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Ionizing Layers in the Plasma Propulsion Devices

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Introduction

For longer space missions chemical and even nuclear rockets seem to be inadequate because of the low economic usage of propellant (low specific impulse). This is due to the fact that the exhaust velocity is limited because of the limitation of temperature in the combustion or reaction chamber. The maximum exhaust velocity into the vacuum is equal to

$$V_{max} = \sqrt{\frac{2\gamma}{\gamma-1}\,\frac{kT_c}{M}} \tag{1}$$

where k : Boltzman constant

T_c : chamber temperature

M : molecular mass of exhaust gases

Improvement of the thermal device can be obtained by increasing T_c by heating the gas electrically and moving it out from the solid walls by replacing the walls with a magnetic nozzle. However, here also, there is the limitation of temperature due to radiation. For example, the temperature of hydrogen cannot be much higher than 20 eV ($2.32 \cdot 10^5$ °K). Small impurities result in increased radiation and a significant decrease in maximum temperature. Using $Tc = 20$ eV for hydrogen Eq. (1) gives

$$V_{max} \cong 10^5 \text{ m/sec},$$

and for nitrogen the maximum temperature would be lower, taking $T_c \cong 10$ eV

$$V_{max} \cong 2 \cdot 10^4 \text{ m/sec}.$$

These numbers are of the order of magnitude of those obtained in experiment. However, if electrical currents are flowing in the gas they will interact with the magnetic field resulting in a Lorentz force acceleration ($\underset{\sim}{j} \times \underset{\sim}{B}$ acceleration).

Generally the predominant acceleration phenomena depends on the relative value of the gas pressure $p = knT$ and the magnetic pressure $\frac{B^2}{2\mu}$. If $p > \frac{B^2}{2\mu}$ the accelerator works on the principle of thermal expansion. On the other hand if $\frac{B^2}{2\mu} \gg p$ the predominant effect is the $\underset{\sim}{j} \times \underset{\sim}{B}$ acceleration.

However, even in the last case the experimentally measured exhaust velocities do not exceed about 10^5 m/sec.

Despite the intensive effort in the field of plasma propulsion the acceleration process is far from being fully understood.

The urgent interest of NASA to obtain an efficient plasma motor in a relatively short period of time forced many laboratories to optimize the plasma device by experimental

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tries rather than an approach from the point of view of basic physics. On the other hand, the physical phenomena are so complicated that most of theoreticians stay away from this subject. In the present paper, we shall discuss some physical phenomena in the current layer which apparently are responsible for energy losses.

In the field of plasma propulsion, there are essentially the following types of devices:

1) Steady state D. C. arc jet accelerators (without applied magnetic field);
2) Hall current D. C. accelerators (with applied axial magnetic field) or quasi-steady pulsed Hall current accelerators;
3) Magnetic piston type of accelerators.

The efficiencies of these devices range from 20 to 90% depending probably in some degree on the methods of measurement. It is essential that the efficiency be optimized, since the larger the losses the larger the size of the radiator that is required to reject the heat.

The main advantage of pulsed devices is that they operate periodically and therefore the mean power level could be much lower than in D. C. devices, for which the minimum power for efficient operation is around 200 KW.

A disadvantage of pulsed self triggered devices is the loss of gas and the energy storage problems. However, a break-through by developing very efficient, light pulse line of long life time (Ref. 1) makes it attractive for space application. To get smaller mass losses, the gas has to be introduced to this device in as short a time as possible, and this in turn requires high pressures and small volumes.

In the devices operating with non-steady cycle (pulsed devices) maximum velocity can be $\sqrt{\frac{2}{\gamma-1}}$ times higher. In spite of this, the average velocity is not higher.

