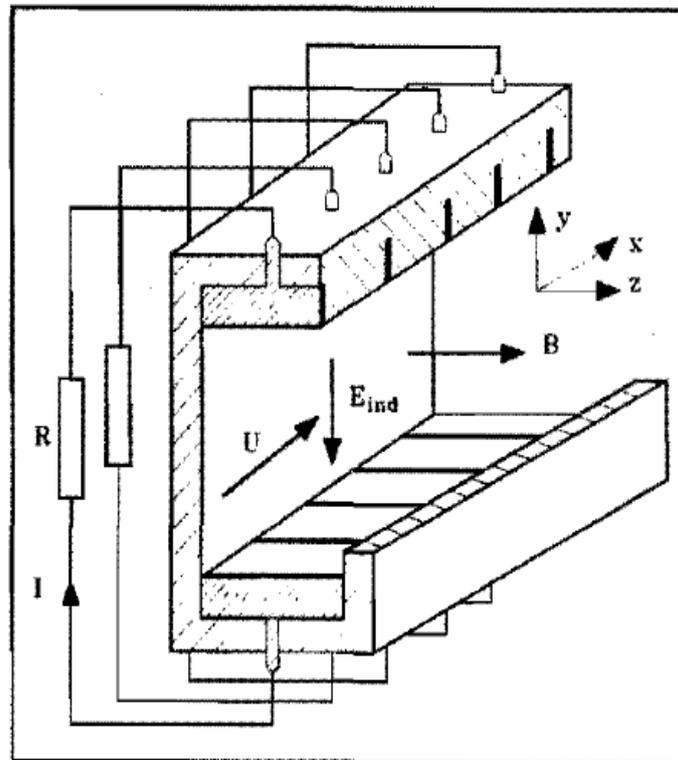


Fig.3 Principle of MHD generator[9]

When an electrical conductor is moved so as to cut lines of magnetic induction, the charged particles in the conductor experience a force in a direction mutually perpendicular to the B field and to the velocity of the conductor. The negative charges tend to move in one direction, and the positive charges in the opposite direction. This induced electric field, or motional emf, provides the basis for converting mechanical energy into electrical energy. At the present time nearly all electrical power generators utilize a solid conductor which is caused to rotate between the poles of a magnet. In the case of hydroelectric generators, the energy required to maintain the rotation is supplied by the gravitational motion of river water.

One of the earliest serious attempts to construct an experimental MHD generator was undertaken at the Westinghouse laboratories in the period 1938-1944, under the guidance of Karlovitz (see Karlovitz and Halasz, 1964). This generator (which was of the annular Hall type) utilized the products of combustion of natural gas, as a working fluid, and electron beam ionization. The experiments did not produce the expected power levels because of the low electrical conductivity of the -gas and the lack of existing knowledge of natural gas, as a working fluid, and electron beam ionization.

III. MHD Generator Description

If gas flows in x direction and magnetic field B acts in y direction, the force on the particle acts in z direction.

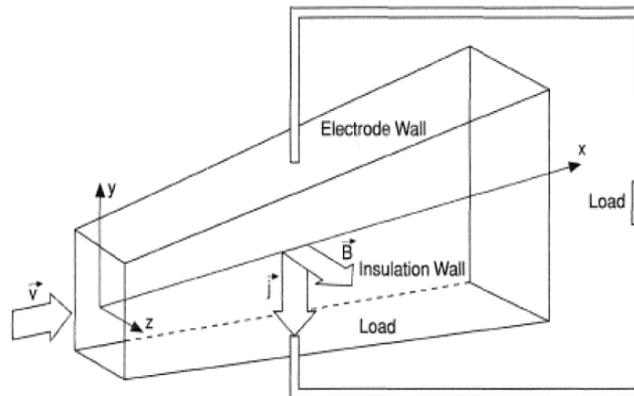


Fig.4 Direction of magnetic field, gas velocity and force in MHD system

MHD design problems:

- Efficiency attained are so far have been relatively low and life of the equipments has been short.
- Combustor, MHD-generator, channel, electrodes and air-prep-heater are exposed to corrosive gases at very high temperature. So material must be developed to permit long operating life.
- The ash (slag) residue from the burning coal is carried over with combustion gases and cause erosion of the exposed surface.

