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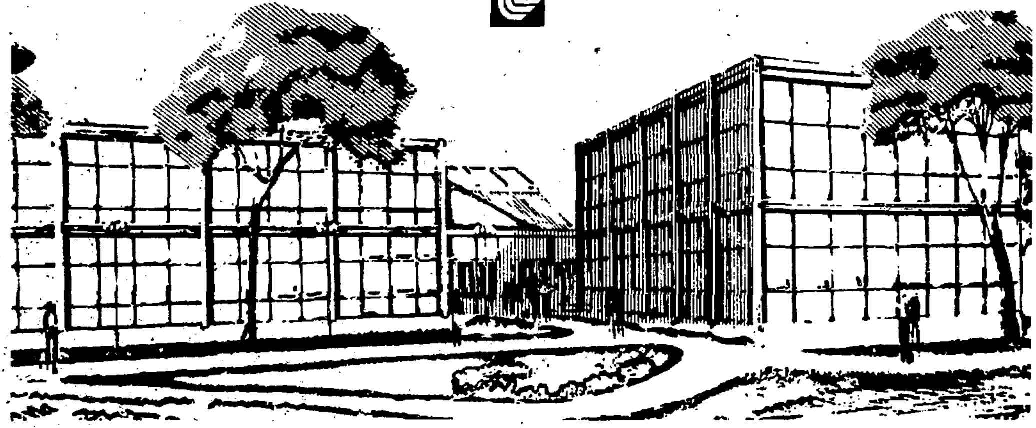

THERMAL-MECHANICAL DESIGN OF A 150-mA, DIRECT-CURRENT, 400-keV ACCELERATOR FOR PRODUCTION OF 14-MeV NEUTRONS*

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Summary

Several unique accelerator components have been designed and built for the Rotating Target Neutron Source Facility at the Lawrence Livermore Laboratory. Particular consideration was given to material selection and cooling design of components because the facility will have a large steady-state beam energy. Components discussed in this paper include the system composed of the ion source and 90-deg double-focusing magnet in the high-voltage terminal, a water-cooled 400-keV acceleration column, a pyrolytic-graphite beam collimator, and quick-disconnect beam-tube couplings.

Introduction

Two 400-keV air-insulated accelerators that bombard rotating titanium tritide targets[1] with deuterium ions (D^+) are being built at the Lawrence Livermore Laboratory.[2] The 14-MeV neutrons produced by the resulting reaction will be used for studying material damage that would occur in fusion reactors.

The accelerator design (Fig. 1) includes several unique features to overcome thermal-mechanical problems produced by a continuous 60-kW ion beam. Unproductive sources of heat, such as the accelerated molecular components of the beam, are eliminated in the high-voltage terminal by a 90-deg double-focusing magnet. A trap in the accelerator column (not visible in Fig. 1) diverts backstreaming electrons, which would not only heat the electrodes but also produce x rays. Critical components such as electrodes, beam-stops, and collimator liners are made of refractory metals such as molybdenum or pyrolytic graphite. Cooling has been applied to all hot spots that would occur in steady-state operation of the accelerator. Special pyrolytic-graphite lined collimators, designed to withstand the heat from a stray beam, prevent the beam from melting a hole in the beam tube. Quick-disconnect vacuum couplers have been designed to provide reliable beam-tube connections in a high-level radiation area.

Bend-Chamber Cooling

The ion source produces a 300-mA beam of 20-keV D_1^+, D_2^+, D_3^+, and neutrals in the high-voltage terminal. It is desirable to remove the molecular component of the beam (50%) to eliminate its heating effect on downstream accelerator components and increase the lifetime of the rotating target. A 90-deg double-focusing magnet in the

