TFTR NEUTRAL-BEAM TEST FACILITY*

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DISCLAIMER

Summary

TFTR Neutral Beam System will have thirteen discharge ion sources, each with its own power supply. Twelve of these will be utilized for supplemental heating of the TFTR tokamak plasma, while the thirteenth will be dedicated to an off-machine test chamber for source development and/or conditioning. A test installation for one source was set up using prototype equipment to discover and correct possible deficiencies, and to properly coordinate the equipment. This test facility represents the first opportunity for assembling an integrated system of hardware supplied by diverse vendors, each of whom designed and built his equipment to performance specifications. For the installation and coordination of the different portions of the total system, particular attention was given to personnel safety and safe equipment operation.

This paper discusses various system components, their characteristics, interconnection and control. Results of the recently initiated test phase will be reported at a later date.

Physical Layout

The Neutral Beam Test Facility consists of an outdoor substation yard and an indoor installation. An existing building adjacent to the experimental complex at PPPL was modified to serve as the test facility. Figure 1 shows diagrammatically the overall layout of equipment.

FIG. 2 OUTDOOR YARD

The Switchgear, Voltage Controller, Transformer Rectifier, Accel Dummy Load and the auxiliary pulsed load Substation are located in the outdoor yard. Due to the building wall material, it was necessary to erect a firewall adjacent to the transformer-rectifier. Figure 2 shows the outdoor yard.

The remainder of the equipment is housed indoors. The Surge Room, Cooling Water Skid, High Voltage Enclosure, and Target Chamber are located in a pit area. The Modulator-Regulator is on the main floor. The Power Distribution Center, Filament Low Voltage Equipment, Arc Low Voltage Equipment, Local Control Center, and Decel Power Supply were placed on a mezzanine erected for this facility. The Surge Room,

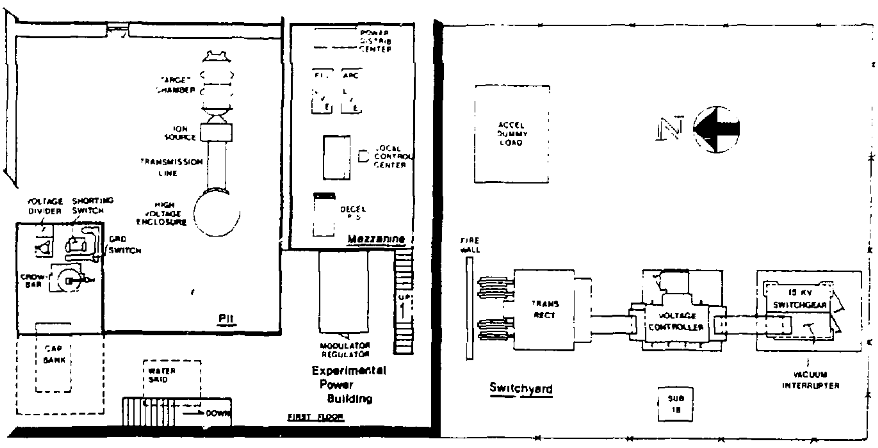

FIG. 1 TFTR NEUTRAL BEAM TEST FACILITY

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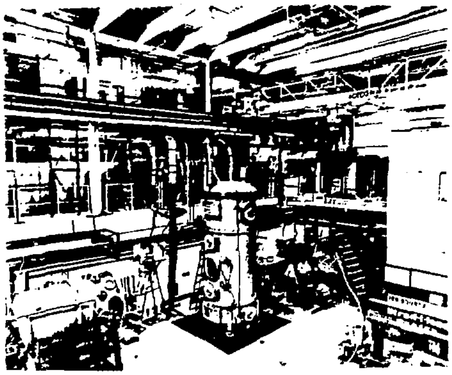

FIG. 3 INDOOR INSTALLATION

where 168kV equipment is housed, is under positive air pressure to minimize dust intrusion. Figure 3 shows the indoor installation. A 2-ton monorail hoist serves the mezzanine area and the Modulator-Regulator; the building 20-ton bridge crane services the pit area.

