Experiments on a Spherical Tokamak Employing Energetic Pulse Forming Line

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Introduction

In general, the methods of plasma production, heating and confinement are well known. Taking into consideration of fusion reactor scales, in the updated experimental devices, the non-inductive current drive [1], RF current drive [2], helicity injection [3], boot-strap current generation [4] and beam or compact toroid injections [5,6] methods, realizing by different techniques, are applied to the tokamak and spherical tokamak systems. In some cases, in order to heat the plasma, the wave heating and current drive mechanisms are applied as an associated complex procedure [7]. In this study, an energetic pulse forming line connected with a magnetically driven plasma gun by a different structure, are inserted into the flux conserver directly and for the purpose of either the production and control of the spherical tokamak plasma or heating, a novel method is submitted. In addition, this method has been applied to the conceptual design of STPC presented at Maastricht Conference [8] and preliminary experimental results obtained from modified version of STPC-M machine are discussed.

STPC-M machine

The system of STPC-M is based on the moduler design concept. At the STPC-M, a simulated single turn, high current toroidal field coil is controlled by a Magnetically Driven Plasma Gun combined with an Energetic Pulse Forming Line (MDPG+EPFL). The main parts of the toroidal field coil consist of the shock heated, time varying, non-linear plasma belt in the flux conserver and the complementary back strap at outside. The poloidal current loop is completed by the pre-programmed trigatron switch and EPFL. The complete STPC-M is formed by the multi-segmented MDPG+EPFL system modules located around the flux conserver. In order to occur either the pre-ionization or the pre-heating, a separate internal Fast Compact Toroid Injector (FCTI) is added to this MDPG+EPFL assemble. The each module consists of three MDPGs together with one EPFL, one FCTI and one trigatron switch. Besides; at the STPC-M, it is added a central solenoid in order to control the interlink between toroidal and poloidal field lines, in the flux conserver center. Morover, for controlling the eddy currents created at the flux conserver, two passive rods are connected separately to the top and bottom walls of the flux conserver near to the center. For single-null poloidal divertor in STPC-M, an external solenoid is employed.

Current drive

In order to form and control the plasma core of Spherical Tokamak Plasma (STP) in the STPC-M machine, an Alternative Non-Inductive Current Drive (ANICD) method is applied.

From the view point of description of this noval method; it is possible to specify an analogous with the conventional RF-Non-Inductive Current Drive (RNICD) mechanism. In fact, at this mentioned ANICD method, an EPFL and its direct coupling open circuit transverse termination are used in place of the RF power amplifier and its launching electrostatic antenna at that of the RNICD method. Because of the noticeable level of temperature and density gradients of plasma belts, pushed towards the center of the flux conserver by Lorentz forces, either the toroidal or poloidal bootstrap currents are generated. On the other hand, by the influence of the helicity injection of the MDPGs, a second current drive mechanism is come into existance.

Results

Figure 1 shows the effect on the impedance of STP at the center, due to non-linear-time-varying pushed plasma belts, and as a result, the variation of toroidal field density of STPC-M machine in time. In this case, Z_o is 4.2 Ω and constant. Sustainment time of stepping discharge is about 10.5 ms. Maximum toroidal field density is 1.2 kG. Figure 2 gives the toroidal field density variation in time of FCTI at start-up phase. In this figure, paramagnetic and diamagnetic effects are seen in first 60 μs duration. The magnitude of difference between self generated toroidal field and diamagnetic field is about 2.5 kG. The compact toroid produced by the FCTI at on-set phase is presented in Fig. 3. The life time is about 1.2 ms and the toroidal magnetic field density is about 0.22 kG. Chopper sampling oscillograms are obtained by the multi-turns magnetic loop, located at a distance of 4.0 cm away from the wall of flux conserver (Figs 4,5). Upper traces in these figures are the derivative signal of toroidal field density and the lower ones are their integration in time. These oscillograms show the start-up phase of STP in time domain, where x axis is 0.1 ms/div and y axis is 0.370 kG/div. Figure 6 shows the starting of instability by increasing the input power of FCTI. In the figure, x axis is 0.5 ms/div and y axis is 0.370 kG/div. Figure 7 demostrates the photograph taken from circular diagnostic window by means of the open-shutter integrated post-fogging method. Here; FCTI has exposed right side of the film before hand, with an operating time of 60-70 μs, in on-set phase. But, the formation of STP and the enclosed surroundings of the passive floating central electrode at the center of the flux conserver are occurred by means of EPFL, having linear step by step discharge with the duration of 10.5 ms, as shown in Fig. 1 Thus, the integration of start-up, on-set and sustainment phases can be described. Utilizing the mentioned photograph (Fig.7) STP s aspect ratio in the range of 1.7-2.2 is found.