IV. MHD For High speed Propulsion

1. MHD Aerodynes

MHD (Magneto Hydrodynamic) propulsion has been extensively studied since the fifties. To shift from propulsion to an MHD Aerodyne, one only needs to accelerate the air externally, along its outer skin, using Lorentz forces. A set of successful experiments, obtained on a disk shaped model, placed in low density air, dealt with various problems: wall confinement of two-temperature plasma obtained by inversion of the magnetic pressure gradient, annihilation of the Velikhov electro thermal instability by magnetic confinement of the streamers, establishment of a stable spiral distribution of the current, obtained by an original method. Another direction of research is devoted to the study of an MHD-controlled inlet which, coupled with a turbofan engine and implying an MHD-bypass system, would extend the flight domain to hypersonic conditions.[3]

During the sixties it was shown that if the electrical conductivity of the gas was large enough (3,000S/m), Lorentz forces $J \times B$ ($B = 2$ teslas) could deeply modify the gas parameters of a supersonic flow ($M = 1.4$) in a Faraday MHD converter. In a constant cross section channel, when slowing down the gas (short duration argon flow, $T = 10,000^\circ\text{K}$, $p = 1$ bar, $V = 2750$ m/s, delivered by a shock driven wind tunnel) when slowing down, the deceleration was strong enough to create a front shock wave, without any obstacle. Accelerating the gas, velocity gain of 4,000 m/s was obtained along a 10 cm MHD channel. In supersonic flows, shock waves occur when the local slowing down is strong enough to produce self crossing of Mach lines.

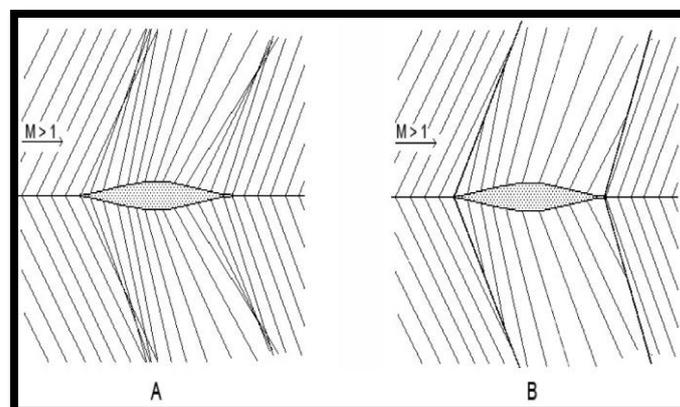


Fig.5-Two dimensional flows around a flat wing. Mach lines computed from Navier-stokes .[4]

It was shown, based on 2d-numerical calculation and hydraulic simulation that those shock waves could be eliminated if a suitable Lorentz force was applied around the model.

