A Novel ST Configurative Events with Controllable and Reproducible Alternative Self-organization Process

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1. Introduction: The aim of this study is to identify the physical bases of an alternative self-organization mechanism that exists on the STPC-EX machine [1,2] and to determine complementary features with respect to present compact toroid concepts. The operational properties of last version of STPC-EX is modified with the new dense plasma creation method [3] such as the stepping discharge (STPD). The spherical tokamak plasma (STP) in the envelope of spherical snowplough (SSP) is shaped relating to m = 0 mode of the dual-axial z-pinch (DAZP). The demonstration of the STP creation using the SSP by the DAZP and/or the self-reversed field pinch (RFP) combined with DAZP are presented.

2. Coil-less STPC-EX machine: In the STPC-EX machine, four simulated single turn, high current toroidal field coils are controlled by four magnetically driven plasma guns (MDPG) placed with 90^0 angular intervals, combined with an energetic pulse forming line (EPFL). The main parts of these toroidal field coils consist of the shock heated, time varying and non-linear plasma belts in the flux conserver and complementary back-strap at the outside of the flux conserver. The poloidal current is completed by the pre-programmed SCR switch and the output terminal of the EPFL. In order to produce either pre-ionisation or pre-heating, a separate internal spheromak-like fast compact toroid injector (FCTI) is added. The cross-sectional layout of the STPE-EX machine are shown in Figs 1 and 2.

3. Dense plasma creation by stepping discharge: For the conventional pulsed discharge, the gas pressure, the pulse height, the pulse duration and the repetition rate are the basic collective dischage parameters of a gas breakdown, whereas in the stepping discharge (STPD) procedure, these collective discharge parameters are not necessary. The basic operational principle of the STPD depends on the shut-down of the open ended terminal of the EPFL at the stand-by. Its attitude is converted by means of the hot and dense $\cong 10^{22}$ m^{-3} plasma core produced by the FCTI (see prgh. 2). Thus, the repeated discharge steps last up to the exhausting of the magnetic energy of the EPFL in time, according to the magnitude and the conditions of $Z_0 > Z_p$, $Z_0 < Z_p$ and $Z_0 = Z_p$, where Z_0 and Z_p are the characteristic impedance of the EPFL and the complex plasma core impedance, respectively. For the assessment of Figs 3 (a) and (b) the termination model is developed [1].

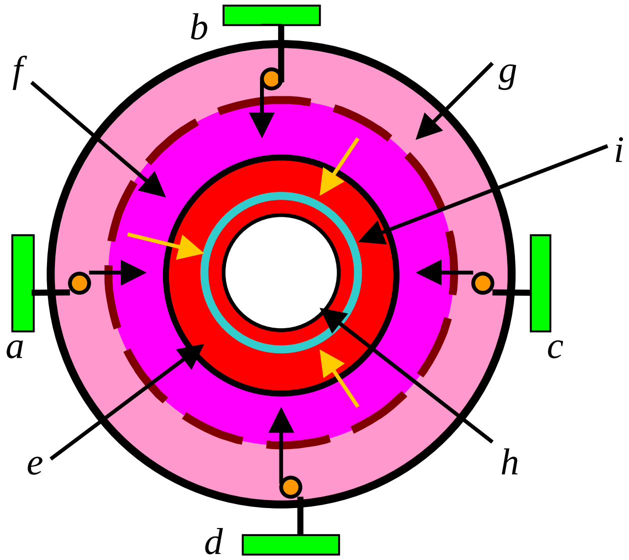

Fig. 1. (a, b ,c ,d) The back-strap electrodes connected with anode electrodes of MDPG; (e) The compressed and formed plasma current channel (PCC) by RFP; (f) The pre-formed PCC by pushed plasma belt; (g) The quiescent PCC before FCTI in operation; (i) The separatrix created by DAZP; (h) The floating conductive hollow rod (FCHR).

