MECHANICAL DESIGN AND FABRICATION OF A 425-MHz H⁻ BUNCHER*

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Abstract

A beam buncher has been designed, fabricated, and installed on the accelerator test stand (ATS) to match the 2-MeV output beam of a 425-MHz H^- radio-frequency quadrupole (RFQ) into a 425-MHz drift-tube linac (DTL). The buncher configuration provides integral-matching permanent-magnet quadrupoles (PMQ) at the exit of the RFQ and one $\beta\lambda$ across the buncher accelerating gap; a third PMQ is the first DTL half-cell magnet. Located between the second and third PMQs is a 50-Ω, capacitively coupled, beam-sensing pickup loop. Cooling channels are provided in each of the brazed OFHC copper wall sections. Vacuum pumping of the buncher is provided by a cryogenic refrigerator vacuum pump through an array of small-diameter holes in the buncher cavity wall. Mechanical features of the buncher, the brazing and electron-beam welding of the solid-copper buncher structure, and the beam pickup loop are described in this paper. The buncher has been tuned, installed, and operated at full power on the ATS.

Introduction

The accelerator test stand, in operation at the Los Alamos National Laboratory, uses a 425-MHz radio-frequency quadrupole linear accelerator to accelerate H^- ions to 2 MeV, matched by a single-cell, 425-MHz buncher to a 5-MeV, 39-cell, 425-MHz post-coupler-stabilized drift-tube linac (DTL). The buncher-cavity structure incorporates permanent-magnet quadrupoles at the RFQ output, at one $\beta\lambda$ spacing from the RFQ PMQ, and in the DTL entrance half-cell, which is also spaced one $\beta\lambda$ away from the tertiary PMQ in the buncher. Thus the buncher, while providing the powered matching cavity, is the RFQ cavity high-energy end wall and is the low-energy end wall of the DTL. Figure 1 shows the cross sections of the RFQ, buncher, and DTL. SUPERFISH calculations indicate that a peak power of 26 kW will provide the longitudinal beam matching necessary.

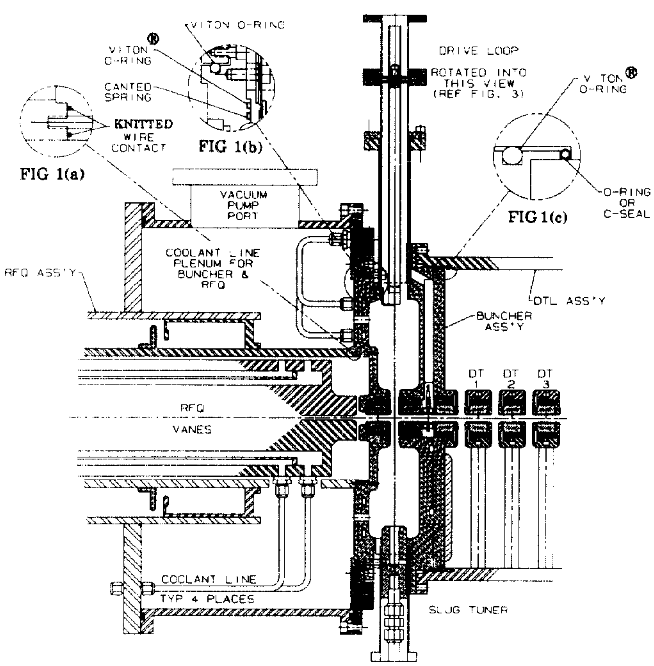

Fig. 1. Cross section of buncher, RFQ, and DTL.

Discussion

Mechanical configuration of the ATS buncher is severely constrained by the extremely limited space between the RFQ and the DTL. The cavity provides the end walls of both RFQ and DTL mounting for the three PMQ s, space for the rf drive loop, slug tuner, rf pickup loop, evacuation ports, gauge port, and a 50-Ω-impedance beam sensor. Figure 1 shows the RFQ, buncher, and DTL cross sections as well as the cavity separation interface required for assembly of the RFQ cavity side to the RFQ, rf joint, and the DTL end wall. Water-cooling channels are also incorporated in the buncher walls to remove rf heating-loss power in the RFQ end wall, the buncher cavity walls, and the DTL end wall. Figure 2, a longitudinal cross section of the buncher, shows the PMQs, the cavity, and the 50-Ω beam sensor. Figure 3, a transverse cross-sectional view through the buncher cavity, shows the slug tuner, rf drive loop, rf pickup loop, vacuum gauge, and an optical view port for observation of the accelerating gap.

