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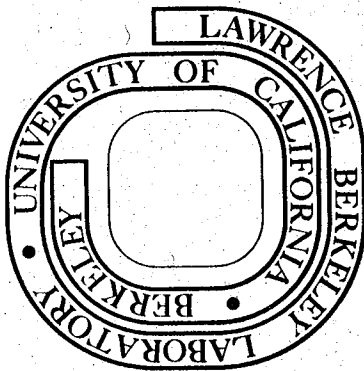
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UPDATE ON THE DEVELOPMENT OF 120-keV MULTI-MEGAWATT NEUTRAL BEAM SOURCE*

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Introduction

The next generation of U.S. fusion experiments, which includes TFTR, MFTF, and Doublet III, will utilize neutral-beam injection for plasma heating. TFTR, for example, desires 20 MW of 120-keV deuterium atoms in pulses of 0.5-sec duration at 5-minute intervals from a total of 12 individual neutral-beam modules.

This paper discusses some of the design details of a 15-A, 120-keV, 0.5-sec ion-source module that has recently been built to test design concepts for TFTR sources, and some of the features of the facility where it is presently under test at the Lawrence Berkeley Laboratory.

The 15-A, 120-kV, 0.5-sec Module

The 15-A, 120-kV module designed for 0.5-sec pulses at one-minute intervals is shown schematically in Fig. 1. It is comprised of a plasma generator, accelerating electrodes, and an outer insulating support structure. The 40-cm o.d. outer vacuum wall of the accelerator section consists of a cylindrical ceramic insulator sectioned to distribute the potential. To keep these sections reasonably short, the space outside of them is pressurized with two atmospheres (absolute) of SF₆. The cylindrical jacket that forms the pressure vessel (not shown) is made of filament-wound fiberglass. It is held in place between end-flanges with Nylon tie-rods. Pressure sensors insure the presence of the insulating gas during operation, and standard safety features prevent over-pressurization of the vessel. The neutralizer to which the source is attached is constructed of mild steel to shield the beam from stray magnetic fields. A bellows section between the source-accelerator module and the neutralizer allows the emerging beam to be steered to the calorimeter¹ at the far end of the test facility's beam line.

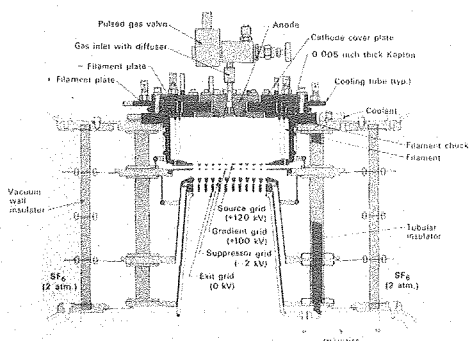


Figure 1. 15-A, 120-kV, 0.5-sec Source Module Assembly.

The plasma generator and the accelerator-grid assembly are mounted on an inner plug-in structure, shown in Fig. 2. The design features of the plasma

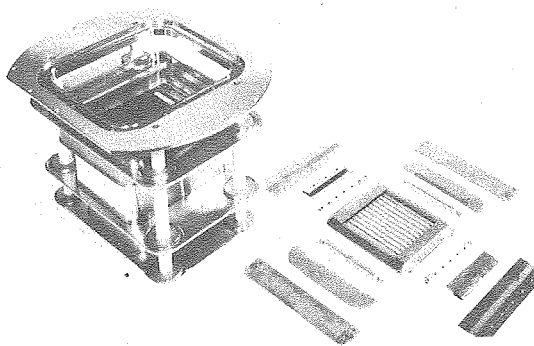


Figure 2. Accelerator Plug-in Structure.

generator, or ion source, have been described in earlier papers.^{2,3} In brief, the source is a high-current low-voltage discharge with no external magnetic fields. In this version the cathode consists of an array of 84 0.05 cm-diam tungsten filaments around the periphery of the chamber. The isolated back plate of the source, through which the gas is introduced, forms the anode. This source, shown in Fig. 3, provides a hydrogen or deuterium ion-current density of 0.25 A/cm² for 0.5 sec.

