INSTALLATION OF A CW RADIOFREQUENCY QUADRUPOLE ACCELERATOR* AT LOS ALAMOS NATIONAL LABORATORY

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Introduction

Chalk River Laboratories (CRL) has had a long history of cw proton beam development for production of intense neutron sources and fissile fuel breeders [1]. In 1986 CRL and Los Alamos National Laboratory (LANL) entered into a collaborative effort to establish a base technologies program for the development of a cw radiofrequency quadrupole (RFQ) [2]. The initial cw RFQ design had 50-keV proton injection energy with 600-keV output energy. The 75-mA design current at 600-keV beam energy was obtained in 1990 [3]. Subsequently, the RFQ output energy was increased to 1250 keV by replacing the RFQ vanes, still maintaining the 75-mA design current [4]. A new 250-kW cw klystrode rf power source [5] at 267-MHz was installed at CRL. By April of 1993, 55-mA proton beams had been accelerated to 1250 keV. Concurrent developments were taking place on proton source development and on 50-keV low-energy beam transport (LEBT) systems. Development of a dc, high-proton fraction (≥ 70%) microwave ion source [6] led to utilization of a single-solenoid RFQ direct injection scheme [7].

It was decided to continue this cw RFQ demonstration project at Los Alamos when the CRL project was terminated in April, 1993. The LANL goals are to (1) find the current limit of the 1250-keV RFQ, (2) better understand the beam transport properties through the single-solenoid focusing LEBT, (3) continue the application of the cw klystrode tube technology to accelerators, and (4) develop a two-solenoid LEBT which could be the front end of an Accelerator-Driven Transmutation Technologies [8] (ADTT) linear accelerator.

In May, 1993 the CRL RFQ equipment was sent to Los Alamos. By December, 1993 the 50-keV LEBT was operational at Los Alamos in an offline configuration where beam transport to the RFQ matchpoint could be studied. The injector measurements are reported in these conference proceedings [9]. The klystrode tubes have been operated at Los Alamos, and this progress is also reported here in a separate paper [10]. The name given to this installation at Los Alamos is CRITS - Chalk River Injector Test Stand.

Installation Status

Figure 1 shows the layout of the major cw equipment in a high-bay experimental area. The cw RFQ is in a fixed location, while the 50 keV injector may be moved either to the RFQ or to a separate emittance measuring unit (EMU). The CRITS control room is located to the west of the high bay area. The original PC-based control computer and Taurus control system have been used to perform the LEBT experiments, and to monitor the klystrode controls system. A hard-wired safety system protects personnel from high voltage and radiation hazards.

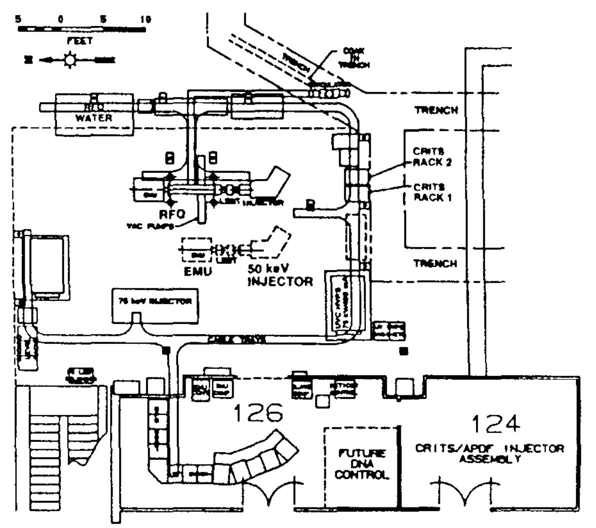

Fig. 1. Line drawing of the facility for cw accelerator development.

Two 250-kW cw klystrode tube transmitters are located in a low-bay area east of the experimental equipment installation. The 267-MHz rf source is connected to the RFQ via nine inch coaxial transmission line. A 2-MVA power station, located outdoors adjacent to the klystrode area, was installed to provide power for the two 2400-Vac klystrode high-voltage dc power supplies. The unit substation transforms the ac voltage and provides isolation from other disturbance generators connected to the ac power distribution system.