Conclusions

The main contributions achieved in this study have been:

- At the SPCP-M machine; the eddy currents occurred at the surface of the flux conserver can be controlled. Producing a surrounded magnetic axis through the upper and lower corners of the flux conserver, these controlled eddy currents have been transformed into the cusped type of magnetic field having 150-200 G. Thus, the life-time of the spheromak-like-compact-toroid formed at the center of flux conserver at on-set phase has been expanded up to 1.2 ms.
- The minimum input energy level of the FCTI needed for the preionization of the plasma medium has been found about 400-600 J. At the operating condition for Helium with pressure of 70 mTorr, between the formation time-lag and the statistical time-lag, a difference arriving to 300 μs has been observed (Fig.5). If the input energy of FCTI is rised to 800 J, for the pre-ionization very good reproducibility has been determined and than the formative time-lag has

dropped to the levels of 50-100 μs (Fig.4). In the case of higher input power selection for FCTI between 800 J and 1200 J, due to the strong energy trasport between spheromak-like-compact-toroid and the spherical tokamak plasmas, in the poloidal plasma current channel the radial instability of low frequency oscillations with 4.3-6.5 kHz have appeared.

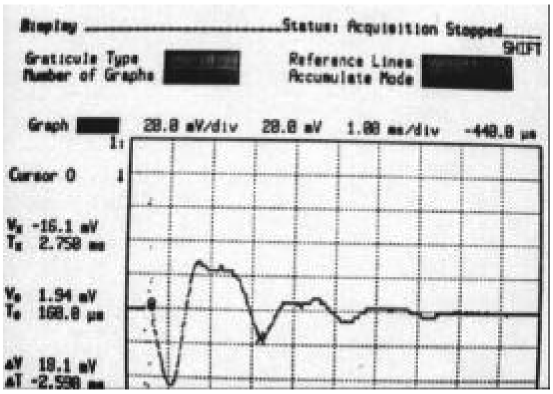

Figure 1.

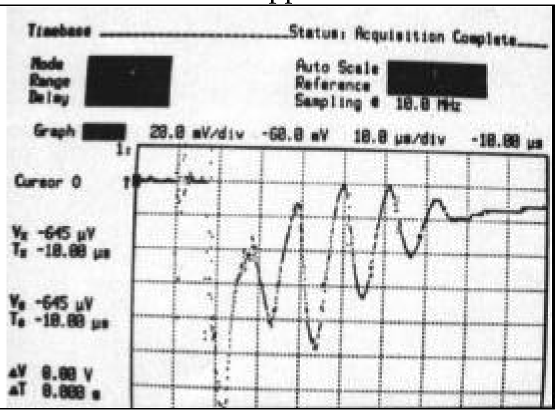

Figure 2.

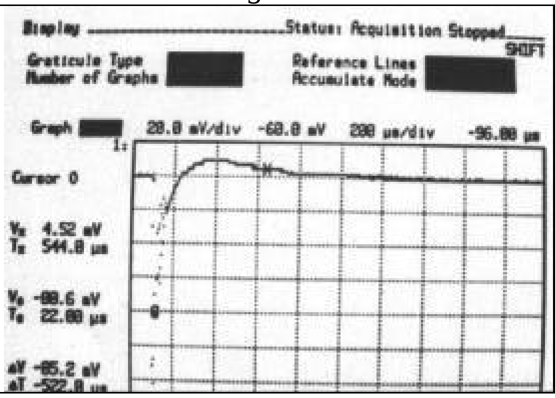

Figure 3.