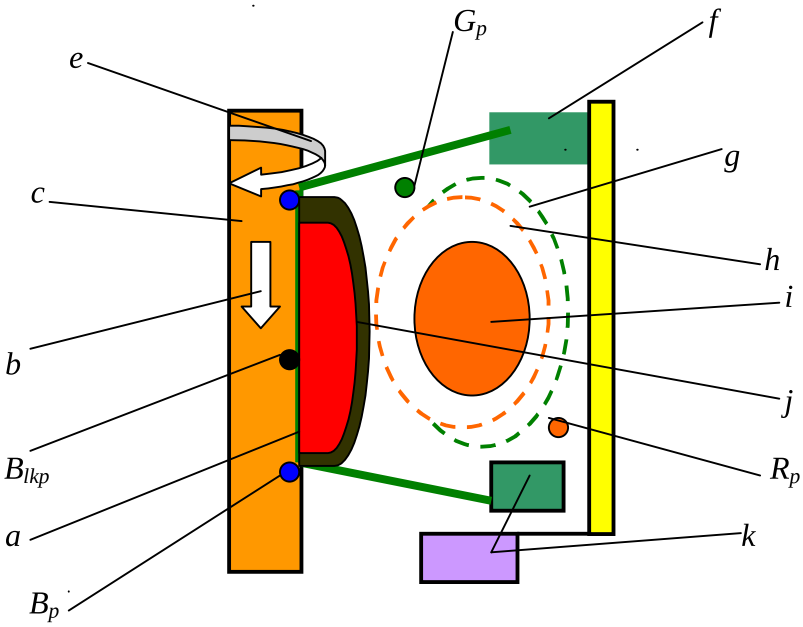

FIG. 2. (B_p) where, magnetic pressure greater than kinetic pressure; (a) Final position of the FPPB at the equilibrium state; (B_{lkp}) where, kinetic pressure greater than magnetic pressure in the equilibrium state with spherical snowplough starting; (b) Direction of belt current touched on the cylindrical surface of FCHR during spherical snow-plough equilibrium state; (c) FCHR as in (Fig. 1(h)), (e) Direction of poloidal magnetic field at the spherical snow-plough equilibrium state; (G_p) Direction of the toroidal magnetic field generated by belt current is out of paper; (f) In (Fig.1(a-d); (g) Inductive poloidal current contour of the belt during spherical snowplough equilibrium state; (h) Poloidal magnetic field of compressed plasma channel before into equilibrium state of snow-plough; (i) Approximate cross section plasma current channel before irreversible heating by adiabatic compression; (j) Current carrying sheath acts as a magnetic piston to be formed by compressed plasma core; (R_p) Direction of toroidal magnetic field generated by inductive poloidal current contour of compressed plasma core is into paper; (k) The direct electrostatic current-launcher.

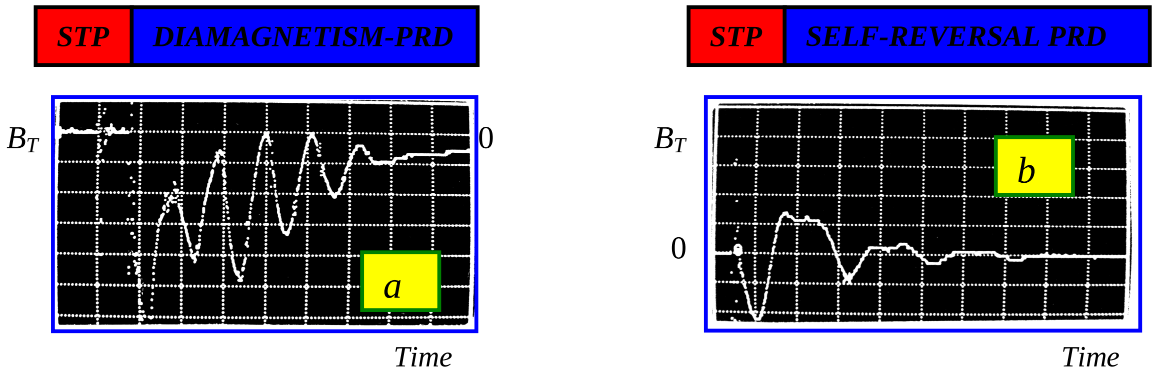

FIG. 3. Typical stepping discharge oscillograms taken from STPC-EX machine showing the variation of the toroidal magnetic field in Tesla vs time $B_T(t)$. a) The preliminary phase, time scale: 10μs/div and vertical scale:0.035 T/div. b) The final phase, time scale: 3.5 ms/div and vertical scale:0.07 T/div.

4. Dual-axial z-pinch: The preliminary phase starts by the loading of EPFL with the spheromak like compact toroid (SLCT) created by the FCTI. Besides, startup of the STPD seen in Fig.3 (a) continues about 60 μs. In the plasma medium produced in this period, the paramagnetic-diamagnetic toroidal magnetic field transformation comes into existence. The absolute value of this transform is 0.21T. Just after, STPD begins (Fig.3 (b)) and it lasts about 14 ms. In the first half period of the STPD lasts 1.75 ms.The repeated plasma current channels (Fig.1 (g, f)) and their poloidal fields together moving towards Fig.1(a-d)) the FCHR (Fig.1 (h)) join in the startup period. This mentioned dynamic phenomena take part in the cross section of the plasma belt (see prgh.2) package touching the FCHR (Fig.1(h)). The plasma belt currents touching the FCHR, are in fact the composed of many coaxial current sheaths (Fig.1(ylw-arrows)). This evolution with the separatrix (Fig.1 (i)) obtained, come into a stable state in 2-10 μs. In this case, through the effect of mutual inductance between the separated current sheat groups and the current vectors would be in opposite directions. So, by means of the poloidal magnetic field produced by the separated current sheath groups at the surface of the FCHR (Fig.1 (h)) and the poloidal magnetic field of the toroidal plasma current channel (Fig.2 (i)), the DAZP effect commences.

