COMPONENTS FOR CW RFQ'S*

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Abstract

Many components have been designed and tested in cw operation using the RFQ1 accelerator structure as a test bed. Improved VCR's (vane-coupling-rings) have been in service for over a year with no sign of deterioration. Dynamic tuners were developed and performed flawlessly at cw power levels approaching 8 W/cm^2. Recently, the design of the drive loop has been modified after some problems were encountered in operation. Calculation of the field enhancement at the end of the vane showed that the racetrack-shaped gasket, which makes the rf and vacuum joint between the tank and the vane, withstands a factor of 5 higher power density than expected.

Introduction

The RFQ1, a 75 mA cw proton accelerator, has been used as a test bed for developments aimed at building a firm technological base for the design of cw RFQ's. Components such as rf drive loops, slug tuners, vane-coupling-rings (VCR's), rf and vacuum joints have been designed, tested and improved.[1] The design features of these components, their recent performance in testing and operation, and design improvements, will be discussed in this paper.

RF Drive Loop

The drive loop, shown in Fig. 1, is mounted in one of the four centre ports of the RFQ. The inner and outer conductors of the drive loop are water cooled. The vacuum window is an air-cooled ceramic (99.9% alumina) cylinder. Mechanical clamps engage split rings seated in grooves near the ends of the ceramic cylinder to compress O-rings and make the vacuum seals. This type of removable joint permits easy disassembly of the loop for inspection or servicing.

The loop conductor is cooled by the main assembly cooling circuit. The loop body, sized to compensate for the open volume of the port, maintains the correct rf field balance and frequency for the tank.[2]

The original loop design operated without any major problems for about 2 years at cw power levels up to 175 kW. However, after a 2-month shutdown, attempts to recondition the RFQ were unsuccessful and excessive arcing was observed in the drive loop. Upon disassembly of the loop, the section of the ceramic cylinder facing the tapered portion of the inner conductor was found to be heavily coated with copper (about 0.03 mm thick) which had sputtered from the neighbouring copper surfaces on the inner and outer conductors. The loop was refurbished by grinding and cleaning the inside of the ceramic cylinder and smoothing the eroded copper surfaces.

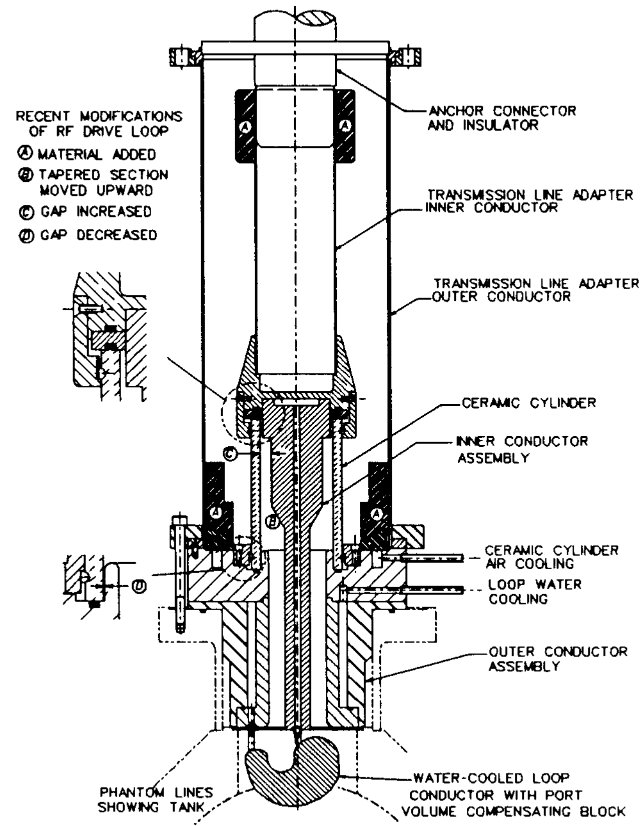
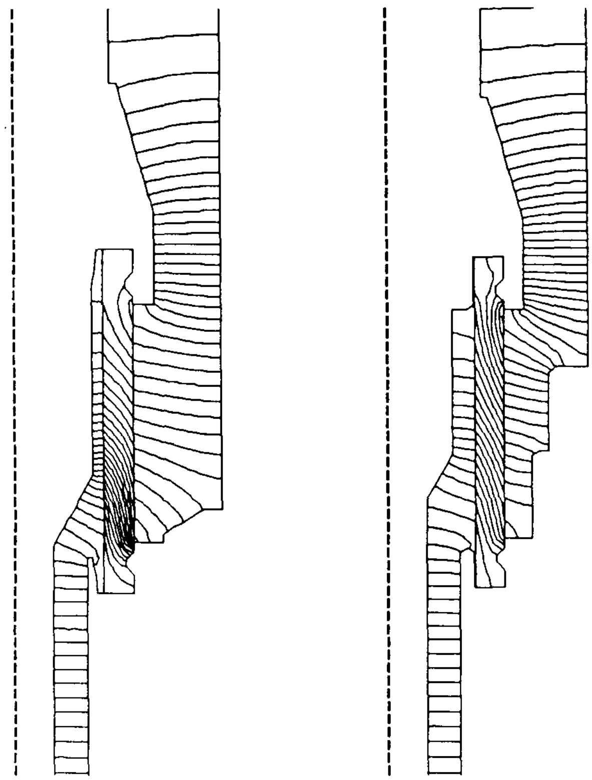


Fig. 1. RFQ1 drive loop

When the loop was re-installed, only a few tens of watts could be delivered to the RFQ. Much higher power could be delivered without vacuum in the RFQ, indicating that multipactoring was the likely cause of the problem. The ceramic cylinder was coated with chromic-oxide to reduce secondary electron emission, but no improvement was observed. The ends of the RFQ were then opened for a thorough cleaning of the interior surfaces in the region of the end tuners and VCR's. It was then possible to break through the multipactoring levels, and a tank power of about 100 kW (80% of normal operating level) was reached before a large vacuum leak developed in the loop after more arcing. The ceramic had fractured, presumably due to thermal shock in the region where copper had again sputtered on the inner surface. The geometry of the loop conductors in this region was then modified in an attempt to decrease the field intensity. This changed the pattern of copper plating and erosion, but did not prevent the arcing or eventual destruction of the ceramic.