Radiation and Ionization Energy Losses

Main radiation losses are associated with electronic excitation and (bound-bound radiation) deexcitation of plasma. These are given by

$$E_{exc} = n_e(n-n_e)L\cdot W\left|\frac{\text{joule}}{\text{sec }m^3}\right| \tag{2}$$

where

n_e is the electron number density
n is the gas number density
L rate of excitation
W energy of excitation (excitation potential)

The rate of excitation L is given by the expression (Ref. 2)

$$L = 1.7\cdot 10^{-10}\frac{f}{T_e^{1/2}W_{ex}}\,10^{-5040\frac{W_{ex}}{T_e}}\,P\left(\frac{W}{kT_e}\right)\left[\frac{m^3}{\text{sec}}\right] \tag{3}$$

where P is tabulated in Ref. (2) and plotted in Fig. 1. Besides bound-bound radiation losses, the free-free radiation can be taken into account (bound-free radiation can be completely neglected), however in these applications they are generally much smaller.

According to Spitzer (Ref. 3) the radiative power is given by

$$E_{RAD} = 1.42\cdot 10^{-40}\,T_e^{1/2}n_e^2\left|\frac{\text{joule}}{m^3\text{ sec}}\right| \tag{4}$$

Ionization energy is

$$E_{ion} = n_e(n-n_e)\,\Gamma V_i,$$

where Γ is the rate of ionization equal to

$$\Gamma = n_e\left[(n-n_e e)\,S - n_e\beta\right] \tag{5}$$

where S is the ion source term and β is the rate of recombination.
According to Allan (Ref. 2, p. 42)

$$S = 1.1 \cdot 10^{-14} T_e^{1/2} V_{ter}^{-2}\, 10^{-(5040 V_{ter}/T_e)} \tag{6}$$

$$\beta = 5.2 \cdot 10^{-20} \chi^{1/2}\left[0.429 + \frac{1}{2} \ln \chi + \frac{0.469}{\chi}\right] \tag{7}$$

where $\chi = \frac{V_{ter}}{T_{e(er)}}$ except of temperatures lower than 1 eV, $\beta \ll S$.

Neglecting recombination, the ratio of ionization energy to bound-bound (excitation) radiated energy is

$$\frac{E_{exc}}{E_{ion}} = \frac{LW}{SV_i} = \frac{13.3 V_{ter} P\left(\frac{W_{er}}{T_{e(er)}}\right)}{T_{e(er)}} \tag{8}$$

Assuming that at the exit section of the current layer, the gas is fully ionized, energy losses due to ionization and excitation are equal to

$$E_{loss} = A_{ex}\, n_{ex}\, u_{ex}\, V_i\left(1 + \frac{L}{S}\,\frac{W}{V_i}\right) \tag{9}$$

where the subscript "*ex*" denotes exhaust quantities and V_i is the ionization energy per unit of mass.

The efficiency of a thermal plasma device is equal to

$$\eta = \frac{m_{ex}\frac{u_{ex}^2}{2}}{m_{ex}\frac{u_{ex}^2}{2} + E_{RAD} + E_{ion}} \tag{10}$$

Assuming complete expansion into the vacuum using Eq. (1) $\gamma = 5/3$ we get

$$\eta = \frac{\frac{5KT_e}{2}}{\frac{5kT_e}{2} + 1.4 \cdot 10^{-40} T_e^{1/2} n_e t + V_i\left(1 + \frac{L}{S}\,\frac{W}{V_i}\right)} \tag{11}$$

Numerical values for hydrogen plasma at $T_e = 20$ eV ($n_e = 10^{22}$ 1/m^3, $t = 10^{-4}$ sec and the mean ionization temperature is 2 eV).

$$\eta = 47\%$$

From the expression (8) it follows that the ratio of the excitation energy to the ionization energy decreases with increase of the mean electron temperature at which ionization occurs. It increases also with the increased value of the ionization potential V_i (W is roughly proportional to V_i), and P decreases slower than T increases. Therefore total radiation losses should be smaller for alkali gases (like Cesium, Lithium, Potassium). LW/SV_i given by Eq. (8) is plotted in Fig. (2) for hydrogen and lithium. Because of the lower energy consumption for ionization and excitation the average electron temperature at which most of the ionization takes place can be higher and this results in increased efficiency.

