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Study on the Z-Pinch Formation in a Low-Energy Plasma Focus as a Neutron Generation Source

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Abstract

A plasma focus device has been developed as a pulsed neutron generator by using D-T/D-D fusion reactions. During the transfer of energy from the pulsed power system(a capacitor, a spark gap switch and pulse forming line), to the time varying load(a plasma focus device), working gas is broken down and forms a current sheet between the anode and cathode, leading to the formation of Z-pinch. For the first stage, H_2 gas was used and formation of Z-pinch has been studied through the observation of Rogowski coil measurement.

Ⅰ. Introduction

Plasma focus device(PFD) is a pulsed capacitive discharge, in which a dense($n=10^{19}$ cm^{-3}), hot(a few keV), magnetically compressed plasma(pinch plasma) is produced at the end of two coaxial electrodes. It is characterized by the emission of radiation and beams such as X-rays, ion/electron beam, and fusion neutrons[1,2,3,4,5]. The emission of radiation and beams in PFD has been studied as ion/electron beam, X-ray and neutron sources, so that PFD also shows great possibilities as a compact and versatile accelerator for industrial applications[6,7], especially for material and medical applications.

Since Z-pinch in PFD type discharge can make intense pulses of neutrons (10^{10}-10^{11}, 2.5 MeV D-D neutrons in time periods of 50-100 nsec)[1,2,8] with simplicity and low cost, PFD has been a good candidate as a neutron generation source.

The mechanism of generation of neutron, beams and radiation is that electrical energy from high voltage pulsed power system is transferred to stored magnetic energy, and then this energy is converted into kinetic energy of plasma, so that compressed plasma(pinch plasma) is created locally at the end of electrode, and this plasma is hot enough locally to initiate D-D/D-T reactions.

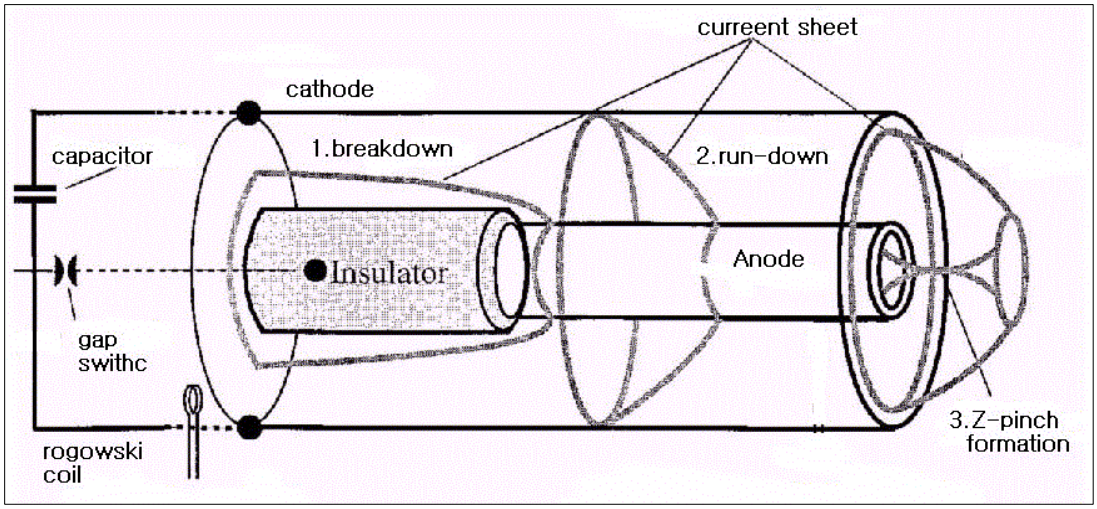


Fig.1 Illustration of pinch plasma formation between coaxial electrodes in PFD device.

Figure 1 shows process of pinch plasma formation as the following:
(1) breakdown phase- high voltage pulse(typically 20-30 kV) from pulsed power system initiates breakdown between electrodes so plasma is created.
(2) rundown phase- $\mathbf{E}\times\mathbf{B}$ force accelerates plasma at z direction[9,10].
(3) Z-pinch formation- at the end of electrodes where pinch plasma is formed, neutron generation takes place as a product of fusion reaction and beam and radiation also are emitted. According to magnetohydrodynamics(MHD) model, m=0 instability disrupts plasma and causes to emit radiation and beams. A low-energy Mather type PFD has been developed, and to check the formation of the pinch at the anode, current drop should be measured by a Rogowski coil.

Ⅱ. Experimental Setup

Neutron generation system consists of pulsed power system[11], vacuum pump, discharge chamber and diagnostics part, which is shown in Fig. 2. Pulsed power system consists of one capacitor(1 μF, 100 kV), high voltage DC power supply(100 kV), spark gap switch(<40 nH), pulse forming line(distilled water as a dielectric, length 21 cm, Z_0=7.3 Ω), trigger generator(100 kV) and time delay generator. Vacuum is made by a rotary pump which can makes the base pressure 10^{-3} torr. Discharge chamber(length 30 cm and radius 10 cm) is made of stainless steel. Rogowski coil, Tektronics TDS 220 digital oscilloscope with sampling rate 1 GHz and a PC is used for diagnostics and data

acquisition.

