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Design and construction of a very small repetitive plasma focus device

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In this paper the design and construction of a very Small Plasma Focus Device (20J) that can operate at repetition rate about 1 Hz are described. In the first experiments with it using Ar as working gas, high negative spikes in current derivative signals have seen, and the proper range of the operation using the Ar is identified.

Keywords: Plasma Focus; energy density parameter; repetition rate.

1. Introduction

With respect to wide applications of Plasma Focus (PF) devices, in the last 5 decades, high research activities have been done in this field and several numbers of Filippov-type and Mather-type PF devices with energies less than 1J to several Mega Joules have been constructed.[1-5] Low energy PF devices can operate with high repetition rate and as a result, they can generate and emit neutron and x-ray pulses with high repetition rate. While the high energy PF devices generally work as single pulse sources.[5-7]

With respect to advantages of very small PF devices like high repetition rate, portability, little variations in the beam emission in discharges with similar conditions, in recent years high research activities have been done in this field, the smallest PF device in the world is Nanofocus (0.1 J).[5-7]

In this article, we explain the design and construction of a very small PF device (SORENA-1) that is constructed in Plasma physics and Nuclear Fusion Research School of Nuclear Science and Technology Research Centre of Iran and present the results of the first experiments with it.

2. Design of Device

A very important feature of Plasma Focus devices is that in them some parameters like temperature, the velocity of current sheath in axial and radial phases that in every optimized PF are in order of 1×10^5 m/s and 2×10^5 m/s, respectively. There are two very important parameters, energy density parameter and drive parameter that are used in design of PF devices.[8,9] The energy density parameter is defined as

$$\frac{E}{V_p} = \frac{28\,E}{a^3}$$

where, E, V_p and a are the energy of capacitor bank, the volume of pinch and radius of anode, respectively, that its value for PF devices in a wide domain of energies is between $1\text{-}10\times10^{10}$ J/m^3. Drive parameter is defined as

$$\frac{I_0}{ap^{\frac{1}{2}}}$$

where I_0, a and p are the maximum current, anode radius and gas pressure for the case of optimum neutron flux, respectively, its value for PF devices in a wide domain of energies is between 77±7 kA/cm.mbar$^{1/2}$.[8,9]

The radius of anode are calculated by using the energy density parameter $28E/a^3 = 5\times10^{10}$ J/m^3 and $I_0/ap^{1/2} = 77$ kA/cm.mbar$^{1/2}$, and with respect to that for optimum operation the pinch time must be equal with the maximum current time, effective length of anode Z_a is calculated using

$$\frac{Z_a}{v_a} + \frac{a}{v_r} = \frac{T}{4}$$

where, v_a, v_r are the axial and radial velocities that are about $(0.8 - 1)\times10^5$ m/s and $(2 - 2.25)\times10^5$ m/s, respectively, and T is the discharge period.[8,9]

After calculation the anode radius and effective length of anode, since that the ratio of the anode length to its radius in Mather-type devices is more than 1 (about 4 or more),[10] a proper value for anode length would select that is 5 – 10 times of the anode radius. Then, we can calculate the insulator length from $L_{ins}=Z - Z_a$ and estimate a proper value for internal radius of cathode (b) on the base of the relation[11]

$$1 \leq \frac{L_{ins}}{b-a} \leq 1.8.$$

3. Results and Discussions of Iranian Very Small Plasma Focus (SORENA-1)

This device has been designed and constructed in Plasma Physics and Nuclear Fusion Research School and the experiments with it started at December 2012. A fast high voltage capacitor (190 nF, 5 nH, 25 kV) has been used as capacitor bank.

$$T = 2\pi\sqrt{Lc} = 193.5 \text{ ns}$$

By using the energy density parameter, the proper value for anode radius is calculated about 3 mm, using the $Z\approx 10a$ estimation, and the relation of

$$\frac{Z_a}{V_a} + \frac{a}{V_r} = \frac{T}{4}$$

that $V_a = 1\times10^5$ m/s and $V_r = 2\times10^5$ m/s, $L_{ins}=Z - Z_a$ the values of anode length, anode effective length and the insulator length are estimated about 30 mm, 3.3mm and 26.7mm, respectively.

