A DRIFT-TUBE LINAC INCORPORATING A RAMPED ACCELERATING FIELD*

D. J. Liska and L. B. Dauelsberg
Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

A short, high-power linac structure has been designed and is being built; it incorporates a ramped accelerating field for matching a radio-frequency quadrupole (RFQ) to a high-gradient drift-tube linac (DTL). The tank is made of aluminum and can operate at high duty factor. The drift tubes are copper and use new neodymium-iron-boron quadrupoles. The linac is tuned using conical-sweep post couplers and is driven by multiple rf loops. Rapid acceleration of the beam occurs from low to high gradients in a short, compact, and lightweight structure.

Because this linac will also be used to test open drift tubes, test results are included on vacuum measurements of high-grade epoxies and plastics that might be used in a drift-tube body.

Design Features

Proton drift-tube linacs today are capable of reaching accelerating gradients of 5 MV/m in UHF band. An RFQ functions as the injector for these powerful, compact machines; most RFQ accelerating sections reach gradients of only about 2 MV/m. It is necessary, therefore, to provide a matching section between the RFQ and the high-gradient DTL. One way of accomplishing this is to establish a field ramp that smoothly joins the two gradients.[1] Such a machine has been conceptually designed at Los Alamos for 5% duty factor at 425 MHz and is now under final design and fabrication for us by the Grumman Aircraft Co. of Bethpage, New York. It is called a ramped-gradient drift-tube linac (RGDTL). Grumman is doing the final design and fabrication of several major components while Los Alamos is providing the drift tubes, quadrupoles, and end walls. The RGDTL operates between 2.07 and 6.7 MeV with a 100-mA hydrogen beam at a maximum of 4.4 MV/m and is connected to a 5-MV/m flat gradient DTL that takes the beam to 50 MeV.

From outward appearances, the RGDTL design resembles any typical flat-gradient tank, as shown in Fig. 1. The drift tubes are supported by a girder structure as has been done at Los Alamos for the Fusion Materials Irradiation test (FMIT) facility[2] and for the accelerator test stand (ATS)[3] project. However, the RGDTL girder and the tank are both fabricated of aluminum. Below are listed the advantages of aluminum.

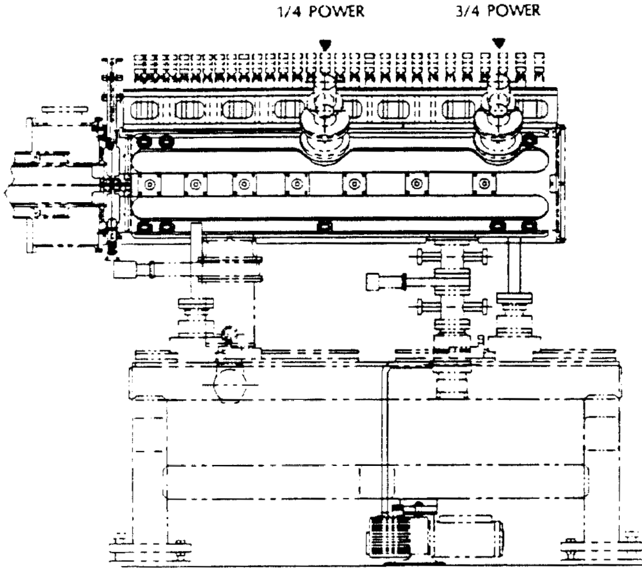

Fig. 1. Ramped-gradient DTL.

- Lightweight, cheap, easy to machine
- High thermal conductivity
- Low residual radioactivity

It is estimated that several tons of structure can be saved by using aluminum in a 50-MeV accelerator. The excellent thermal conductivity of aluminum permits operation at high duty factor (5% minimum) with efficient cooling-jacket design. Finally, at higher energies, residual radioactivity and resulting maintenance difficulties are reduced because of the short half-life of the radionuclides formed in an irradiated aluminum structure.

Field ramping of the accelerating gradient is accomplished using post couplers with angled tips that are rotated to provide differential electric coupling to every second drift-tube body. Strong differential coupling is essential to establish a field ramp of almost 4% per cell. Cold testing has demonstrated that sufficient differential coupling can be provided through rotation of the post-couplers to accomplish the field ramp without having to offset or angle the post coupler stems. However, strong differential stem currents are generated that require high-quality rf seals and adequate cooling. The field ramp imposed in the RGDTL design, which gives the power distribution as a function of length, is shown in Fig. 2. We have located the rf drive loops and automated tuners at the quarter and three-quarter power locations for balanced power demands.