Equipment Description

The TFTR Neutral Beam Test Facility is a low impedance power system with an output of 65 amps at 120kVDC, with a pulse duration of 5 seconds at a duty factor of 0.033[1]. It is shown schematically in Figure 4. Each subsystem is described below.

1. Disconnecting Switch. This is a manually-operated no-load disconnect switch for primary power isolation, rated 600 amps continuous, with fault current capacity of 57,000 amps peak asymmetrical.

2. Vacuum Interrupter. A fast-acting vacuum interrupter has a continuous duty rating of 1200 amps at 13.8kV, an interrupting capacity for a primary fault of 52,000 amps peak asymmetrical, with an interrupting time of 25 milliseconds.

<u>Voltage Controller</u>. The oil immersed, 3-phase autotransformer is fed from the switchgear unit by bus duct. The output voltage is variable from 2.76kV to 13.8kV, in 17 discrete values. A separate impulse from the control station is required to move from one step to the next one. No tap change can be made during the pulse. The tap changer returns automatically to its lowest position after opening of the vacuum interrupter. Normal pulse load on the autotransformer is a maximum of 530 amperes for 5 seconds. It can withstand a fault current of 57,000 amperes asymetrical. The voltage controller weighs approximately 20,000 pounds.

<u>Transformer-Rectifier</u>. The output of this unit at rated pulse current of 55 amps will range from 30kVDC to 168kVDC as selected by the tap changer.

1. <u>Power Transformer</u>. The oil filled transformer has a step-up line-to-line ratio of 1 to 7.78. The primary winding is wye-connected to the output of the autotransformer by bus duct. The two secondary windings, wye and delta, are connected for 12-pulse operation. The pulse rating of the transformer is 10.5MW; equivalent thermal rating is estimated to be 3MW. The transformer has been designed to witnstand simultaneous faults of the ion source and the modulator-regulator. It weighs approximately 115,000 pounds.

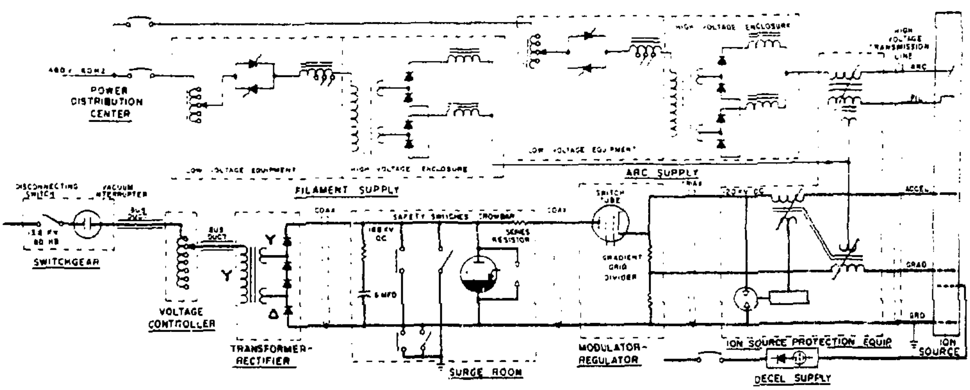

FIG. 4 SCHEMATIC DIAGRAM OF NEUTRAL BEAM POWER SUPPLY

Primary Power Subsystem

Energy for test facility operation is supplied by the local public utility system. An existing 138kV substation transforms it to 13.8kV through a 50 MVA transformer.

<u>Switchgear</u>. This is a self-contained metal-clad unit. It includes:

2. 12-Pulse Rectifier. Two 3-phase full-wave bridge networks are connected in series, resulting in an output ripple frequency of 720 Hz. Each bridge leg is made up of 96 silicon power diodes connected in series, for a total of 1152 diodes. These are grouped into 6 strings and are immersed in transformer oil. Each diode is rated 300 amps RMS, 2500 PIV.

Surge Room. The equipment in this room is fed from the transformer-rectifier by a run of high voltage coaxial cable. This room contains:

1. Transient Suppression Capacitor. This unit increases the rate of rise of the leading edge of the current pulse when the load is switched on. The capacitor bank consists of six parallel strings of four 4 microfarad, 50kV capacitors in series, resulting in a 6 microfarad, 200kV unit which is charged to 168kVDC. Each capacitor has a 300 ohm current limiting resistor and a neon bulb to indicate its charged conditon.