Finally, we notice that the energy input must be accomplished in a relatively short period, so that the electrons are heated to much higher temperatures than the gas temperature. Because of the slow energy exchange between electrons and heavy particles (especially for rarefied plasma) the electron temperature can remain much higher than that of the ions. The expansion of the electron gas produces a corresponding expansion of the heavier ions due to the strong field generated by charge separation.

To expand the plasma to its maximum velocity a nozzle of large area ratio is needed. But this will lead to a long nozzle and large heat conduction losses.

The best solution is to employ a magnetic nozzle like that in the so called Hall current accelerator, where the main role of the Hall currents is to confine the plasma.

For non-steady cycles, no nozzle is necessary to expand the gas to its maximum velocity.

Energy Losses Due to Wall Bombardment by Ions

Ion Current

In a collisionless gas, the mean position of the ions which are produced in an ionization process in an electromagnetic field is shifted by one gyroradius (Fig. 3). This is associated with a net ion current equal to

$$j_i = \Gamma l e \qquad (12)$$

where l is the ion gyro radius $\left(\frac{uM}{Be}\right)$ and Γ is the ion source term given by Eq. 5.

This current was first noticed by R. Lovberg (Ref. 4) who using a Shlieren system observed a dense gas layer at the cathode. In fact Lovberg showed that the main acceleration in a parallel plate device occurred due to the ion current.

In the collision dominated process ($\omega_i \tau_i \ll 1$) an expression for the electric current density has been derived by the author of this paper in an unpublished paper (Ref. 5) using multifluid quasi-hydrodynamic equations. But even in the collision-model the net effect should be similar to that of the collisionless due to the fact that ions will collide with other heavy particles and will be pushed in the direction of the cathode resulting in the wall energy losses. It is obvious that these losses depend on the ratio of the ion gyro-radius to the electrode spacing. To obtain a more efficient device it is necessary to keep this ratio as small as possible or to build a shorter cathode (Fig. 4) which will cause the ions to miss the cathode. Another way is to inject the gas at the anode and thereby localizing the ionization region far from the cathode.

A different possible source of ion current is the ion drift due to the gradient of the magnetic field.

This drift is perpendicular to $\underset{\sim}{B} \times \underset{\sim}{\nabla} B$ and the drift velocity is equal to (Ref. 3)

$$v_d = \frac{l\nabla B}{2B} \qquad (13)$$

For a typical plasma device the order of magnitude of the drift velocity due to longitudinal gradient of the magnetic field is the same as the sheet velocity ($\sim 10^4$ m/sec). Alfven (Ref. 6, pp. 173–175) proved in his book that the ion drift doesn't produce any macroscopic current providing that the ion gyro-radius is small as compared to physical dimensions and if the velocity distribution is isotropic. Physically, ions which have a center of gyration outside the volume (Fig. 5) can result in a cancelling of the drift velocity, so that the mean ion velocity can be zero. However, in the typical plasma propulsion device the velocity distribution is not isotropic and the ion gyro-radius is comparable to the size of the apparatus. Moreover, ions which are outside the accelerator and which have very large gyro-radii are prevented from entering the electrode spacing by virtue of collision with the walls. Therefore, there should be a net current due to the ion drift. It is interesting to point out that in the plasma accelerator (Fig. 6) the drift current due to the longitudinal magnetic field gradient has the opposite sign to the ionization current.

At the limit as $B \rightarrow 0$ and $\underline{\nabla} B \rightarrow 0$ the ion drift current is opposite and exactly equal to the electron plus ionization current. The drift current J_D must also be associated with the longitudinal current j_{xD} as indicated in the ion momentum equation. But the sign of j_{xD} is opposite to j_{xi}. Inside the layer the ionizing current and j_D have opposite signs and therefore they tend to cancel. This will result in decreasing j_x to zero. In such a case the one-dimensional model will be valid. Fig. 7 shows the deviation from the one-dimensional motion due to axial current j_{xi} caused by the ionization distribution.

It is interesting to point out that in a coaxial accelerator (Fig. 8) there is a drift current in axial direction due to the radial magnetic field gradient and this results in a force directed toward the center (pinching effect).