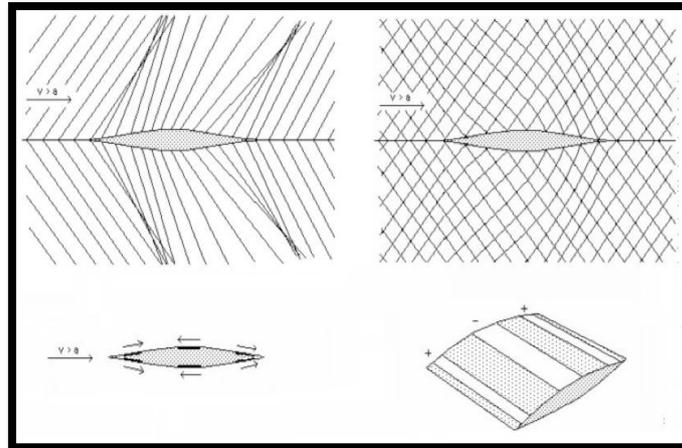


Fig.6 Elimination of shocks around a flat wing by convenient Lorentz force field

Elimination of shocks around a flat wing by convenient Lorentz force field. The gas must be accelerated around the leading edge and the bottom, and slowed down between the two to prevent the expansion fan. By the way, this introduced the concept of MHD bypass. In the eighties it was planned to use a shock tube as a supersonic, high electrical conductivity gas flow generator, to operate this key-experiment [5]. But, due to the connection to UFO phenomenon (supersonic silent flight, as reported by witnesses) this was no longer possible in institutional structures. Years after, the Lambda Laboratory was created in 2007, with private funding. The use of a shock tube was too complex and expensive, so that the team shifted to experiments in low pressure hypersonic wind tunnel, providing natural high electrical conductivity.

Then disk shaped MHD aerodynes, are more suitable, due to the high Hall parameter conditions. This arises specific difficulties, such tendency of the discharge to be blown away, due to the magnetic field gradient. This was rapidly solved, by wall confinement through inversion of magnetic gradient.

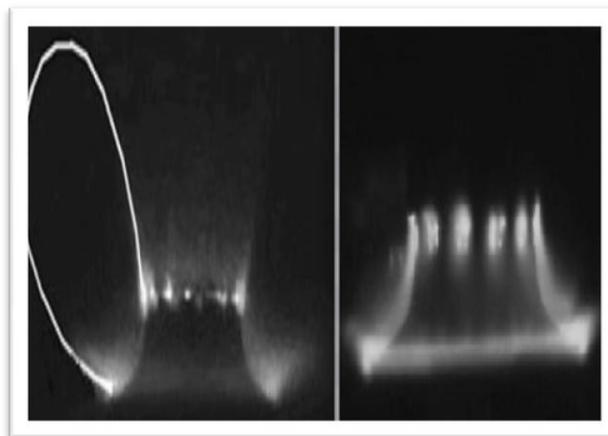


Fig.6 Left: the discharge is blown away by the magnetic gradient.
Right: wall confinement by inversion of this magnetic gradient

V. Sunspot Modelling

Sunspots are central to our understanding of solar magnetism in several aspects. Sunspots are the most prominent manifestation of the large scale cyclic solar magnetic field. Understanding their subsurface structure as well as the processes of formation, dynamic evolution, and decay is crucial for connecting them to the dynamo and flux emergence processes in the solar convection zone. On smaller scales sunspots provide an ideal environment for studying magneto-convection for a variety of different field configurations [9]. While quiet Sun regions have been modelled very successfully for almost 3 decades using 3D radiative MHD simulations, such models were only applied to sunspots in the past five years.

VI. MHD For Space Vehicles

Several Authors have investigated the possibility to utilize MHD energy conversion systems in the space. Many of them proposed a plasma MHD generator feed by fuel in liquid or solid state (liquid hydrogen, liquid oxygen, kerosene, and nuclear fuel). The fuel contained in heavy vessels, have to be carried to space together with MHD generator. To do this a large amount of energy is needed. An electrical power generation on-board system was also considered. The MHD generator proposed is built in supersonic nozzle of rocket engine utilizing liquid hydrogen and liquid oxygen. A. Kantrovitz presented one of the first studies on MHD interaction generated by space vehicles at hypersonic velocities.[6]

During re-entry into atmosphere between 80 and 60 Km of altitude at velocities 7,000-11,000 m/s strong shock waves occur with highly non-uniform flow field. The temperature of air behind the shock reaches 10,000-20,000 K and due to relaxation near vehicle surface is between 10,000 and 5,000 K. This produces sufficient ionization to sustain a significant MHD interaction level.

As a consequence of ionized boundary layer of hypersonic vehicle.