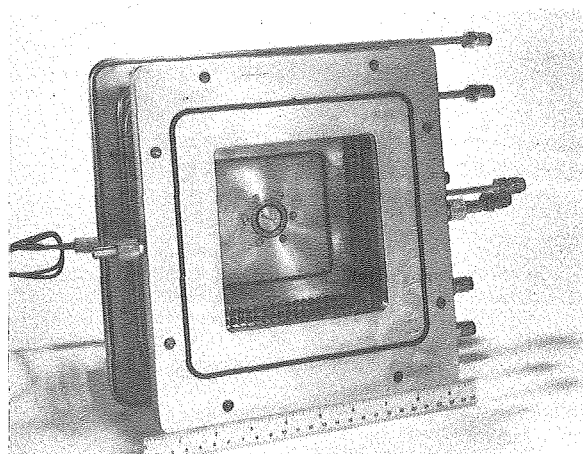


Figure 3. 10-cm x 10-cm Source Chamber.

*Work done under the auspices of the U.S. ERDA.

Ions from the plasma generator are accelerated in a multiple-slot grid array; the molybdenum rails that form the slots were designed for minimum beam divergence with the aid of the WOLF code.⁴ A cross section of a single slot of the ion accelerator is shown in Fig. 4. The shapes of the second (gradient) grid and of the third (suppressor) grid were chosen to minimize energy deposition in the structure by secondary particles created in the beam or from surfaces. We anticipate a maximum temperature rise of 500°C in any electrode during the 0.5-sec pulse.

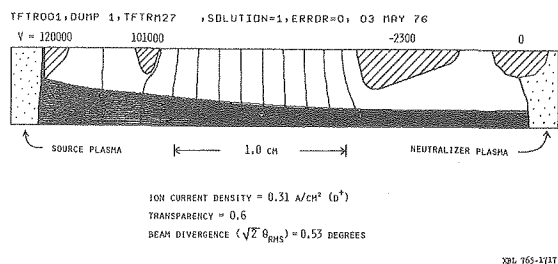


Figure 4. 120-kV Accelerator Cross Section.

The source and gradient grid rails are rolled to shape from solid round stock. After rolling, they are heated in vacuo and straightened, then cut to proper length. The suppressor and exit grid rails are machined from solid plate by conventional methods. Care was taken in the choice of machining coolants to avoid the use of chlorinated hydrocarbons that would leave residual chlorine ions after the brazing operation. It was found that water-soluble coolants or non-sulfur bearing cooling oils provided adequate cooling during machining and reduced tool wear to an acceptable level.

The grid rails are arranged in a 10-cm wide, 60% transparent array, to form 10-cm long slots. They are brazed into water-cooled comb-like assemblies. These rails are allowed to expand in the long direction, thus preventing buckling when heated. The heat is conducted and radiated away in the one-minute interval between pulses.

After inspection, the parts were chemically cleaned by standard techniques,⁵ and dry-hydrogen fired at 1000°C for ten minutes. After firing, the parts for a grid assembly were located on a molybdenum aligning fixture prior to the brazing operation. The assembly was then brazed in a dry-hydrogen atmosphere using a broad melting range (950°C liquidus - 900°C solidus) filler composed of 25% palladium, 21% copper, and 54% silver. At every stage of the operation, from cleaning through to final assembly, all parts were handled using disposable surgical-type plastic gloves to minimize surface contamination.

The grid-rail assemblies are mounted on stainless steel sheet-metal "hat" structures. Gaps between adjacent grid assemblies are controlled with adjusting screws. In addition to providing for adjustment of the gap, the adjusting screws of the first two grid assemblies are used to bend the grid rails in their long dimension to provide for beam focusing at the calorimeter, 8 meters downstream. Molybdenum sheet-metal shields cover sharp corners in the high voltage regions, trim the beam to desired size and shield portions of the ceramic insulators.

