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THE 13TH INTERNATIONAL STELLARATOR WORKSHOP

DESIGN AND CONSTRUCTION PROGRESS OF THE COMPACT TOROIDAL HYBRID

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Abstract: The Compact Toroidal Hybrid (CTH) is a stellarator/tokamak hybrid device currently under construction at Auburn University. The primary goal of CTH is to investigate both ideal and resistive current-driven instabilities in low aspect ratio ($A_p \leq 4$) stellarator plasmas. Current-driven MHD instabilities in stellarator plasmas are generally of interest because the bootstrap and Pfirsch-Schlüter currents could potentially destabilize external kink modes in high β stellarators. Of particular interest is the susceptibility of current-driven stellarator discharges to major disruptions, and the extent to which the helical stellarator field can passively stabilize them. Previous studies on W7-A[1] and JIPPT-II[2] have shown that the stellarator field can extend the stable regime of tokamak operation and suppress disruptions, yet current-driven disruptions can still be obtained in stellarator plasmas with a relatively small fraction of the rotational transform derived from the plasma current.[3] The issue of MHD stability of current-carrying stellarator plasmas is important within the US stellarator program since two low aspect ratio stellarators under consideration, NCSX[4] and QPS[5], will have significant levels of bootstrap current. In CTH, the susceptibility and severity of current-driven stellarator plasmas to disruptions will be experimentally examined with ohmic currents applied to RF-generated stellarator plasmas. Both peaked and hollow bootstrap-like current profiles will be generated in CTH and comparisons will be made with 3-D stability theory. 1-D and some supporting 3-D stability studies show that CTH can be made to operate at the predicted stability boundary of ideal kink and vertical instabilities. Disruptions from resistive tearing modes can be expected, as observed in the previous current-driven stellarator experiments.

Experiment

The magnetic configuration of the CTH device is designed to be highly flexible. The main torsatron field is provided by an l =2, m=5 helical coil. The average magnetic field strength will be $B_o \leq 0.5$T. The design parameters of CTH are shown in Table 1. Auxiliary toroidal field (TF) coils will be used to increase the overall rotational transform profile with the edge vacuum rotational transform being variable from $\iota_V(a) = 0.2$ to 0.5. Currents generated by the OH system will further modify the transform up to $\iota_J(a) \leq 0.5$. Dipole, vertical field coils will provide the fields to maintain equilibrium. A set of shaping, quadrupole poloidal field coils (SVF and IVF) will provide the capability of modifying the elongation of the plasma as well as altering the shear in the rotational transform profile.

The core of the CTH facility showing the helical coil and its support structure is illustrated in Fig. 1. The relative positions of all major coil sets and the vacuum vessel are shown in Fig. 2. A typical set of vacuum flux surface plots generated from the IFT code[6] are shown in Fig. 3., and a range of attainable vacuum rotational transform profiles (also computed from the

IFT code) are shown in Fig. 4. The VMEC code[7] is used to model profiles in current-carrying CTH plasmas.

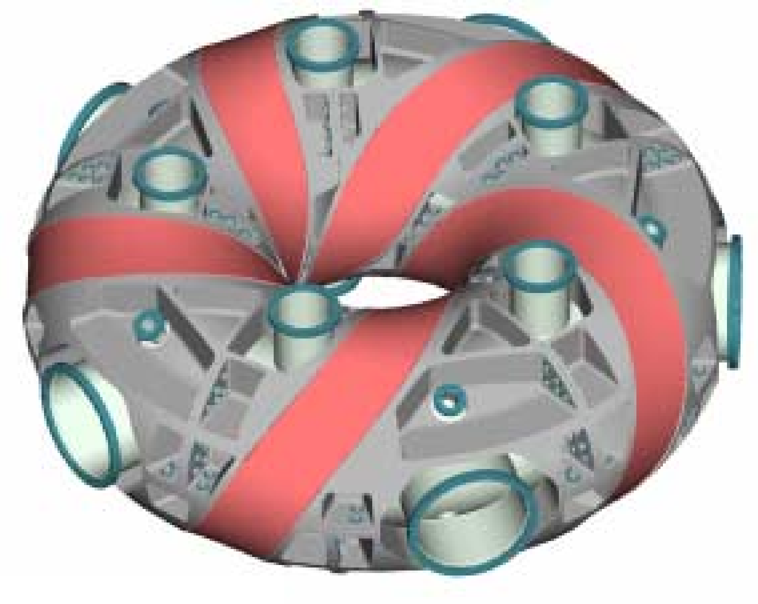

Fig. 1. Core of the CTH device. The vacuum vessel is shown in green. The helical coil frame surrounds the vacuum vessel and the helical coil itself is shown in red and is wound directly onto the helical coil frame.