2. Safety switches.. These switches discharge the capacitor bank, with a time constant of 800 μsec. One switch is electrically held open and gravity closed. The second switch is a manual switch operated from the outside of the surge room, and serves as a back-up. This switch is key interlocked with power carrying elements of the system. The surge room door cannot be entered unless all power is removed, the key interlock chain is satisfied, and the switch is locked in its grounded position.

3. Crowbar. This unit consists of six ignitron tubes in series, with corona rings and protective spark gaps. It is fired from a light pipe signal into a trigger generator which utilizes a kryotron tube to develop the firing pulse. The crowbar diverts fault energy away from the modulator-regulator within 2 to 3 microseconds after fault detection. The crowbar handles a charge of approximately 20 coulombs until the vacuum interrupter opens and disconnects the power supply.

4. Series Resistor. This 5 ohm resistor serves as a damping impedance for the high voltage coaxial line between the capacitor bank and the modulator-regulator. It consists of ten power resistors connected in parallel, each rated 50 ohms, 125kV, 50 kilojoules, mounted atop the crowbar stack.

Modulator-Regulator Subsystem

This unit switches and regulates the voltage delivered to the ion source through a high voltage switch tube. Major components are:

High Voltage Switch Tube. This is a high power tetrode, specially designed for this application, rated at 2 megawatt anode dissipation for a 5 sec. pulse and 200 kV holdoff[2]. The anode is cooled by circulating low-conductivity water at about 250 GPM. Electrical insulation of the external portion of the tube is achieved by circulating SF_6 at about 20 CFM at a pressure of 8 PSIG. The voltage drop across the tube will vary linearly to compensate for the voltage droop from the transformer-rectifier during the power pulse; a minimum of 3kV is needed for regulation. Linear operation up to 30kV across the tube with 65 amps is possible without exceeding anode dissipation. The nominal filament current is 4620 amps at 3.85VDC. The tube is connected in a floating deck configuration with its anode at primary power supply potential and the cathode connected to the ion source.

Gradient Grid Divider. A compensated RC voltage divider sets the potential of the ion source gradient grid at values ranging from 75% to 90% of the switch tube cathode potential. Current is in the milliamp range. Heat produced in the resistors is dissipated by boiling freon in a closed-loop system.

Auxiliary Supply Subsystem

Ion Source Filament Supply. The filament supply is split into two portions. The circuitry referenced to ground is in the Filament Low Voltage Equipment cabinet. This consists of a motor-operated variable voltage transformer, a soft-start network and a tapped line inductor. Input is from a 480V, 3-phase 60Hz distribution bus of the Power Distribution Center. Output is 0-400VAC, 3-phase, pulsed on and off from the Local Control Center. The circuitry refe enced to the accel high voltage is contained in a portion of the High Voltage Enclosure. This consists of a step-down transformer and a 12-pulse rectifier rated 6000 amps, 13VDC for 6 seconds every 2.5 minutes.

Arc Supply. The arc supply is nearly identical to the filament supply. Its output is rated at 3000 amps, 60VDC for 5 seconds every 2.5 minutes.

High Voltage Enclosure. This unit houses those portions of the filament and arc power supplies which are referenced to the accel high voltage, and a circuit for passive limiting of energy available to a source fault, until the modulator-regulator can switch off accel and gradient grid voltages. The High Voltage Enclosure is internally cooled and insulated by SF_6 at 30 PSIG. It is connected to the Modulator-Regulator with a triaxial cable.

Auxiliary Services Subsystem

Power Distribution Center. This unit switches and monitors all non-pulsed AC power for the system. It contains protective circuitry and distribution transformers.

Local Control Center. The control center contains equipment for local operation of the Test Facility. Its mimic panel with status lamps, digital meter displays and fault annunciators monitors the system status. A panel containing test points and a multichannel oscilloscope provides additional information. A CAMAC crate is provided for computerization of data and operational parameters, for generating timing signals, and for monitoring events and fault sequences. Other modules are available for buffering and storing data for use by the TFTR real-time system control computer facility (CICADA), and to emulate CICADA for local (stand-along) operation.

