THE ORNL 150 keV NEUTRAL BEAM TEST FACILITY*

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Summary

The 150 keV neutral beam test facility provides for the testing and development of neutral beam injectors and beam systems of the class that will be needed for the Tokamak Fusion Test Reactor (TFTR) and The Next Step (TNS). The test facility can simulate a complete beam line injection system and can provide a wide range of experimental operating conditions. Herein is offered a general description of the facility's capabilities and a discussion of present system performance.

General Facility Description

Flexibility of Design

A total neutral beam system is essentially made up of three major sub-systems; the beam handling system, the vacuum system, and the electrical system. In a fully developed on-line system one would expect these sub-systems to be fully compatible with and matched to the ion injector, since this component is the heart of any neutral beam system. However, for a development facility such as this a foremost requirement must be experimental flexibility. The facility must meet the needs of an ever changing experimental program, whether it be due to successes, failures, new ideas within the neutral beam community, or changing injection requirements within the fusion community as a whole. Hence, an important by-product of such attention to functional flexibility will be the ability to adapt this facility to multiple tasks beyond the near term TFTR goals.

Beam Handling

The purpose of the beam handling system is to accept the ion beam from the injector, neutralize a fraction of this beam, remove the charged fraction from the neutrals, provide a drift space to simulate the connection to a fusion device, and have beam stops so located as to handle and measure the power loading and energy deposition from the charged fraction as well as the neutrals. The geometry of such a system is shown schematically in Fig. 1. In the spirit of maintaining experimental flexibility, the beam line has been modularized as indicated in Fig. 2. Each basic module then is a gas sink adjacent to each gas source, which includes the injector, the neutralizing gas cell, and the deposited ion and neutral beams at the beam stops. As located in Fig. 2 from right to left, we have the injector, gas sink, neutralizing gas cell, gas sink with charged fraction bending magnet and dump, drift tube, and gas sink with neutral beam target.

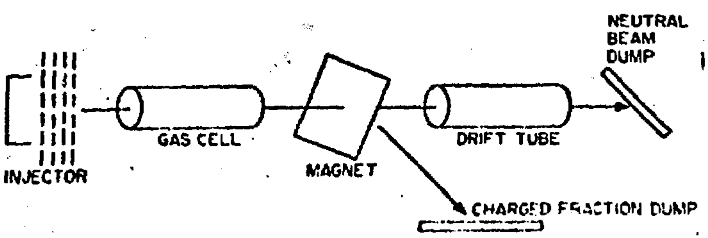

Fig. 1. Beam Line Schematic

Because the proposed injectors for this facility will be capable of converting 7.5 MW of electrical power to a partially neutralized energetic ion beam for times up to 0.5 sec., both the charged particle dumps and the neutral beam target must be able to transfer full power safely to cooling water. This is accomplished by using arrays of twisted tape vortex or swirl tubes for heat transfer, tilted with respect to the incident beam to reduce the power flux below a safe limit of 5 kW/cm^2. Because there is always a possibility for the occurrence of conditions such that the beam will become defocused or mis-steered, substantial beam power may be deposited on the internal structures of the beam line. The gas cell and drift tube, being most sensitive to these abnormalities, were designed as inertial targets able to survive full beam power for several milliseconds. Power loading and energy deposition on various sources and beam line components, as well as total power accountability, are determined calorimetrically.

Vacuum System

The basic requirement for the vacuum system is to remove the excess gas produced by the various gas sources as mentioned above. Hydrogen gas is injected into both the source and the neutralizing cell at varying rates, so there must be sufficient pumping speed to handle a wide range of local gas loads and maintain the desired local pressure. Furthermore, the pumping system must be clean and compatible with the high power beam environment.

Because the risk and expense of a system built around a cryopumping scheme was prohibitive at the time, the basic pump chosen for this facility was a 35 inch oil diffusion pump. The hydrogen pumping speed of this pump at the vacuum chamber is ∿ 40,000 ℓ/sec. The use of a polyphenyl ether pump fluid (Santovac 5) with its low vapor pressure of $< 10^{-9}$ torr at 25°C allows the use of only a high conductance "halo" baffle and water cooling, and still achieve an oil backstreaming rate given by the 25°C oil evaporation rate. The resulting equilibrium oil vapor pressure in the vacuum chamber of $< 10^{-9}$ torr is of no concern, since the chamber operating pressure is $>10^{-5}$ torr and the high voltage electrodes of the injector are quickly discharge cleaned by beam operation.

