CW PROTON LINAC FOR THE BNCT APPLICATION

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Abstract

A 2.5-MeV, 20-mA, cw, proton linac for the Boron Neutron Capture Therapy medical application is under construction at Linac Systems. The system consists of a 25-keV microwave ion source, a solenoid lens based low energy beam transport system, a 0.75-MeV RFQ linac, a 2.5-MeV RFI linac, and the necessary service systems. Because of the superb low energy capabilities of the RFI structure, the RFQ linac need only go to 0.75 MeV, resulting in a cavity dissipation of 74 kW for the RFQ section. Because of the high rf efficiency of the RFI structure, the cavity dissipation is only 35 kW for the RFI section. Extensive thermal studies have been made to accommodate these cw heat load. The beam power is 50 kW. The rf power system is designed for an average power output of 200 kW. The RFQ and RFI sections are coupled into a single resonant unit by a quarter-wave-stub resonant coupler. The combination is driven at a single point in the RFQ structure. The total length of the linac is 2.84 meters.

INTRODUCTION

There are very few cw linacs in the world. Our proprietary linac structures offer the best chance to realize a commercially viable cw linac product. Features of our patented Rf Focused Interdigital (RFI) linac structure make it practical to consider cw linac systems for applications requiring very high average beam intensities. BNCT and Isotope Production are two such medical application. Solid state materials modification is another such application.

A 2.5-MeV, 20-mA, cw, proton linac for the Boron Neutron Capture Therapy (BNCT) medical application is under construction at Linac Systems. The system consists of a 25-keV microwave ion source, a solenoid lens based low energy beam transport (LEBT) system, a 0.75-MeV RFQ linac, a 2.5-MeV RFI linac, and the necessary service systems. This 2.84-m linac system is shown in Fig. 1.

The largest engineering challenge for cw operation is the removal of the heat generated by the cw operation. To mitigate this problem, we have performed extensive thermal management studies on the critical parts of the system. The highest power density in the RFQ linac structure is the RFQ bar supporting strut. The highest power density in the RFI structure is the main drift tube support stem.

Because of the superb low energy capabilities of the RFI structure, the RFQ linac need only go to 0.75 MeV, resulting in a cavity dissipation of only 65 kW (30% beyond theoretical) for the RFQ section. Because of the high rf efficiency of the RFI structure, the cavity dissipation for the RFI section is only 35 kW (30% beyond theoretical). The beam power is 50 kW. The total rf power required is 150 kW. The two linac structures are resonantly coupled, providing a single drive point for the combination. The details of this coupler are presented in another paper at this conference[1].

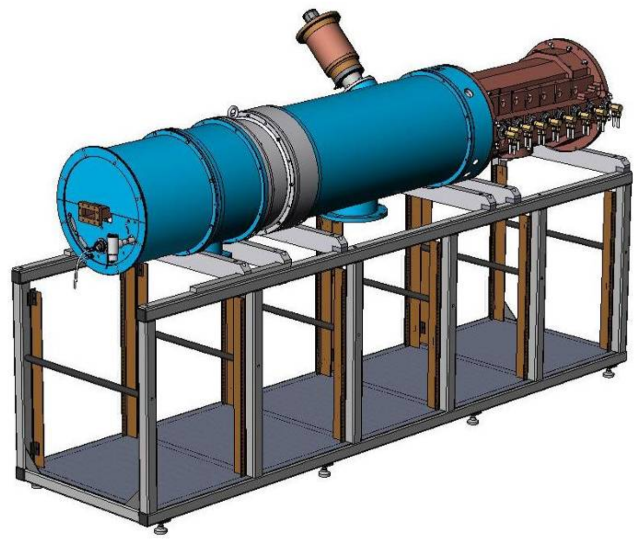

Figure 1: Cw proton linac.

Abundant quantities of epithermal neutrons are produced when the 50 kW, 2.5-MeV proton beam falls on a solid lithium target, which is under design and fabrication at Linac Systems. The details of this target are presented in another paper at this conference[2].

THE INJECTION SYSTEM

The first section of this accelerator is an ion source and low-energy beam transport (LEBT) system. The ion source is a microwave ion source which produces a 25-keV, 30-mA, dc, proton beam with low emittance and high proton fraction. A drawing of the injection system is shown in Fig. 2. The total distance from the ion source to the RFQ is 540 mm.

