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INFLUENCE OF FLUCTUATIONS AND NONUNIFORMITIES ON PERFORMANCES OF CLOSED CYCLE MHD GENERATORS

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ABSTRACT

Seed fraction fluctuation and ionization instability are discussed as a reason of plasma nonuniformities and fluctuations of MHD generator performances nearly fully ionized seed. The measurements of seed fraction fluctuations and radiation from plasma taken during recent experiments with FUJI-1 facility, experiments with a model of seed injection system with water instead of seed, linear and nonlinear theory of ionization instability are used for this purpose. Three different ranges of fluctuations frequency of plasma parameters were detected in experiments: several hertz, about 100 hertz and several tens kilohertz. First two are caused by imperfection of existent seed injection system. As for fluctuations with a frequency about several tens kilohertz those were observed even at highest enthalpy extraction. Seed fraction space nonuniformities caused by droplet structure of seed injection and ionization instability are examined as possible reasons for this kind of fluctuations. Seed fraction space nonuniformities are seemed one of the reasons of these fluctuations in FUJI-1 experiments. It is pointed out the necessity of considerable improvement of seed injection system in order to increase MHD power conversion efficiency.

INTRODUCTION

To achieve high values of both enthalpy extraction and isentropic efficiency of nonequilibrium MHD generator it is necessary to provide the absence of output parameters fluctuations and local plasma nonuniformities in the whole volume of MHD channel. In this paper the phenomena leading to output parameters fluctuations and local plasma nonuniformities and their possible influence on performances of disk type MHD generators are considered.

One of the main sources of local nonuniformities of electrophysical plasma properties is the ionization instability. The linear theory of the ionization instability predicts that MHD-plasma is stable at nearly full seed ionization /1,2/. This concept is being realized at Tokyo Institute of Technology and good results have been achieved during recent years /3-6/. High enthalpy extraction was observed in experiments with shock tube driven disk MHD generator - 32.5 % /3,4/, and FUJI-1 blow-down facility - 18 % /5,6/. As for isentropic efficiency in these experiments and previous ones it was noticeable less than calculated one in assumption that ionization instability is absent.

A significant influence upon the isentropic efficiency can be exerted by two kinds of phenomena. One includes gas-dynamic losses (in boundary layers, oblique shock waves, etc.). The other one is plasma nonuniformities and fluctuations of MHD generator performances which are the subject of this paper. Seed fraction fluctuation and ionization instability are discussed as a reason of plasma nonuniformities and fluctuations of MHD generator performances nearly fully ionized seed. The measurements of seed fraction fluctuations and radiation from plasma taken during recent experiments with FUJI-1 facility, experiments with a model of seed injection system with water instead of seed, linear and nonlinear theory of ionization instability are used for this purpose. Besides simple model of seed injection system with water instead of cesium has been used for qualitative investigations of nonuniformities and fluctuations caused by imperfection of existent at FUJI-1 facility seed injection system.

RESULTS OF EXPERIMENTS WITH FUJI-1 FACILITY

Seed injection and measurement systems

Schematic of seed injection system of the FUJI-1 facility is shown in Fig.1. Detailed description of seed injection and seed fraction measurement system was presented in the paper /8/. The liquid cesium (typical flow rate is 4 g/s) is brought pneumatically into pipe with preheated argon (typical flow rate is 30 g/s) at the T-shaped mixing section. Argon-cesium mixture is transported trough the two phase flow pipe to multihole nozzle and injected into hot duct (diameter 30 cm) upstream the main argon flow (flow rate is 2 - 5 kg/s). There are optical windows at 1.3 - 1.4 m before the nozzle of MHD generator to measure seed fraction by absorption of laser diode radiation. The diameter of radiation beam which cross the hot duct is about 10 mm. Besides an induction type level gauge is used at seed tank to measure cesium flow rate. So two independent methods of seed fraction

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measurements are used.

