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THETA-PINCH FUSION TEST REACTOR

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ENERGY STORAGE, COMPRESSION, AND SWITCHING IN A
THETA-PINCH FUSION TEST REACTOR*

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A new magnetic energy transfer and storage system is being developed for the Scyllac Fusion Test Reactor (SFTR), presently in design at Los Alamos. The machine is designed to "breakeven" by producing as much neutron energy in a pulse as is contained kinetically in the plasma.

The plasma is heated and contained in a 20 cm bore toroidal ring, with a 40 m radius. The programmed magnetic field is generated by two different sources. An implosion heating system initially heats the plasma to 2.6 keV by driving a low inductance end-fed implosion coil with 240 kV capacitors switched separately onto the parallel plate feed line. The field is held at the 8 kG level for 200 μ sec with crowbars until energy from a 488 MJ superconducting storage ring is transferred (in 0.7 ms) to a separate compression coil, raising the field to 55 kG and bringing the plasma to ignition. The coil is crowbarred to give a 250 ms L/R decay of the field, during which time the neutron energy is delivered.

The 5 MJ implosion heating capacitor bank brings the field up to 8 kG in 200 ns, and the circuit is "tuned" to resonate with the plasma motion. The quarter period determined by the capacitor and inductive load matches the time for the plasma to reach its minimum radius at the first "bounce". This resonant mode now under investigation⁽¹⁾, can be very efficient of energy transfer.

The major new system is the 488 MJ superconducting storage and switching system. The system has 1280 modules of 381 kJ coils, each module driving a 20 cm

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section of the torus. One is forced to have many modules by the constraints imposed by the current interrupters required to initiate the transfer of energy from the storage coil to the compression coil. The constraint is easily understood from the simplified circuit for a single module shown in Fig. 1.

To avoid energy dissipation in the switch, a transfer capacitor bank is used to resonantly transfer the energy to the load in the transfer time τ . The bank must handle half the stored energy during the transfer (assuming equal load and storage inductances and, hence, currents), but without it, that energy would be dissipated in the switch. (This follows from flux conservation). Further, a quarter of the energy would be left in the storage coil, giving a maximum of 25% transfer efficiency.

With this transfer circuit, the product of the initial current I and the maximum voltage V (occurring midway through the transfer period) is $\pi E/\tau$, where E is the initial stored energy. The interrupter must break the current I and withstand the voltage V , so its ratings determine the maximum energy E . At present, we envision using vacuum interrupters with $I = 26$ kA, $V = 60$ kV. Using a single Westinghouse vacuum breaker we have achieved 13 kA @ 40 kV, limited by the test facility. The higher voltage requirement should be easily achieved, but the current requirement may be at the limit of reliable, long-life operation.

The storage coils are constructed from low-loss a-c superconductors. To achieve extremely low losses one constructs wires of 1/4 - 1/2 mm diameter containing several hundred filaments embedded in a Cu and Cu-Ni matrix. The Cu-Ni surrounds each filament and resistively separates it from the other filaments, preventing eddy currents which could drive the wire into the normal state. The wires are twisted during drawing, and hundreds of these wires (each carrying

50-100 amps) are woven into a fully transposed braid to make a 10-20 kA cable which can withstand rapidly changing magnetic fields without inducing large losses.⁽²⁾

To date, a 380 kJ superconducting coil has been constructed and successfully tested at LASL. However, the 10 kA wire was a simple rectangular copper conductor with embedded filaments of Nb-Ti and no Cu-Ni. As a result, the coil goes normal during discharge, resulting in somewhat higher losses than allowed for SFTR. Nonetheless, part of the energy was transferred (to limit $V \times I$) to a dummy load coil in 1 ms @ 40 kV using vacuum interrupters and capacitive transfer. (The full 380 kJ was transferred in several milliseconds at lower voltage, hence all required parameters were tested).

A program of industrial development was initiated to produce the low-loss coils. Three suppliers are building 300 kJ coils using 10 kA low loss cables braided from mixed-matrix multifilamentary wire. These will be tested beginning in late 1975.