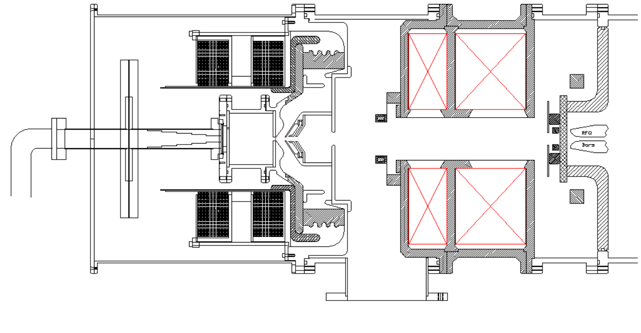

Figure 2: Injection system.

The focusing element in the LEBT is a novel dual-solenoid magnet utilizing two separate tape-wound, edge-cooled coils. The upstream coil produces 25,000 Amp-turns for a current of 85 A. The downstream coil produces twice the Amp-turns for the same current. An x,y steering magnet is suspended a few centimeters in front of the solenoid.

THE RFQ LINAC

The next section of this accelerator is the RFQ linac, which accelerates the beam from the ion source energy of 25 keV to an output energy of 0.75 MeV, in a length of 1.04 m. The RFQ a four-bar RFQ of the Radial Strut design, where the individual bars are supported by radial struts emanating from the walls of the cavity with four-pole symmetry. A significant advantage of the Radial Strut design is that the rf dipole mode is 6 MHz above the quadrupole mode and does not present a problem with rf field stability.

The rf efficiency of the RFQ is expressed in terms of a transverse shunt impedance, Z_{TR} (MΩ-m), defined as V^2/P_L, where V is the bar-to-bar voltage and P_L is the rf power per unit length in the structure. The shunt impedance of the radial strut design is 0.12 MΩ/m, about twice the value of conventional four-bar RFQs.

THE RFI LINAC

The Rf-Focused Interdigital (RFI) linac structure represents an effective combination of the interdigital (Wideröe) linac structure and the rf electric quadrupole focusing used in the Radio Frequency Quadrupole (RFQ) and Rf-Focused Drift tube (RFD) linac structures. This linac structure is three to four times more efficient and three times smaller in diameter than the conventional Drift Tube Linac (DTL) structure in the energy range from 0.75 to 6 MeV. It is ten times more efficient than the RFQ linac structure in the 0.75 to 6 MeV range.

In the RFI structure, when the accelerated particles enter the drift tube, the electric fields are near their maximum. When the accelerated particles are three quarters of the way through the drift tube, the electric fields are zero and changing sign. As a result, the focusing action must be pushed upstream to lie as close to the leading edge of the drift tube as possible, leaving the latter portion of the drift tube solely as a drift action (no focusing, no acceleration). Hence, the drift tubes of the RFI linac structure are asymmetrical, consisting of a minor piece and a major piece.

The rf focusing is introduced into the RFI linac structure by configuring the drift tubes as two independent pieces operating at different electrical potentials as determined by the rf fields of the linac structure. Each piece supports two fingers pointed inwards towards the opposite end of the drift tube forming a four-finger geometry, which produces an rf quadrupole field along the axis of the linac for focusing the beam.

The assembly and alignment procedure goes as follows. After the tank and stems are fabricated, the stems (major and minor) are installed in their hard socket prior to attachment of the major and minor drift tube bodies. Socket for the drift tube bodies are precision machined into the major and minor stems using an extended wire EDM facility that can span the entire length of the tank (≤750mm). In this way, the relative alignment of the drift tube bodies is very good. Following this EDM process, the stems are removed, the drift tube bodies are soldered into their sockets and the stems are re-installed. A picture of this multi-cell structure is shown in Fig. 3.

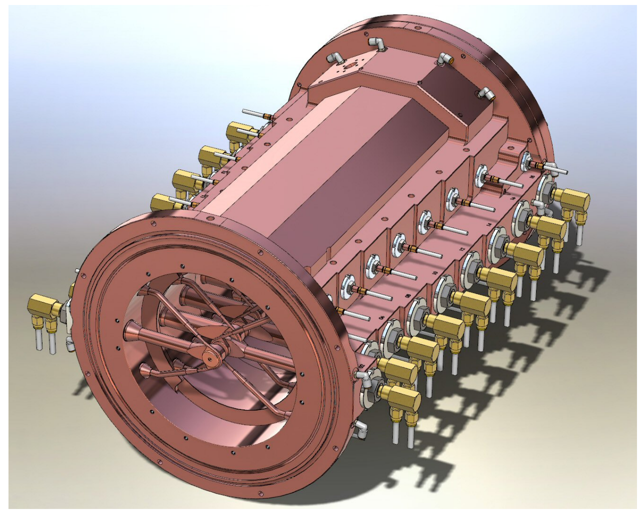

Figure 3: Multi-cell RFI linac structure.