5. Self-reversal field: In the coilless mode of STPC-EX, the self-creation of toroidal field is produced in the following two ways; i) The self toroidal field of the time varying plasma belt in the equilibrium state (Fig.2 (green line, G_p)) and ii) The reversed field of the plasma current contours in the case of inductive coupling by the plasma belt in equilibrium state (Fig.2 (g, h, R_p)). These constitutions are interacted by the poloidal field of the compressed plasma current channel (CPCC) (Fig.2 (i)) effecting from either the outside or inside. As a result, CPCC turns-on into the reversed field pinch mode (RFP). Consequently, the spherical tokamak is constructed by the first CPCC and second one formed by DAZP and RFP respectively, coming together co-axially (Fig.1 (f, e, i)) by means of the magnetic piston (Fig.2 (j, B_p, B_{lkp})) effect of spherical snowplough, (Fig.4 (a, b)) on the surface of FCHR.

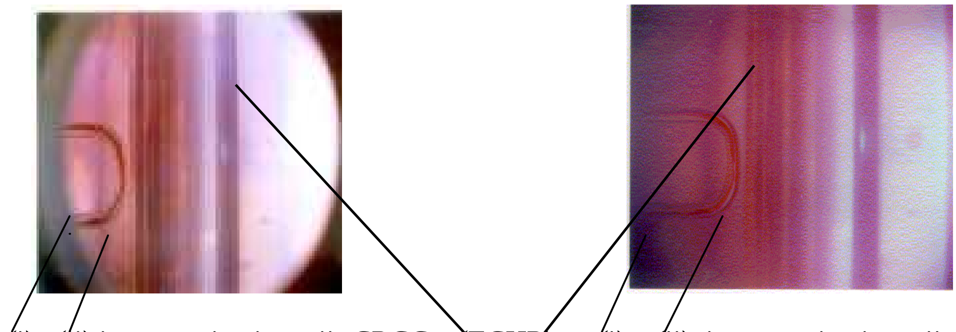

FIG. 4.The typical photographic results: (a) perfectly created spherical tokamak plasma, (b) fairly diffused spheromak like compact toroid. As seen detailed in Figs 1 and 2, this results commence by the MHD activities of both DAZP and RFP, during the created plasma core transport.

6. Conclusions: The STP in the envelope of SSP is shaped relating to $1 > m \cong 0$ modes of DAZP. In this procedure, the basic objects to be characterised at the conventional STP are controlled by the geometry of FCHR (Fig.1 (h)) and previously selected reference data of MDPG combined with electrostatic current-launcher (Fig.2 k)). For instance, the aspect ratio and elongation are depending on the distance between FCHR and back-strap (Fig. 1(a-d)) of MDPG, the belt velocity and the length of FCHR and piston (Fig.2 (j)) velocity (dynamic state of DAZP). On the other hand, triangularity is changing with respect to the belt thickness surrounding the FCHR cylindrically. The STPC-EX is operating in the Helium gas mantle under the dynamic vacuum. $<$ beta $>$ = 0.46 - 0.62; elongation = 4 - 6; triangularity = 0.42 - 0.58 in the case of belt velocity = 5.4×10^4 cms^{-1} - 3.5×10^6 cms^{-1} and electron density = 10^{20} - 10^{22} m^{-3}; plasma temperature = 118 - 177 eV (irreversible heating by adiabatic compression); sustainment time = 6.3 - 8.5 ms; energy confinement time is 45 - 136 ms. All above results have been taken at m = 0 mode of DAZP and RFP. According to the results of toroidal and poloidal flux contours determined, it has been understood that the self RFP has an influence upon excessively the magnetic piston velocity.

References: [1] SINMAN, S., et al., in Fusion Energy 2000 (Proc. 18th Int. Conf., Sorrento, 2000), IAEA, Vienna ,CD-ROM file, IC/P-04, IAEA, Vienna (2001); [2] SINMAN, S., et al., in Fusion Energy 2002 (Proc. 19th Int. Conf., Lyon, 2002), IAEA, Vienna, CD-ROM file, IC/P-01, IAEA, Vienna (2003).
[3] SINMAN, S., et al., in Fusion Energy 2004 (Proc. 20 th Int. Conf., Vilamoura, 2004), IAEA, Vienna, CD-ROM file, IC/P6-49, IAEA, Vienna (2004).