Generation of **Rotational Transform** in a Toroidal Confinement Device with **Tilted Coils**

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Highlights 1: Confinement Concept

• Tokamak-like device with tilted toroidal field (TF) coils needs less plasma current $I_p$ than a conventional tokamak.

• Rotational transform is partly generated by external coils. Device can be considered a tokamak-torsatron hybrid.

• Tilted TF coils are interlinked to each other, which helps to reduce aspect ratio of plasma.
Highlights 2: Exp. Setup & Initial Results

PROTOTYPE: “CIRCUS” (CIRCUlar coil Stellarator)
• Designed and constructed first device of this type.
• Six-coil generalization of CNT stellarator (also Columbia University, two interlinked coils).

INITIAL RESULTS
• Electron beam in gas ➔
  ➔ preliminary evidence of rotational transform, even for $I_p=0$!

WORK IN PROGRESS & FUTURE WORK
• More extensive tests with recent 3D-movable electron gun.
• First plasma with new vessel.
CNT concept can be generalized to more than 2 tilted interlinked circular coils.

D. Spong (ORNL)
Tilted coils generate/amplify rotational transform. Interlinked coils $\rightarrow$ Low Aspect Ratio Stellarators.

- Moroz, PPCF 1996
- Todd, PPCF 1990
18 coil generalization of CNT would be more axisymmetric than 18 coil tokamak

- Tokamak, 18 TF coils.

- Tokamak-stellarator hybrid needing less $I_p$ than tokamak, for same rotational transform $\rightarrow$ less violent disruptions (similar to CTH).

- Variants:
  - Two sets of coils (not shown) tilted opposite to each other, to convert Tokamak in Stellarator before it disrupts?
  - Add VF interlinked coil on HFS?
Tilted coils need less current to achieve same transform. Also, have lower effective ripple than equivalent tokamak.
Earlier Poincaré plots suggested need for $I_p = 2.5\,\text{kA}$
Then, vacuum field-line tracing scans of coil currents, tilts and positions showed that $I_p$ can be $< 0.8$ kA.

- Generator or amplifier of rotational transform?
- Tokamak-torsatron hybrid or pure torsatron? (or pure stellarator?)
- CNT doesn’t need $I_p \neq 0$
VMEC suggests that $I_p=0$ can yield plasma of finite $a$. 
Tilts and radial locations of coils can be varied

TF supports, adjustable tilt=34-61° w.r.t. horizontal
Tilted interlinked TF coils being installed

6 interlinked TF coil rims

TF coil rim with axle

Generate 0.0875 T on axis for 2.45 GHz startup, ECH and ECCD
Construction of CIRCUS Tokamak-Stellarator was completed.

Tilted interlinked coils mounted on central column.
Advantages

- High compressive strength
- Transparent to microwaves → easy heating & C
- Transparent to visible light → broad camera view

Disadvantages

High desorption rate

Nonetheless, $P = 2.2 \times 10^{-5}$ torr, sufficient for EC startup.
Construction of CIRCUS Tokamak-Stellarator was completed.

- Installed 1kW, 2.45 GHz magnetron.
- Installing two paraboloidal mirrors, of which one steerable.
- Coils tested.
- Vacuum tested (2 \cdot 10^{-5} \text{ Torr}).
e-beam from filament biased at -100 V in gas at $10^{-5}$-$10^{-4}$ torr follows rotationally transformed field line
Bird’s-eye view
IGBTs will allow fine adjustment of coil currents and scan of possible plasma equilibria

- Two banks of IGBTs in series with VF and QF coils control coil-currents via voltage across the gates of the IGBTs
- IGBTs because of high maximum collector currents and high power dissipation ratings

- IGBTs installed
- Their LabView control under installation
Electron gun can be scanned in 3D, for fine scans of flux surfaces in field-line mapping.

Sliding feedthrough mounted on tiltable bellow.
Future work

Experiments with present setup:
• Confirm rotational transform for e-beam initialized on high-field-side, by recently installed filament movable in 3D (1 linear, 2 angular).
• Measure flux surfaces for various radial positions and tilts of coils, and compare with calculations. Identify parameter space where $I_p=0$.
• Introduce deliberate error fields. Measure and compare with calculations.

Improved setup:
• Microwave plasma in new vessel
• Fast-camera studies of plasma formation by EC start-up
• Water cool coils, for longer shots or higher repetition rate
• Larger plasmas will require $I_p \neq 0$. If ECCD not sufficient,
  – Central solenoid, for $I_p$ generation and Ohmic heating
  – New form of Rotating Magnetic Field CD (RMFCD)
  – Plasma Gunn [as in Proto-CLEO]
New vessel will allow better vacuum.
Coils will be external, cooled. Longer pulses.