Our first RFI structure was built as a series of unit cells, each containing a major drift tube body mounted on a supporting stem and a minor drift tube body mounted on a supporting stem[1]. Alignment shoulders on each cell provided cell-to-cell alignment. The drift tube alignment was achieved by machining sockets in the major and minor stems for the major and minor drift tube parts, relative to the alignment shoulders, by a precision wire EDM process.

Our present fabrication scheme results in multi-cell RFI tank sections. In this scheme, the tank sections are precision machined with "hard socket" for all major and minor stems. The basic requirement on the hard socket is that the stem location be reproducible – that is, that the stem can be removed and replaced to the same location with considerable precision (~25 microns).

RF POWER SYSTEM

The rf power system is designed to produce a cw power of 200 kW at 200 MHz, and consists of a Low Level Rf chassis, a Solid State Amplifier, an Intermediate Power Amplifiers, and a Final Power Amplifier. The rf systems are designed and built by JP Accelerator Works, Inc.

POWER AND COOLING REQUIREMENTS

The short, 0.75-MeV RFQ linac structure and the very efficient RFI linac structure present a manageable power and cooling requirement for this cw linac system.

The total structure power for the RFQ linac structure is 65 kW. Seventy percent of this power (45.5 kW) is dissipated in the bar/strut assemblies. There are a total of 20 parallel cooling circuits, implying about 2.3 kW per cooling circuit. The majority of this power is in the struts, where we employ a conical spiral cooling path for heat transfer. In all, the RFQ is cooled by 30 parallel cooling circuits. Some cooling circuits are shown in Fig. 4.

The total structure power for the RFI structure is 35 kW. This power is evenly split between the cavity wall and the drift tube stems. The highest power dissipation is in the 18 major drift tube stems, where the power per stem is about 0.8 kW. Each of these stems is cooled by a parallel cooling circuit. In all, the RFI is cooled by 52 parallel cooling circuits. Some cooling circuits are shown in Fig. 5.

CW TEST CAVITY TESTS

The two most difficult components of this linac system to cool are the RFQ strut and the RFI main stem. Both of these components were tested in a Test Cavity set up for this purpose. To expose the main stem to its design level of dissipation required 1162 W of rf power in the Test Cavity. We chose to supply this power as 116.2 kW of power at a 1% duty factor. To expose the strut to its design level of dissipation required 5932 W of rf power. We chose to supply this power as 118.64 kW of power at a 5% duty factor. Both components survived the tests with no sign of damage.

THERMAL CALCULATIONS

Both linac structures are cooled by multiple, parallel, cooling circuits between supply and return manifolds as seen in Figs. 4 and 5. Thermal and flow dynamics calculations were made on all typical cooling circuits. Pressures like 20 psi and flow velocities like 3 m/s keep the temperature rise in the coolant to less than 8 C.

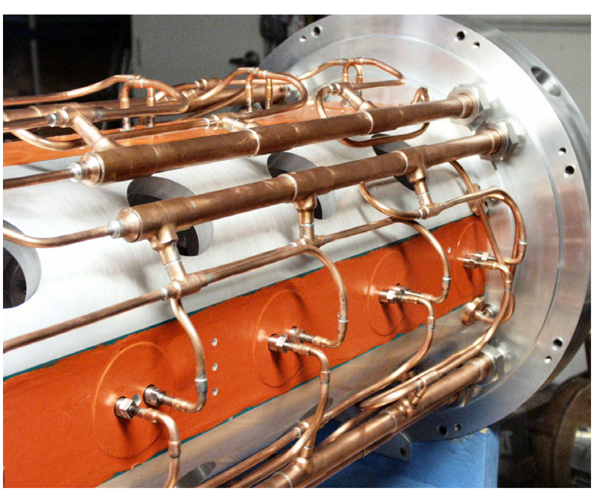

Figure 4: RFQ cooling circuits.

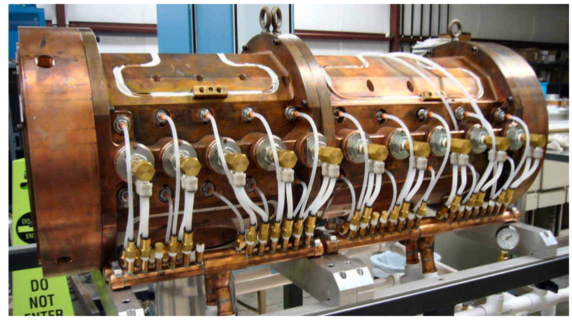

Figure 5: RFI cooling circuits.

ACKNOWLEDGMENTS

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