The circuit to be used in SFTR is shown in Fig. 2, which contains the linked modules and the necessary switches for energizing the full set of coils, and isolating them into the individual circuits of Fig. 1 prior to the transfer of energy to the machine. A prototype engineering section containing 3 linked modules will be constructed in a few years to test the individual components and controls.

The coils are stacked ten to a dewar, with 128 ten-packs around the machine. The coils are electrically in series for charging and separated by cryogenic disconnecting switches submerged in the L He . The functions of each component are described in Table 1, but briefly, the circuit operates essentially like the simplified circuit of Fig. 1. Current is transferred through the vacuum interrupters,

which are closed following charging, by opening the disconnects B_1 . The transfer capacitors are back-biased and discharged through the interrupters after they are opened to give a momentary current zero to extinguish the arc. The counter pulse is applied 5-10 msec after the interrupter contact is broken, which allows sufficient separation of the electrode to withstand the 60 kV voltage. The load current rises like $\sin^2 \frac{\pi t}{\tau}$ and is crowbarred at its peak.

The system described above is at the component development stage, but many of the key features have been tested. Prototype system tests to be made several years from now will determine the viability of this approach in SFTR.

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Fig. 1. A circuit for transferring approximately 100% of the stored energy to a load with a transfer capacitor.

Fig. 2

TABLE I
METS-FTR CIRCUIT COMPONENTS

<u>Main Power Supply</u>	1-2 MW to ramp current to 25 kA in 300 second charging cycle. Energy stored = $800 \times 490 \text{ kJ} = 392 \text{ MJ}$. Current leads from main supply enter circuit at a point which remains at low voltage at all times
<u>Counterpulse Power Supply</u>	50 kW supply. It charges up the transfer capacitors to several kV. 1-2 MJ needed for counterpulse, total.
<u>Inductors</u>	L_1 Storage module, superconducting. $L \approx 1.6 \text{ mH}$ $E = 490 \text{ kJ}$ at 25 kA $V = 60 \text{ kV}$ during 1 ms transfer, peak $B = 2.5 \text{ T}$ L_2 Compression module, multiturn aluminum. $L = 1.6 \text{ mH}$ $\lambda/10$ section, 32 cm of toroidal circumference $B = 6 \text{ T}$ $L/R < 100 \text{ ms}$ $E = 426 \text{ kJ}$ when $B = 6 \text{ T}$ inside bore. L_3 Saturable reactor to allow preferred dI/dt near $I = 0$ during commutation. Parameters to be determined.
<u>Capacitors</u>	C_1 Transfer capacitor $\left\{ \begin{array}{l} C_1 = 127 \text{ } \mu\text{F} \\ V = 60 \text{ kV} \end{array} \right.$ sets transfer time and peak voltage during transfer. It is reverse charged to $< 5 \text{ kV}$ to supply counterpulse current. C_2 Transient capacitor to handle the overcurrent during commutation and limit voltage on HVDC interrupter during deionization period, several 10's usecond. The small series damping resistor eliminates ringing.
<u>Breakers, Contactors, Crowbars</u>	B_1 Cryogenic disconnect within lHe cryostat. It carries the charging cycle current up to 25 kA. It is to be designed for a power loss $< 24 \text{ W}$ at full current. Resistance $\leq 3.8 (10)^{-8} \text{ ohms}$. B_2 HVDC vacuum interrupter, or equivalent. This closes just prior to B_1 disconnecting, current transfers into the pulsed lead ambient temperature loop to B_2. B_3 Isolation contactor. Removes E storage voltage from compression coil module during charging cycle. B_4 Fast crowbar. Crowbars compression coil module at peak current ($I = 20 \text{ Coulombs/ms}$) B_5 Closing contactor. This relieves B_4 after several milliseconds. Voltage drop across each B_5 is insufficient to maintain B_4 conduction, extinguishing all B_4's. B_6 Electrically operated line contactor. The series resistor provides the proper L/R to discharge the storage coil in a short time if the cryogenic disconnect, B_1, fails to open.