The "hat" structures are mounted to flanges separated by 1.3-cm i.d. tubular insulators through

which cooling water is supplied (Figs. 1 and 2). The tubular ceramic insulators of the plug-in assembly are vacuum brazed to metallic cups, which in turn are heliarc welded to the stainless steel flanges of the structure. The flanges of the structure are connected electrically to the gradient rings of the outer vacuum-wall insulator by stainless-steel fingerstock.

Power Supplies

The LBL 150-kV, 20-A, 0.5-sec neutral-beam-source power-supply system has been discussed in two previous papers.^{6,7} Originally, the system was to have a saturable-reactor-controlled constant-current power supply with series-vacuum-tube shunt regulation of the HV dc output. Reference 7, cited above, described a much simpler version where the saturable reactor system was replaced with line reactors in the ac primary feed lines that provide about 40% impedance at the nominal operating level. This limits the short-circuit current to ~ 2.5 times the operating current and provides enough inductance so that, with a fast SCR-type switch in the HV dc, the current does not change significantly during source sparkdown and the subsequent commutation of the switch and transfer of the current to the shunt regulator. In effect, it is not necessary to have a constant-current system for a longer time than the switching time which is only ~ 100 μ sec in our present operation system.

Basically, the system is still the same as that described in Ref. 7 and a block diagram of the overall neutral-beam power-supply system and the simplified schematic diagram of the accel supply is given there.

Some simple but rather important differences, however, have evolved with the considerable operating experience collected over the past few months. The changes that we have had to make in the power supply system can be summed up in a few words. It has been necessary to introduce modulation of the gradient grid potential and ion density during the accel voltage rise at the start of the pulse. This modulation is aimed at maintaining the beam optics at near optimum during the rise, particularly above ~ 20 -30 kV. The philosophy is very different from the earlier work at lower voltages where adjustable, fixed level power supplies were used for the source arc and gradient grid and emphasis was put on a fast rising accel voltage (< 10 μ sec) to bring the system on.

The gradient grid is presently being supplied with a simple 60 k Ω resistive divider across the accel voltage with a tap at the 10 k Ω point to feed it $\sim 1/6$ of the accel potential. Extra current required by this grid during the pulse voltage rise is supplied with a small capacitor and series diode between it and ground.

The arc modulation is done by a shunting capacitor-series SCR switch and resistor network that momentarily diverts some of the arc current from the constant current arc supply when the SCR is triggered on at the beginning of the accel pulse voltage rise. The resistor sets the lower limit of the arc current and the capacitor determines the time for the arc current to rise to the normal full level value.

The accel pulse rise is currently < 10 μ sec but the hope is that a fast rise is no longer required with this new gradient grid and arc supply modulation and that it may be relaxed considerably. Since with a suitable arc-current modulator the neutral-beam divergence should not be appreciably affected by var-

iations of the order of 5% in the accel voltage, even the need for a regulator, either shunt or series type, is no longer clear. Most of the other source-power-supply requirements such as switching, current limiting and fault protection can probably be met without a regulator. If successful, this approach could lead to a much simpler and less expensive neutral-beam power-supply system.

Status

Testing began on the first of two 10-cm x 10-cm, 15-A, 120-keV, 0.5-sec modules in August of 1976, on one beam line of the LBL test facility.⁸ The version of the source-module used in this test, with water cooling on the ends of the last, grounded, grid-rails of the accelerator, has been operated at 100 kilovolts with 10 amperes accel current. This operating level is set because this is the top of the range of our present transformer-rectifier arrangement. The reconnections are being made at this time that will raise this to allow the 120 kV required for the neutral-beam injector model work for the Princeton TFTR.

A second version of the structure shown in Fig. 1 with water cooling on the ends of all four grid structures has been fabricated and is presently being assembled. A 65-A, 120-keV, 0.5-sec ion source module, suitable for use on TFTR, is under construction, and will be in final assembly by late April.

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