Magnetic Piston Discharge Layer

This type of discharge layer typical in a plasma gun has been investigated by many authors. Integrating the equations of motion and energy across the current layer this author (Ref. 7, Eq. 5) obtained the relationship which for the case of the non-leaking magnetic piston can be written in the form (Fig. 9)

$$\frac{dW}{dt} = V_P \frac{d}{dt} \int_M u \, dM - \frac{d}{dt} \int_M \frac{u^2}{2} \, dM \tag{14}$$

$$\frac{dM}{dt} = \rho_1 V_P \tag{15}$$

where $M = \int_0^\delta \rho d\xi$. The quantity M is the mass accumulated in the current layer (δ being the thickness of the layer) and

$$W = \int_M \left(\frac{knT}{\gamma - 1} + \frac{B^2}{2\mu} \right) dM + q_{RAD}$$

is the internal + magnetic energy in the current layer + energy lost by radiation (usually, if the current layer is thin the magnetic energy stored is small as compared to internal energy), V_P being the velocity of the back of the current layer.

If the gas velocity is constant across the discharge layer, $u = V_P$, from Eq. (14) one gets

$$\frac{dW}{dt} = \frac{d\left(M \frac{V_P^2}{2}\right)}{dt} - M V_P \frac{dV_P}{dt} \tag{16}$$

If the magnetic piston velocity is constant the result is that one half of the directed energy goes into internal and radiative energy. If no internal energy can be reclaimed the efficiency of such a device will be limited to 50%. However, for an accelerating current layer, $\frac{dV_P}{dt} > 0$ the velocity distribution is not constant and this should lead to a larger efficiency (Fig. 10).

If there is no gas ahead of the current layer $\rho_1 = 0$ from Eq. (15), and it follows that M = Const, and from Eq. (16), $\frac{dW}{dt} = 0$, so there is no increase of internal energy and the plasma gun should be efficient. These considerations have been supported experimentally at General Dynamics/Convair (Ref. 8). The results are 1) the calorimetric efficiency (ratio of energy collected by calorimeter to the total input of electrical energy) of the plasma gun with a distributed mass never exceeded 45%. 2) In the slug model with an electrically triggered gun the measured efficiency reached 70%. However, the pure slug model leads to instability (formation of a spoke), and to prevent this it is necessary to have some gas ahead of the sheet.

Rarefaction Type of Discharge Layer

In principle there exists a possibility to obtain a stationary rarefaction discharge layer by feeding it with non-ionized gas (Ref. 7). Such a layer has been obtained experimentally at General Dynamics Astronautics (Ref. 9) using a long period pulse line (~ 150 μsec) giving almost a square current pulse. However, it is questionable whether the predominant acceleration effect is that of the $j \times B$ force. It seems to be that the predominant effect is the thermal one. Due to the expansion process the average temperature at which ionization occurs is not very high and therefore according to previous considerations radiation losses should be high. It was found that the efficiency was around 25%.

Hall Current Accelerator

Recently great effort in the U.S.A. was devoted to the development of an accelerator in which the main current is due to $E \times B$ drift (Hall effect) in which the electrons are essentially trapped (Fig. 11) in the magnetic field ($\omega_e \tau_e \gg 1$ where ω_e electron angular velocity, τ_e mean collision time) but the ions can exercise their drift ($\omega_i \tau_i < 1$).

The laboratories involved are Electro-Optical Systems (L. Cann et al, Ref. 10), AVCO (R. Patrick, et al., Ref. 11), and General Dynamics/Convair (A. Larson and Liebing, Ref. 12). All of these devices operate on D. C. power except the last one which is pulsed, using a long period pulse line.

The efficiency reported for these devices is around 25% except Patrick (Ref. 11) who claims an efficiency up to 85%. However, his methods of measurement are suspect.

