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On the possibility of self-cleaning plasma in centrifugal Z-pinch

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Abstract -The article shows the possibility of self-cleaning of plasma in the variety of Z-pinch - centrifugal Z-pinch. This circumstance leads to a decrease in the heat loss due to bremsstrahlung from the plasma.

As a result, there are prerequisites for increasing efficiency of plasma cumulating in a new device.

Key words: plasma focus, centrifugal Z-pinch, pulsed plasma centrifuge.

1. Introduction

The article considers varieties of non-cylindrical Z-pinch - plasma focus device and centrifugal Z-pinch.

Taking into account that these devices are the electrode high- current discharges, plasma in them is contaminated with impurities from erosion of electrodes and insulator between electrodes.

The following version for decreasing impurities in the dense plasma focus device is proposed : addition of "dielectric electrode" into design .

Fig. 1 shows schematic cross-section of improved device.

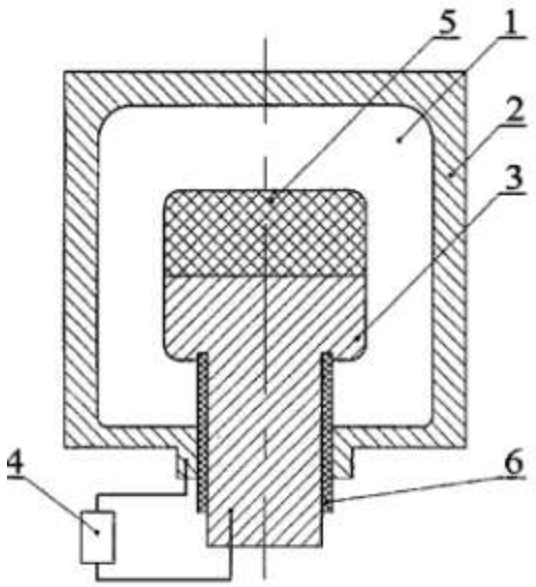

Fig. 1 : 1.Gas filled plasma chamber

2. Cathode

3. Anode

4. Pulse current source (in particular, capacitor bank plus discharger)

5. Dielectric element on the butt surface of anode;

6. Cylindrical insulator of working chamber

The invented device was intended for elimination of the following negative effects:

- non-symmetrical start of discharge, and, as a result , occurrence of intermittent secondary punctures on residual gas nearby insulator;

- influence of effects, associated with interaction of current shell with electrodes of chamber, such as Hall effect or runaway of the evaporation wave from the surface of metal electrode due to high density of current in place , where current from electrode transits into current plasma shell. These effects can bring to the premature focusing of discharge at the chamber axis long before to achieving maximum of current in chamber;

- heavy impurities in gas from electrodes.

The following physical phenomena are typical for new device:

In process of motion of plasma shell along dielectric element the continuous diffusion of magnetic field through pressed plasma into dielectric element compels plasma to be pressed to the surface of dielectric element.

Simultaneously, formed ionized vapors of ceramic material are pressed to the surface of dielectric element, which prevents their penetration into plasma shell. With large densities of current and strong magnetic fields using dielectric element enables to exclude influence of Hall effect, as well as effects associated with vaporization electrode surface during motion of current-plasma shells. Absence of surface effects inherent to metal electrodes gives occasion to exclude premature discharge focusing on chamber axis for achieving maximum current in chamber [1].

The device differs from Filippov and Mather "classic" configuration of plasma focuses by the fact, that anode diameter in it is more than diameter of the spool-type insulator between two electrodes. With such design at the beginning there is occurred a phase of relatively slow plasma heating, as in Mather configuration, and at the end - a phase of relatively rapid collapse of the current-plasma shell like Filippov configuration. Motion of current- plasma shell at the beginning from the insulator to the equator of the anode complies with inverse Z-pinch.

In this case like in inverse Z-pinch there is occurred decreasing of plasma instabilities due to self-regulation of different sections of shell.

In devices of plasma focus the scaling phenomena is occurred – increase of neutron yield and X-radiation with current increasing in chamber.

Saturation of neutron scaling in sphere of mega ampere currents is also typical for existing plasma focuses.

The purpose and manufacture of the considered device with “dielectric electrode” was overcoming restriction of confined growth neutron scaling. Practically there were implemented modes of working with current 2,5 MA. However, no essential increase of thermonuclear efficiency was observed.

With all variety of designs of existing plasma focuses one their significant deficiency, associated with their operation in mode of plasma accelerator should be noted.

At the beginning of works on plasma focuses it was suggested to use such devices as plasma injections for filling magnetic traps (tokamaks, stellarators) with heated plasma.

For example, if you make an opening in the cathode along the installation axis of the Filippov type, then there will be an outburst of accelerated plasma to $2x10^7$ cm / sec of the bunch from the device .