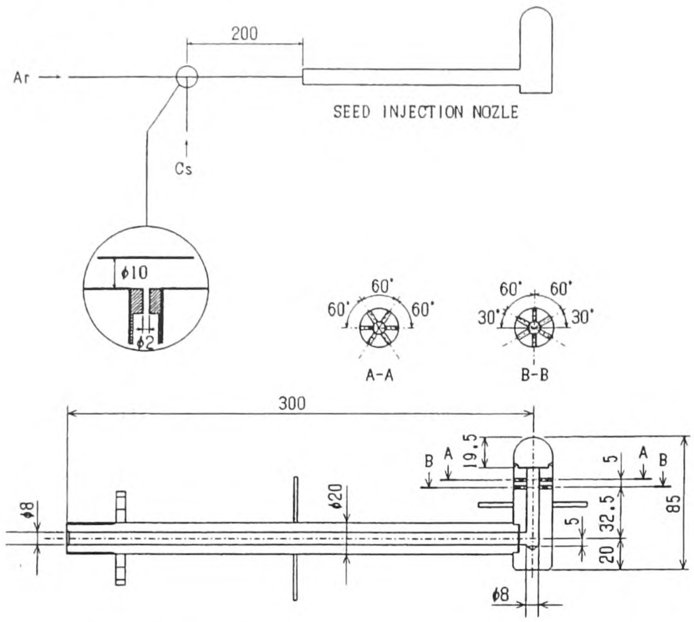

Fig.1. Schematic of seed injection system at FUJI-1 facility

For the measurements of plasma radiation two optical windows (diameter 8 mm) in one of MHD channel walls were used: upstream at r = 295 mm and downstream at r = 360 mm. Wall windows are provided by glass fiber without image transferring and after beam splitters connected with photomultipliers and polychromator with spectral multychannel analyzer (SMA). This system is spectral sensitive, can provide high time resolution and integrate lighting from plasma cylinder with diameter 8mm.

Fluctuations of seed fraction and radiation from plasma

In this paper performances fluctuations and plasma nonuniformities detected in the run A8108 are discussed. Seed fraction change during this run is shown in Fig.2.

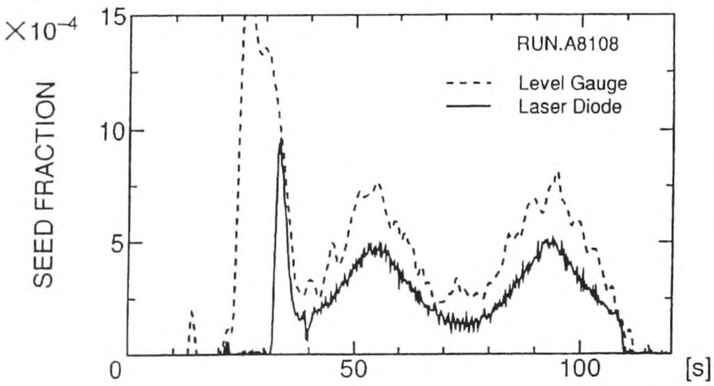

Fig.2. Time dependence of seed fraction in run A8108

Low frequency (several hertz) seed fraction fluctuations are shown in Fig.3. These fluctuations were observed only at low seed fraction (less than 3E-4) during run A8108 and were absent in the next run A8109 which was arranged at the same conditions. The difference is that seed injection system was cleaned up before run A8109. Probably the reason for these fluctuations during run A8108 is some solid phase impurity inside feeding pipes.

