아아크 발생 워터 건 장치의 동작 시험

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Performance of Arc Driven Water Gun

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Abstract : We study both theoretically and experimentally the motion of fluid driven by electro-thermally ablated gas pressure in a cavity with a single exhauster. A possibility of jet propulsion engine for steamers is also discussed as an application of the fluid motion.

1. Introduction

It is important to consider the industrial applications of the modern pulsed power technology$^{1)}$ developed in the field of controlled thermonuclesr fusion research to a domestic utility.

The explosion of inflammable gas in a closed chamber has been the energy source of the internal combustion engines. In this case the confined fuel gas with oxygen catches fire with the help of a fairly weak electric spark through the mixed gas. Once the gas is fired the free energy stored in the fuel gas is released, and the high pressure in the explosion chamber drives the piston, the piston rod together with the crank shaft. Finally the released energy is stored in a heavy fly-wheel as a mechanical motion.

A strong electric spark can induce a non-inflammable material to explode in a closed chamber, because the high current discharge can change the material to a hot, voluminous gas$^{2)}$. If the material is a pure water of 1 cm^3, the electricity of 5000 joule is enough to change it to a hot steam which can drive the piston like that in a standard internal combustion engine.

The most of the steamers nowadays are propelled by screws which can invite trouble in, for example, a shallow harbor because the wings of the screws will hit the sea bottom and so on. The steamer without screw is the ideal goal of the vessels in the harbor. It is possible to realize the ideal steamer by applying the pulsed power technology to the engine of the ships.

The purposes of this work are to consider the generation of water flow in a tube by electro-thermally ablated steam and to discuss a new type of jet propulsion engine for steamers. In section 2 we review the equation for the ohmically heated gas pressure together with the equation of motion of fluid in a pipe. The experimental results is briefly described in section 3.

2. Equations for Electro-Thermally Ablated Gas

One method of accelerating water in a closed, bended tube is shown in Fig.1, where the bent tube is stuffed with a rod-like inner electrode together with the insulator.The water is filled in the bended tube also shown in the same figure. The capacitor C is charged up to the voltage V through the resistor R. Once the switch is turned on, we have the high current discharge along the air-water intersurface in the bended tube or along the inslator surface, provided that the voltage V is larger than the flash over voltage along the interface or the surface.

The high current electron flow interacts with gaseous water and the temperature or the gas increases until the molecules are partially ionized. This suggests that the dense gas gasified from the water are composed of many number of components such as electrons, hydrogen ions, oxygen ions, water molecules and so on. The high pressure of this mixed gas thrusts the water out of the pipe through the outlet[3).

We are now at the positions to estimate the total gas pressure in the closed chamber, where neither stir of gas nor thermal diffusion are assumed. The electron gas presure ,P_e, should be obeyed by

$$\frac{\xi}{2}\frac{d}{dt}P_e = \eta J^2 - Q_H - Q_0 - Q_w, \tag{1}$$

where η is the resistivity for electron flow, and Q_H, Q_0, Q_w are the heat generated in the elctrons as a consequence of collision with hydrogen ions, oxygen ions and water molecules. The quantity J is the current density in the gas. The pressures for hydrogen ion, oxygen ion and water molecule, i.e. P_H, P_0 and P_w, respectively, are assumed to be obeyed by

$$\frac{\xi}{2}\frac{dP_H}{dt} = Q_H, \tag{2}$$

$$\frac{\xi}{2}\frac{dP_0}{dt} = Q_0, \tag{3}$$

$$\frac{\xi}{2}\frac{dP_w}{dt} = Q_w, \tag{4}$$

where ξ depends on the state of ablated gas. If the gas is fully ionized $\xi = 3$. By adding Eqs (1), (2), (3) and (4), we have

$$\frac{dP}{dt} = \frac{2}{\xi}\eta J^2, \tag{5}$$

where $P \equiv P_e + P_H + P_w$

Usually, the mechanical response of fluid in the electrode is sufficiently slower than the pressure increase of the ablated gas. In other words, the mechanecal motion of the water will start sufficiently after the electric energy is dissipated by the high current discharge in the gas. In this case the dissipated energy in the gas must be equal to the energy stored in the capacitor with capacitance C. Then, we have

$$\iint \eta J^2 \, dt dU = \frac{CV^2}{2}, \tag{6}$$

where U corresponds to the volume of the ablated gas.

From (5) and (6) we are lead to an equation for the pressure of the ablated gas.

$$PU = \frac{1}{\xi} CV^2. \tag{7}$$

The water in the pipe should be efficiently accelerated by the ablation pressure until the Rayleigh-Taylor instability occurs due to the shape of the pipe. The equation of motion of the water in the pipe is described by

$$M\frac{d^2z}{dt^2} = PS, \tag{8}$$

where the viscous force between water and pipe is neglected, and M is the mass of the water in the pipe, S the cross-section of the pipe and the distance along the pipe is measured by z which is z_0 initially. i.e.,

$$U = Sz. \tag{9}$$

With the help of eqs. (7) and (9), eq. (8) is reduced to

$$\frac{d^2z}{dt^2} = \frac{F}{z}, \tag{10}$$

where $F \equiv (CV^2/\xi M)$ and $dz/dt = 0$ is assumed at $t = 0$. It should be noted in R.H.S. of Eq. (10) that the acceleration is inversely in proportion to z. This means that the force has a long range. In this case we can approximate eq. (10) as

$$\frac{d^2z}{dt^2} \simeq \frac{F}{z_0}, \tag{11}$$

which means the approximately constant acceleration of water in the pipe.