The control of flight of spacecraft can be obtained by creation of drag forces and tangential forces as well as a controlling moment. The external flow structure including shock wave formation can be influenced too. At lower altitudes and velocities the MHD conversion and the flight control would be possible through pre-ionization or seeding of the working media.[8]

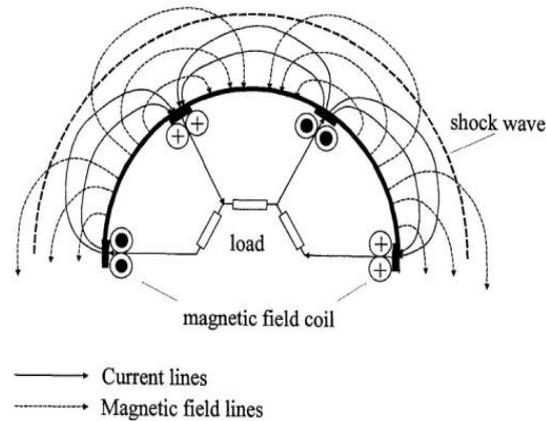


Fig. 7 Scheme of a conversion system realized in Boundary layer of an Hypersonic Vehicle (above: side view - below: cross sectional view)

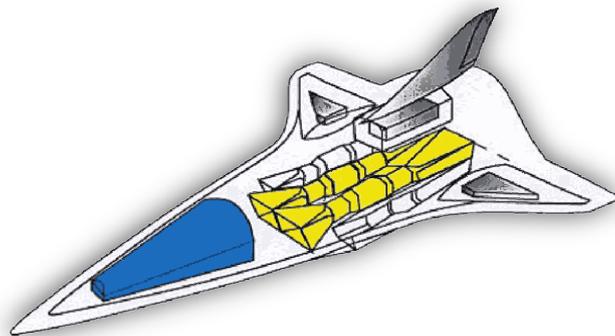


Fig. 8 AJAX spacecraft using MHD[12]

VII. Magneto-Hydrodynamic Design

1st law of Thermodynamics defines the equivalence between work and heat energy, when work is converted into Heat. But the 2nd law of Thermodynamics explains the conversion of thermal energy into mechanical energy on the basis of temperature gradient. The efficiency of ideal heat engine $\eta = (K_1 - K_2)/K_1$ where K_1 and K_2 are absolute temperatures in Kelvin scale of source of heat and sink respectively. This equation can also be stated as $\{1 - (K_2/K_1)\}$. If Q_1 is the quantity of heat observed from the heat source then the quantity of heat that can be converted into work is $Q_1 \{(K_1 - K_2)/K_1\}$ or $Q_1 \{1 - (K_2/K_1)\}$. [10]

That means the entire quantity of heat cannot be converted into work unless K_2 is 0 or -273^0C . The conversion of heat into work is dependent on the temperature gradient.

The fraction (K_2/K_1) can be defined as “non-convertible fraction” of heat energy. So, the conversion ratio can be increased only by decreasing the non-convertible fraction (K_2/K_1).



Fig. 9 Space vehicle using MHD[10]

VIII. The Secret Of Hypersonic Flight: MHD

The faster an airplane flies the higher it must climb and cruise. It is not possible to fly at ground level at high Mach number just for mechanical constraint due to high pressure. Over Mach 3-3.5 flight is possible with turbo reactors (up-left figure). At higher Mach numbers these rotating machines cannot be used any longer. One can shift to stato-reactor (right). At Mach number up to Mach 6.5 scramjets can be used (below). The leading edge is cooled by liquid hydrogen an oxygen circulations. The mixture burns in annular combustion chamber at supersonic velocity.[17]