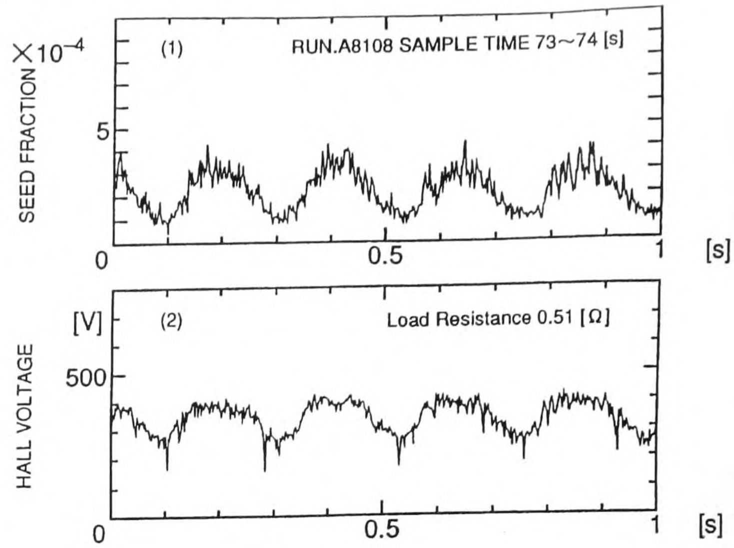

Fig.3. Low frequency seed fraction fluctuations

Figure 4 shows fluctuations with a frequency about 100 Hz. Fluctuations with this frequency always exist in FUJI-1 experiments. Apparently the reason of these fluctuations is the result of some gasdynamic instability development either in hot duct near seed injection nozzle or inside the pipe for two phase flow before seed injection nozzle.

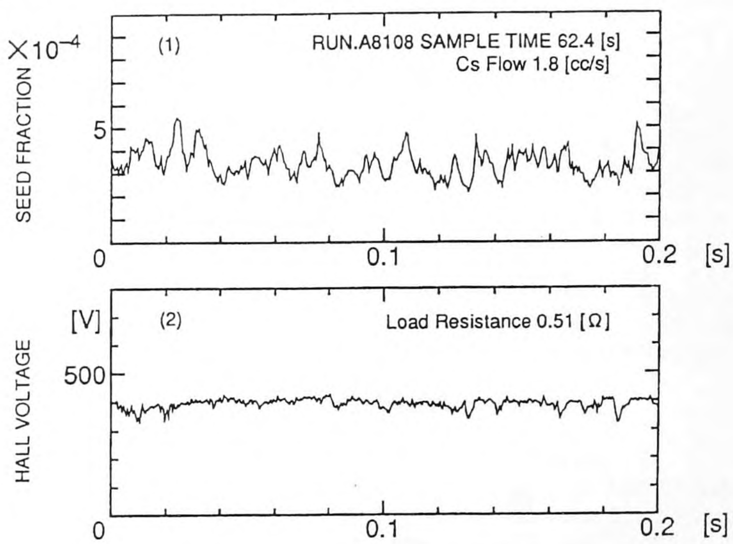

Fig.4. Permanent seed fraction fluctuations

The measurements of local radiation from plasma with high time resolution were performed during recent experiments with FUJI-1 facility. Fig.5 shows high frequency fluctuations of plasma radiation which also always were observed during run A8108. Strait lines on this figure indicate signal at the absence of radiation (calibration level). Considerable radiation fluctuations have been detected even at highest values of enthalpy extraction. It means that the plasma is still locally nonuniform and suppression of these nonuniformities is the way for further improvement of MHD power conversion efficiency.

