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PHYSICAL PROPERTIES OF COMPACT TOROIDS GENERATED BY A COAXIAL SOURCE

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In the CTX experiments we have been studying CTs generated with a magnetized coaxial plasma gun. CTs have been generated in prolate and oblate cylindrically symmetric metalilc flux conservers. The plasma and magnetic field properties are studied through the use of magnetic probes, Thomson scattering, interferometry, and spectroscopy.

In the prolate case a simple circular cylinder is used as the flux conserver. The initial poloidal field strength of the coaxial source can be adjusted so that the CT configuration comes to rest within the flux conserver and separates from the gun. In some cases the CT stops with its axis parallel to the common axis of the source and the flux conserver, and then it rotates (as predicted by Rosenbluth and Bussac)[1] until its axis is orthogonal to the axis of the flux conserver. In most cases the stopped CT when first observed has already partially rotated. The rotated CT appears to be MHD stable and its magnetic fields (≈ 2 kG for the prolate case) decay with about a 100 μs time constant. Interferometric measurements show an initial density of about 10^{14} cm^{-3} and a density lifetime similar to that of the magnetic field. Details of the verification of this tilting as well as details of the gun operation and geometry are reported elsewhere.[2,3]

We have produced compact toroids when an initial axial magnetic "guide" field was established within the cylindrical stainless steel flux conserver. In the presence of this field the compact toroid is observed to rotate 180°. The characteristic decay time of the magnetic field configuration was only 10-15 μs, i.e., much shorter than comparable conditions without the guide field. We speculate that the rapid destruction in the guide field case is due to reconnection of magnetic field lines in the high shear regions which occur after the toroid rotates, opening previously closed field lines.

In an attempt to stabilize the tilting of compact toroids produced by the magnetized gun, we have generated compact toroids in other flux conservers having oblate regions incorporated into their geometry. A cross section of one such flux conserver is shown in Fig. 1b. The plasma from the magnetized gun is injected from the left through the 0.34-m diameter entrance cylinder into the confining region. With this geometry the tilting no longer occurs and the configuration is stable throughout its lifetime. In order to achieve this stability we increased the amount of initial gas puffed into the gun from 0.5 to 3 torr liters. We also tried a 0.46-m diameter entrance cylinder and found that the compact toroid then tilted again. With the elimination of the complication of tilting, three distinct time scales emerge. The first (~ 1 μs) is the time required to fill the flux conserver with magnetic field and plasma. The second (~ 12 μs) is the time for the decay of the fields in the entrance cylinder. Figure 2a shows this decay. We interpret this decay as being due to field line reconnection which is completed in about 30 μs. The third time (~ 150 μs) is the characteristic time for the decay of the fields in the flux conserver measured after reconnection has occurred. Figure 2b shows this decay. It is interesting to observe that the three time scales 1 μs, 12 μs, and 150 μs have the proper relative values to be an Alfven time, a resistive tearing time, and a resistive decay time respectively.[4]

If it does not tilt then one expects to have only B_z on axis. For the case in Fig. 1 the peak transverse components are measured to be less than 15% of the peak B_z and are not shown. The measurement of all components of the magnetic fields on the axis of the flux conserver is a powerful means of determining the extent of tilting. We have spent considerable time searching for a field and flux conserver configuration which gives a stable CT with