There is tendence now to move the acceleration process from the inter-electrode space to the plume downstream of the electrodes. L. Liebing (Ref. 13) measured asimuthal currents in the plume which were around 10 times larger than radial currents using small Rogowski's belt. He evaluated experimentally the Lorentz force due to the Hall current and the radial component of the magnetic field. This was found to be about twice the Lorentz force that arised from the radial currents and their own magnetic field.

However, both forces seem to be small as compared to pressure forces even at the temperature 2 eV.

Nevertheless, even if it does not contribute significantly to the direct acceleration the Hall current plays an important role in confining the plasma and forming the magnetic nozzle.

For $\omega_e \tau_e \gg 1$ and $\omega_i \tau_i < 1$ the main Hall current is due to azimuthal electron motion with drift velocity E/B and is equal to (Ref. 6, p. 181)

$$i_H = en_e \cdot \frac{E}{B}$$

Electrons are trapped in the magnetic field shells as presented in Fig. 12. Far downstream $\omega_e = \frac{B_e}{m_e}$ decreases and the electrons current loops can be closed. Due to Hall current interaction with the magnetic field the resulting Lorentz force is directed perpendicular to the magnetic field lines and so tend to pinch the plasma. This force is balanced by the radial pressure gradient and the centrifugal acceleration of plasma.

Because of the charge separation field, ions will also move essentially between coaxial magnetic shells which therefore act like nozzle walls. This is true with the exception of the initial ionization layer where there must be an ion current according to Lovberg's model. Assuming that the current is only due to ion motion (electrons are trapped in the magnetic field), we shall show that some part of acceleration is due to this motion.

From the Maxwell law in a one dimensional motion and the conservation of mass for an electron gas $\left(\frac{dn_e u_e}{dx} = \Gamma\right)$ it follows that $(u = u_e)$:

$$\frac{1}{\mu}\frac{dB_\theta}{dx} = j = el\frac{dn_e u}{dx}$$

where $l = \frac{ME}{eB_x^2}$ is an ion gyro radius assuming $B_x \gg B_\theta$; B_θ is the induced magnetic field due to the radial electric currents (ion currents). Therefore, integrating with $(n_{e(x=0)} = 0)$,

$$\frac{B_{\theta 0}}{\mu} - \frac{B_\theta}{\mu} = el_m n_e u$$

where l_m is the mean gyro-radius.

At the back of the current layer $B_\theta = 0$ and therefore

$$u = \frac{B_\theta B_x}{\mu M E n_e}$$

Using the experimentally obtained values

$$B_\theta = 0.01\frac{web}{m^2}, \quad B_x = 0.1\frac{web}{m^2}, \quad n_e = 10^{21}\frac{1}{m^3}, \quad E = 5 \cdot 10^4 \frac{\text{volt}}{m}$$

yields the result

$$u \cong 10^3 \frac{m}{\text{sec}}$$

This expression is highly sensitive to electron number density which is not well known. On the other hand, the velocity increase calculated from the momentum equation (neglecting pressure gradients and assuming $\rho u = \text{const}$ and fully ionized gas)

$$\rho u \frac{du}{dx} = \frac{1}{2\mu}\frac{dB_\theta^2}{dx}$$

would be of the same order of magnitude

$$u - u_0 = B_\theta \sqrt{\frac{1}{2\mu\rho}} \cong 1.58 \cdot 10^3$$

This velocity change can lead to transition to supersonic velocity only in the case where the initial velocity is close to sonic velocity. Another possibility is that the initial acceleration is mainly due to heating the gas (it is known that in a subsonic flow gas can be accelerated to a sonic velocity by simple heat addition), and the final transition to supersonic speed results from ionization current. The rest of the acceleration from sonic conditions can occur due to thermal expansion in the magnetic nozzle formed by the divergent magnetic field lines, and due to the ion current. However, plasma acceleration in a Hall current accelerator occurs not only because of transfer of thermal energy into the directed energy, but also because of transfer of the kinetic energy of rotational motion of plasma into the axial motion. This last fact results from the law of conservation of angular momentum. Because of expansion of plasma in the divergent magnetic nozzle to conserve the angular momentum, energy of rotational motion must drop down and is transformed into the directed motion of plasma. The main difference between this form of energy and the thermal energy transfer is that the latter is associated with radiation losses but the former is not. For this reason the efficiency of Hall current accelerator should be greater than the efficiency of the pure thermal accelerator. The heat addition in a supersonic flow will tend to slow down the gas. The velocity distribution should be that presented in Fig. 12. Due to the fact that electrons have trouble moving along the magnetic field lines the electric potential will remain almost constant along the magnetic field lines. Because these lines are divergent the electric field and the Hall current is decreasing downstream.