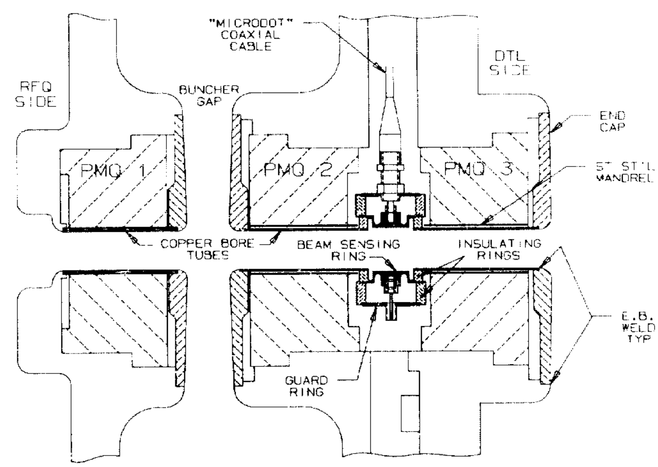

Fig. 2. Cross section of beam sensor, PMQ, and GAP.

The rf joints required at the three rf current-carrying demountable joints are critical features of the buncher design. The joint at the RFQ end wall is provided by a close mechanical fit between the copper-plated RFQ resonant-cavity cylinder, the copper buncher-cavity section, and the knitted-wire,[1] rf gasket material integral to the joint [Fig. 1(a)]. This joint configuration has been used in this RFQ location since 1982. The cavity joint itself [Fig. 1(b)] uses a copper-plated Inconel X750 canted-spring contact.[2] The DTL interface uses a copper- or silver-plated metallic O-ring[3] or C-seal[4] [Fig. 1(c)]. Initial operation of the DTL with a silver-plated Inconel X750 O-ring has indicated fully satisfactory joint operation with

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[1] Tecknit, EMI Shielding Products Division, Cranford, NJ 07016.
[2] Long Spring Company, Santa Ana, CA 92707.
[3] Advanced Products Company, North Havery, CT 06423.
[4] Pressure Science Incorporated, Bobville, MD 20205.

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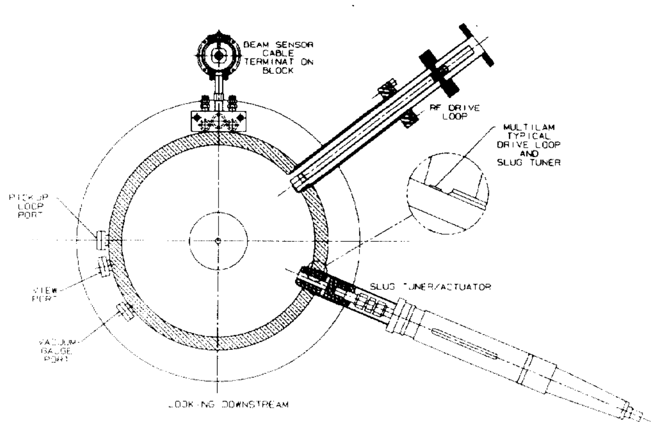

Fig. 3. Cross section of buncher cavity.

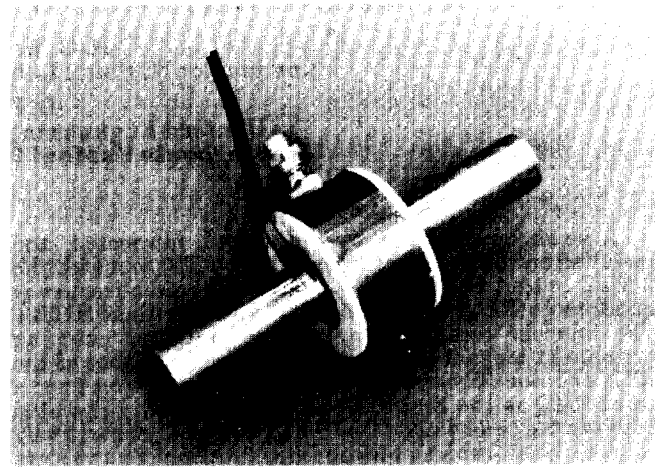

Fig. 4. Beam-sensor assembly.

