Present Research Status of MHD Electrical Power Generation

Susumu Shioda

Tokyo Institute of Technology

4259 Nagatsuta, Midori-ku, Yokohama 227 Japan

Abstract: Recent research activities for open and closed cycle MHD electrical power generations are reviewed. World first full scale 500MWe natural gas fired open cycle MHD is now under construction in USSR. Coal-fired open cycle MHD researches are in the stage of proof of concept and retrofitting of old coal power stations with MHD is planned in US and other countries. Basic research for closed cycle MHD is most actively pursued in Japan, which potentially can provide a very high efficiency and a simple and reliable system.

1. Introduction

Magnetohydrodynamic electrical power generators(1) can supply electricity to external loads by utilizing voltage and current which are induced when an electrically conductive fluid crosses an applied magnetic field with a high velocity. The principle of MHD generators is shown in Fig.1.1. A working fluid passes through an MHD channel against Lorentz force, which is the cross product of current and magnetic field, and a part of its enthalpy is converted to an external circuit.

Three kinds of working fluids are considered; a combustion gas, an inert gas such as helium or argon, and a liquid metal. Correspondingly, we have three kinds of MHD generators; open cycle, closed cycle and liquid metal MHD. Because, presently, the liquid metal MHD is considered to be applied for a small electrical power generators, attentions are paid to open and closed cycle MHD generators in this paper. Making working gases electrically conductive, we put a smat amount of alkali-metal such as potassium or cesium or its compound into them, which is called seeding. Seed material has a low ionization potential and becomes thermally ionized for temperature higher than around 2500K. Physics related to both open and closed cycles are described in the reference(2).

For the case of open cycle MHD, the gas temperature at the MHD generator inlet is around 3000K, which can be realized by firing fossil fuel with air preheated up to 2000K or with oxygen enriched air. Mole fraction of seed, which is usually K_2CO_3, is the order of a percentage.

For the case of closed cycle MHD, the mole fraction of seed, which is metallic potassium or cesium, is 10^{-5}-10^{-4}. Because helium or argon consists of monoatomic particles, the energy exchange between electrons and atoms is inefficient (there is no vibration or rotation mode in the energy exchange process), electron temperature can be elevated to values higher than gas temperature, which can enhance the ionization degree of seed material. This non-equilibrium ionization can even make seed material fully ionized, when electron temperature is increased higher than 4000K. Therefore, electrical conductivity of the seeded inert gas can be increased to values larger than 100Ω/m, even when gas temperature is 2000K, which can be compared to 10 Ω/m for the case of the seeded combustion gas.

A typical power plant system for coal-fired open cycle MHD is shown in Fig. 1.2. Pulverized coal is burned in a two stage cyclone slagging combustor. In the first stage, combustion takes place under the condition of fuel-rich with relatively low temperature around 2100K. Slag is extracted through taps located on combustor walls. In the second stage chamber, coal burning is completed and temperature of the combustion gas is increased up to 3000K. Some amount of slag(10-20%) is vaporized and carried over towards an MHD channel. I order to recover the heat after the MHD generator, there are heat exchangers for preheating of air, a radiant boiler and a feed water heater in the downstream part of the system. Potassium compound seed(K_2CO_3) reacts with sulfur contained in combustion gas, forming K_2SO_4 which is recovered in the heat exchangers and a electric precipitator. Therefore, there is no need for a de-sulfurization equipment. But blockage of seed and slag accumulation in canals of beds in high temperature regenerative heat exchangers, which heats air up to 1800-2000K, is a serious problem. Presently, the regenerative heat exchangers are abandoned and, alternatively, metallic tube heat exchangers up to 700℃ and oxygen enrichment of air are adopted. In this case, a total efficiency is decreased because a larger amount of heat is put to a steam turbine bottoming system.

The basic system of the closed cycle MHD cycle is shown in Fig. 1.3. Inert gas such as helium and argon is heated to around 2000K in a regenerative heat exchanger with a ceramic heat storage bed, which is heated by combustion gas. Then it is seeded with cesium or potassium and enter into an MHD generator. After expanding through an MHD generator, inert gas is introduced into a metallic regenerative heat exchanger. Then it is cooled and compressed for recirculation. Seed material is extracted from the metallic heat exchanger and a cooler. Steam and gas turbine systems are considered as a bottoming part. It is an advantage for closed cycle MHD that the top temperature in the closed cycle MHD coincides with the combustion temperature around 2000C which is given when combustion takes place with an ambient air.