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References

1. Hayworth, B. R., White, C. W. and Miller, A. R., "Energy Storage Capacitors for Pulsed Plasma Thrusters" AIAA Paper No. 65-337, AIAA Second Annual Meeting, San Francisco, (July, 1965).
2. Allen, C. W., "Astrophysical Quantities" The Athlone Press, (1963), p. 42.
3. Spitzer, L., "Physics of Fully Ionized Gases" Interscience, New York, (1962).
4. Lovberg, R., "Acceleration of Plasma by Displacement Currents Resulting from Ionization" Comptes Rendus de La V-ie Conférance, Internationale Sur les Phénoménes D'Ionization Dan Les Gaz, Paris, (1963), pp. 235-239.
5. Rosciszewski, J., "Electric Current Density in an Ionizing Layer" unpublished.
6. Alfvén, H. and Falthammar, C., "Cosmical Electrodynamics" Oxford, (1963).
7. Rosciszewski, J., "Energy Partition in the Current Layers in Plasma" AIAA Journal, Vol. 3, No. 2, pp. 373-375.
8. Larson, A. V., Private Communication.
9. Ashby, D. E. T. G., "A Coaxial Plasma Gun with Stationary Current Distribution" paper presented at the Sixth Annual Meeting of the Division of Plasma Physics of the American Physical Society, (Nov. 4, 1964).
10. Cann, G. L. and Harder, R. L., "Follow-on Investigation of a Steady State Hall Current Accelerator" NASA Contract Report CR-54062, Electro-Optical Systems, EOS REP 4010, (Oct., 1964).
11. Patrick, R. M. and Schneiderman, A. M., AVCO Research Rep. 209, (March, 1965).
12. Larson, A. V., Liebing, et. al., private communication.
13. Liebing, L., Paper Presented at 7th Annual Meeting of Plasma Physics, Division of the American Physical Society, Nov. 8-11, San Francisco, (1965).

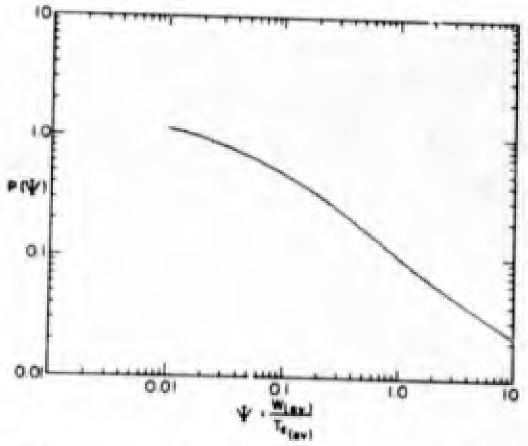

Fig. 1. Value *P* as a function of the ratio of excitation energy to plasma temperature.

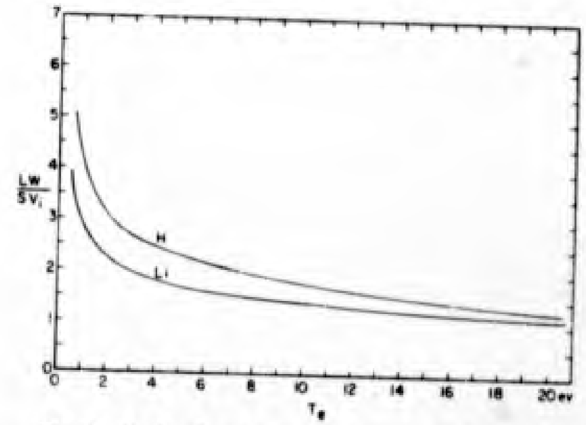

Fig. 2. Ratio of excitation energy to ionization energy.