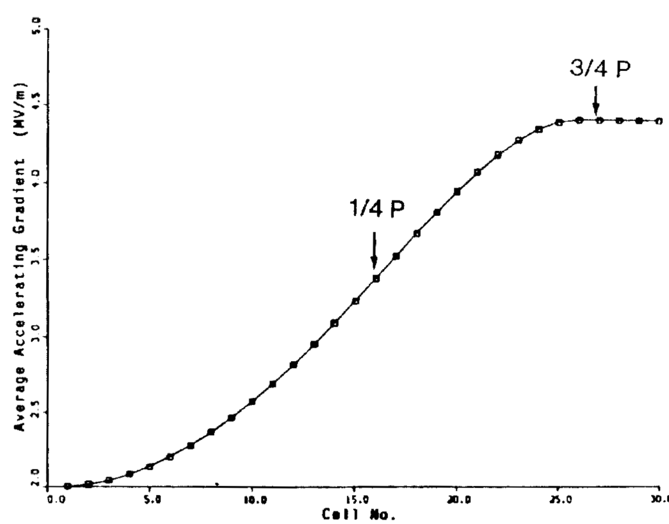

Fig. 2. Average accelerating gradient vs cell number, cubic ramp 2.0 to 4.4. MV/m over 150 cm, 3° face angle.

Two tuner designs are being considered: one, a conventional slug tuner and the other, a rotary tuner capable of very smooth vernier frequency control. The rotary tune option is shown in Fig. 3. It is capable of over 100 kHz of frequency control and does not couple significantly to the electric field in the cavity. It uses a ferrofluidic bearing that, because of its low friction, permits very linear servo-control and fine tracking of resonance changes in the tank.

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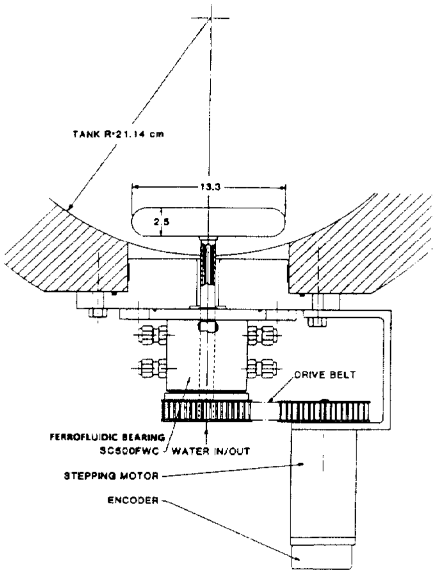

Fig. 3. Rotary tuner concept.

Radio-Frequency Considerations

The 425-MHz operating frequency of the RGDTL permits either waveguide or coaxial-loop drive. Because of the thrust toward high-powered, solid-state power amplifiers in the UHF band that couples easily into coaxial drive lines, we have equipped the tank with two coaxial drive loops rated at 500 kW each. The tank requires 806 kW of rf power (including beam power), and this can be supplied by two or more independent solid-state power amplifiers or by one 1.25-MW BMEWS-type klystron, either system working through power splitters where required. The drive-loop concept provides modular flexibility in the rf drive system. The impedance of the drive line on both the air and vacuum sides of the ceramic window is set at 50 Ω. The loop steps down from 6.125 in. (commercial size) to 3.75 in. at the tank, using an impedance-matched tapered section. The loop is adjustable in penetration as well as in rotation.

At 5% duty factor, good surface conductivity is required to reduce average power demands; therefore, the drift-tube bodies are fabricated of OFHC copper, and the aluminum tank wall is copper plated to a nominal thickness of 0.075 mm. Intense magnetic fields at the high-gradient end of the tank approach 6000 A/m, and good adhesion of the copper to the aluminum is essential. For this reason, we have chosen the most reliable copper-plating technique known, the zincate process. The age-old trepidation concerning zinc is dealt with by the following arguments: a zinc-flash is well adhered to the aluminum and is buried under a coat of copper about a hundred times the thickness of the flash itself. Furthermore, trace amounts of zinc are unavoidable as alloying agents in many grades of aluminum. Finally, no intense electric fields are present on the accelerator tank wall. Where these exist (at drift-tube gaps), solid OFHC surfaces are present. The tank end walls are also OFHC-clad plates. Therefore, only the tank barrel and girder are made of aluminum alloy.