In this way, MHD generators play a role as a topping part for converting heat to electricity and it belongs to a category of Brayton cycle because the working gas expands along the channel yielding a power as is the case for a gas turbine. Generally, walls of the MHD channels should be cooled to keep its surface temperature low and, therefore, the surface-volume ratio should be kept small to reduce the cooling loss of heat. From this reason, MHD generators are applicable to power stations with a large capacity in the range of 100-1000MWe. The efficiency of the open cycle MHD generator is expected to be to 50-55% (based on a high heat value of fossil fuels) when an high temperature regenerative heat exchanger directly pre-heats air and 45-50% when oxygen enrichment is adopted. Efficiency of closed cycle MHD is estimated also to 50-58%.

2. Present status(3) of research and development

As for open cycle MHD, directly fired coal combustion MHD is most emphasized. MHD channels can torelate a dirty combustion gas while for gas turbine system, coal gasification is required which losses considerable amount of energy. R&D status for major components of coal fired open cycle MHD are summarized in Table 2.1. Durability tests for 200-1300 hours under power generation conditions have been made in US, USSR and Japan. Results indicate MHD channel durability of several thousands hours. Coal combustor with 50MW thermal input has been developed in US and tested for over 200 hours. Scaling to larger capacity is a remaining subject. At present, long duration tests of slagging MHD channels combined with coal combustor are conducted in US, USSR and China. For instance, 50MWt CDIF facility located at Montana, US, has demonstrated 8 hours continuous operation with the maximum output power of 1.7MWe and accumulation of 1000 hours operation is planned. Typical capacity of superconducting magnets for open cycle MHD is several GJ with the maximum magnetic field strength 5-7T at a bore of the magnet. The first MHD power generation with a 4.5T superconducting magnet with 60MJ capacity was successfully conducted at ETL, Japan in 1974. Then after, 168MJ magnetic was constructed and tested in US. It is anticipated that there is no technical problem for construction. Downstream parts of MHD system, which is called heat and seed recovery system have been tested with CFFF facility, Tennessee, US. It has been found that the MHD downstream system can meet the environmental regulation standards.

Natural gas fired open cycle MHD is in the stage of a demonstration plant. In USSR a 500MWe plant (U-500) is under construction at a suburban area in Moscow, from which 270MWe is from MHD and 312 is from a steam turbine. Construction was started in 1982 and it was planned to be completed in 1989. But due to re-designing of a 3000tons superconducting magnet its final completion is announced to be delayed by 3-5 years. Fig. 2.1 shows the system of U-500[4]. Air is pre-heated in a high temperature regenerative heat exchanger up to 1700℃ by firing natural gas (indirect preheating). There is another burner in the boiler which enable them to operate the steam turbine part separately.

As for closed cycle MHD, power extraction experiments with thermal input 3-5MW blow down facilities have been conducted at Tokyo Institute of Technology and Eindhoven University of Technology (the Netherlands). Fig.2.2 shown the system of FUJI-1 closed cycle MHD experimental facility at TIT. Enthalpy extraction of around 15% with 500-700KW power output was achieved at both institutes. Power density up to $70MW/M^3$ was recorded at TIT, which is one-order higher than values in open cycle MHD. Experiments with disk geometry channels at TIT also indicate a longer durability of generator electrodes. These results encourage us to proceed to a next step; blow-down experiment with thermal input in the level of 100MW and a closed loop experiment with a thermal input of 5MW and over 100 hours continuous operation.

3. Conclusion

According to increased world-wide interest for solving a global environmental problems such as acid rain and increased concentration of carbon di-oxide, MHD electrical power generation tends to be more emphasized. It is expected to deliver the highest conversion efficiency from heat to electricity. Natural gas fired open cycle MHD is in the stage of demonstration. Coal fired open cycle MHD is in the stage of engineering proof of concept. Closed cycle MHD has a potential for a higher efficiency and longer durability.

REFERENCES

(1) R.J.Rosa, MHD Energy Conversion, Hemisphere Publing Co., 1987.

(2) R.J.Rosa, C.Kruger & S.Shioda, MHD, Special Issue on Application of Partially Ionized Gas, Transaction of IEEE, June,1989.

(3) S.Shioda(editor), Status Report of MHD Electrical Power Generation, International Liaison Group on MHD,1987.

(4) A.E.Scheindlin, Ryazan Pilot MHD Power Plant, International Scientific Session on MHD Electrical Power Generation, Tampere, Finland,August, 1988.