From the $1 \leq \frac{L_{ins}}{b-a} \leq 1.8$ relation, proper value for cathode radius estimated 20 mm.

Therefore, the characteristics of (SORENA-1) Plasma Focus are:

Type: Mather
Material of electrodes: Steel
Geometry of cathode: Solid cylinder
Insulator: Pyrex glass with 2 mm thickness
a=3 mm
z=30 mm
L_{ins}=27 mm
b=20 mm

The diameter of the vacuum vessel is 20 cm and its height is 25 cm.

For prevention of mechanical tension, anode and insulator are separated by a Teflon layer with 0.5mm thickness.

Figures 1 and 2 show the general structure of 20 J device while Figure 3 reveals the complete design as shown.

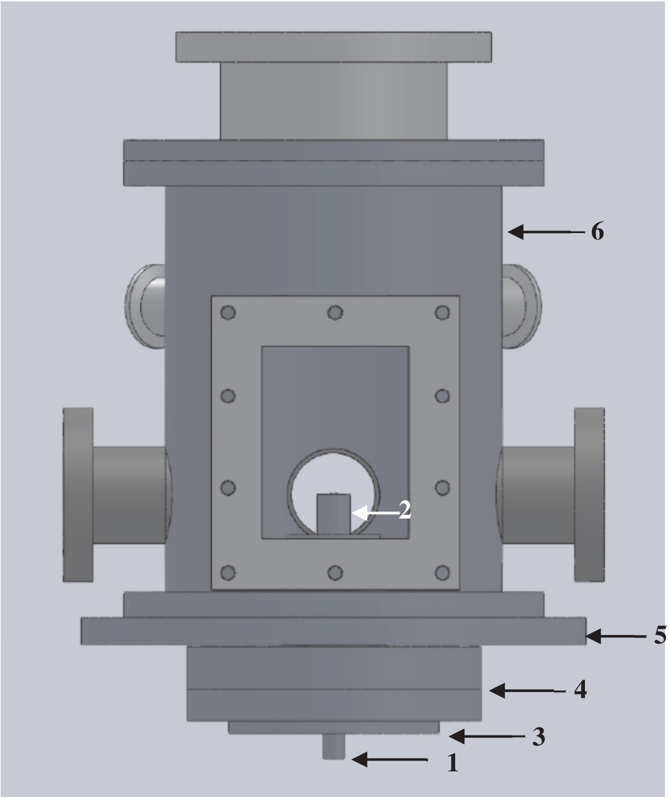

Fig. 1. 1-Anode rod 2- Cathode 3-Anode plate 4- Insulator 5-Cathode plate 6-Vacuum Vessel.

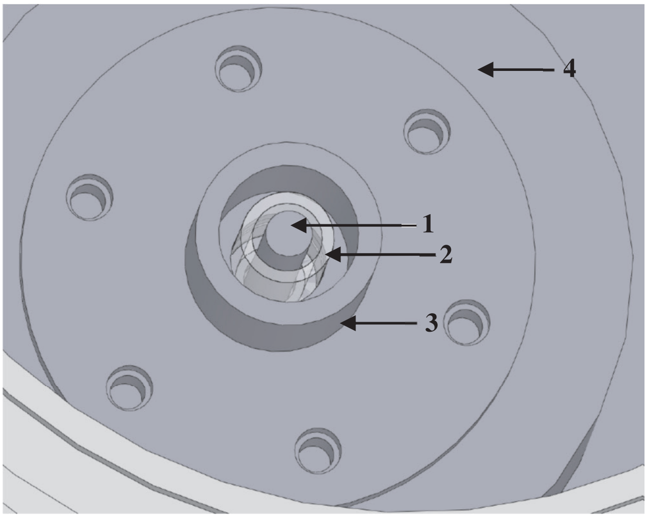

Fig. 2. 1-Anode 2-Insulator (Pyrex glass) 3-Cathode 4-Cathode plate.