50-keV Injector

Figure 2 shows the microwave ion source and 50-kV column as installed at Los Alamos. The WR284, 2.45 GHz waveguide from the magnetron power source is on the extreme left in the photograph. The waveguide attaches to the high voltage break (disk structure in Fig. 2) which isolates the magnetron power supply from the beam

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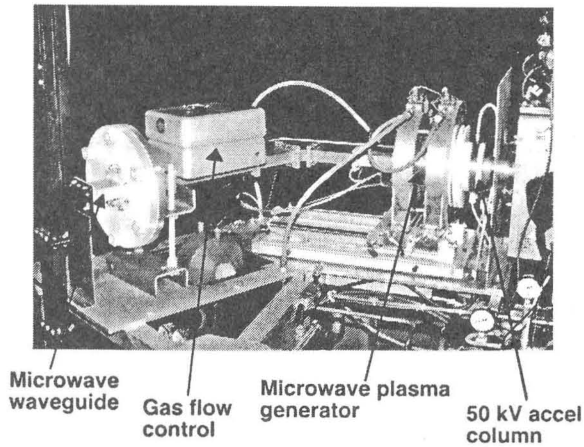

Fig. 2. Photograph of the 50 keV injector installation at Los Alamos.

extraction voltage. The gas flow controller, ion source plasma chamber, and a section of WR284 waveguide are the only items located at high voltage. Less than 100 W isolation power is required to operate this source. A pair of solenoid magnets provide the 930 - 980 G field used to form the optimal ion source discharge. Better ion source performance [6] is found at magnetic fields 6 - 12% greater than the 875 G field for the electron-cyclotron resonance at 2.45 GHz. The solenoids are separated from the high voltage on the plasma chamber by a 6.4 mm thick acrylic insulator, thus allowing the solenoid power supplies to be operated at ground potential. Most of our microwave proton source operation has used 550 - 700 W microwave power which gives 75 % proton fraction with 325 - 400 mA/cm^2 hydrogen ion beam current density. More ion source details may be found in the literature [6, 11].

Beam profile measurements have been made in the 50-keV LEBT using two dimensional Cohu [12] and Reticon [13] imaging systems. The Cohu diagnostic gives a typical ion source divergence of 20 mrad. Figure 3 shows the beam widths (FWHM) from the Reticon diagnostic plotted vs. the beam perveance. Several different ion source

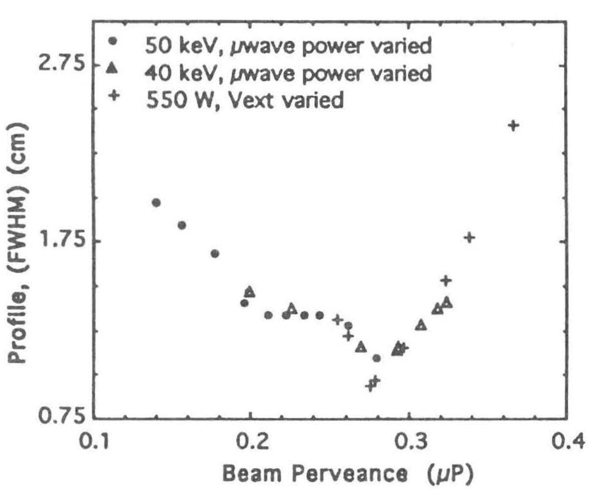

Fig. 3. Plot of the measured beam profiles vs. the beam perveance.

conditions (extraction voltage, discharge power) were studied. A universal curve is observed, with minimum beam width at 0.28 μP. Further LEBT details are discussed in a companion paper to this conference [9].

RFQ Tuning

The first use of the CRITS RFQ at LANL is to gain experience in the operation of a cw accelerating structure as a load for the klystrode rf system and as the next input stage for a dc proton beam. Since the RFQ had been operated previously at CRL in 1993 [14], the focus during the installation at LANL became the restoration of the RFQ to the last operating condition.