Unfortunately, mass of substance, emissed with such high velocity, in first injector devices – plasma guns of the considered types did not exceed a tenth hundred shares of a percent from total mass of gas in discharge chamber [2]. In principal, installation diagram of plasma focus do not differ from plasma injectors and, respectively, they do not exhibit growth of percent relation of accumulated plasma.

For volume gain of cumulation there was proposed and patented device – centrifugal Z-pinch :

https://patents.google.com/patent/RU2586993C1/en

In the claimed invention it was proposed to eliminate plasma instabilities during its heating due to plasma rotation, while moving along surfaces of electrodes and to replace configuration of cumulated plasma bunch to rotating ring without its contacts with electrodes, without possibility of emission from device and relative gain of bunch volume compared to plasma focus.

Principal diagram of device is shown in Fig.2

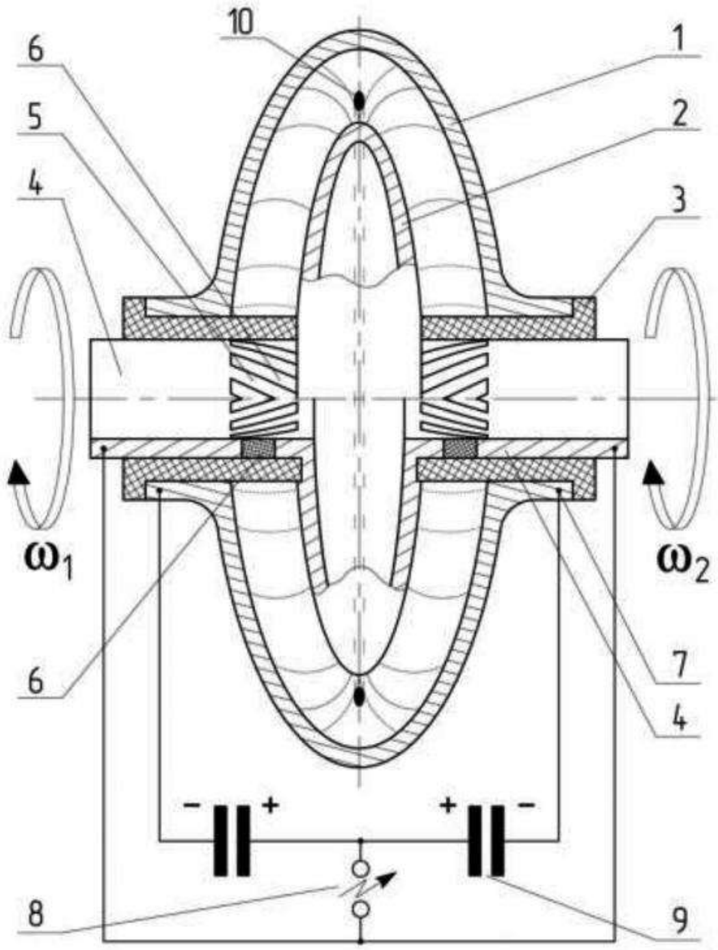

Fig.2:   1. Cathode;

2. Working part of anode;

3. Spool-type insulator between electrodes;

4. Tubular current lead of anode;

5. Open-circuited electrically conductive coil of multifillar helix;

6. Insulator of neighbour coils of multifillar helix;

7. Current lead of cathode;

8. Discharger;

9. Low inductive highvoltage capacitor bank;

10. Quasi-stable plasma focus;

$\omega_1 = \omega_2$ - respectively equal in value and direction angular speeds of rotation of two initial mirror plasma whirls.

In patent application description the centrifugal Z-pinch operates in the following way.

After supplying voltage from capacitor bank to anode through discharger two cylindrical plasma shells having fibrous structure are formed near insulators. Under the action of electrodynamic forces plasma shells symmetrically move from insulators. Due to pulse current in multifillar helixes of two current leads of anode the shell obtain additional rotational-azimuthal motion to already existing axial movement. At the expense of this rotation the filaments of current-plasma shells mix with formation of shear. Two whirls unwind in two parallel coaxial gaps between electrodes. Diameters of whirls increase all the time. Plasma formed in front of shells from two impact waves obtains torque.

In the course of definite time the current-plasma shells under action of ponderomotive and centrifugal forces enter with their shoes on perimeter of anode.

Here they encountered by their side surfaces. Geometry of chamber, inductance of chamber and condenser bank are matched so, that maximum impulse of current coincides in time with moment of encounter of shell surfaces. Further occurs collapse of wedge-like annular channel at the expense of merging spiral current shells with whirling outflow of partial plasma toward inside perimeter of cathode.

This focused plasma quasitor is a source of neutrons and X-rays [3].