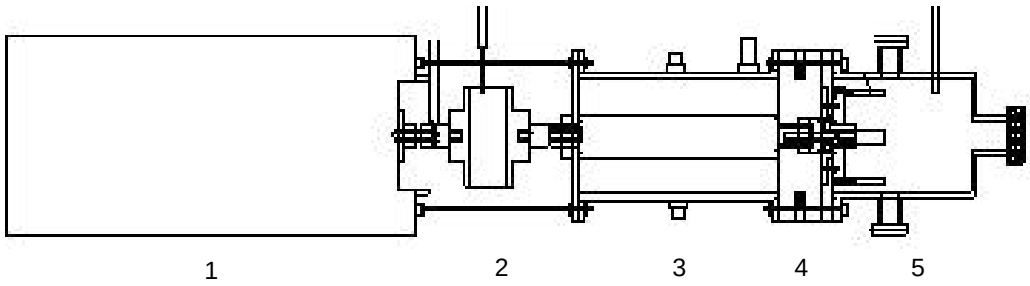


Fig.2 Schematic diagram of Plasma Focus System: 1. capacitor 2. spark gap switch 3. pulse forming line 4. plasma focus device as a load 5. discharge chamber

As a load, PFD, consists of outer electrode 10 cm long, 1 cm thick bronze 77 mm diameter and center electrode 10 cm long copper rod with 25 mm diameter. Pylex glass tube with 2 cm length and 3 cm diameter is inserted between the anode and cathode. Fig. 3 shows a plasma focus.

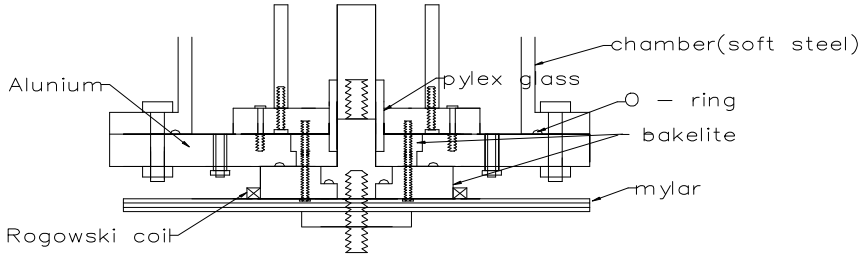


Fig.3 schematic diagram of plasma focus

A Rogowski coil[12,13] measuring current flowing through plasma is inserted between PFD and PFL. Since PFL makes current pulse a rectangular one transferring maximum power to the load, a high density compact pulsed power system can be made such that a PFL with the constant charging current I_0, the characteristic impedance Z_0 and the length l has the output voltage $V_{out}=Z_0I_0/2$, the current $I_{out}=I_0/2$, and the pulse width $T_{out}=2\ l\ \varepsilon_r^{1/2}/c$, where ε_r and c are the dielectric constant and the light velocity, respectively[14,15,16].

This system can be analyzed by the following lumped circuit model(Fig. 4).

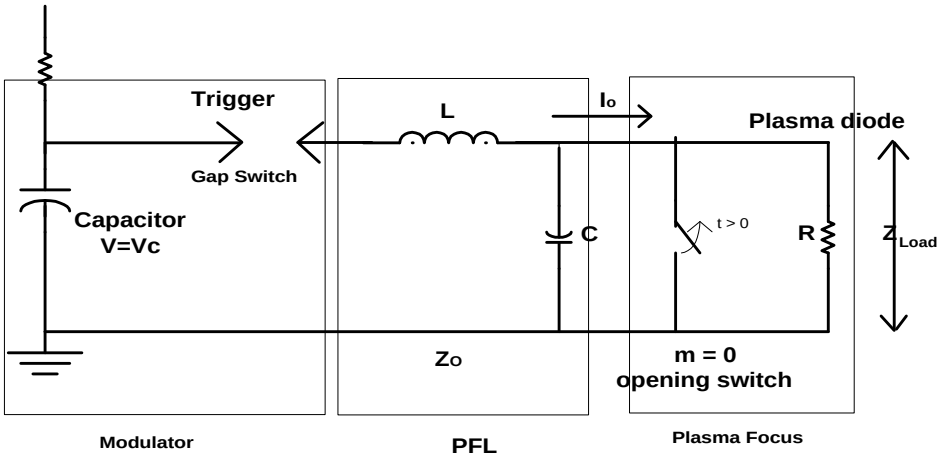


Fig4. circuit model of pulse power system and plasma focus.