a measured DTL cavity "Q" >24 000 and the apparent absence of discharging/sparking. The metallic O-ring was installed in this assembly because of its availability; either seal configuration provides a flange loading of approximately 280 lb/linear in. The reduced flange loading appears to be desirable in this joint because of the high susceptibility of the very soft OFHC copper structure of the buncher to distortion at the seal interface.

The PMQ magnets used in the buncher assembly were initially developed for use in the ATS DTL. The magnet used in the RFQ side of the buncher (Fig. 2), which uses a copper bore tube/assembly mandrel, is identical to the magnet used in the ATS-DTL drift tubes. To permit assembly of the beam sensor, magnets used in the tertiary and DTL side locations are different from the magnet used in the RFQ side location. This configuration (Fig. 2) uses a thin-wall stainless steel (ASM Type 310) as an assembly mandrel that is thermally isolated from the copper bore-tube sections of the beam-sensor assembly.

Cooling of both buncher sections, i.e., the RFQ side and the DTL side, is provided by water channels machined into the copper cavity walls that are then furnace brazed to seal the flow channels.

The rf drive loop used in the buncher cavity is identical to a loop previously used in a high-power RFQ vane test structure, where peak power of 400 kW at 0.50% duty factor has been achieved.*

The slug tuner incorporated in the buncher uses a remotely operated linear actuator that inserts or retracts the slug from the cavity through a MULTILAM** band, gold-plated rf contact shown on Fig. 3. A 4-MHz tuning range is provided by inserting the slug into the cavity. Water cooling of the slug tuner is provided by a re-entrant squirt-tube that provides circulating water to the copper tuning slug.

The beam sensor incorporated into the buncher is a capacitive pickup. Figure 4 shows the sensing ring furnace brazed to insulators that are then brazed to copper bore tubes. The bore-tube sensing-ring assembly, when welded in place, provides a vacuum-tight envelope in the DTL side of the buncher cavity. The capacitive pickup and its coaxial cable provide a 50-Ω signal system. The coaxial cable, placed in ducts through a machined channel in the cavity structure and led to a terminal block external to the cavity structure, is isolated in the buncher assembly to permit proper signal termination at the signal monitoring instrumentation. This sensor has been in continuous use in the ATS since April 1986. This sensor is the only monitor of RFQ beam current output to the DTL.

Evacuation of the buncher cavity is provided through fifty, 0.410-in.-diam holes in the RFQ side of the cavity; pump of 3600 ℓ/s pumping speed. The effective pumping speed at the plane of the buncher evacuation holes is calculated to be 510 ℓ/s; effective speed inside the buncher cavity is calculated to be 145 ℓ/s. An unpowered operating pressure of 1×10^{-8} torr is expected in the buncher cavity while an operating cavity pressure of approximately 1×10^{-7} torr is expected from the buncher outgassing rate. Vacuum sealing of the buncher cavity is provided by elastomer (Viton®) O-rings located behind each rf contact and at the mating interfaces of the buncher assembly.

Conventional machining, brazing, and specialized electron-beam welding techniques were used to produce the major components of the buncher cavity. To provide the most efficient fabrication schedule, detailed intermediate fabrication steps were designed to permit initial rough machining of the prebraze components followed by brazing to provide a rough-machined major component. The rough-machined major components were then finish machined with numerically controlled milling machines. Because the principal construction material of the buncher-cavity components is OFHC Type-102 copper, all fabrication processes were developed to accommodate its unique characteristics. Sulfur-free cutting coolants were used for all machining operations. Brazing of the copper components for the two major cavity sections was performed by vacuum furnace brazing using copper-silver eutectic alloy for the primary braze cycle in which the cooling channels were completed. Brazing of the stainless steel slug-tuner, rf drive loop, vacuum gauge, and rf pickup-loop ports was performed in a second braze cycle using copper-silver eutectic alloy.