If the effective length of the pipe for the acceleration is L, the relation between L and the acceleration time, t_a, becomes

$$t_a \simeq (2z_0L/F)^{1/2}. \tag{12}$$

The kinetic energy, T, of water transfered from the capacitor at $t = t_a$ is

$$T = MF^2 t_a^2 / (2 z_0^2) \tag{13}$$

From eqs.(12) and (13) we can estimate the efficiency, ζ, of this jet propulsion engine.

$$\zeta \simeq \frac{2}{\xi} \frac{L}{z_0} . \tag{14}$$

We try to understand the physical reason of this low energy efficiency, ζ, from the Rayleigh-Taylor instability. The growth rate, γ, of the instability is described by

$$\gamma = (2\alpha k)^{\frac{1}{2}} , \tag{15}$$

where $\alpha \equiv F/z_0$ and k is the wave number of the instability. The accelerated distance, L, may be written by

$$L = \frac{\alpha}{2} \tau^2 \tag{16}$$

where $\tau \equiv \gamma^{-1}$.

After this instability grows up, the acceleration of water stops. From (15) and (16), the expression for the efficiency ζ reduces to

$$\zeta \simeq \frac{1}{2\xi k z_0} , \tag{17}$$

3. Experiment

In order to test this theory we built an arc driven water gun as shown in Fig. 1.The gun discussed here accelerates about a half liter of water to a velocity of approximately 10 m/sec and deposits more than 1 % of the electrical input energy at its terminals into kinetic energy of the water jet. The coaxial tube geometry is used with a bent gun barrel. The inner electrode has a thin connecting rod which is in contact with a blob of water loaded in the bent barrel. Since the water works as a good electric conductor, this thin connecting rod fixes the electrical potential of the inner electrode. Without the thin rod the water gun did not fire, because the air gap switch could not fire. Once the air gap switch turns on by itself, the high current arc discharge is initiated in the discharge chamber as shown in Figure 1. The high pressure of the gas occupying the discharge chamber presses the water down to the exhaust of the barrel. For this experiment, the capacitance ,C, of the capacitor bank was C = 28μF. And the charging voltage of the capacitor was changed up to 15 kV in order to see the effects which depended on the stored energy.

From the experimental observations, the water ejected from the gun barrel was made of a lot of small water drops. This suggests that the wave number k is a large number. In other words, we can expect that kz_0 is large . In this case, Eg.(17) shows that ζ becomes small.

4. Discussions and Conclusions

From a straight forward but tedious culculation of eq.(10), the result (14) is also obtained when $|L/z_0| < 1$.

We need to focus our attention to get small kz_0 in the future works in order to improve the energy efficiency ζ.

The circuit of the repetitive discharge for this type of liquid mass driver is not unique and it depends on both the situations and the purposes of the engine.

We may conclude that this type of liquid flow driven by electro-thermally ablated gas pressure should be useful for steamer engine and the multiple uses of this pipe-like ingine can give a steamer a smooth motion in the sea, although a design work of the practical engine remains to be studied extensively.$^{5)}$

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References

1) See, for example. H. Knoepfel : High Magnetic Fields (NorthHolland Publishing company. Amsterdam, London. 1970) p.1.

2) A.J.Cable : High-Velocity Impact Phenomena. Edited by R. Kinslow (Academic Press, New York and London.1970) p.10.

3) This type of an explosive spill of fluid out of a pipe is often ovserved when we meet some emergent discharge of capacitor bank to

the liquid resistors stored in a insulator pipe.

4) S.I.Braginskii : Review of Plasma Physics, Edited by M.A.Leontovich (Consultant Bureau, New York, 1965) vol.1, p.275.

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Figure Caption

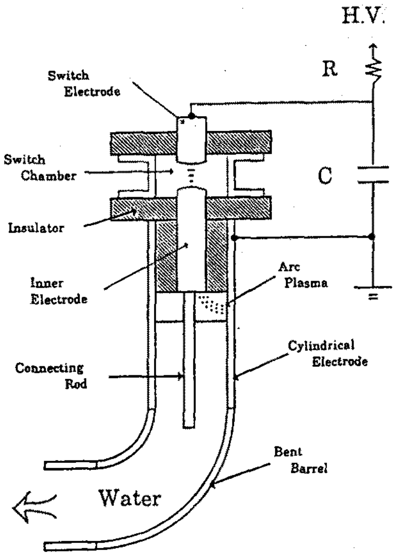

Fig.1 Structure of the water gun. Note the connecting rod in contact with water as a bullet. Without this rod electrode the initiation of the water gun is impossible when the air gap is used as a starter switch.