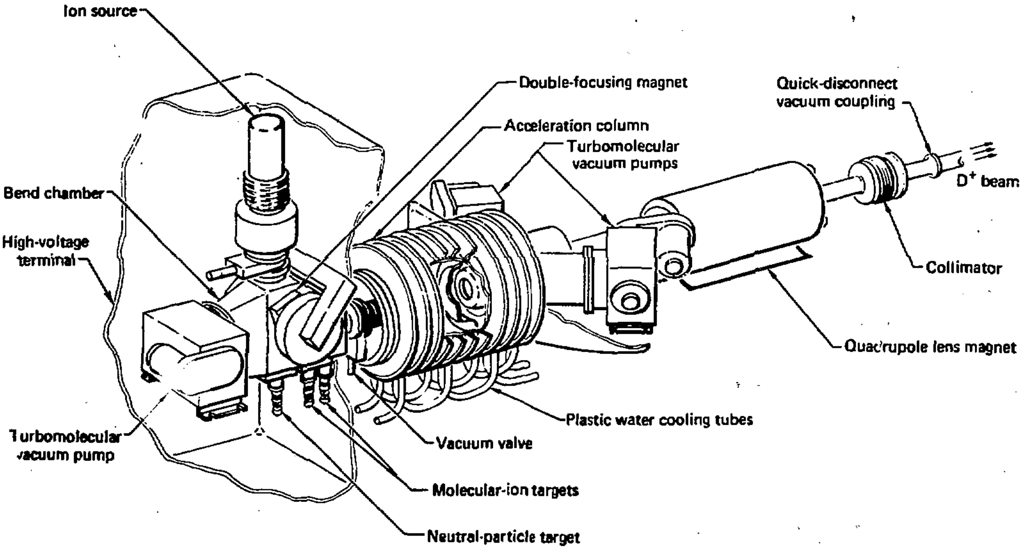

Fig. 1. Design of 400-keV accelerator for Rotating Target Neutron Source Facility.

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high-voltage terminal separates the D^+ from the molecular components and neutrals, which are stopped in the bend chamber (see Fig. 2). The heat produced from these collisions is removed by water-cooled, molybdenum-covered targets. These targets are also electrically insulated so that the current caused by ions colliding with them can be measured. During startup of the ion source, the neutral-beam target will be exposed to a heat flux of 500 W/cm^2.

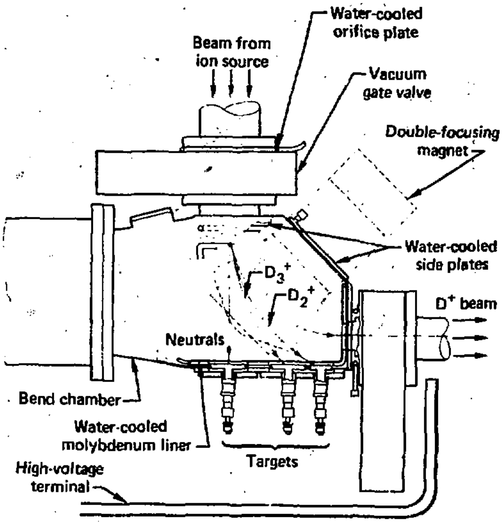

Fig. 2. Bend chamber of accelerator.

The lower portion of the bend chamber is shielded by a water-cooled copper-brazed molybdenum liner with cutouts for the targets and the D^+-beam exit orifice. The stainless-steel side plates and top entry port of the bend chamber are provided with internal water-cooling channels to remove heat caused by the divergent portion of the beam.

Accelerator Column Cooling

The function of the accelerator column (Fig. 3) is to focus the D^+ beam and increase its energy to 400 keV. The steady-state temperature of the electrodes will probably be high because the 150-mA beam is continuous and the electrodes will be bombarded by stray ions and backstreaming electrons.

A water-cooling system that is an integral part of the ceramic-and-copper column assembly cools the molybdenum electrodes continuously by conductive heat transfer. Copper tubing, 1-mm (3/8-in.) o.d., on the outside of the column is brazed to a pair of 0.08-mm (1/32-in.) hydroformed copper sheets to provide a heat-transfer path to the inside of the 40.6-mm- (16-in.-) i.d. ceramic assembly. The electrode holders are fabricated from 0.6-mm- (1/4-in.-) thick copper and are chrome-plated to reduce surface damage from high-voltage breakdown. The thermal load on each of the electrodes in the center area might reach 2.5 kW, while that on the entry and exit electrodes may reach 5 kW. The stainless-steel entry electrode and the molybdenum exit electrode are directly water cooled. An electron trap is mounted directly downstream from the exit electrode to reduce electrode heating and x-ray production caused by backstreaming electrons.