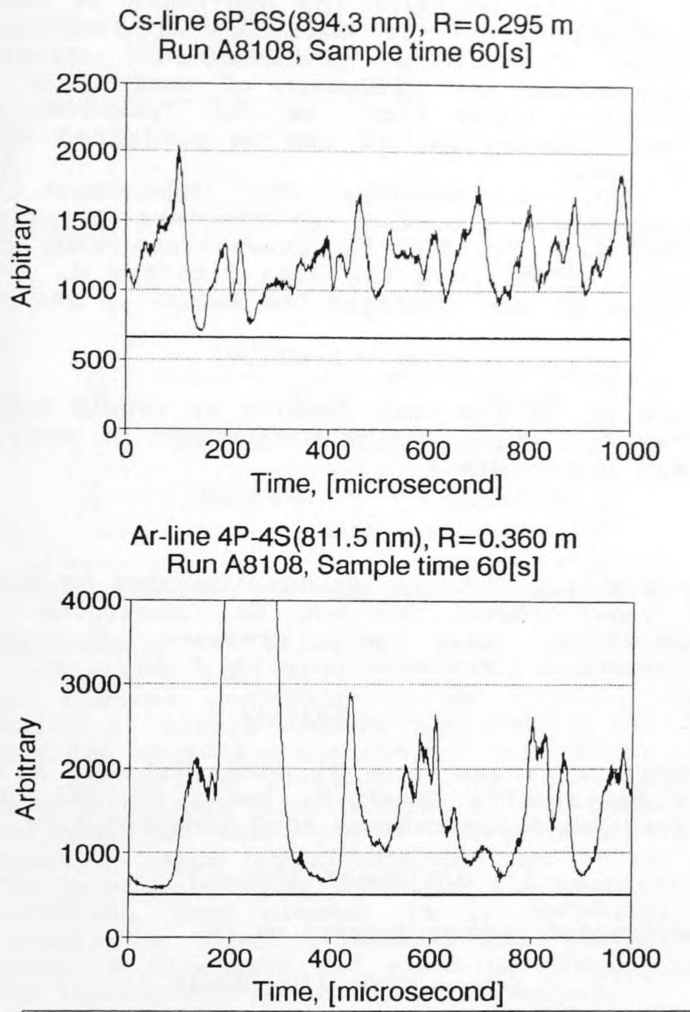

Fig.5. High frequency fluctuations of plasma radiation

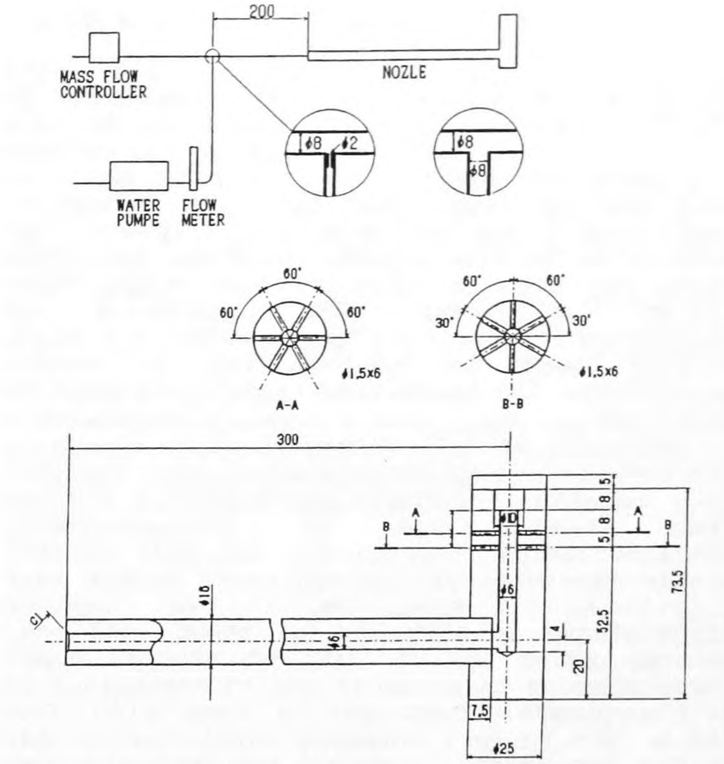

Fig.6. Schematic of water model of seed injection system

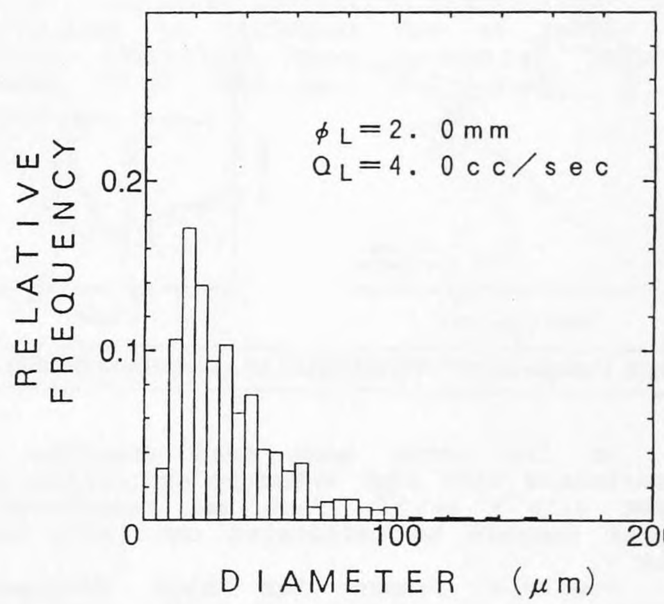

Fig.7. Distributions of droplets sizes

EXPERIMENTS WITH A MODEL OF SEED INJECTION SYSTEM

In order to investigate the fluctuations and nonuniformities which arise from imperfection of existence at FUJI-1 facility seed injection system its simple model with water instead of cesium has been used (Fig.6).