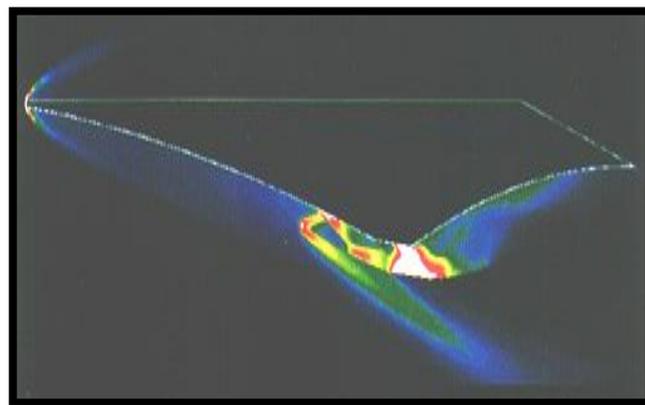


Fig. 10 Ajax with stato

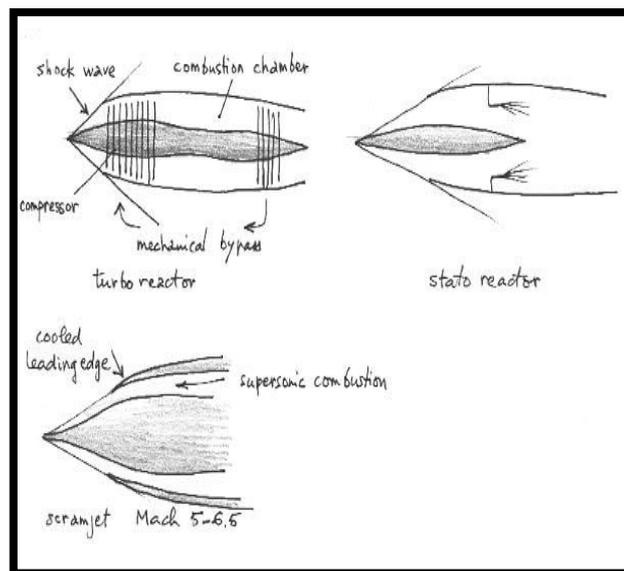


Fig. 11 Turbo Reactors [12]

IX. Magnetic Plates

The area of each magnetic plate is 3 m² and the distance between the plates is 6m. The following are the properties of the magnetic plates:

- The Magnetic plates both together weigh 12,000 tonnes
- The plates are 100,000 times stronger than the Earth's magnetic field,
- stores enough energy to melt 18 tonnes of gold.
- Uses almost twice much iron as the Eiffel Tower.

X. Basic Formulae Used In MHD Calculations

Max Power = E²/4R

E and R are calculated as follows:

Open circuit voltage **E = BUD**

Where B is Magnetic Flux density,

D is Distance between plates

Generator resistance **R = D/σ A**

Where σ is Average gas density

A is plate area

6.2 Capacity Calculations:

Plate Area (A)	= 3 m ²
Distance between plates (D)	= 6 m
Flux density (B)	= 5 Wb/m ²
Average gas density (U)	= 1000 m/s
Gaseous conductivity (σ)	= 10 Mho/m
Open circuit voltage (E)	= BUD = 5x1000x6 = 30,000 volts
Generator resistance (R)	= D/σ A = 6/ (10x3) = 0.2 ohm
Max Power (P)	= E ² /4R = (30,000) ² / (4x0.2) = 1125 MW

XI. Comparison With Other Magneto Hydro Dynamic Generators

1. Comparison with IITK MHD calculations

IITK calculations

A	= 0.25 m ²
D	= 0.5 m
B	= 2 Wb/m ²
U	= 1000 m/s
σ	= 10 Mho/m
E	= BUD = 2x1000x0.5 = 1000 volts
R	= D/σ A = 0.5/ (10x0.25) = 0.2 ohm
Max Power	= E ² /4R = 1000 ² / (2x0.2) = 1250 KW

Eco-MHD calculations

A	= 3 m ²
D	= 6 m
B	= 5 Wb/m ²
U	= 1000 m/s
σ	= 10 Mho/m
E	= BUD = 5x1000x6 = 30,000 volts

$$\begin{aligned} R &= D/\sigma A \\ &= 6/(10 \times 3) = 0.2 \text{ Ohm} \\ \text{Max Power} &= E^2/4R \\ &= 30000^2/(4 \times 0.2) \\ &= 1125000 \text{ KW} \end{aligned}$$

A is Plate Area
D is distance between plates
B is flux density
 σ is gaseous conductivity
U is average gas density
R is generator resistance
E is open circuit voltage

The Eco-MHD capacity is 1125 MW which is greater than the IITK MHD capacity which is 1250KW.