Drift Tubes and Diagnostics

To meet the power demands of 5% duty factor, high thermal conductivity is essential. One must consider the fact that a 4.4-MV/m accelerating gradient in a 425-MHz accelerator structure represents almost twice the average power density of the 80-MHz FMIT structure operating cw. The need for high thermal conductivity is one of the major reasons for choosing aluminum for the RGDTL tank, and also why the drift-tube bodies are fabricated **from OFHC copper. The drift tubes are brazed to stainless steel stems and contain neodymium iron quadrupoles.[4] For the RGDTL, the drift-tube bores are welded shut as shown in Fig. 4; for succeeding tanks, we intend to expose the interior of the drift tube to tank vacuum for installing instrumentation probes as shown in Fig. 5.**

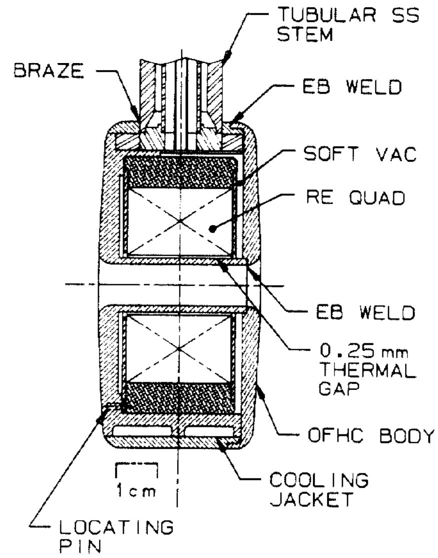

Fig. 4. Noninstrumented drift-tube body.

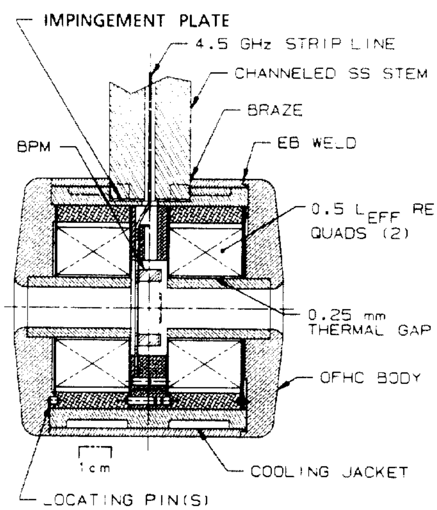

Fig. 5. Instrumented split-quadrupole drift-tube body.

The open drift-tube concept allows high-quality beam diagnostics to be obtained.[5] The diagnostic probes are designed to fit into any split-quadrupole drift tube above 4 MeV. The probes consist of a transmission-line circuit board that encircles the beam in the bore-tube gap and supports four microstrip circuit boards that form orthogonal beam-position capacitive pickups. The rf signals are delivered to the circuit board and up a flexible strip line inserted through the diagnostic slot in the drift-tube stem. At the top end, outside the vacuum boundary, SMA connectors are attached to permit easy access to the diagnostic signals.

By using two probes along the beamline, beam current, position, longitudinal profile, and energy can be determined in a noninterceptive manner. This information will allow all temporal and spatial beam variations to be detected simultaneously and, therefore, permit experiments on remote automatic control of the accelerator.

Vacuum-Grade Plastics and Epoxies

The open drift tubes expose the kapton diagnostic probes to hard vacuum. In addition to this, epoxies may be used to pot the permanent magnetic quadrupoles. For these reasons, a test program was initiated to select high-grade epoxies and sealing agents for use in the split-quadrupole drift tubes. The apparatus to test these materials is shown in Fig. 6 and resembles a drift-tube body with a 2.1 ℓ/s conductance restriction to simulate the bore tube. Vacuum measurements were made both inside the chamber and on the pump side of the bore tube. The chamber pressures for various materials are plotted as a function of time to help determine the pressure spike that may exist at the gap in the drift-tube bore caused by the outgas load of the various organic materials.

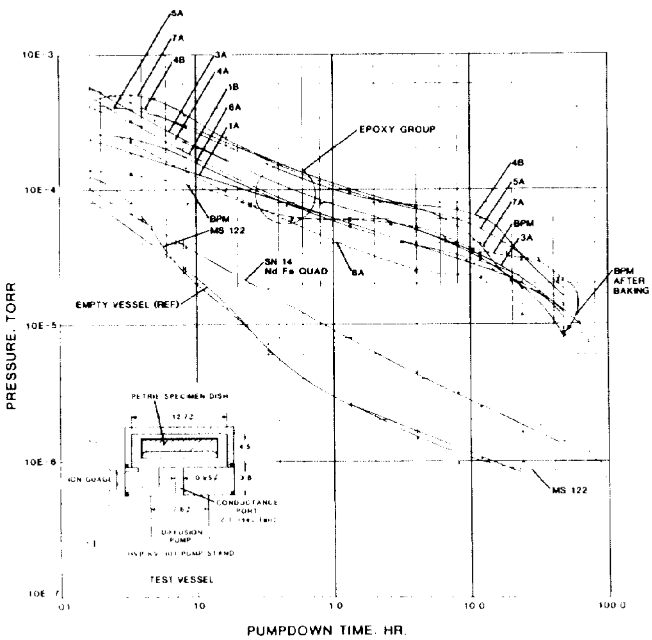

Fig. 6. Pump-down characteristics of high vacuum-grade epoxies.