Some new qualitative results were obtained with this model. It can be clearly seen even visually that liquid phase after the T-shaped mixing section practically does not mix with gas phase and flows on the internal surface of the pipe. Horizontal orientation of this pipe lead to unsimmetric injection of liquid into hot duct: lower part of hot duct takes more seed compare to upper part.

Diameter distributions of droplets after multihole nozzle are measured in these experiments. Figure 7 shows an example of relative frequency versus droplets diameter. Average diameter of droplets is about 40 mkm.

One of conclusions from these experiments is that low frequency (4 Hz and 100 Hz) fluctuations of seed fraction in FUJI-1 experiments are obviously caused by imperfection of existent seed injection system.

THEORETICAL ANALYSIS OF HIGH FREQUENCY FLUCTUATIONS

High frequency nonuniformities of plasma radiation can be caused by two kind of phenomena. First one is the ionization instability which can be developed either because of imperfect shape of MHD channel leading to impossibility of full seed ionization in whole volume of MHD channel at any load resistance or because of metastable plasma state nearly full seed ionization /9,10/ leading to the nonlinear nonuniformities development under existence of disturbances with high enough amplitude. Second one is space fluctuations of seed fraction caused by droplet structure of seed injection.

Ionization instability at fully ionized seed

It follows from linear /1,2/ and quasilinear theory /7/ that the boundaries of stable plasma region nearly fully ionized seed are very sensitive to plasma parameters fluctuations. Seed fraction fluctuations must have the amplitude less than 5%. It can be seen from fig.8 borrowed from /11,12/. But seed fraction fluctuations have the amplitude about 40% even at highest power output (see fig.4). It means that conditions for ionization instability suppression by fully ionized seed do not realize in FUJI-1 experiments and ionization instability must be developed. In this case considerable fluctuations of Hall voltage have to repeat in synchronism the fluctuations of seed fraction with relatively higher amplitude as follows from sharp shape of voltage-current characteristics (see fig.8). But Hall current weakly fluctuate at highest power output (see fig.4). At the same time if seed fraction fluctuations amplitude is about 40% the average power output must be several times lower compare to designed one in assumption of stable plasma. That can be seen also from fig.8. But in fact enthalpy extraction at 63s in the run A8108 is almost 20% that also can not be explained from considered point of view.

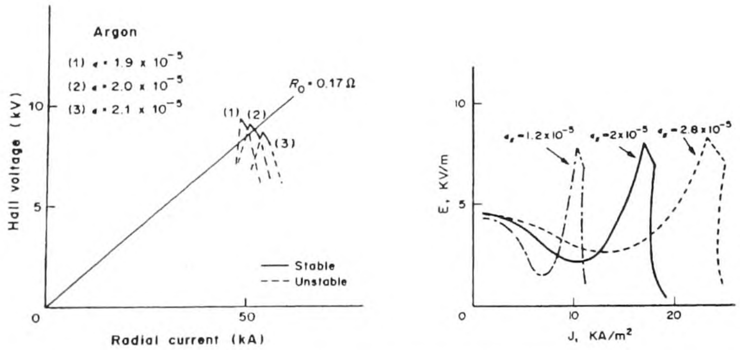

Fig.8. Voltage-current characteristics for various seed fraction

On the other hand seed fraction in experiments with high enthalpy extraction was about 1×10^{-4} – 4×10^{-4}. That was considerable higher compare to calculated one (less than 1×10^{-4}).

Possible reason for high frequency radiation fluctuations and at the same time for ionization instability reduction can be space seed fraction fluctuations in MHD-channel caused by droplets of seed in hot duct.

Space plasma nonuniformities caused by seed droplets

Existent at FUJI-1 facility seed injection system feed main flow by liquid droplets of cesium. High seed fraction spots appear in main argon flow after vaporization each droplet downstream from the seed injecting nozzle. The distance between seed injecting nozzle and MHD-channel is not high enough to mix argon with cesium properly and get uniform seed fraction. Some space fluctuations of seed fraction in MHD-channel caused by droplets in hot duct are expected.