A complete pumping package consists of a 61 ℓ/sec (air), two-stage rotary piston pump exhausting into a hydrogen vent line, a 34 ℓ/sec (air) Roots blower having an ∿ 10^{-5} torr ultimate pressure, and two of the 35 inch diffusion pumps. Vacuum diagnostics and controls are based on standard ion and thermocouple gauges, with logic interlocks controlling electropneumatic valves for system protection.

Electrical System

The electrical system as depicted in Fig. 3 was designed to provide a wide range of voltages, currents, and pulse widths, such that it could be matched to the ever evolving requirements of our plasma sources and ion beam accelerators.[1] These sources are and will be of the modified duoPIGatron type developed at ORNL[2] and will incorporate a four grid (two-stage) ion accelerating structure for good beam optics.

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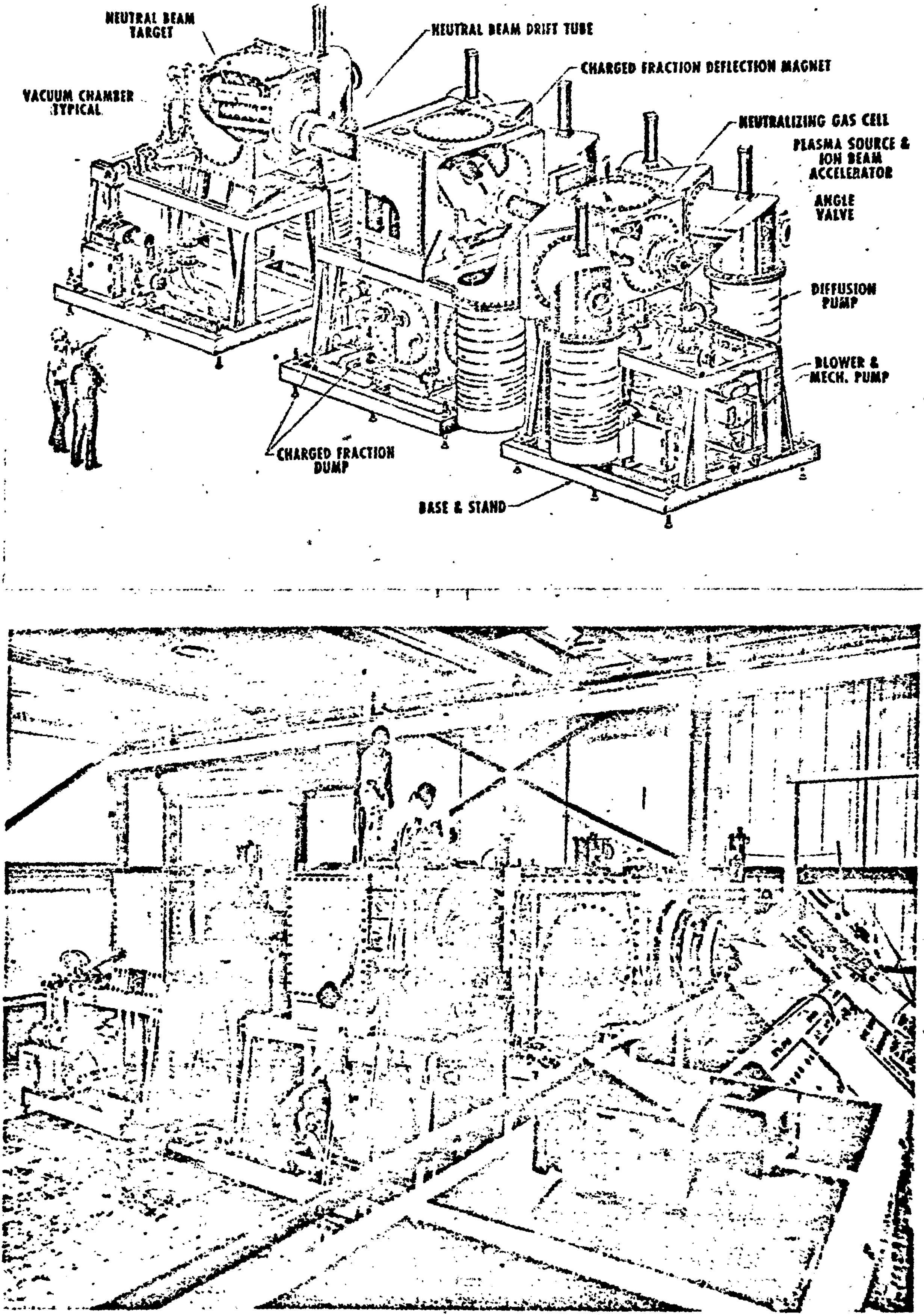