Comparison of capacities between Eco-friendly MHD and KTPS

Kothagudem Thermal Power Plant is located at Paloncha in Andhra Pradesh, India. The power plant has an installed capacity of 1,720 MW with 11 units in operation. It is one of the coal based power plants of APGENCO. [14]

In January 2012, it was reported that the Andhra Pradesh government has decided to build additional unit with capacity of 800 MW.

Currently, Kothagudem thermal station space available at the site has been surveyed, it has been confirmed that another unit of 800 MW capacities can come up there.



The calculated Eco-MHD capacity found to be 1125MW, and the KTPS capacity is 800MW
 $1125 \text{ MW} > 800 \text{ MW}$.

Thus Eco-friendly MHD has more capacity than the existing Thermal power station capacity.

XII. Results And Conclusion

The MHD generator Resistance increases with the decrease in the Area of the plates, and increases with increase in the distance between the plates. The open circuit voltage varies increasingly with the Magnetic flux density, average gas density and also the distance between the two plates. The overall capacity or the maximum power generated increases with increase in the Open circuit voltage and decrease in the resistance of the generator.

The Magnetic flux is taken 5 Wb/m^2 . The two plates, each of area 3m^2 are separated by the distance 6m. The open circuit voltage is calculated to be 30,000 volts, and the Generator resistance 0.2 Ohm.

The Eco-Friendly Magneto Hydrodynamic Generator is capable of producing capacity of 1125MW. The Power generation is Eco-Friendly using the salt water as fuel and capacity is comparatively greater than the existing KTPS (Thermal power station) in India. The possibility of stacking the output of many such systems in series and the absence of many disadvantages associated with non-renewable methods of electric power generation should make MHD using flowing salt water a very attractive alternative for energy generation.

Harnessing power by employing an MHD generator with salt water as its fluid conductor is hugely advantageous in that the source is renewable, it requires no external energy input to facilitate its operation, it has no moving parts and as such does not contribute to mortality of aquatic organisms and finally, it does not pose problems of pollution.

XIII. Future-Scope Of Magneto Hydro Dynamic Generator

The Eco-friendly MHD Generator design, calculations and analysis of the results will be given to an industry which will be able to develop the Eco-friendly power generation using MHD. Power generation capacity has to increase rapidly[16]. To reduce pollution, and to improve overall efficiency the coal has to be gasified at pitheads and the gas, SNG, transported by pipe-grid to all thermal stations. This facilitates conversion of all stations into combined cycles initially. Later MHD generators or thermal cells can be added to the power stations. This is the only way beneficial to one and all. The MHD Generator can be equipped with solar panels, so that the power generation becomes easier.

Recently, sunspot models have undergone a dramatic change. In the past, several aspects of sunspot structure have been addressed by static MHD models with parametrized energy transport. Models of sunspot fine structure have been relying heavily on strong assumptions about flow and field geometry (e.g., flux-tubes, "gaps", convective rolls), which were motivated in part by the observed filamentary structure of penumbrae or the necessity of explaining the substantial energy transport required to maintain the penumbral brightness[15]. However, none of these models could self-consistently explain all aspects of penumbral structure (energy transport, filamentation, Ever shed flow).

In recent years, 3D radiative MHD simulations have been advanced dramatically to the point at which models of complete sunspots with sufficient resolution to capture sunspot fine structure are feasible.

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