In order to estimate the amplitude of these fluctuations it is necessary to consider pretty complicated processes of droplet vaporization and diffusion of seed vapor in turbulent argon flow. As for frequency of these fluctuations it can be estimated much more easy.

Let us consider the dependence of fluctuations frequency on droplets sizes at given seed fraction in assumptions that all seed droplets have the same diameter d. Each droplet of seed contains the amount of seed m_s

$$m_s = 1/6\pi d^3 \rho_{sl} \qquad (1)$$

where ρ_{sl} is the mass density of liquid seed. After full vaporization this amount of seed m_s takes the volume v_d

$$v_d = m_s/\rho_{sv} \qquad (2)$$

where ρ_{sv} is the average mass density of seed in vapor phase. ρ_{sv} can be calculated in dependence from gas pressure P, gas temperature T and seed fraction S as

$$\rho_{sv} = \mu_{as} SP/(kT) \qquad (3)$$

where μ_{as} is the mass of seed atom and k is the Boltzmann's constant. Using (3)-(5) the average distance between seed droplets δ is

$$\delta = d/2[\pi\rho_{sl}kT/(PS\mu_{as})]^{1/3} \qquad (4)$$

and droplet number density n_d is

$$n_d = 6PS\mu_{as}/(kT\pi d^3\rho_{sl}) \qquad (5)$$

The frequency f of seed fluctuations and as a sequence current fluctuations can be estimated as

$$f = w/\delta \qquad (6)$$

where w is the gas velocity, or, using (4)

$$f = 2w/\{d[\pi\rho_{sl}kT/(PS\mu_{as})]^{1/3}\} \qquad (7)$$

Dependencies of the distance between droplets δ and the frequency f of seed fraction fluctuations from diameter of seed droplets d for typical parameters of FUJI-1 experiment are given in Fig.9. Estimated frequency has the order of magnitude hundred kHz for conditions of run A8108. This estimated frequency and the frequency of radiation from plasma in FUJI-1 experiments (see Fig.5) coincide in order of magnitude. It means that fluctuations of radiation from plasma can be caused by space seed fraction fluctuations. Probably these fluctuations can improve effective plasma parameters by means of ionization instability reduction /13/.

CONCLUDING REMARKS

Three different ranges of fluctuations frequency were detected in FUJI-1 experiments : 3-5 Hz, 100-200 Hz and 10-30 kHz. Probably all of them caused by imperfection of existence at FUJI-1 facility liquid phase seed injection system.

Existent at FUJI-1 facility seed injection system is needed in considerable

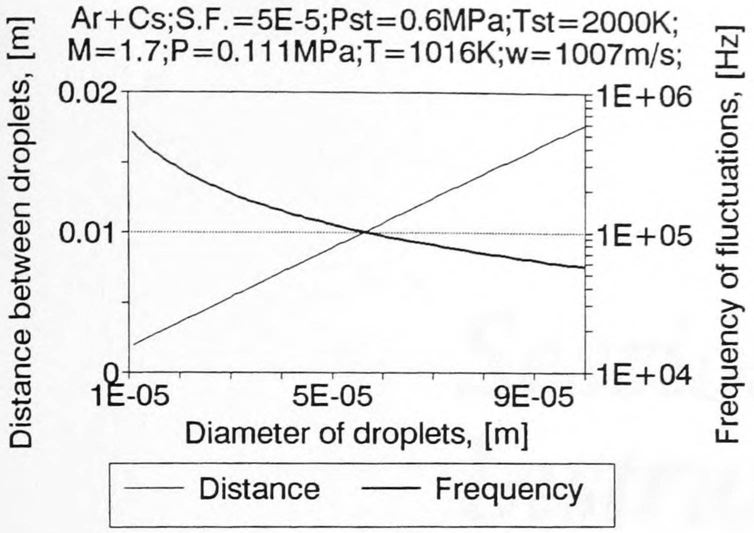

Fig.9. Frequency of seed fraction fluctuations

improvement. To eliminate first two kind of fluctuations and theirs negative influence on MHD channel performances the piston dosage system of liquid cesium, improvement of feed duct and injection nozzles are considered.

