MECHANICAL FEATURES OF THE ATS RFQ LINEAR ACCELERATOR*

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Summary

A radio-frequency quadrupole (RFQ) linear accelerator has been constructed and placed in operation on the Los Alamos National Laboratory accelerator test stand (ATS). This accelerator uses an evacuated rf manifold to distribute rf excitation from the 425-MHz rf power supply to the slot-coupled, RFQ vane-cavity, resonator assembly. The RFQ vanes are supported on commercially available copper-plated, linear, resilient "C-seals" to provide a high-conductivity rf contact that permits aligning and positioning the vanes during tuning, and demounting the vanes for evaluation and modification as necessary. All rf structures are fabricated from stress-relieved, bright-acid copper-plated carbon steel.

Measurements made on the accelerator as assembled have demonstrated >8000 vane-cavity Q at the quadrupole's ~423.400-MHz accelerating-mode frequency.

Operating manifold vacuum of $3\text{--}6 \times 10^{-8}$ torr has been observed after rf conditioning; conditioning required 150 h for stable high-power rf operation.

Experience to date has indicated the desirability of modifying the vane rf-contact seat configuration to improve assembly and alignment procedures, improving vane-machining processes to increase vane straightness, installing periodic vane-shorting rings to minimize the effect of dipole modes in the quadrupole accelerating structure, and modifying the waveguide-coupling slot in the manifold to improve forward rf power flow.

Introduction

Construction and operation of the proof-of-principal (POP) RFQ¹ has clearly demonstrated the utility of rf-manifold-driven vane structures. Design of the ATS RFQ began in late 1980 with the intent to make maximum use of this foundation of previous technology. Although some features of the ATS RFQ depart from the POP work (that is, plated-steel structures, one-piece vane base/vane tips, demountable vane, vane-cavity/cylinder assembly, two-section cavity vane assembly, and reduced dependence on brazed assemblies), the major accelerator-configuration features and physics design are based on the earlier POP RFQ.

Design Criteria

ATS RFQ physics design parameters² are shown on Table I. Detailed RFQ design is based on these characteristics, as well as on SUPERFISH and PARMTEQ calculations that validated the detailed vane shape and the rf-structure configuration. A cold model of the rf-manifold/vane-cavity assembly using these parameters was constructed and tested in early 1981, which validated the design calculations and manifold end-capacitor configuration.

Mechanical Design

Using previous experience with the POP accelerator, we determined a $\pm 0.005\text{-cm}$ tolerance for aligning

TABLE I

RFQ DESIGN PARAMETERS

Frequency	425 MHz
Length	289.23 cm
Average radius (r_0)	0.394 cm
Tip radius (r_s)	0.270 cm
Modulation (m_f)	1.830
Number of cells	356
Vane voltage	111.34 kV
Maximum surface field	41.4 MV/m (2.06 Kilpatrick)
Peak structures power	551 kW
Peak manifold power and structure losses	327 kW
Peak beam power at 100 mA	190 kW
Duty factor	1%
Repetition rate	10 to 12 Hz

and fabricating the vane assemblies. This tolerance was used to choose dimensional tolerances for all components. The importance of this parameter later was observed to be critical for this RFQ.

An overall vane-cavity Q of at least 6000 is considered necessary to permit adequately driving the RFQ by the 1-MW, 425-MHz power supply. A theoretical 8000 vane-cavity Q was calculated, using practical values of surface conductivities, etc. Previously, copper-plated steel had produced acceptable surface conductance. Assembly joint designs were not well proven and therefore were subject to further design evolution for the ATS RFQ. In particular, the prior successful use of brazed structures in many assemblies did not appear practical for most structures; therefore, a different assembly method was dictated. Of major importance here was the desire to develop a demountable and adjustable vane base with adequate contact conductivity to assure the acceptable 6000 Q. The vane-base/cavity-cylinder joint that evolved uses a commercially available copper-plated Inconel X-750 linear metal C-seal as a contact interface (Fig. 1).

