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Magnetohydrodynamic Power Generation Experiments with Fuji-1 Blowdown Facility

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Experimental results of nonequilibrium plasma magnetohydrodynamic (MHD) power generation from the Fuji-1 blowdown facility are presented. The Fuji-1 experiments have been conducted since 1983, and the disk-shaped MHD generators called Disk-F3a, F3r, and F4 have been tested during the last decade. In the experiment with the newest Disk-F4 generator, which was designed based on the results of previous experiments with the Disk-F3a and F3r generators, an output power of 506 kW and an enthalpy extraction ratio of 18.4% for thermal input of 2.75 MW were simultaneously obtained. During the experiment, however, the deposition of seed material on the electrodes and the insulator walls was revealed, and large amount of impurity (water vapor) contamination in the working gas was detected. In the last experiment the stainless-steel-coated anodes were used instead of copper anodes to prevent the seed material from depositing on the generator walls, and the impurity contamination was reduced by increasing the bottom temperature of the heat exchanger. Consequently, an output power of 544 kW for thermal input of 3.38 MW and an enthalpy extraction ratio of 18.9% for thermal input of 2.17 MW were successfully demonstrated. Each value is the highest among those achieved with the Fuji-1 facility.

Introduction

IN the last few decades open- and closed-cycle magnetohydrodynamic (MHD) systems have been investigated and are continuing to be investigated as possible candidates for high-efficiency electrical power-generation applications.[1–4] In the open-cycle MHD power generation combustion gas is used as a working gas, where the plasma is in a thermal equilibrium state. In the closed-cycle MHD system, on the other hand, a nonequilibrium plasma, alkali metal seeded noble gas, is utilized as a working medium. One of the advantages of the closed-cycle MHD is that higher power density can be achieved because of the higher electrical conductivity in the generator channel. This fact leads to a compact generator with a smaller superconducting magnet as compared to the open-cycle MHD generator, although the closed-cycle power plant system is relatively complicated. Another advantage is that the high power generation is possible even under relatively low gas temperature, about 2000 K, because the electrical conductivity in the nonequilibrium plasma depends on the electron temperature and not on the gas temperature. Of course, higher gas temperature will also provide higher plant efficiency in a conventional thermodynamical system.

Studies on the closed-cycle MHD power generation have been conducted with the Fuji-1 blowdown facility at Tokyo Institute of Technology since 1983 (Ref. 5). One of the main objectives in the Fuji-1 experiments is to demonstrate the high enthalpy extraction ratio (electrical output/thermal input) with a disk-shaped generator for a period of several tens of seconds under low seed fractions. For this purpose attention has been paid to the achievement of stable and uniform nonequilibrium plasma with full seed ionization[6,7] under the condition of strong MHD interaction. In a disk MHD generator the electromotive force is induced by the radial plasma flow and the magnetic field applied perpendicularly to the flow and yields the azimuthal current (Faraday current). The interaction between the Faraday current and the magnetic field results in the radial Hall electric field. Thus, the electric power is extracted with a load resistance connected between inner (anode) and outer (cathode) electrodes. In the Fuji-1 blowdown facility the disk-shaped MHD generators called Disk-F3a, F3r, and F4 have been tested during the last decade, and the newest Disk-F4 generator has been in service since 1994 (Refs. 8–12).

The test results from the Disk-F3a and F3r generators[8,9] are reviewed briefly in this paper in order to clarify the aim and meaning of the experiment with the Disk-F4 generator. As will be described later, although the high performance has been demonstrated in the experiments with the Disk-F3a and F3r generators there was still room for improvement in the generator performance. The newest Disk-F4 generator was designed on the basis of the information obtained by scrutinizing the results of experiments with the Disk-F3a and F3r generators. Thus, the design concept of the Disk-F4 generator is mainly based on the reliability for high power generation. For this purpose, as will be mentioned in detail, the Mach number at the generator inlet is increased slightly as compared to those in the earlier generator designs. Furthermore, attention has been paid to the realization of suitable working gas conditions for high power generation.

In the experiment with the Disk-F4 generator, an output power of 506 kW and an enthalpy extraction ratio of 18.4% for thermal input of 2.75 MW were simultaneously obtained. In the experiments, however, the reduction of output power was observed at the early stage of the power-generation run, which could be attributed to the deposition of seed material on the water-cooled electrodes and insulator walls. Furthermore, a large amount of water vapor was detected in the working gas. In the last power-generation experiments with the Disk-F4 generator, the stainless-steel-coated anodes were used instead of copper anodes in order to prevent the deposition of seed material onto the electrode surface. Moreover, an attempt was made to reduce the impurity contamination by increasing the bottom temperature of the heat exchanger. As a result of these efforts, an output power of 544 kW for thermal input of 3.38 MW and an enthalpy extraction ratio of 18.9% for thermal input of 2.17 MW were successfully demonstrated. Each value is the highest among those achieved with the Fuji-1 facility. In the present paper the results of the recent Fuji-1 experiments are presented in detail.

Fuji-1 Facility and the Disk MHD Generator

A schematic diagram of the Fuji-1 facility is shown in Fig. 1. The explanation of each component was given previously in Ref. 5.

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