Ionization instability can not explain main details of fluctuations of MHD generator performances and plasma parameters. Seed fraction space nonuniformities can be one of the reasons of high frequency fluctuations of radiation from plasma. It is necessary to investigate these phenomena more deeply in order to eliminate all kinds of fluctuations and improve MHD generator performances.

REFERENCES

1. Velikhov, E.P., Dykhne, A.M. and Shipuk, I.Ya., "Ionization Instability of Plasma with Hot Electrons", Proc. 7th Int. Conf. on Phenomena in Ionized Gases. Vol.1. Belgrade. 1965, pp.675-681.

2. Nakamura, T. and Riedmuller, W., "Stability of Nonequilibrium MHD Plasma in the Regime of Fully Ionized Seed", AIAA Journal, Vol.12, 1974, No.5, pp.661-668.

3. N.Harada, et. al., "High Enthalpy Extraction Demonstration with Closed Cycle Disk MHD Generators", Proc. 28th Symp. on Eng. Aspects of MHD, 1990.

4. Kizuka, N., Okamura, T., Nakamichi, K., Noma, A., Harada, N., Yamasaki, H. and Shioda, S., "Increasing of Enthalpy Extraction from Disk MHD generator Caused by Inlet Swirl", 15th Symposium on Efficient Use of Energy and Direct Electrical Power Generation, Sapporo, March, 15-17, 1993, pp. 5.1.1-5.1.10.

5. Nob.Harada, et. al., "Experimental Studies of Closed Cycle MHD Power Generation with FUJI-1 Blow-Down Facility", Proc. of 11th Int. Conf. on MHD, Vol. IV, pp. 1153-1160, 1992.

6. Suekane, T., Sakano, M., Kariya, M., Kawai, H., Tsunoda, K., Okamura, T., Harada, N., Yoshikawa, K., Kabashima, S., Shioda, S., Yamasaki, H., Ikeda, S., Douzono, Y., Ishimura, M., Hasegawa, H., "High Enthalpy Extraction Experiment with FUJI-1 Facility - Effect of Channel Shape", 15th Symposium on Efficient Use of Energy and Direct Electrical Power Generation, Sapporo, March, 15-17, 1993, pp. 4.1.1-4.1.10.

7.Solbes, A., "Quasi-Linear Plane Wave Study of Electrothermal Instabilities", Proceedings of International Symposium on MHD Electrical Power Generation, Vol.1, Warsaw, 1968, p.449.

8. Hasegawa, Y., Gejo, T., Tsuji, K., Yamasaki, H. and Shioda, S., "Seed Fraction Measurements in the FUJI-1 Facility", Proc. of 10th Int. Conf. on MHD, Tiruchirapally, India, 1989, pp. XI.64-XI.71.

9. Zubtsov, V.M., "Nonlinear Waves in a Thermally Nonequilibrium, Partially Ionized Plasma in Crossed $E \times H$ Fields", Soviet Physics, Doklady, Vol. 26, 1981, No. 1, pp. 56-58.

10. Zubtsov, V.M., "Linear and Nonlinear Analysis of the Ionization Instability of Nonequilibrium MHD Plasma", Proc. of 10th Int. Conf. on MHD, Tiruchirapally, India, 1989, Later Papers.

11. Okuno, Y., Kabashima, S., Yamasaki, H., Harada, N. and Shioda, S., "Comparative Studies of the Performance of Closed Cycle Disk MHD Generators Using Argon, Helium and an Argon-Helium Mixture", Energy Conversion and Management, Vol.25, 1985, No.3, pp.345-353.

12. Abe, T., Kabashima, S., Yamasaki, H. and Shioda, S., "Numerical Studies of a High Interaction MHD Generator with Fully Ionized Seed", Energy Conversion and Management, Vol.22, 1982, pp.251-261.

13. Zubtsov, V.M., "A Method of Dynamic Stabilization of Ionization Instability", 15th Symposium on Efficient Use of Energy and Direct Electrical Power Generation, Sapporo, March, 15-17, 1993, pp. 3.3.1-3.3.10.