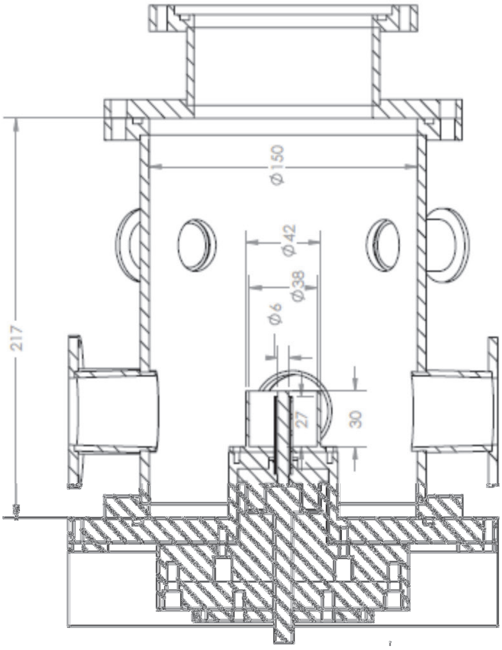

Fig. 3. Schematic of device and its dimensions.

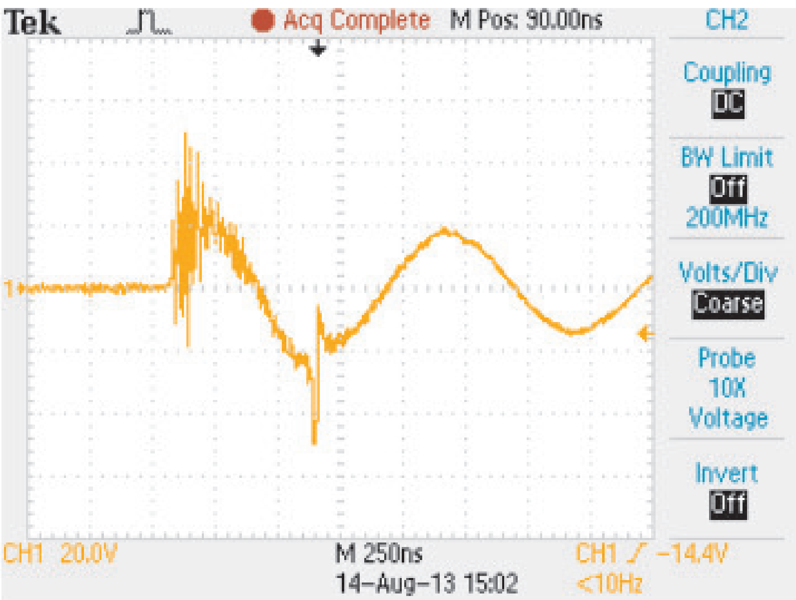

Fig. 4. A good sample of current derivative signal (initial pressure: 1.6 mbar, discharge voltage: 15 kV).

The electrical system of this device consists of a 20 kV power supply, one adjustable Spark gap (5-20kV), a fast high voltage capacitor (190 nF, 25kV) and a digital control system. This control system is a simple circuit on the base of AVR microcontroller (Atmel company) that can be used automatically or manually by using it, the discharge voltage, the number of discharges (from 1 to 12) and the repetition rate of discharges (from 0.1 to 10 Hz) can be adjusted.

For early studies in this device, the current derivative signal in it has measured by a 12 turn magnetic probe and displayed on a 200 MHz digital oscilloscope TDS-2022C. In the experiments that we have done with Ar as working gas, in a wide domain of discharge voltages and pressures good discharges happened and we have seen shining plasma, in some experiments negative spikes have seen that one of them is shown in Fig. 4.

4. Conclusions

In this article the first Iranian Very Small Plasma Focus (SORENA-1) and its specifications have been presented. It is seen that as we have expected, in optimum conditions this device works properly in energy range 18-25 J at repetition rate of about 1 Hz.

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