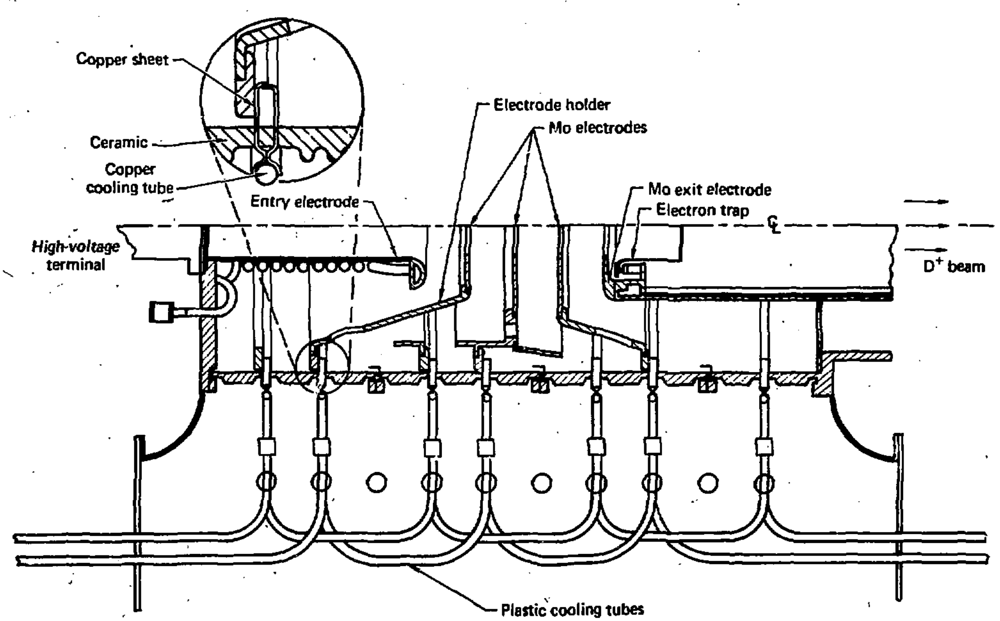

Fig. 3. Accelerator column assembly.

Special Beam Collimators

The D$^+$ beam has considerable energy (60 kW) after leaving the accelerator column and must be collimated to limit damage to accelerator components. The collimators will probably be exposed to full-beam power only momentarily. In steady-state operation, probably 10% of the beam energy, or 6 kW, will be absorbed by the collimators.

A collimator lined with pyrolytic graphite (Fig. 4) has been designed for this purpose and to serve as a flexible coupling in the beam line. The collimator is electrically insulated from the beam tube so that current caused by the interrupted portion of the beam can be measured. The inner surface of the graphite is tapered to lower the incoming heat flux. The outer surface is also tapered to improve heat transfer by increasing the surface pressure between the water-cooled copper support ring and the graphite. Eight 0.6-mm- (1/4-in.-) diameter bolts with conical spring washers apply 8889 N (2000 lbs) lineal force to the assembly. During thermal cycling, the assembly is free to expand and contract under pressure. Each 1.3-mm- (1/2-in.-) thick pyrolytic-graphite liner is precisely machined to match the taper in its copper support ring. Gaps between liners and between holders assure that the compressive force of the eight bolts will be uniformly distributed to all heat-transfer joints.

Pyrolytic graphite was selected as the liner material because in vacuum it has a low sublimation rate at relatively high temperatures and does not melt. The methane and other hydrocarbons produced from the graphite will be removed by the accelerator's vacuum-pumping system.[3] Clarke and Fox[4] have found that below 3000 K and at about 1 kPa (~0.01 atm), the production of methane decreases proportionately to the hydrogen pressure. They also found that at this temperature the sublimation of graphite did not affect the quantity of methane produced.

