ELECTRICAL CONFIGURATION FOR MAGNETIC DRIFT PUMPING ON THE TANDEM MIRROR EXPERIMENT-UPGRADE (TMX-U)

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Abstract

Magnetic drift pumping on TMX-U involves driving four antennae through high Q-resonant circuits. One of the key elements in the resonant circuit is a variable inductor able to carry the 3500 amperes through the circuit and maintain its shape and inductance. The eight resonant circuits can be combined to feed the four antennae with one or two frequencies on each antenna, or frequency shift keying between two frequencies. Each resonant circuit is fed by two 10 to 30 kHz exciters capable of delivering 80 kW each to the circuit. Each exciter receives its power from its own adjustable 0 to 400 volt power supply. The entire system is controlled by a CAMAC control system over a fiber-optic link. The control system checks interlock status, controls "On" and "Off" status, calculates and adjusts phasing of the exciters for addition or deletion of the proper beat frequencies, and monitors operation.

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Introduction

The TMX-Upgrade incorporated several new features into the Lawrence Livermore National Laboratory (LLNL) Tandem Mirror Program not present in the original experiment. One of these changes was the thermal barrier in the end plugs. This barrier, formed by high-power microwaves, helps to separate the end plugs from the central cell. This isolation in turn helps to reduce the end losses out of the vessel.

One of the problems associated with this thermal barrier is the ions trapped in this region begin to deplete the barrier. These ions are presently removed by neutral beam injection to help to charge/exchange many of the ions out of this region. The intent is to soon install a new coil at each end of the machine which will create a six Tesla field pinch at each end of the central cell. This coil interferes with the neutral beam axis and therefore precludes the use of the neutral beam approach to removing the unwanted ions.

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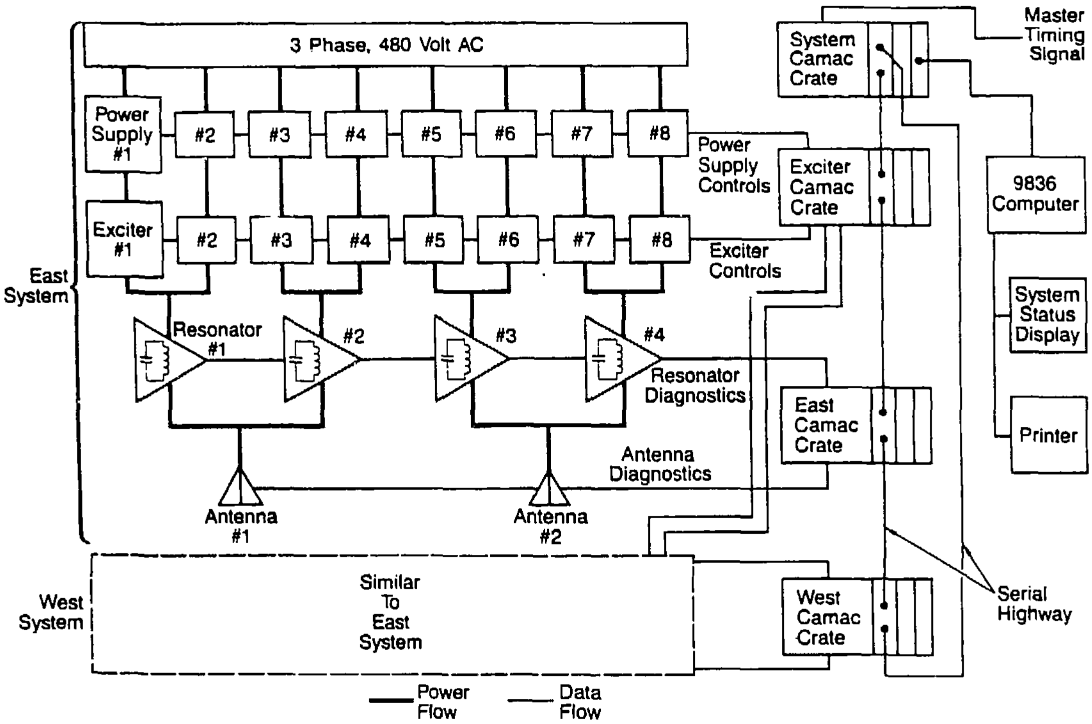

Figure 1. System Schematic

The method, we are presently planning to use to remove these ions, is a concept called magnetic drift pumping. The idea is based on the principle of axially perturbing the magnetic field by introducing a 300 Gauss/meter field variation at frequencies from 10 to 30 kHz. This perturbation increases the stochasticity in ion motion at that region and will cause it to be lost to magnetic field confinement by increasing collisions and radial drift on the ions. The equipment necessary to perform magnetic drift pumping is the subject of this paper.