The CRITS RFQ was shipped to Los Alamos National Laboratory in a single unit with minimal disassembly. In order to reduce the size and preclude damage to extruding equipment, the four vacuum cryopumps and their valves, the motorized slug tuner assemblies, and the driveloops were removed and shipped as separate units. The slug tuners and the driveloop affect the rf parameters of the RFQ; therefore, these items were carefully checked and reinstalled. The rf parameters of the RFQ are shown in Table 1, where f_0 is the resonance frequency (no power), β is the power coupling parameter, and Q_u is the unloaded cavity Q. These are in close agreement to those measured at CRL.

Table 1. Comparison of RFQ parameters measured at Los Alamos with CRL results.

	LANL	CRL
f_0	267.15	267.1
β	1.18	1.15
Q_u	7150	7325

The RFQ will be ready for high-power rf conditioning after the vacuum and water cooling systems are made operational.

Klystrode Tests and Status

The klystrode transmitter installation at Los Alamos was completed in June, 1994, and preliminary testing of the klystrode transmitter has commenced. The properties of the klystrode transmitter are described in Table 2. Some of the preliminary test results are provided below.

Table 2. Klystrode operating requirements.

Waveform	Continuous Wave
Frequency	267 MHz
Output Power	> 250 kW
Transmitter Gain	> 80 dB
Bandwidth (1.0 dB)	> 1 MHz
Efficiency	> 70%
Klystrode Beam Voltage	-68 kV
Klystrode Beam Current	< 5.5 A

Our interest in the klystrode is motivated by its high efficiency and control characteristic. All high power klystrode developments to date have achieved an efficiency in excess of 70 percent which is quite high when compared to the klystron and gridded tube technologies. Moreover, the klystrode (class B amplifier) has a soft saturation characteristic that allows the user to provide control over the output power while still achieving the full, saturated efficiency. The power transfer characteristic of a klystron actually becomes flat and then rolls over when the klystron is driven into saturation. Unfortunately, the klystron provides its maximum efficiency only at saturation. With a klystron operated at saturation we cannot rapidly control the accelerating cavity field level to compensate for beam induced disturbances by varying the drive power because the power transfer characteristic is flat. Therefore, with a klystron it is necessary to provide a typical 10-20% control margin which translates to a 10-20% decrease in klystron efficiency. In contrast, the soft saturation characteristic of the klystrode provides a power transfer function which flattens out as saturation is approached but still has a positive slope. With this characteristic, we can exercise control over the accelerating cavity fields without paying the efficiency penalty required by the klystron.

Preliminary test results are provided in Figs. 4(A) and 4(B). Figure 4(A) shows the power transfer characteristic of the high power klystrode demonstrating the soft saturation characteristic. Figure 4(B) illustrates the klystrode efficiency as a function of output power. It shows that the klystrode efficiency is greater than 70% over a output power level from 160 kW to 250 kW. These tests were performed cw on a dummy load.

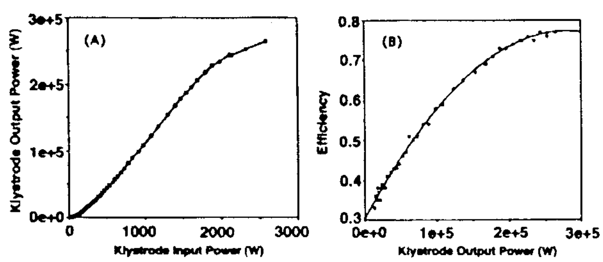

Fig. 4. (A) Output power from the final power amplifier vs. input power. The power gain is greater than 20 dB. (B) Klystrode efficiency vs. output power.

Summary

A cw accelerator facility has been moved from CRL to LANL. The ion source, LEBT, and rf klystrode tubes have been put into operation at Los Alamos. The cw RFQ is in place with most utilities attached. A high-current cw proton beam development program has now been started at Los Alamos.

Acknowledgments

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