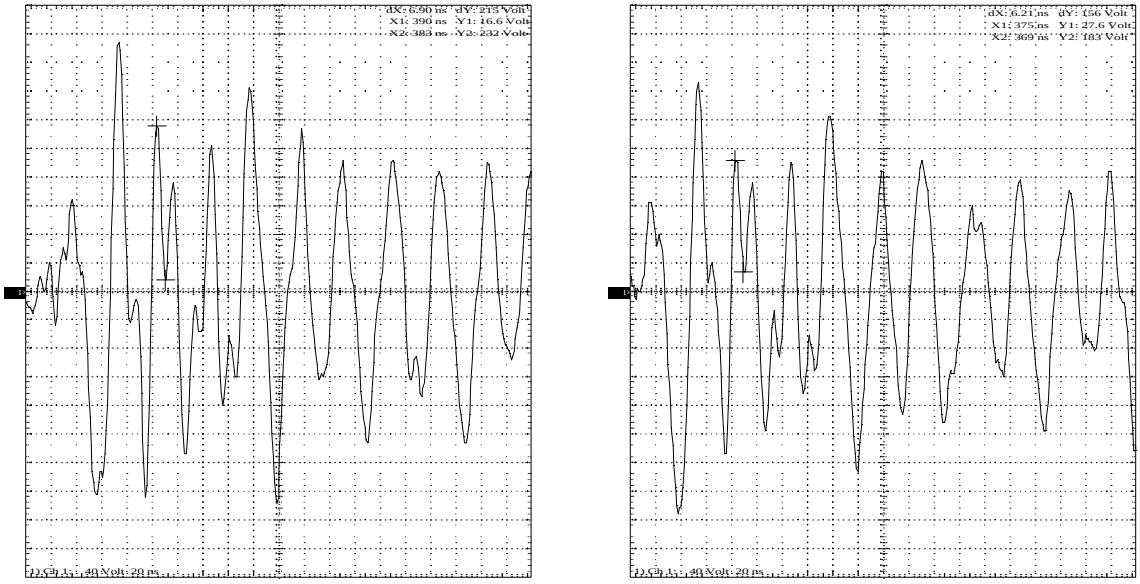
Current flowing through plasma, I_0, makes plasma created in PFD as a MHD plasma compressed by magnetic field. Considering the parameters of pulsed power system, I_o, is approximately 46 kA if charging voltage, V_c, is 30 kV and matched with the load. High voltage pulse width is 13 nsec with distilled water as a dielectric medium.

Ⅲ. Experimental result

For the present work, capacitor is charged by 30 kV and working gas is H_2 and base pressure is 10^{-3} torr and working pressure is 3.0-3.5 torr, at which pinch formation seem to be optimized. Rogowski coil should measure the drop of $I_{0,}$, which indicates the formation of pinch formation. RC integrator with 2.5μsec RC time is used to integrate differential current wave form. During the formation of pinch, current drop occurs because of m=0 instability by MHD model indicating formation of Z-pinch.

Figure 5 shows the current wave forms during the pinch formation. Repeated shots assume the Z-pinch formation and the following is the tentative interpretation, which should be detailed:

$\triangle t$ = 6.04±0.66 nsec and $\triangle I$ = 180±60 volts



(a) (b)

Fig 5. Current wave form from PFD(Working Pressure:3.0 torr)

Ⅳ. References

[1] J. W. Mather, Phys. Fluids. **8,** 366 (1965).

[2] S. P. Gary, Phys. Fluids. **17,** 2135 (1974).

[3] M. Liu et al., IEEE Trans. Plasma Sci. **26,** 135 (1998).

[4] M. Mathuthu et al., IEEE Trans. Plasma Sci. **25,** 1382 (1997).

[5] J. R. Smith et al., Phys. Fluids. **28,** 2305 (1985).

[6] Robert P.Hoyt et al., IEEE Trans. Plasma Sci. **23,** 481 (1995).

[7] Kurt F. Schoenberg et al., Phys. Plasmas. **5,** 2090 (1998).

[8] H. Kelly and A. marquez, Phys. Control. Fusion **38,** 1931 (1996).

[9] S. Lee et al., "Laser and Plasma Technoloy" (World Scientific, 1985).

[10] S. Lee et al., "Small Plasma Physics Experiments" (World Scientific, 1985).

[11] W. James et al., "High-Power Electronics" (TAB Books, 1989).

[12] V. Nassisi and A. Luches Rev. Sci. Instrum. **50,** 900 (1979).

[13] D. Pellinen et al., Rev. Sci. Instrum. **51,** 1535 (1980).

[14] M. J. Rhee and R. F. Schneider, IEEE Trans. Nucl. Sci **30,** 3192 (1983).

[15] R. F. Schneider, M. J. Rhee and J. R. Smith IEEE Trans. Nucl. Sci **32,** 3536(1985).

[16] John R. Smith, Phys. Fluids **28,** 2305 (1985).