Fig. 2. Artist's Cutaway and Photograph of the ORNL 150 keV Neutral Beam Test Facility

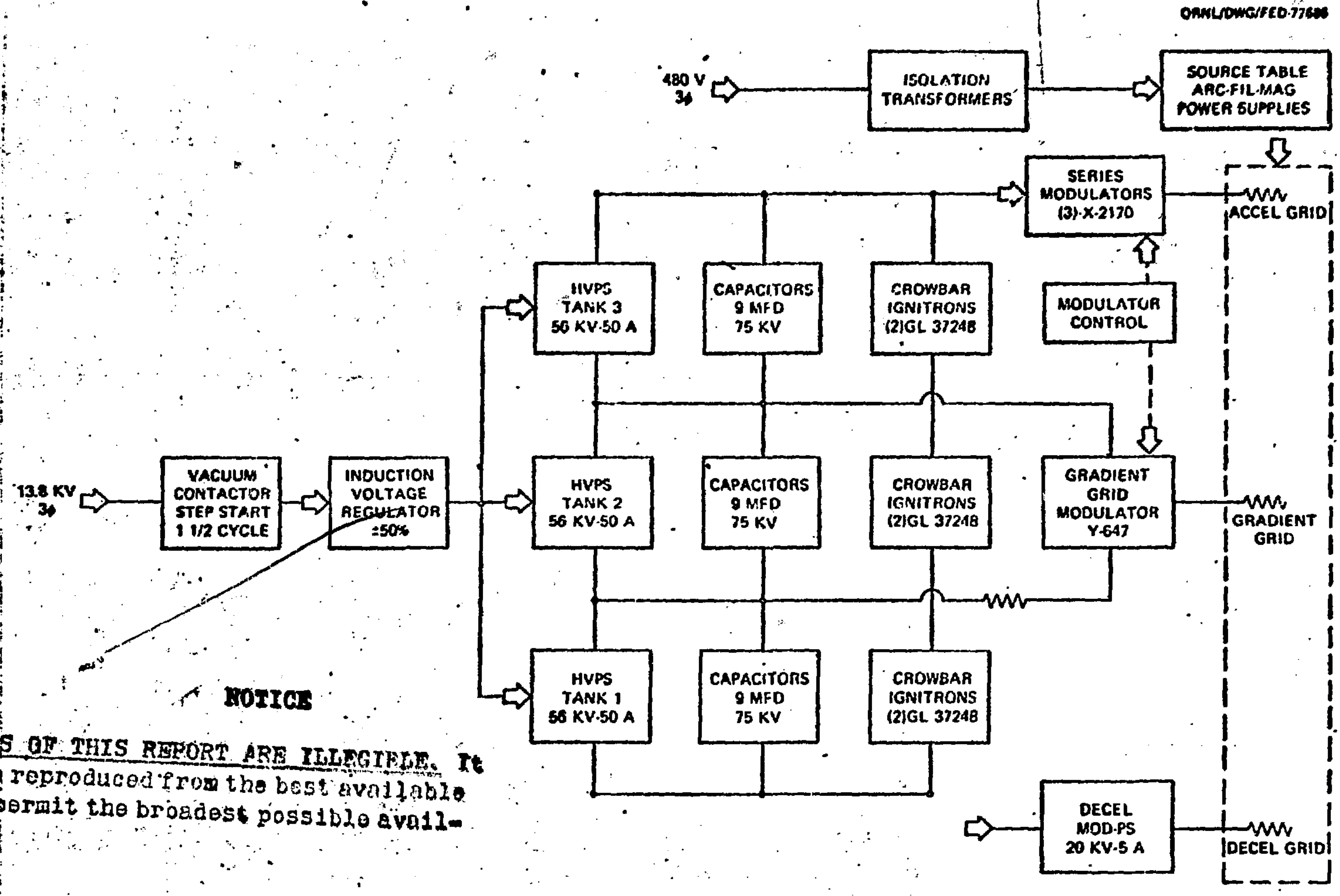

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Fig. 3. Block Diagram of the 150 keV Neutral Beam Electrical System