Microstructure of the copper-weld interface zones before and after welding was investigated metallurgically during electron-beam weld-design development. Figure 5 shows the weld penetration of a bore tube in a test weld. Conditions for the weld were 110 kV and 0.008 A, with the beam focused to provide a minimum penetration of 0.030 in. Of particular importance in the weld development was a requirement to prevent the magnet temperature from exceeding 100°C; this requirement was successfully achieved by using intermittent welding and chill blocks according to a schedule developed during test welds in which the bore-tube temperature was monitored continuously. Control of bore-tube temperature was critical in the RFQ side-magnet installation because the copper bore tube of the magnet assembly was itself welded to the cavity structure. The DTL side-bore-tube weld is less demanding because the beam bore tube is thermally isolated from the Type-310 stainless steel magnet assembly mandrel (Fig. 2). The bore-tube welds of both assemblies required the use of a Mumetal field shunt on

*G. O. Bolme, Los Alamos National Laboratory, private communication, October 1985.

**Hugin Industries, Los Altos, CA 94022.

®E. I. duPont de Memours, Wilmington, Delaware.

Fig. 5. Cross section electron-beam weld.

the face plate to minimize steering of the electron beam by the magnet fringe fields; using the Mumetal shield resulted in less than 0.020 in. of electron-beam steering.

Figure 6 shows a typical electron-beam weld arrangement for the face-plate welds for both RFQ and DTL sides of the cavity. Welding procedures generally proceeded without incident, except for intermittent gas bursts from the weld zone. These gas bursts sometimes resulted in significant "cratering" from the gas evolution zone. No specific characteristic of the metal has been identified as the cause of the gas bursts; however, it is clear that inclusions of a higher vapor-pressure substance than that of the OFHC copper were present in the bulk copper. These craters were leveled by making a defocused electron-beam-weld pass over the cratered area. In one instance, a large-pulse yag laser was used to add pure

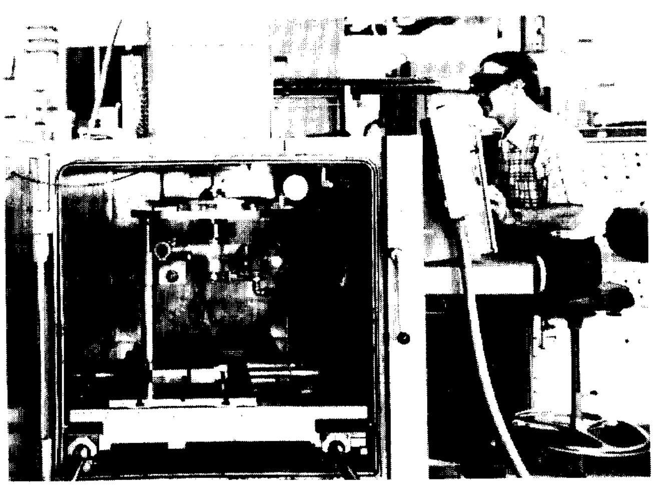

Fig. 6. Electron-beam weld setup.

copper to the cratered weld area before the defocused electron-beam-weld pass.

Before assembling the buncher, all components were checked for fit on a precision assembly table. The individual component alignment, designed to produce a radial displacement error of less than 0.005 in., was verified during the preassembly procedures. Following preassembly tests, the RFQ side of the cavity was mated to the RFQ resonant cylinder. The floating interface ring shown in Fig. 1 permits minor misalignment of the RFQ manifold end cap through the compliance of the vacuum-sealing Viton® O-ring. After mating the RFQ side of the cavity to the RFQ, the DTL side of the cavity was assembled to the RFQ side to complete the buncher assembly. The DTL, which had been prealigned on its mounts to the RFQ, was then mated to the assembled buncher without incident.

Recommendation

As with all complex apparatus produced the first time, there were unexpected characteristics that should be improved in future versions. For any future buncher, we specifically recommend eliminating any mechanical load-carrying copper-flange interface. Although copper is the material of choice because of its electrical and thermal conductivity properties, its very low mechanical strength (particularly after furnace brazing) and low creep strength result in very low strength bolted flanges and load-bearing load points. Composite steel/copper structure is recommended to eliminate these problem areas in future designs.

Acknowledgments

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