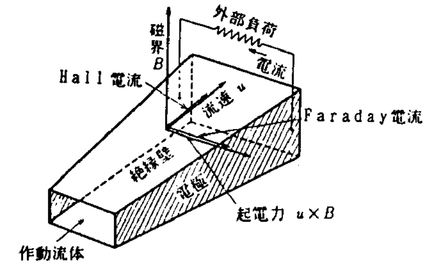
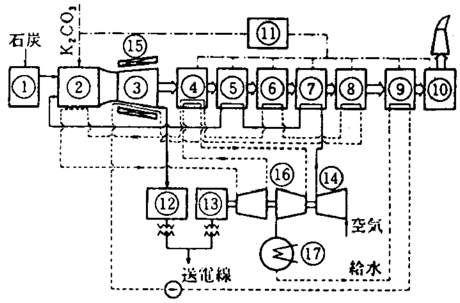


Fig. 1. 1. Principle of MHD generators



①石炭前処理、②燃焼器、③MHD発電流路、④Radiant boiler、⑤高温空気予熱器、⑥中間boiler、⑦低温空気加熱器、⑧排熱boiler、⑨Exaust gas冷却器、⑩電気集塵器、⑪Seed回収・再生装置、⑫直交変換装置、⑬発電機、⑭空気圧縮機、⑮超電導磁石、⑯蒸気turbine、⑰復水器

Fig. 1. 2. Power plant system for coal-fired open cycle MHD

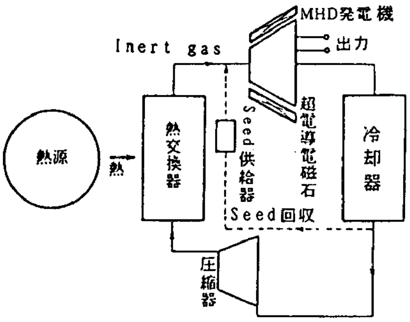


Fig. 1. 3. Basic system of closed cycle MHD

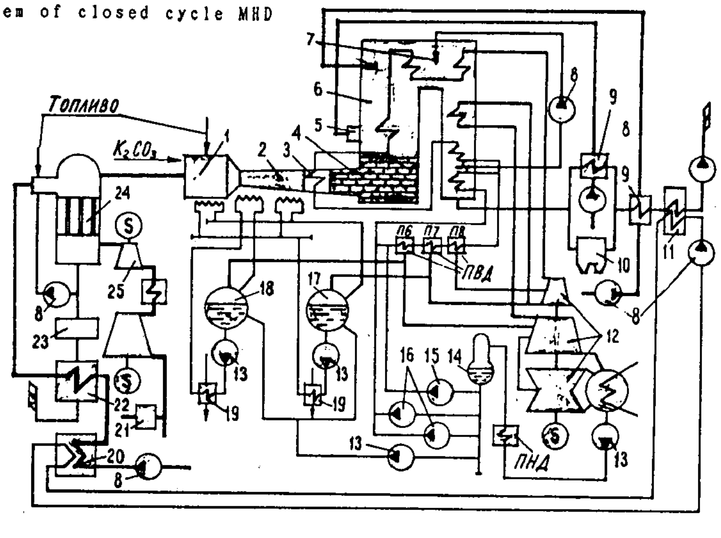


Fig. 2. 1. The system of U-500

1, combustor; 2, MHD generator; 3, water-cooled portion; 4, ceramic diffuser and holding chamber; 5, burner for autonomous operation; 6, steam boiler; 7, inlet of air for afterburning and recirculation; 8, smoke exhausters, fans; 9, preheaters of air for autonomous operation and afterburning; 10, electrostatic precipitators; 11, preheaters of water for air heaters; 12, steam turbine; 13, pumps; 14, deaerator; 15, feedwater turbopumps; 16, standby and emergency electric pumps for feedwater; 17,18, separating drums for 45 abs.atm and 20 abs.atm; 19, standby cooler of circulation water of the cooling systems; 20, air heater; 21, air separation unit; 22, preheater of combustion air for high-temperature oxidizer heater (shown at 24); 23, catalytic reactor; 24, high-temperature oxidizer heater; 25, compressor unit