Cooling Water System. A low-conductivity closed-loop water system supplies cooling for the Modulator-Regulator, High Voltage Enclosure, and Decel Supply. This unit is rated 350 GPM at 100 PSIG of 5 megohm-centimeter water.

Source Protection Subsystem

Fault Detector. Two basic types of faults are possible, each requiring a different response. One type is due to accel faults, characterized by a sudden collapse of accel voltage, necessitating a turn off of power to the Ion Source for several msec, before restart. Such faults are common, occurring almost every pulse. The second type of faults, due usually to an arc spot, occur less often and require a termination of the pulse.

The fault detector observes Accel, Gradient Grid, and Decel voltages and currents, either by capacitive or inductive sensing. It compares each waveform to a reference. If the current waveform exceeds the reference for some period of time or the voltage waveform goes below it, a block command is transmitted to the Modulator-Regulator to interrupt momentarily the power. If the Modulator-Regulator fails to respond, the Crowbar is commanded and the system is powered down.

The determination of Arc faults is more difficult because arc spotting can occur without any significant change in Arc current. To detect a spot, plasma probe voltages are examined for noise and/or sudden changes in amplitude. A signal is then sent to the local control center to shut the power down[3].

Ion Source Protection Equipment. A Saturated Time Delay Transformer (STDT) is connected between the modulator-regulator and the ion source. A DC bias current saturates the iron core of the STDT in the opposite sense to that produced by fault current. The ion source fault current causes the STDT to come out of saturation; a large impedance appears between the supply and the ion source. This lasts for tens of microseconds before the STDT saturates in the opposite direction. This time is long enough for the switch tube to block the supply to the ion source[4]. If the switch tube fails to block, the crowbar is automatically fired. At the same time a winding on the STDT produces a signal, triggering a spark gap which shunts the energy stored on stray capacitance away from the ion source.

Arc Modulator. An arc modulator circuit located in the high voltage enclosure controls the shape of the arc current pulse and shunts the arc current away from the ion source immediately prior to the application of accel voltage. This minimizes the incidence of faults from ion collisions with the extraction structure.

Decel Power Supply. This water-cooled vacuum-tube regulated supply feeds the ion source grid which suppresses free electrons from backstreaming into the ion extraction chamber. The decel power supply produces a pulse of -[illegible]kV at 15 amps.

Pulsed Loads

Load Banks

Accel. The accel dummy load, enclosed in a metal housing, consists of a number of vertical stacks of carbon resistors which can be connected in series and parallel to yield a range of values from 1800 to 4150 ohms. Forced air keeps the resistors cool during pulsing. Connection to the output of the modulator-regulator is via RG-19/U coaxial cable.

Arc/Filament. These dummy loads are housed together in a high-voltage case located above the target chamber. Nichrome elements used for the load are forced air cooled.

Target Chamber

This vacuum vessel carries the ion source and contains an instrumented, water-cooled calorimeter for particle beam power measurements. Both mechanical and turbomolecular pumps maintain the vacuum. A specially designed high-voltage transmission line connects the ion source to the High Voltage Enclosure, providing filament, arc, accel and gradient grid power, and 19 digital and analog data channels. This transmission line is filled with SF_6 at 3 to 4 PSIG for cooling and insulation[5].

Conclusion

This facility closely duplicates the TFTR power supply system configuration. It was not intended to provide beamline functions such as beam neutralization, bending magnet, drift tube gas dynamics, or cryogenics, these parameters will be investigated in the Neutral Beam Test Cell, presently under construction at PPPL.

The usual stringent PPPL safety requirements were imposed on all phases of this installation. Equipment and personnel interlocks, isolation devices, warning lights, and grounding were carefully engineered. Oxygen concentration in the equipment pit and around the equipment is continuously monitored since SF_6 and freon gasses are used in the high voltage enclosure and the modulator-regulator

Acknowledgements

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