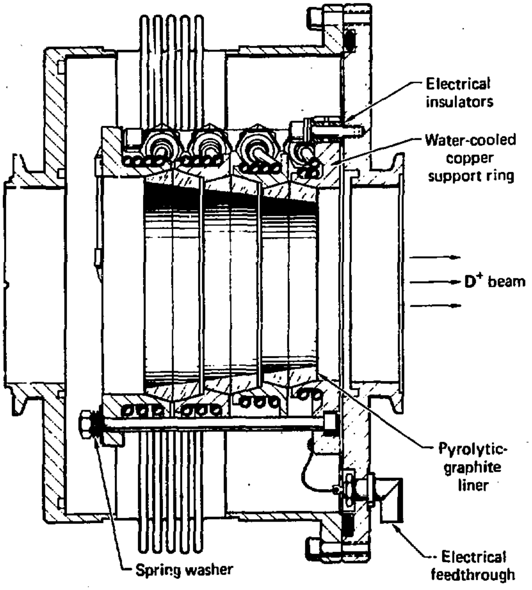

Fig. 4. Collimator lined with pyrolytic graphite. The 60-kW D$^+$ beam passes through this collimator after leaving the accelerator column.

Pyrolytic graphite has a unique physical property in that its thermal conductivity in the radial direction is as high as copper's at low temperatures and as high as tungsten's at 1850 K. Perpendicular to the radial direction, it performs the function of a thermal insulator. The combination of high heat conductivity in the radial direction and the ability to withstand high temperatures without melting makes pyrolytic graphite an excellent liner material.

Special Vacuum Couplings

A special quick-disconnect vacuum coupling (Fig. 5) was designed and built, with water cooling to protect the seal from heat damage. The quick-disconnect reduces the assembly and disassembly time of beam-line components in high-level radiation areas. The seal can be a plastic O-ring or an indium-coated metallic C-ring. The inner diameter of the ring groove was made smaller than recommended by the manufacturer so that the C-ring would not seize to the vacuum flange after compression. Use of the metallic C-ring provides a quick-disconnect vacuum coupling that resists damage from neutron and gamma radiation.

A special version of this joint (Fig. 5b) permits the assembly of the vacuum seal after the 10-mm- (4-in.-) o.d. beam tube has been inserted through a quadrupole triplet lens magnet. This joint permits a sliding fit between the beam tube and the magnet-pole tip and retains the quick-coupling feature.

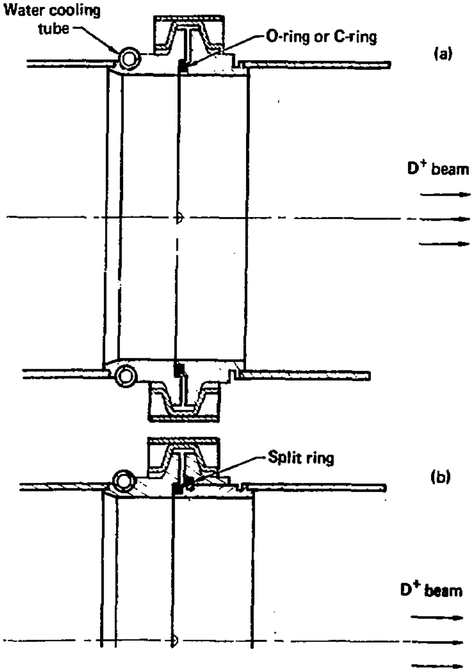

Fig. 5. Water-cooled quick-disconnect vacuum couplings: (a) type usually used, (b) special type that permits a sliding fit.

Conclusion

The system composed of the ion source and the 90-deg double-focusing magnet has been used extensively in the Ion-Source Test Facility at LLL since January 1977. Except for additional cooling in an orifice plate near the ion source, no changes appear necessary. Sputtered molybdenum deposits appear on viewing windows and inner bend-chamber parts but no damage is apparent.

The accelerator column and pyrolytic-graphite collimator are complete and will be tested in a prototype accelerator at LLL in the Fall of 1977. Though cooling has been provided to all critical components, other thermal and high-voltage breakdown problems may appear in tests at full beam current and energy.

After the performances of the prototype accelerators are evaluated, two accelerators with rotating targets will be installed in a new shielded facility at LLL. Final installation of these machines should be complete by mid-1978.

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