3. Problematic characteristic of the centrifugal Z-pinch

As it was mentioned earlier the centrifugal Z-pinch is patented as a device. That is why it is an authorized practice to make additions on as-needed basis and technical credibility to mode of operation of device described in application. Reason for making additions is a fact, that in centrifugal Z-pinch during collapse of the current-plasma shell there is considerably decreased the current density in contact spot of plasma with anode compared to plasma focus. The patent was issued due to technical advantages of device in process of plasma heating compared to plasma focus.

4. The solution of this problem

Search of new technical capabilities for new device in this article is directed to smoothing of described drawback of the centrifugal Z-pinch.

Building principle and operation of patented thermo-nuclear device turns around of centrifugal effects.

In would be reasonable to analyze design of centrifugal Z-pinch concerning its possibility to operate additionally as a pulse plasma centrifuge.

Search for analogs has indicated, that for possibility to use centrifugal separation of gas and isotope mixtures in rotatable plasma was firstly mentioned by Swedish physician Bonnevier B., who worked in research area on controlled nuclear fusion.

Specific diagrams of typical devices are shown in Fig. 3

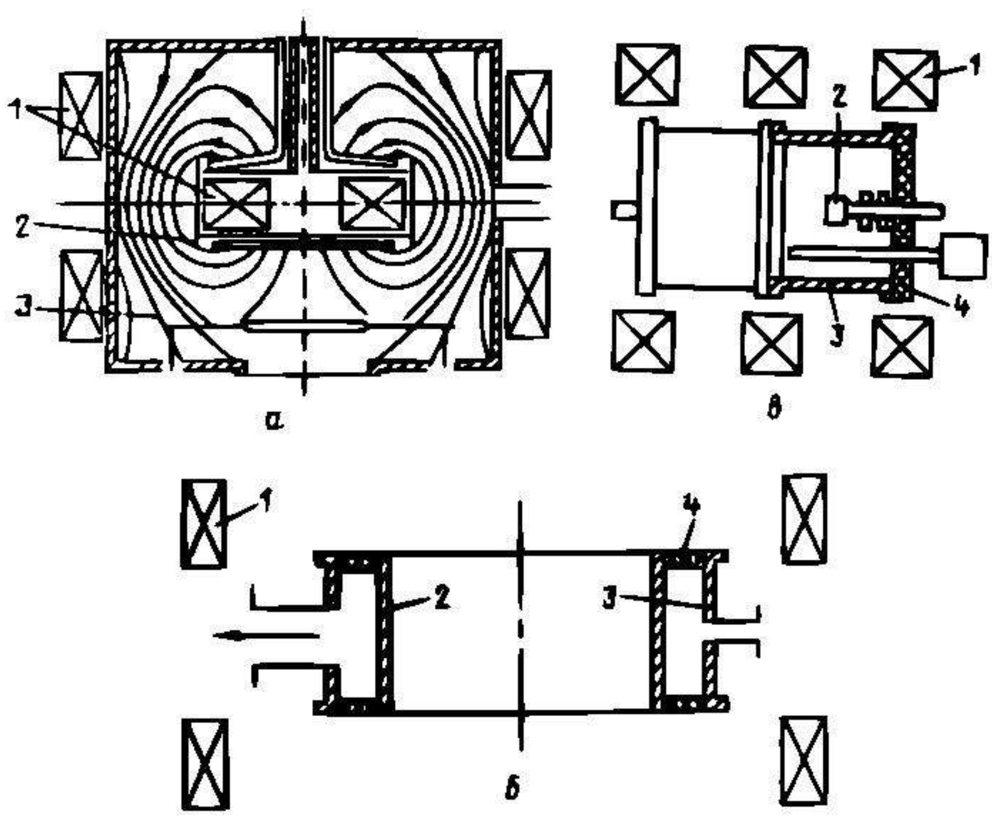

Fig.3: a) Diagram of Bonnevier B. device;

b) Diagram of Cairns J.D.S. device;

c) Diagram of Belousov A. V. device;

1) Coils of magnetic fields

2) Anode;

3) Cathode;

4) Insulators

The considered devices previously served as a basis for thermo-nuclear studies [4].

Their design comparison with centrifugal Z-pinch indicates to resembltnce in positions of electrodes: cathode serves as a body of working chamber, and anode is inserted into cathode.

There are differences also: magnetic coils do not serve as inductors and positioned beyond dimensions of chamber or beyond zone of cylindrical insulator. At any case, in the centrifugal Z-pinch there will be observed rotation of plasma with its centrifugal separation in crossed electrical and magnetic fields, as it happens in pulsed plasma centrifuges.

3. Conclusions.

Centrifugal separation effect will enable to clean plasma better then in device with “dielectric electrode”. The matter is that heat removal from the current surfaces in process of centrifugal separation is not inconvenient with low heat conductivity of insulator cover plates.

Previously found unspecified reserve in improving characteristics of the centrifugal Z-pinch along with those described in patent creates some expectations for increasing efficiency of plasma cumulating in a new pinch.

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