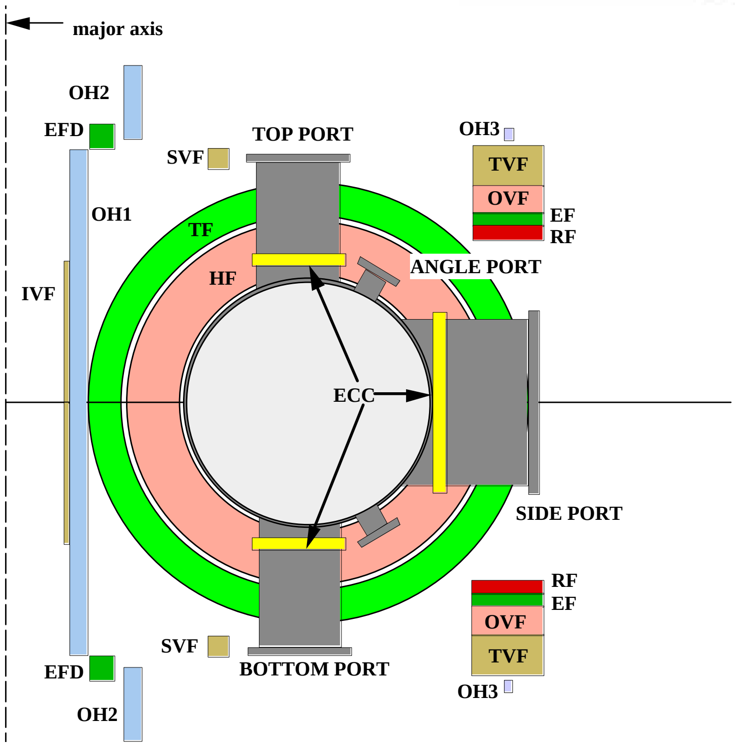

Fig. 2. Combined poloidal cross-sections of CTH showing the vacuum vessel, ports and coil sets. The top and bottom ports are in different poloidal planes from the side and angled ports. The coil sets are as follows:
OH1, OH2, OH3 – Ohmic Coils
HF – Helical Field Coil
OVF – Outer Vertical Field Coils
SVF – Shaping Vertical Field Coils
IVF – Inner Vertical Field Coils
TVF – Trim Vertical Field Coils
TF – Toroidal Field Coils
TRF – Trim Radial Field Coils
EF – Equilibrium Field Coils
EFD – Equilibrium Field Decoupler Coils
ECC – Error Correction Coils

Table 1: Parameters of the CTH device.

Major Radius (m)	0.75	Ion Temperature (eV)	≤ 50
Vessel Minor Radius (m)	0.30	Plasma Current (kA)	0-60
Avg. Plasma Radius (m)	0.19	Input Power (kW)	200-250 (ICRF); 100 (OH)
Magnetic Field (T)	0.5	Pulse Duration (s)	0.4 (magnets); 0.1 w/ OH
Density (m^{-3})	0.5 – 1 x 10^{19}	Edge Transform	0.15–0.5 (vac);+ 0-0.5(OH)
Avg. Elec. Temp. (eV)	325	Plasma β (%)	≤0.5

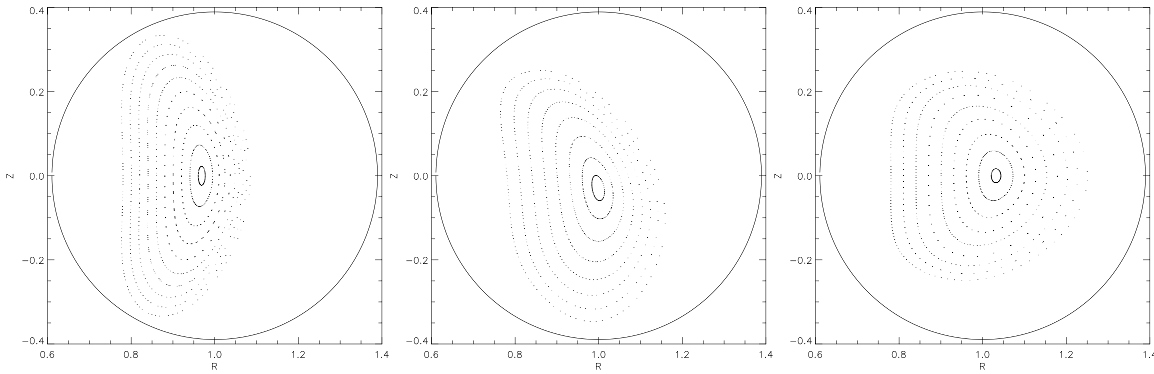

Fig.3. Vacuum magnetic field surface of section plots at three toroidal angles within a field period.

