§18. Control of Gas Injection Velocity into an Arcjet Source by Means of a Laval Nozzle

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It has been known that the electromagnetic (EM) accelerator of the plasma can be quite a high power beam source. The key item for success has been shown to be in the super thermal plasma injection into the system[1,2]. Therefore, development of the source becomes important that boosts the injected cold gas up to the plasma flow of a super thermal state. Such process must be of the entropy acceleration mode since the EM force chokes the sub thermal plasma.

The present report concerns a new proposal of how gas is to be injected into the system. Here, the system shown in Fig.1 is taken up. The cold H_2 gas is injected into the heating up zone between the nozzle exit and the cathode via the Laval nozzle. The gas is fully ionized in the zone before it is accelerated up to near thermal velocity on the cathode surface. It is already shown[3] that the plasma must have such velocity on the cathode surface for the entropy acceleration to be effective in the main arc column. Hence, acceleration of the flow is important in the heating up zone. Here, by using the ideal model, the fluid motion there is solved so that the conditions are over viewed to accelerate it up to near the thermal velocity on the cathode. The solution is written in the form below:

$$\sqrt{\alpha T}(u+1/u)=\sqrt{T_0}(u_0+1/u_0) \quad , \qquad (1)$$

where the suffix 0 denotes the quantity on the nozzle exit surface, u the fluid velocity normalized by the characteristic one of $v_c=\sqrt{k\alpha T/2m}$, and α is the numbers of particles produced by one diatomic molecule under the influence of dissociation and ionization. It is noted that $\alpha=1$ holds for cold gas and $\alpha=4$ does for fully ionized state.

Equation (1) shows that the heating up zone has similar property to the converging nozzle since u has the 2 branches: the sub thermal and the super thermal ones. However, the sub thermal one of $u\le 1$ has the realistic meanings. If the ideal state of $u=1$ is assumed on the cathode surface, then the velocity through the nozzle exit is obtained by Eq. (1) as

$$(u_0)_{\max}=\sqrt{T_0/T_p}/4 \quad , \qquad (2)$$

where T_p is the arc plasma temperature and the suffix "max" is given to u_0 since it is the largest velocity for the flow not to be choked back. The similar one is also known in the converging nozzle flow.

The main part of the present report is on the property of the Laval nozzle; the flow velocity is adjusted by itself to the value as specified by the main arc plasma temperature T_p through the shock relaxation process. The main reason of such a useful behavior arises by the fact that the heating up zone has the same property to the converging nozzle. That is to say, the Laval nozzle and the heating up zone form a super sonic diffuser; thereby super sonic flow is relaxed into sub sonic through shock relaxation process.

The solution to the Rankine-Hugoniot gives the shock position in the diverging part of the nozzle as a function of T_p. Figure 2 gives such an example. It is seen that the shock position from the Laval nozzle throat is limited rather small range for wide range of T_p . The ideal gas injection, therefore, may be expected for wide range of the arc temperature.

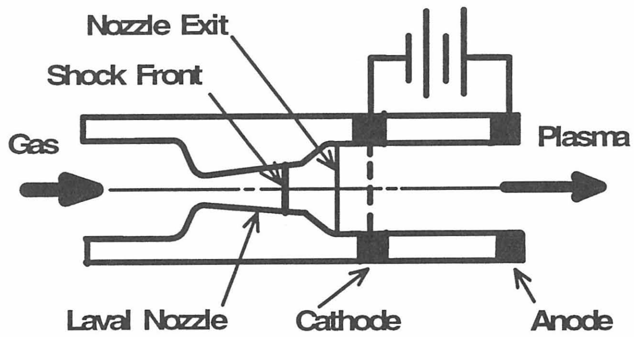

Fig.1. A model arcjet system ejecting super thermal plasma flow by injection of cold H_2 gas through the Laval nozzle. The fully ionized arc plasma of the temperature $T>3$ eV is assumed to fill the volume between the cathode and the anode, where the main entropy acceleration takes place.

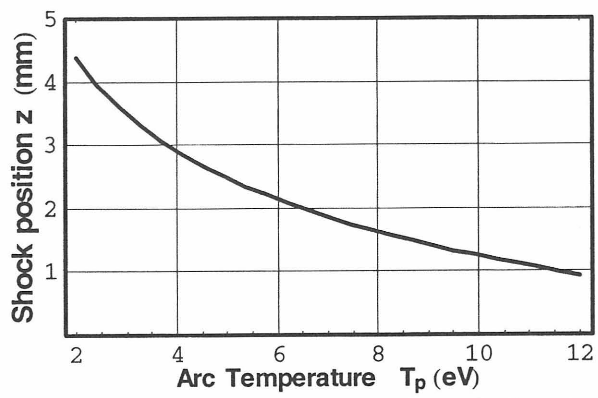

Fig. 2. Shock position from the Laval nozzle throat as a function of the arc temperature.

References:
1 Hirano, K., Journal of Plasma and Fusion Research 69 (1993) 684
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