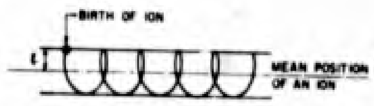

Fig. 3. Ion motion in a collisionless gas in a constant electric and magnetic field.

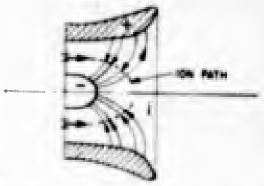

Fig. 4. Short electrode coaxial accelerator.

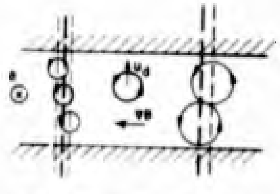

Fig. 5. Macroscopic motion due to magnetic field gradient.

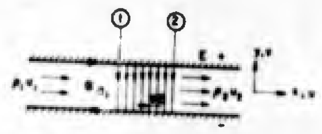

Fig. 6. Ion drift in a stationary current sheet.

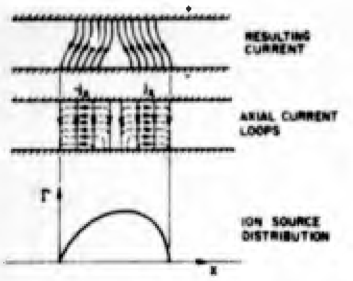

Fig. 7. Longitudinal current associated with ionization current.

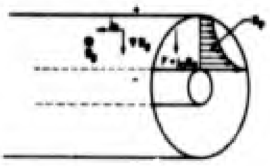

Fig. 8. Ion drift current due to radial gradient of the magnetic field.

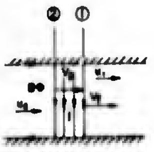

Fig. 9. Magnetic piston type of the current layer.

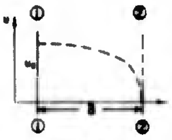

Fig. 10. Velocity distribution for accelerating current layer.

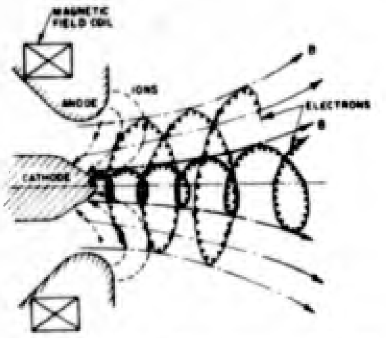

Fig. 11. Ion and electron motion in a Hall current accelerator.

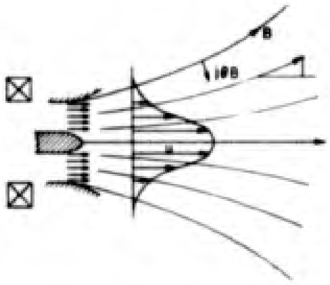

Fig. 12. Velocity distribution in a Hall current accelerator.

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13. ABSTRACT

In the field of plasma propulsion, there are essentially the following types of devices: 1) Steady state D. C. arc jet accelerators (without applied magnetic field); 2) Hall current D. C. accelerators (with applied axial magnetic field) or quasisteady pulsed Hall current accelerators; 3) Magnetic piston type of accelerators.

The efficiencies of these devices range from 20 to 90% depending probably in some degree on the methods of measurement. It is essential that the efficiency be optimized, since the larger the losses the larger the size of the radiator that is required to reject the heat.

In this paper the author examines the following topics: The radiation and ionization energy losses, the energy losses due to wall bombardment by ions and the ion current, magnetic piston discharge layer, rarefaction type of discharge layer and he finally analyses the equations of the Hall current accelerator.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ionizing layers						
Plasma Propulsion Devices						
Energy losses due to wall bombardment by ions						
Magnetic piston discharge layer						
Rarefaction type of discharge layer						
Hall current accelerator						