Typically, the plasma generator with its associated low voltage power supplies located on an isolated deck floats at the accelerator potential with power brought across this potential via isolation transformers.[3] The low voltage power supplies provide a wide range of arc parameters with up to 150 Vdc/800 A in the arc supply, 6 Vdc/225 A in the filament supply, and 6 Vdc/100 A in the magnet supply. Signals for monitoring and control of these supplies and for diagnostic monitoring of the plasma generator are transmitted across the accelerator potential through light pipes.[4] At one end a voltage-to-frequency converter and LED convert the desired signal to a frequency modulated light signal, while at the other end of the light pipe a photo-transistor and a frequency-to-voltage converter reconstruct the original signal.

Ion accelerating voltage and current are provided by a 168 kV/50 A/20 s transformer-rectifier supply with sufficient flexibility to enable testing of single- and two-stage accelerator designs from 78 kV/100 A to 150 kV/50 A. This supply consists of three 56 kV units in series with internal connections that can be easily changed to allow either 50 A or 100 A operation. An external capacitor bank shunts switching transients at the output, and output voltage control is achieved by an induction voltage regulator on the supply input.

For pulse formation and protection of the vulnerable source grids under high voltage breakdown, a modulator has been installed between the accel power supply and grids.[5] The circuit, consisting of three X2170 power tetrodes in series, is designed such that the high voltage will be interrupted for a brief interval (typically < 10 msec) until the fault clears. Voltage is then reapplied for the remainder of the beam pulse. This present modulator configuration will meet the design goal of the system, namely 150 kV/50 A/0.5 sec, but would require substantial modification to utilize the full capability of the power supply, i.e., 78 kV/100 A operation.

To supply voltage regulation for the gradient grid of two-stage sources a series resistor and 40 kV modulator combination have been placed across the middle power supply module. This combination acts as a voltage divider with the gradient grid voltage taken from the point between the resistor and modulator as shown in Fig. 3. Voltage control is obtained by varying the drop across the modulator tube.

In addition to the accel supply and modulator there is a 20 kVdc/5 A/20 sec transformer-rectifier supply and modulator to provide power, pulsing, and protection to the decel grid. Furthermore, the decel modulator is interlocked with the accel modulator to prevent improper operation.

Should the accel modulator fail in its protective function, a trigger signal fires a separate crowbar string short-circuiting the output and at the same time initiating the opening of the input vacuum breakers of the power supply.

Facility Operation

The first attempt at experimental work on this facility was to study the beam optics of a single aperture, two-stage ion source up to 120 kV ion energies. Since this experiment was done before the accel power supply had been installed and tested, a portable high voltage, low current power supply charging a capacitor bank was used for ion extraction and acceleration. A second small supply was used to provide decel voltage. This study allowed us the opportunity to do initial testing and debugging of the low voltage supplies and to scope potential high voltage problems before connecting a source to the main high voltage supplies. Though 120 kV operation was achieved, reliable operation actually occurred around 100 to 110 kV. Beam optics proved to be very good at these energies yielding a beam divergence as low as 0.3° HWHM under optimized conditions.

Recently, a source with a 20 cm extraction area of the type used on PLT was attached to the beam line. The plasma generator was run up to the full 800 A capability of the arc power supply and operated stably at this level. For the first time the main high voltage supplies and modulator have been connected to a source and a 30 kV/20 A/0.1 sec ion beam has been successfully extracted. Our next efforts will be centered around testing and calibrating diagnostics,and optimizing electrical and beam line parameters. The present source testing to an operating level of 50 kV/40 A/0.1 sec will be followed by the testing of a nominal 80 kV/60 A/0.5 s two-stage source and accompanied by testing of the 40 kV gradient grid modulator. The knowledge obtained from these source tests and the previous two-stage optics study will then be incorporated into the design and fabrication of a 150 kV/50 A/0.5 sec source of the type required for TFTR neutral beam injection.

In summary, we have a very flexible, operating, high energy neutral beam test facility, which will allow us to develop the high energy neutral particle injectors and beam line components for the next generation of fusion experiments.

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