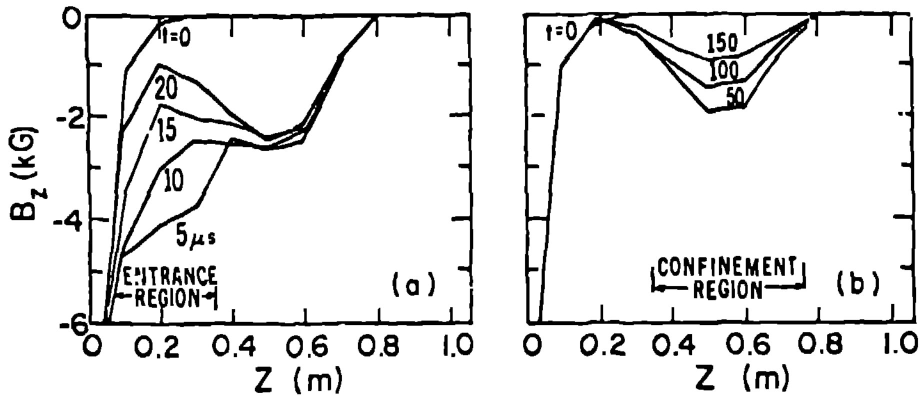

Fig. 1.
Plots of the axial component of the magnetic field on axis at various times. Figure 1a shows plots at various times during the decay of the field in the entrance cylinder. The time elapsed between plots is 5 μs. Figure 1b shows plots at various times during the decay of the compact toroid and the time between plots here is 50 μs. The gun discharge is initiated at t=0 and the plot labeled t=0 shows the value of the axial component of the magnetic field in this region due to the coils which supply the initial axial flux for the plasma gun.

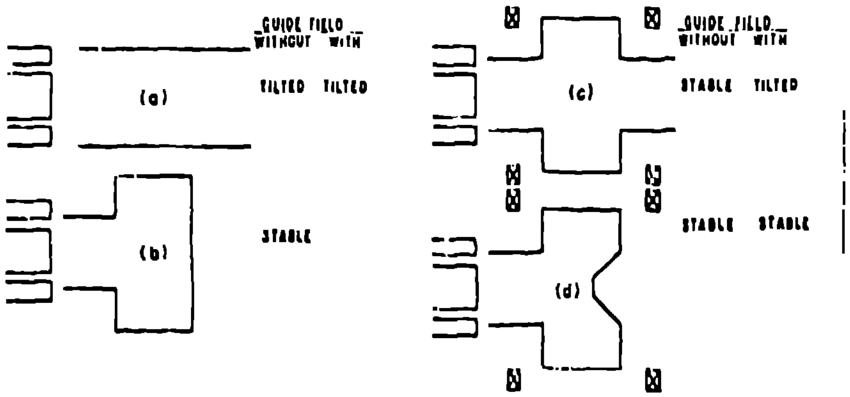

Fig. 2.
Various flux conserver and magnetic field geometries tried in order to stabilize the tilting.

guide field. Fig. 2 shows a summary of the geometries tried with comments as to the stability of the CTs created in these geometries.

Some properties of the CT plasma are measured for the no guide field case of the geometry shown in Fig. 2b. The density as a function of time as measured by a 3.39 μm wavelength HeNe interferometer is shown in Fig. 3. Observe that the time behavior of the magnetic field and density are similar. Spectroscopic data are taken with a 5-channel polychrometer, a monochrometer, and a spectrometer. The polychrometer has five channels spaced one angstrom apart. Photomultipliers are on each channel for time resolution. The monochrometer is set up to look across two angstroms. Using both the polychrometer and the monochrometer two regions of wavelength can be monitored on each shot. In addition, we have a spectrometer which can look at a region of approximately 100 Å, time integrated, and is used to look at the regions of interest to identify lines. Nickel and iron impurities have been identified. The region of the CV triplet (2270.91 Å, 2277.25 Å, 2277.92 Å) has been studied extensively with all three instruments. A line suitably close (within the resolution of the polychrometer and spectrometer ~ 1/2 Å) to the CV line (2270.91 Å) was identified at approximately 2270 Å and a similar time history was observed for data taken in the 2277 Å region. Unfortunately, these lines are all very close (within 1 Å) to Ni II lines - 2270.213 Å, 2277.28 Å, and 2278.77 Å. Their time history also correlated well to two other nickel II lines outside of the region of interest (2264.457 Å and 2287.084 Å). Thus the ~ 2270 and the ~ 2277 lines are more likely NiII than CV lines. OIV was also detected at 2781.05 Å indicating a temperature on the order of or higher than 20 eV at the beginning of formation. CIII radiation is observed during the lifetime of the plasma. It must be added that the spectroscopic measurements are line integrated and we look through regions of cold plasma and regions of hot plasma may not be evident. Thomson scattering has been used to measurethe electron temperature at various times. We have taken some preliminary data at a position 5 cm from the midplane of the confinement region and at a radius equal to two-thirds of that of the confinement region. There is a large shot-to-shot variation of the temperature and density at this position especially early in time. However, the plasma does appear to be fairly cool ($T_e \lesssim 10$ eV) for the times shown in Fig. 1b ($t \geq 50$ μs). Early in time ($t \simeq 5$ μs) temperatures as high as 60 eV have been measured. Quartz pressure probe data are consistent with this by showing a rapid drop early in time. This rapid cooling during reconnection is probably due to transport along open field lines. It may be possible to lower the energy lost on open field lines by shortening the time for reconnection. One method of doing this is to apply a fast rising external field in the entrance region. The external coil producing this field is called a snipper coil.

