Title: INITIAL DESIGN OF THE 60 MEGAWATT ROTATING MAGNETIC FIELD
(RMF) OSCILLATOR SYSTEM FOR THE UNIVERSITY OF WASHINGTON
"TCS" FIELD REVERSED CONFIGURATION EXPERIMENT

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INITIAL DESIGN OF THE 60 MEGAWATT ROTATING MAGNETIC FIELD (RMF) OSCILLATOR SYSTEM FOR THE UNIVERSITY OF WASHINGTON "TCS" FIELD REVERSED CONFIGURATION EXPERIMENT

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I. ABSTRACT

This paper presents the initial electrical and mechanical design of two phase-locked 30 Megawatt RMS, 150 kHz oscillator systems used for current drive and plasma sustainment of the "Translation, Confinement, and Sustainment" (TCS) field reversed configuration (FRC) plasma. By the application of orthogonally-placed saddle coils on the surface of the glass vacuum vessel, the phase-controlled rotating magnetic field perturbation will induce an electric field in the plasma which should counter the intrinsic ohmic decay of the plasma, and maintain the FRC.

Each system utilizes a bank of 6 parallel magnetically beamed ML8618 triodes. These devices are rated at 250 Amperes cathode current and a 45 kV plate voltage. An advantage of the magnetically beamed triode is their extreme efficiency, requiring only 2.5 kW of filament and a few amps and a few kV of grid drive. Each 3.5 uH saddle coil is configured with an adjustable tank circuit (for tuning). Assuming no losses and a nominal 18 kV plate voltage, the tubes can circulate about 30 kV and 9 kA (pk to pk) in the saddle coil antenna, a circulating power of over 33 megawatts RMS. On each cycle the tubes can kick in up to 1500 Amperes, providing a robust phase control. DC high-voltage from the tubes is isolated from the saddle coil antennas and tank circuits by a 1:1 coaxial air-core balun transformer. To control the ML8618's phase and amplitude, fast 150 Ampere "totem-pole" grid drivers, an "on" hot-deck and an "off" hot-deck are utilized. The hot-decks use up to 6 each 3CPX1500A7 slotted radial beam triodes. By adjusting the conduction angle, amplitude may be regulated, with inter-pulse timing, phase angle can be controlled. A central feedback timing chassis monitors each systems' saddle coil antenna and appropriately derives each systems timing signals. Fiber-optic cables are used to isolate between the control room timing chassis and the remote power oscillator system. Complete system design detail will be presented in addition to anticipated (computer generated) performance characteristics.

Initial design and construction began in FY97, and will continue through FY98, with delivery to the experiment in FY99, for commencement of physics experiments on sustaining the FRC.

II. OSCILLATOR

The oscillator circuit is configured as shown in Figure 1. The six parallel ML8618 triodes are operated class "E", a square wave grid excitation when the plate voltage is at its' minimum potential. This methodology seems to help provide reliable operation at the required power levels of

interest. An "on-deck", consisting of 6 parallel 3CPX1500A7's are operated with a lower filament rating of 5 Volts. The 5 volt filament provides a longer tube lifetime, yet each tube can provide 25 amps output, with little negative grid impedance. With 150 amps of 8618 grid drive, risetimes should be in the 50 nS regime. Four tubes in the "off-deck" should provide a 75 nS turn-off time. The intent of the fast switching is to provide good phase control to the plasma excitation waveforms. The authors experience with the Los Alamos ZT-40 (an RFP), 70 megawatt "Oscillating Field Current Drive" system, was that plasma response was "soft" to phasing. It seemed that noticeable differences in plasma response could be determined in about 15 degree increments. This system should be able to maintain a phasing accuracy of better than 10 degrees. The 8618's have cathode current viewing resistors to determine when a tube arc occurs. In this event, a shunt bypass spark gap is triggered and diverts fault energy from the tube and an additional crowbar ignitron discharges the capacitor energy store, 520 uF at 22 kV (125 kJ). To couple the pulse into the vacuum chamber saddle coil antenna and tank circuit, a 1:1 coaxial balun transformer is utilized. This has the added benefit of maintaining the vacuum chamber coils at DC potential, minimizing the probability of arcs.

To interconnect the various system modules, multiple parallel coaxial cables are utilized, as shown in Figure 2. Six parallel RG-220 cables are used, except for the coaxial balun, which uses low inductance RG17/14 60 kV "Scyllac" cable. The system modules consist of the capacitor bank, charging power supply, tube power module, balun transformer assembly, antenna tuning (tank) network, and the saddle coil antenna. The modules may easily be shipped, with the power module being the largest, 7' x 11' x 6' tall.

III. CALCULATED PERFORMANCE

A SCEPTRE-like circuit code model was used to determine the expected oscillator performance. The equivalent model, as shown in Figure 3, includes the lump element, parasitic, and fault damping components. Damping in the capacitor bank is required to prevent ringing in the event of a crowbar or arc. The ML8618's also require plate De-Q's to prevent oscillation. The air core balun transformer provides only a 20 uH magnetizing inductance and the length of the parallel array of RG17/14 cables give a 300 nH leakage inductance. The plasma load impedance (.15 Ohm) is a guess based on field penetration and plasma density. The modeled performance shows a 9.2 kA pk to pk oscillation through the 3.5 uH saddle coil antenna, an "RMS" power of almost 37 megawatts. The machine

Figure 3. Equivalent Circuit Model

Figure 4. Antenna and Tube Currents

(supposedly) only requires 25 MW, this extra compliance permits either operation at a lower bank voltage or with a reduced tube count. In the event of a tube failure, operation may be continued without any detriment to operation, by simply disconnecting the terminals of the faulty tube. Additionally, when the full output swing is obtained, the tubes are only switching about 500 amps. A pair of the 250 amp ML8618 tubes could bring the system to full ratings, but with a slow build-up of circulating power. A higher switching capability would help maintain the proper phasing between the two oscillator systems.

IV. CONCLUSION

The TCS FRC oscillator power system is designed to be a utility for the physics experimental program, not a development project. The systems are conservatively designed of known technology of proven performance in similar and previous fusion applications. These previous systems operated many years with little maintenance and few "down" times. Similar performance for this system can be expected. To minimize cost, material and expertise has been leverage from the Los Alamos fusion program to assist in the continued work on alternate concepts. This work is supported through the DOE Office of Fusion Energy Sciences, and Contract No. W-7405-ENG-36.