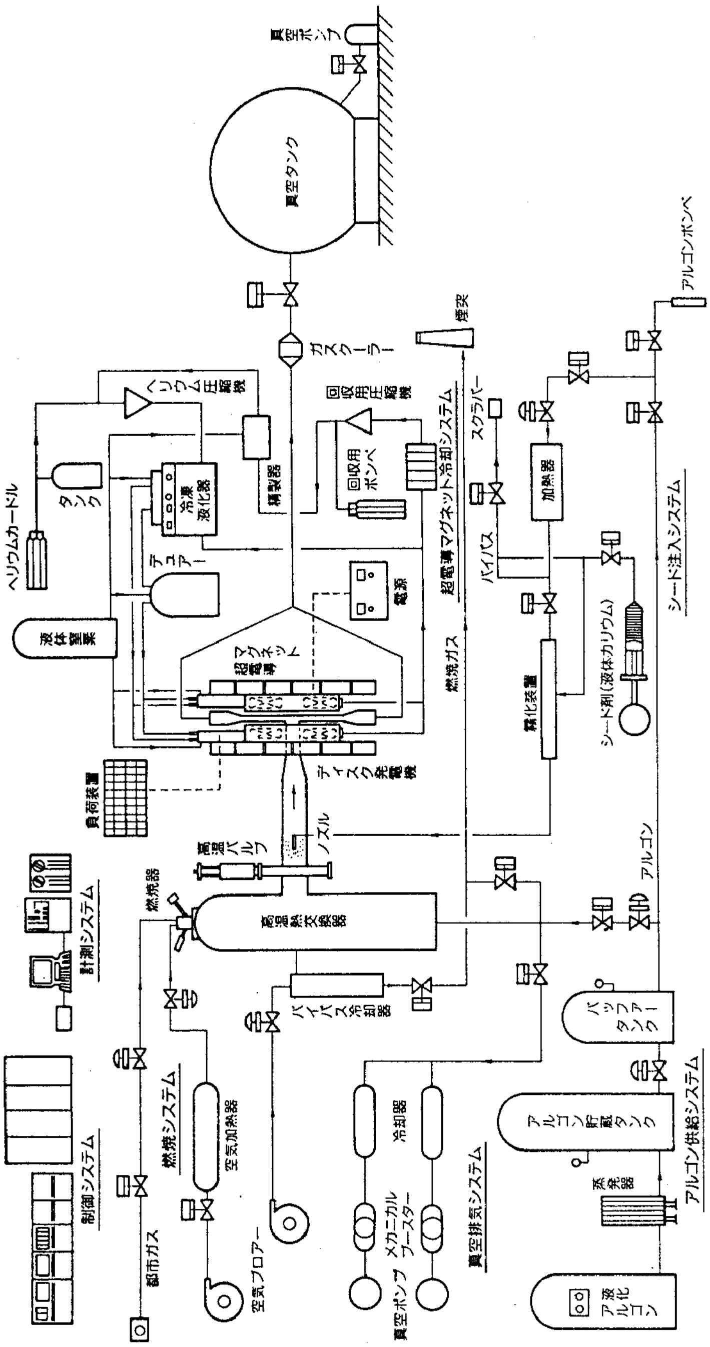


Fig. 2. 2. FUJI-1 facility

Table 2.1. Status of main components for open cycle MHD

Components	Requirements	Targets	Prospect	Achievement (nation, facility)
MHD channel	Enthalpy Extraction	20～25%	○	11.6 % (10 sec)(USA;HPDE) 7 % (30 min)(USSR;U25) 4.8 % (1 min)(Japan; MarkII)
	Durability	more than 4,000～ 8,000 h	○	1,300h (oil+ash)(USA;AVCO Mark VII) 250h(natural gas)(USSR;U25) 430h (oil+SO_2)(Japan; MarkVII)
Combuster	Temperature Capacity	3,000 K 500～2,000 MWt	○	3,000 MWt(natural gas)(USSR; U25) 50 MWt (pulverized coal) (USA;CDIF) 25 MWt (oil)(Japan;MarkV)
Air pre-heater	Direct heating	1,300～ 2,000 K mass flow: 500kg/s (clean fuel)	◎	1,470K, 40kg/s (USSR;U25) 1,970～2,320K, 0.4～1.2kg/s (USSR;U02) 1,650K, 15kg/s (Japan; blast furnace
	Indirect heating	1,300～ 2,000 K mass flow: 500kg/s (Seed Slag	△	basic research (USA) 1,770K, under seed (Japan; Mark VI)
Supercon-ducting magnet	Stored energy	5～6 T ～15GJ	○	6T, 168MJ (USA;CFFF) 5T, 34MJ (USA;U25B) 4.5T 60MJ (Japan;MarkV)
Seed cycle	Recovery	more than 95%	○	～90% (USA, CFFF) more than 99.9% (Japan; Mark VI, VII)
	Regeneration	economical process	○	conceptual design(Japan, USA)
Environment	SOx	regulation standard	○	< 1 ppm (Japan; Mark VII) de-surfurazation more than 90 % (USA; CFFF)
	NOx		○	< 100 ppm (Japan; Mark VII) < 0.2 lbm/MBTU (USA;CFFF)
	Dust		○	< $22mg/Nm^3$ (Japan;Mark VII) less than regulation standards (USA;CFFF)