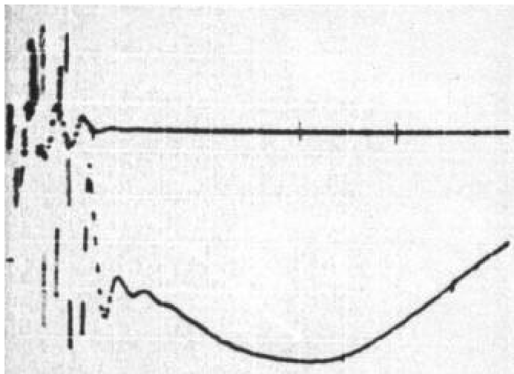

Figure 4.

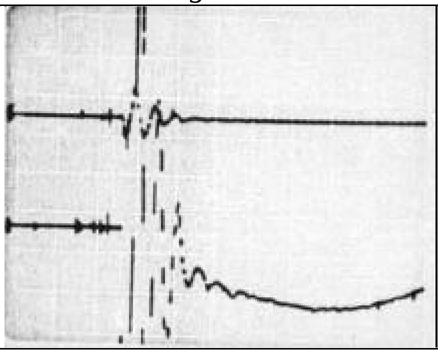

Figure 5.

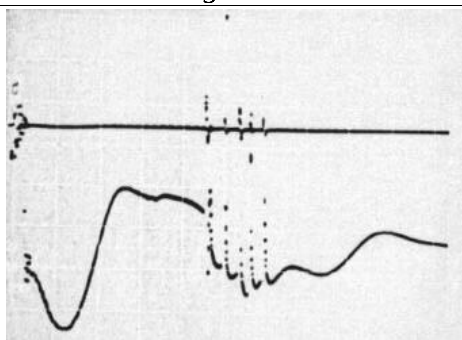

Figure 6.

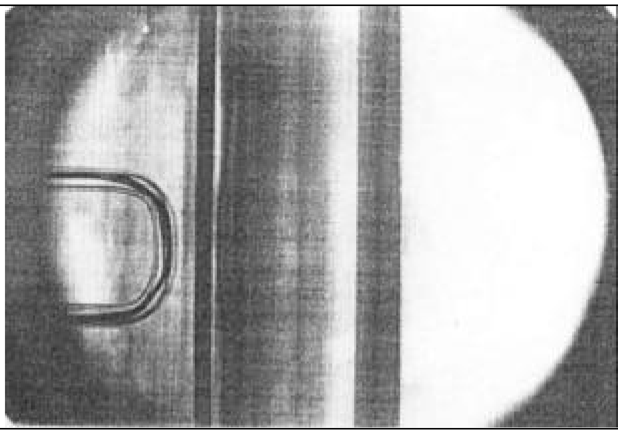

Figure 7.

- Increasing the number of modules, selecting differently the characteristic impedance of EPFL with respect to the STP impedance and controlling the discharge with the merging programme, the sustainment time of STP can be easily extended up to 150 ms orders.
- The high edge gradient of electric field of the MDPGs may be the reason of L-H transition-like mechanism. Therefore, it may be the responsible for the improved confinement regime. The measured basic plasma parameters of STPC-M machine are as follows: Electron densities (rms) and average temperatures at the belt, at FCTI and at STP are 10^{15}-$10^{16}cm^{-3}$, 10^{14}-$10^{15}cm^{-3}$, 10^{14}-$3\times10^{14}cm^{-3}$ and 22 eV, 8.2 eV, 14 eV ($\beta_p \cong 0.4$ max), (after 3D adiabatic compression) respectively. The overall temperature is 42 eV, $t_{conf.}$=45-60 μs, $<I_p>$=1.5-1.8 kA in helical form, B_p^{max}=0.8 kG. and deposition energy efficiency from capacitor bank to spherical tokamak is about 0.33-0.45.

References

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