The RFQ's 289.23-cm length placed several limitations on the detail design because of available manufacturing capability. Particularly significant were the conclusions that brazing a vane tip to the vane base was not practical, and the vanes and vane-cavity cylinder should be in two sections because of length limitations in vane-tip machining and drilling capabilities.

Because of the low duty factor (1%), cooling was provided only for the RFQ vane-cavity assembly, which has cooling channels in each vane and in the cavity-cylinder wall.

Vane Fabrication

Vane fabrication required several different facilities because conventional machining, computer-controlled machining, heat treating, electroplating, precision mechanical inspection, and plating-thickness measurements are necessary in the production processes. The vane blanks were heat treated at several points in the rough- and finish-machining sequence. Vane-tip machining (Fig. 2) was performed by a numerically controlled milling machine; after completion, precision mechanical inspection and bright-acid copper plating was performed.

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Fig. 1
ATS RFQ cross section.

Fig. 2. ATS RFQ vane-modulation machining.

Vane production to ± 0.005 -cm accuracy was the fabrication goal. The goal was met in most cases; however, the tip straightness on two vanes exceeded this limit, as did the plating thickness variation. Process-development dry runs for both vanes had been performed to assure accuracy of the parts fabricated, but in actual production, deviations occurred that will need additional process development to bring the vanes within specifications. The worst case of vane-straightness deviation resulted in a 0.014-cm error; the worst case of plating thickness was 0.008-cm variation from end to center of one vane section.

Vane-Cavity Cylinder/rf Manifold

The vane-cavity cylinder (a precision-bored two-section, rigid, copper-plated steel structure) serves several critical functions: (1) a precision mount for the four quadrupole vanes; (2) coupling slots for the RFQ resonant quadrants; (3) mounting of the cavity in the RFQ manifold on the manifold tuning capacitors (Fig. 3). The cavity cylinder also incorporates deep-drilled water-cooling channels under each vane-contact C-seal (Fig. 1). Copper plating the cavity cylinder using vertical plating tanks deeper than the longest 160-cm cylinder section, was accomplished at a commercial plating facility,* using UBAC-HS† commercial plating solutions. The rf manifold, which distributes the 425-MHz rf power supplied by the klystron rf power supply to the RFQ cavity, is the mount for the RFQ

Fig. 3. ATS RFQ end of vane/manifold arrangement.

cavity cylinder, the vacuum chamber for the RFQ cavity and the tuned circuit. Structurally it is a copper-plated, carbon-steel weldment. Incorporated into the manifold are the vacuum-pump mounting ports, feed-throughs for the 16 water-cooling circuits in the vane-cavity cylinder, and 8 feedthroughs for the rf pick-up probes in each end of the four quadrupole quadrants. Figure 4 shows the RFQ assembly.

C-Seals

The vane-base to cylinder-interface C-seal is a patented sealing device* fabricated of Inconel X-750 in a fully heat-treated condition. This seal, when compressed to the vane design zero position (a condition that requires yielding of the C-seal), exerts an ~ 325 -kg/cm contact force.

Vacuum System

The vacuum environment needed to permit the RFQ's high-power rf operation is provided by two 9000 l/s (condensable gas) helium refrigerator cryopumps, mounted on the rf manifold. Each pump communicates with the manifold through machined slots in the manifold wall of ~ 1850 l/s conductance. The rf coupling slots in the vane-cavity cylinder provide a >1800 -l/s calculated conductance to its interior. Pressure measurement of the vacuum system operation is provided by Bayard-Alpert-type hot-cathode ionization gauges in the manifold-pump ports. Manifold and cavity vacuums $<5 \times 10^{-8}$ torr were expected, on the basis of

Fig. 4. ATS RFQ assembly.

*Industrial Plating Inc., Seattle, Washington.
†UDYLITE bright-acid-copper formula HS.

*Pressure Science Incorporated, Beltsville, Maryland.

calculations, using measured outgassing rates for clean, unbaked, copper surfaces of 4×10^{-10} torr l/s.