The list of some materials tested is given in Table I. All materials pump down into the low 10^{-5} range in a reasonable length of time (<60 h). This gives us a good selection of vacuum-grade epoxies to choose from for future development of this accelerator. It is interesting to note that the familiar Torr-seal (Sample 8A) is one of the best materials tested. Even though the quadrupole magnet (SN14) was plotted with DOW DER 332 (Jeffamine T403 curing agent), which in bulk was not as good as Torr-seal, the small areas of this epoxy exposed to vacuum resulted in a decade overall improvement for SN14 and made it about as good as the empty vessel.

Tests of the samples with a residual-gas analyzer showed that water vapor was the only contributor to the outgassing—no organic gases were detectable, even into the 10^{-7} ton range. This leads us to believe that there should be no significant degradation of rf performance caused by organic deposits on the high field-gradient surfaces.

Conclusions

The use of high thermal-conductivity materials such as aluminum and OFHC in the design of the new ramped-gradient drift-tube linac at Los Alamos has resulted in a compact, lightweight, powerful accelerator structure. It operates at a high average-power density exceeding that of lower frequency cw machines such as the FMIT. Advanced beamline-instrumentation techniques downstream of the RGDTL should provide comprehensive beam-related measurements.

TABLE I

TESTS OF VACUUM-GRADE EPOXIES

Sample No.	Material	Mix Ratio	Mix/Cure Process	Vacuum Bake
1A	DER 332 T-403	100 Parts 47.1 "	Mix @ RT, degas cure 16 h @ 40°C (1atm)	75°C for 268 h
1B	DER 332 T-403	100 Parts 46.0 "	Same as above	75°C for 218 h
3A	EPON 828 T-403	100 Parts 43.8 "	Same as above	75°C 48 h
4A	DER 332 Versamid 140	100 Parts 100 "	Warm to 40°C, mix, degas & pour, cure overnight @ RT (1atm) [postcure 16 h @ 40°C (1atm)]	
4B	DER 332 Versamid 140	75 Parts 25 "	Same as above	75°C for 52 h
5A	DER 332 Isophorone Diamine	100 Parts 23 "	Mix & degas @ RT, cure overnight @ RT, postcure overnight @ 40°C (atm)	75°C for 137 h
6A	Hysol RE 2038 HD 3475	100 Parts 25 "	Mix @ RT, degas & pour. RT cure for 16 h (1atm)	75°C for 135 h
7A	Hysol Re 2039 HD 3475	100 Parts 25 "	Same as above	75°C for 142 h
8A	Torr-seal	1 tube resin 1 tube hardener	Same as above	75°C for 140 h
MS 122	Fluorocarbon Mold Release	---	Sprayed coating on inside of aluminum petri dish	75°C for 166 h
BPM	Strip-line probe	---	Cleaned but not baked	
SN14	NdF Quadrupole	---	Cleaned but not baked	

Acknowledgments

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References

1. G. P. Boicourt and M. C. Vasquez, "Two New Possible Designs for the Ramped ATS-DTL," Los Alamos National Laboratory internal memo AT-6:85-180, November 27, 1985.

2. D. J. Liska, R. G. Schamaun, C. Potter, C. W. Fuller, D.Clark, D. R. Greenwood, and J. Frank, "Design of the Accelerating Structures for FMIT," IEEE Trans. Nucl. Sci. 26 (3), 3052 (1979).

3. R. A. Michelotti, R. A. Tennant, N. K. Bultman, J. L. Uher, R. J. Brewton, and A. Mayer, "Materials Considerations for a High Power-Density Accelerator," IEEE Trans. Nucl. Sci. 32 (5), 2849 (1985).

4. D. J. Liska, N. Bultman, and L. O. Carlisle, "Thermal Design of Drift Tubes for High-Gradient Linacs," Proc. 1986 Linac Conf., Stanford Linear Accelerator Center, Stanford, California, June 2-6, 1986, to be published.

5. J. D. Gilpatrick and D. L. Grant, "Multiple-Measurement Beam Probe," Proc. 1986 Linac Conf., Stanford Linear Accelerator Center, Stanford, California, June 2-6, 1986, to be published.