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Stabilization of Ionization Instability in an MHD Generator

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Reduction of ionization instability by making seed material fully ionized was observed experimentally by Nakamura[1] under the externally applied electric field, which means that the current was essentially supplied from the external circuit in this particular experiment.

In this paper, the steady relation between magnetic field B and the spatially averaged electron temperature $\langle T_e \rangle$ is discussed under the actual generator conditions. In the steady state, we have[2]

$$\langle j \rangle = \sigma_{eff} UB(1-\langle K \rangle) \, , \quad (1)$$

$$\langle j \rangle^2 / \sigma_{eff} = Q_c + Q_r \, , \quad (2)$$

where $\langle \ \rangle$ denotes the spatially averaged value, j, U, K, σ_{eff}, Q_c and Q_r are the current density, the gas velocity, the load factor, the effective conductivity and the collisional and radiative energy loss terms, respectively. Q_c, Q_r and σ_{eff} depend strongly on T_e. σ_{eff} can be expressed by

$$\sigma_{eff}/\langle \sigma \rangle = \begin{cases} 1 & \text{for} \quad \beta \leq \beta_c \, , \\ \beta_c/\beta & \text{for} \quad \beta \geq \beta_c{}^{2)} \, , \end{cases} \quad (3)$$

where β is the Hall parameter and β_c is the critical Hall parameter for ionization instability.

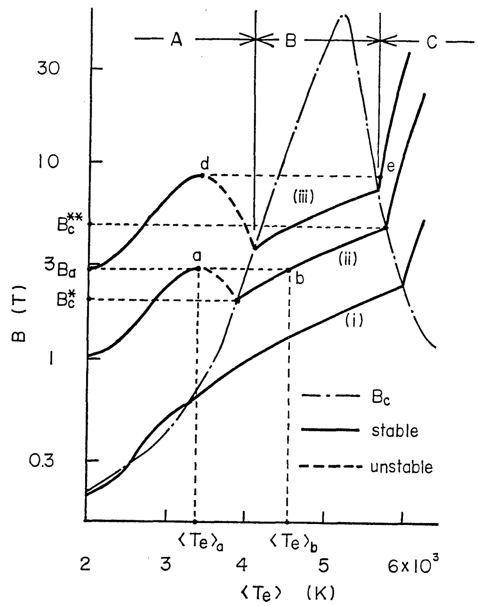

Fig. 1. The relation between B and $\langle T_e \rangle$. (i) $U(1-\langle K \rangle)=550$ m/sec, (ii) $U(1-\langle K \rangle)=250$ m/sec and (iii) $U(1-\langle K \rangle)=150$ m/sec.

Figure 1 shows the results of the $B-\langle T_e \rangle$ relation obtained from eqs. (1)-(3) together with the variation of $B_c (=\beta_c m\nu/e$, where m is the mass of an electron, ν is the collision frequency of an electron and e is the electric charge of an electron) under the following conditions; the working gas is Ar/K, the gas temperature is 1500 K, the argon number density is 10^{19} cm^{-3} (the gas pressure is 2.0 atm), the seed fraction is 10^{-5}, the height between upper and lower electrodes is 5 cm and $U(1-\langle K \rangle)$ is 550 m/s, 250 m/s or 150 m/s. In the region A in Fig. 1, the ionization of seed material is sufficient to induce the instability. In the region B, seed material is nearly fully ionized and, therefore, the instability is reduced. And in the region C, the instability is again induced due to the ionization of argon.

Stability of the steady solution is known from the non-steady energy equation for electrons;

$$A\frac{d\langle T_e \rangle}{dt} = f(\langle T_e \rangle) \equiv \langle j \rangle^2/\sigma_{eff} - Q_c - Q_r \, , \quad (4)$$

where

$$A = \left(\frac{3}{2}k\langle T_e \rangle + eV_I\right)\frac{dn_e}{dT_e} + \frac{3}{2}k\langle n_e \rangle > 0 \, ,$$

(V_I is the ionization potential of seed material and n_e is the electron number density). The dotted parts of lines in Fig. 1 are known to be unstable because $f(\langle T_e \rangle)<0$ when $\langle T_e \rangle < T_{e,0}$ and $f(\langle T_e \rangle)>0$ when $\langle T_e \rangle > T_{e,0}$ ($T_{e,0}$ is the steady solution).

If magnetic field is increased sufficiently slowly and $\langle K \rangle$ may be assumed to be constant, in the case (ii) in Fig. 1, for example, $\langle T_e \rangle$ increases suddenly from $\langle T_e \rangle_a$ to $\langle T_e \rangle_b$. Then, we know that the stable state may be realized in the B-region only between $B_a (> B_c{}^*)$ and $B_c{}^{**}$. Similarly, in the case (iii), $\langle T_e \rangle$ jumps from $\langle T_e \rangle_d$ to $\langle T_e \rangle_e$ as B increases from B_d. So, the stable state can not be realized in the whole region of $\langle T_e \rangle$.

It must be noted that the similar situation may occur when the gas velocity is increased, keeping the B-value fixed.

References

1) T. Nakamura and W. Riedmüller: *Proc. of 5th Int. Conf. on MHD Electrical Power Generation* (IAEA, Vienna, 1971) II. 291.
2) G. Brederlow and K. J. Witte: *13th Symp. on Engineering Aspects of MHD* (1973).