Overview

The drift pump system consists of two antennae located at each end of the vessel in the thermal barrier region. These four antennae will provide the field perturbation at each end of the machine. These antennae are additionally part of and are driven by a high Q-resonant circuit "ringing" at the desired drift frequency. Each resonant circuit is in turn driven by two exciters. Each of these exciters can cause 3500 Amps to flow in the resonant circuit. Each exciter is in turn fed by a 400 Volt DC supply to supply the necessary power to the system. A schematic of the system can be seen in Fig. 1. (see page 1)

Antenna

The drift pump antennae and magnetic field perturbation information are covered in detail in a separate paper [1]. The antennae are mentioned here for completeness and to help the reader in understanding the basic configuration of the system. The antennae are all alike electrically but come in two different shapes because of their positioning in the vessel. Since each antenna wants to closely follow the plasma shape to maximize coupling and the plasma is fanning out toward each end of the vessel. the antennae as they are positioned farther from the center must also fan out (See Fig. 2).

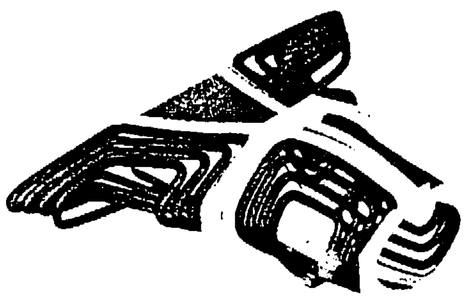

Figure 2. Drift Pump Antenna

Ideally each antenna should have as many turns as possible to get the greatest field perturbation per amp of current. The magnet system for the six Tesla field pinch, however, is already constructed and with the other magnets and supporting structures we were not given the luxury of adding a great number of turns. It was decided that for the voltages present and the current values associated with the various numbers of turns that it was possible to get four turns on each antenna.

Resonant Circuit

In order to supply as much current to the antenna as possible with as little input power as possible, a resonant circuit approach was taken. This allows a 10 to 30 kHz signal of approximately 2000 amps to be amplified to the 3500 amps necessary for the proper field perturbations at the antenna. The circuit is series resonant and is composed of the antenna, capacitors, and variable inductor The capacitors have a Q of 510 at 10 kHz and 260 at 30 kHz which allows the resonant circuit to "ring" longer and minimizes both the input power supplied and the capacitor temperature.

The variable inductor is of a special homemade design to be variable over a small range but yet take the current and forces without a change in inductance and still maintain a very low loss. The losses were kept to a minimum by making the inductor out of Litz wire [2]. This wire consists of approximately 7680 individually insulated wires, wound in a configuration designed to eliminate the skin effect and allow the current to flow evenly throughout the wire with a minimum of loss. The wire was wound around a 12 inch diameter plexiglass cylinder with a 1.5 inch fire hose between each wrap (See Fig. 3).

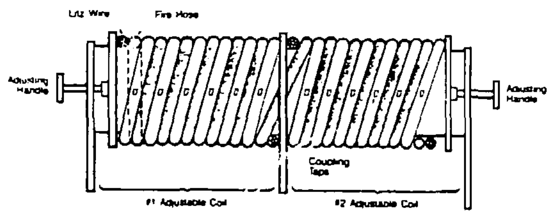

Figure 3. Variable Inductor

The hose can be pressurized with 100 psi once the inductor has been adjusted, via axial compression, to its desired inductance to hold the coils from moving during the tremendous forces from the 3500 amps. In addition, the inductor is also used as a coupling transformer to connect the exciter to the resonant circuit. This is accomplished by removing one of the sub-bundles from the Litz wire and feeding the exciter in at that point. Additionally, on this sub bundle, there are various taps for use in feeding the signal into the tank circuit to aid in optimizing the coupling resistance.

The frequency at which the resonant circuit oscillates is determined by the capacitor and inductor combinations. The capacitors are sized in one microfarad steps and the inductor has two sections which are adjustable from 3.5 to 5 microhenries. The appropriate frequency is, therefore, adjustable by series-parallel combinations of the capacitors and the adjustment of the two sections of the inductor. Since the drift frequencies are a spectrum around a center frequency, we only have to get the resonant frequency adjusted to within plus/minus 100 hertz of the requested frequency to meet the physics requirements. For this reason, this "crude" adjustment method works quite nicely.