Capacitor Fabrication

The RFQ cavity support capacitors provide support for the cavity inside the rf manifold and tuning of the rf manifold. These capacitors, are fabricated of copper-plated carbon steel. After copper plating, the components are hydrogen-furnace brazed with CuSi1.*

RFQ Assembly

RFQ assembly was accomplished in subassembly steps. The vanes were first loosely mounted in their respective upstream and downstream vane-cavity/cylinder sections. The two sections then were joined at the cylinder's attachment ring, and the C-seals were inserted under each vane; the vane-mounting bolts then were tightened to a predetermined torque. Woven wire-mesh rf gaskets† were incorporated into all other rf current-carrying joints. The vanes were optically aligned to the "best" straight line in a quadrature configuration with appropriate targets in each end of the vane-cavity/cylinder. Further alignment to position the vanes at their required tip-to-tip spacing was accomplished with the aid of go-no-go plastic pin gauges inserted through the cylinder coupling slots, while adjusting the C-seal compression with the vane-mounting bolts. Final vane adjustment was performed during rf tuning of the vane-cylinder/cavity. Final RFQ tuning resulted in an ~ 423.4 -MHz resonant frequency and a >7500 Q. After we tuned the vane-cavity/cylinder, the completed assembly was installed in the rf manifold by placing both in a vertical position and lowering the vane assembly into the manifold with an overhead vane. Vane-cavity end-support/rf-manifold tuning capacitors were installed during this procedure; the completed RFQ assembly, tuned with these capacitors, was the final assembly step before installation on the ATS. Figure 5 shows the RFQ assembly mounted on the ATS.

During initial RFQ tuning, we determined that the previously noted vane-straightness deviation generated mixed dipole-quadrupole rf excitation of the RFQ vanes. Vane potentials observed in the RFQ vary by $>30\%$ from design values. Effects of vane potential variations are being investigated further because they relate to mechanical alignment requirements as well as RFQ performance. Several modifications being considered to correct these effects are modification of the C-seal seat to permit greater compliance, repair of the crooked vane to bring it within design specifications, installation of periodic vane-shorting rings at each coupling slot position to provide dipole-mode shorting along the RFQ's full length, and enlarging of the aperture in the wave-guide to manifold-cylinder transition.

Operation

Initial RFQ operation revealed vacuum operating levels $<5 \times 10^{-8}$ torr with "heated" water (120°F) used in the cooling circuits to enhance system cleanup. Operation under high-power rf conditions indicated some sparking. An ~ 150 -h conditioning period was adequate to reduce sparking to an insignificant degree. An interesting observation made during the conditioning procedure indicated better sparking stability at elevated water temperatures; the RFQ is now operated at 110°F. On-line system Q >8000 is routinely

Fig. 5. RFQ on the ATS.

observed through VSWR measurements in the rf system wave guide, at power levels >700 kW in the RFQ assembly. Detailed discussion of the RFQ operation is beyond the scope of this paper.

Conclusion

The ATS RFQ incorporates a number of features that simplify fabrication and assembly. Included are the use of copper-plated carbon steel rf structures, demountable, adjustable vanes using copper-plated C-seals, minimum use of brazed components, application of an advanced numerically controlled milling machine for vane modulation generation, and straightforward high-vacuum pumping apparatus. The RFQ thus produced has performed in accordance with analytical beam dynamics simulation and as an accelerator system in accordance with design analysis predictions.

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References

1. C. W. Fuller, S. W. Williams, and J. M. Potter, "Mechanical Design Considerations in the FMIT RFQ Developments," Proc. 1979 Linear Accelerator Conf., Montauk, New York, September 10-14, 1979, Brookhaven National Laboratory report BNL-51134, p. 401 (1980).
2. K. R. Crandall, R. H. Stokes, T. P. Wangler, "RFQ Final Design for Group AT-2," Los Alamos National Laboratory, Accelerator Technology Division, Group AT-1 memorandum No. 81-38 (February 2, 1981).

*CuSi1, Western Gold and Platinum, Belmont, California.
†TECKNIT, Santa Barbara, California.