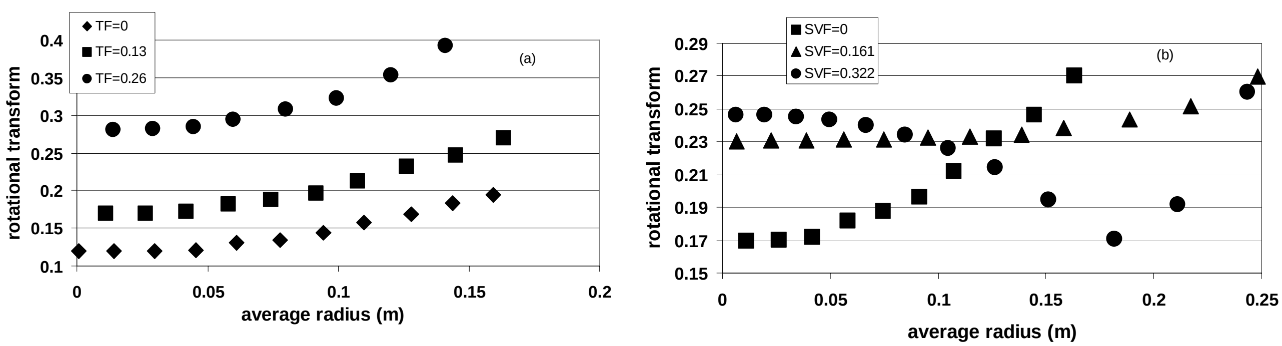

Fig. 4. CTH vacuum rotational transform profiles. (a) Variation of the transform profile with TF current. The values in the legend refer to the ratio $I_{TF}/I_{L=2}$. (b) Variation of the profile with SVF current for $I_{TF}/I_{L=2}$=0.13.

Vacuum Vessel & Helical Coil Frame

The CTH vacuum vessel is a continuous circular torus of major radius R_o = 0.75 m and minor radius a_v = 0.29 m. To facilitate poloidal flux penetration during ohmic operation, the vacuum vessel chamber is being made with Inconel 625. The estimated flux penetration time is in the range of 1 –2 msec. The vacuum vessel halves are fabricated by spinning. The halves are welded together, and SS port extensions are then welded on. The vessel is scheduled for delivery in May of 2002.

The Helical Coil Frame (HCF) forms the major support structure of the CTH device. The 5-field period, l=2 helical coil will be wound into precision-machined, cast aluminum supports surrounding the vacuum vessel. The frame pieces will be cast in ten identical sections using a machinable Aluminum alloy. After the sections are cast, the coil troughs and fastening edges of the parts will be machined to a tolerance of $\pm$1mm. This level of coil winding error has been shown to have a negligibly small effect on the calculated vacuum magnetic surfaces.

The sequence of assembly is shown in Fig. 5. Insulating supports will cradle the vacuum vessel within the HCF. Heating pads will be affixed to the vacuum vessel for low-temperature bake-out (T ≤ 120°C). Magnetic diagnostics such as Rogowski coils and flux loops will be installed between the HCF and the vacuum vessel during the assembly of the machine to allow measurement of vacuum vessel currents.

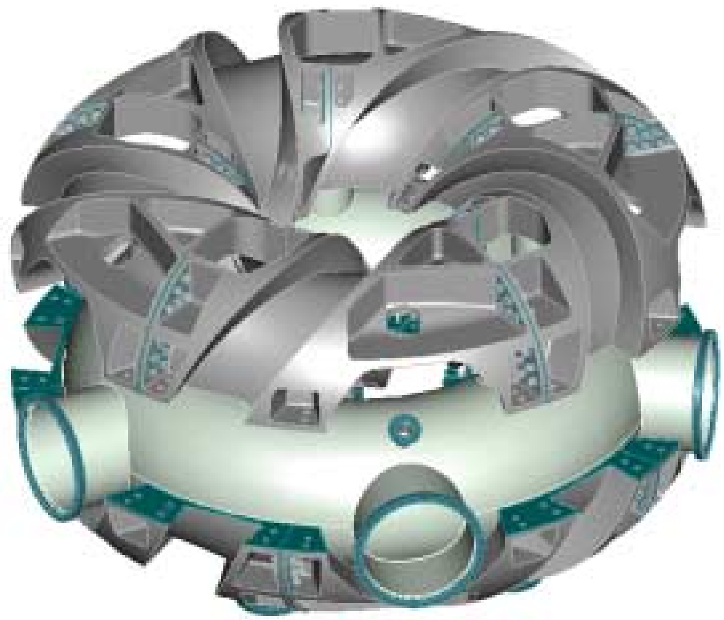

Fig. 5. A Sketch of the assembly of the Helical Coil Frame around the vacuum vessel. Five pieces of the HCF will be joined to form the lower section. Next, the vacuum vessel will be lowered in place. The upper part of the HCF will then be constructed, lowered and attached to the lower section.

With the focus of the CTH experiment on current-driven instabilities, it is necessary to have the ability to measure the fully 3-D magnetic equilibrium configuration of the current-carrying plasma in order to make valid comparisons with stability theory. Efforts are underway in the stellarator community to develop a 3-D equilibrium reconstruction method. We intend to test this technique in CTH using segmented Rogowski coils, magnetic B-dot probes, and flux loops near the plasma boundary to provide the magnetic measurements for the reconstruction method. Plans are also under development to use the MSE/LIF technique[8] to measure the pitch angle of the internal magnetic field to provide constraints on the local rotational transform for the reconstruction process. Defining satisfactory magnetic diagnostics for the equilibrium measurement in CTH is a priority and an ongoing process at this time.

Schedule

The vacuum vessel, helical field coil molds, and magnet copper are all expected to have arrived by the Summer of 2002 and the winding of the CTH coils will begin at that time. The CTH device is scheduled to be completed and operational in late 2003.

Acknowledgements

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