Exciters

The resonant circuit is driven through the coupling transformer arrangement of the variable inductor by a device called an exciter. This device like the antenna is described in a separate paper [3] but is described here for completeness. The exciter takes a DC signal and via SCR switching generates a train of alternating polarity, half-sine-wave pulses. Because the exciter uses SCR switching, it can only operate up to 6000 pulses per second and still be able to turn off. The pulses, therefore, only run at the third and fifth harmonic component of the tank circuit. With such a high Q configuration, this harmonic drive is enough energy to sustain the oscillations. In essence, the tuned resonator acts like a filter on the stream of SCR current pulses, extracting only the harmonic nearest the natural frequency of the tank.

The exciter is adjustable to within 10 hertz between the 10 to 30 kHz operational limits. This allows the operator to obtain quite a good match to the natural frequency of the tank circuit.

Power Supplies

The power to each exciter is a 0 to 400 Volt DC power supply. Each power supply is fed with 480 Volt three-phase AC and converted to DC by way of a six-pulse AC/DC convertor. The DC voltage is additionally maintained by a capacitor bank. This bank is sized such that it will hold up the voltage long enough for the voltage regulator to pick up the voltage without allowing the exciter to trip offline from an under-voltage condition. The actual size of the capacitor bank ended up being 1/16th Farad in order to accomplish this feat. Additionally, every effort was made to insure that the AC system feeding the supply was as stiff as possible to eliminate any additional cause of a low-voltage condition.

Control System

The system can be controlled locally but because of the sixteen power supplies, sixteen exciters, and precise timing necessary; this method is only used for tuning purposes and maintenance. The more typical method of control is with a computer controlling the system. The actual control system consists of a HP9836* computer controlling one local CAMAC crate and three remote CAMAC crates. The local crate handles system interlocks and interfaces the computer to the serial highway. One of the remote crates is located in the area with the power supplies and exciters and the other two are at each end of the TMX-U vessel near the resonator enclosure (see Fig. 4).

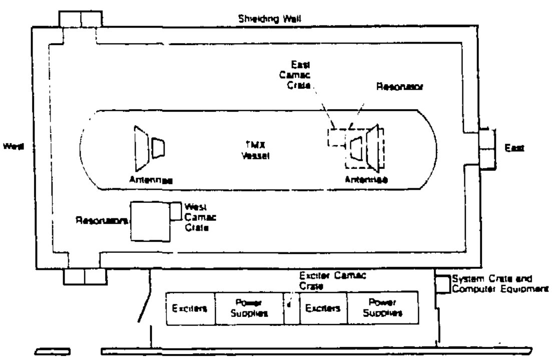

Figure 4. Drift Pump Layout

The crate near the power supplies and exciters monitors the power-supply voltage, local interlocks, exciter status, and sends the run and FSK signals to the exciters. The crates near the vessel monitor local interlocks, resonator current, and system diagnostics.

The computer has various color displays for interfacing with the operator. A typical operational display is shown in Fig. 5.

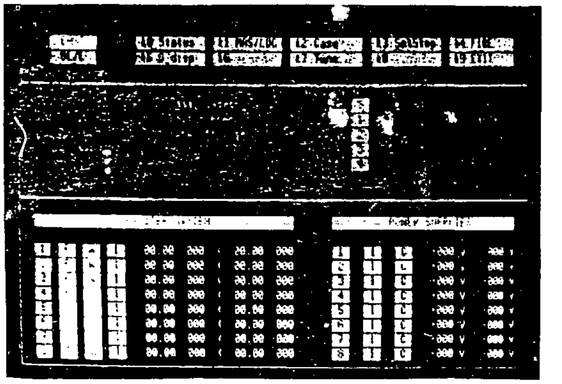

Figure 5 East System Interlock and Operational Display

This display is the system interlock and operational status of the various elements of the system that operate the east end of the TMX-U vessel. With this display, the operator can configure the system as it is to be run including such features as phasing between starting times of successive exciters, power supply voltage (effective power), and the FSK option.

The computer additionally is used as a post-operational tool to analyze the signals concerning the drift pump system. The only one of these diagnostic features presently available is performing a fast Fourier transform on selected signals to analyze the frequency content to assure the appropriate frequency is being coupled into the plasma. In the near future diagnostics to measure field perturbation are also planned.

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[1] R. J. Kane, L. R. Pedrotti, W. F. Cummins, P. Poulsen, P. Ver Planck, C. A. Brooksby, and M. C. Jackson, "Concepts and Development of Drift Pumping for the Tandem Mirror Experiment-Upgrade (TMX-U)," Eleventh Symposium on Fusion Engineering.

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