CONCLUSION

A compact toroidal plasma configuration is generated in a cylindrical flux conserver using a magnetized coaxial plasma gun. If the initial poloidal field strength of the magnetized gun is adjusted appropriately the configuration is observed to stop within the flux conserver. For a straight cylindrical flux conserver the axis of the toroid is observed to rotate so that it is orthogonal to the original axis of symmetry. After this rotation, the deformed toroid appears to be MHD stable and decays away with about a 100-μs time constant. Interferometric measurements show an initial value of about 10^{14} cm^{-3} and a lifetime for the plasma density similar to the magnetic

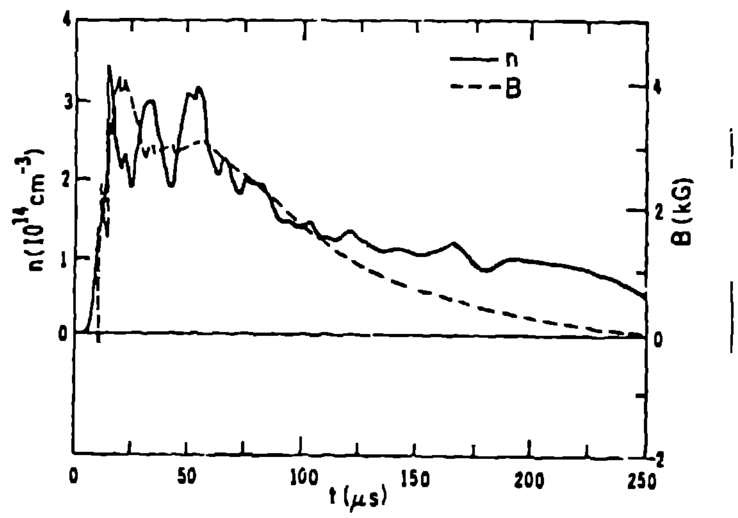

Fig. 3.
Density and magnetic field vs time. These data were taken with an interferometer and a magnetic probe located near the midplane of the confinement region of the flux conserver. The density is the line average on a diameter and the magnetic field is B_z on axis. Density and B_z are from different shots.

field lifetime. When a compact toroid is generated in an oblate flux conserver under proper conditions it does not tilt as verified by the fact that the transverse fields on axis are small compared to the axial field. In this stable case the reconnecting time (12 μs) can be observed and it is much shorter than the decay time of the fields of the compact toroid (150 μs). The density has a similar decay time in this case also. See Fig. 3. From the spectroscopic data the OIV signals indicate an initially warm plasma. The plasma cools rapidly after which time the Ni II lines appear. This interpretation is consistent with the Thomson scattering data which show the rapid early cooling. Guide fields can be added to some flux conservers without causing tilting. However, when the relative strength of the guide fields become high enough the CTs rotate 180° and flux is annihilated.

REFERENCES

1. M. N. Rosenbluth and M. N. Bussac, Nucl. Fusion 19, 489 (1979).

2. T. R. Jarboe, I. Henins, H. W. Hoida, J. Marshall, D. A. Platts, and A. R. Sherwood, "The Motion of a Compact Toroid Inside a Cylindrical Flux Conserver," Phys. Rev. Lett. 45, 1264 (1980).

3. T. R. Jarboe, I. Henins, H. W. Hoida, J. Marshall, and A. R. Sherwood, "Magnetized Gun Experiments," Symposium on Compact Toruses and Energetic Particle Injection, Princeton Plasma Physics Laboratory, Princeton, NJ, December 12-14, 1979.

4. H. P. Furth, J. Killeen, and M. N. Rosenbluth, Phys. Fluids 6, 459 (1963).