*This work was partially supported by Los Alamos National Laboratory under contract No. 9-X5D-7842D-1.

Most recently, the loop was modeled using the new code SEAFISH, a SUPERFISH-like code able to compute complex-valued travelling-wave rf field distributions and VSWR's.[3] The calculations showed an electric field concentration at the end of the ceramic cylinder where fracturing occurred (see Fig. 2a). They also indicated that the modifications highlighted in Fig. 1 would improve the design by: (i) giving a more uniform rf field distribution through the ceramic (see Fig. 2b), which would reduce the field stress by a factor of 2; (ii) improving the match of the loop (from a VSWR of 1.66 to 1.07) ; and (iii) eliminating standing waves between the ceramic and the loop termination. A loop with these modifications is presently being tested on RFQ1.



(a) (b)

Fig. 2. Rf field distribution in the gap between inner and outer conductors and through the wall of the ceramic window a) before modification b) after modification

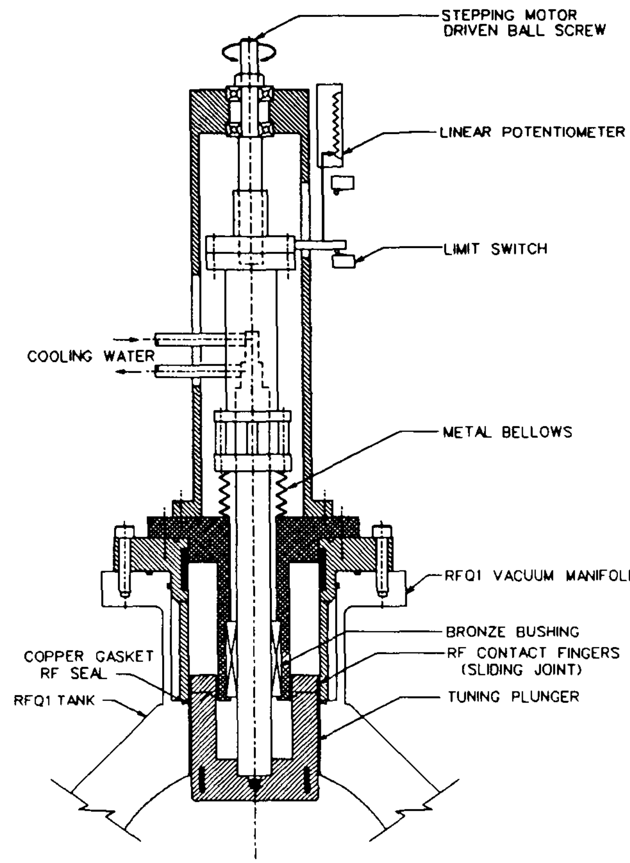


Fig. 3. RFQ1 dynamic tuner

Dynamic Tuners

One static plug-tuner is mounted in the RFQ1 centre-port directly opposite to the rf drive loop and 2 motor-driven plug-tuners (see Fig. 3) are installed in the adjacent ports. The tuning plunger diameter and the plunger-to-tank gap are 96.4 mm and 1.0 mm, respectively. The design mechanical stroke and speed of the dynamic tuners are ± 20 mm and 2.5 mm/s, respectively.

Figure "H" contact fingers are used at the plunger sliding joint. The fingers are cooled by direct conduction to the outer cylinder and plunger. Water channels in the outer cylinder and a coaxial flow circuit in the centre shaft of the tuner provide good cooling of all parts exposed to significant rf heating. A bronze bushing, located close to the front end of the tuner, keeps the various moving parts concentric and assures uniform compression of the sliding contact fingers. The surfaces that they contact are made of solid OFHC copper to provide good electrical conductivity. Stainless steel walls on the cavity behind the contacts attenuate any rf field that may leak past the joint. A metal bellows, remote from rf fields, forms the flexible vacuum barrier.

Positioning of the tuning plunger is by a ball nut and screw, directly driven by a stepping motor. A motion control indexer-module, a linear-potentiometer, limit-switches and a fail-safe brake are the critical components of the position control system.

During commissioning, insertions to 9.6 mm and retractions to 7.6 mm, from a position flush with the tank wall, were tested. Moved in tandem, the 2 tuners changed the tank frequency by 625 kHz. Moved in opposition (one inserted, the other retracted) a dipole field of up to 10% was introduced. The tuners performed flawlessly up to cw power levels approaching 8 W/cm^2 (1.6 Kilpatrick vane tip fields). The tuner moved smoothly under high power, with no indication of sparking. Visual inspection of disassembled components after the tests revealed no sign of damage.

VCR's

A pair of VCR's are used at each end of the RFQ1 vanes to suppress dipole components in the RFQ field.[1] These are made of 6.3 mm OFHC copper tubes, which are water cooled by bypassing the flow from cooling channels on the connected vanes. The water-to-vacuum joints are soft-soldered to allow easy removal, and we had problems with the solder melting during the first year of operation. Since then, the VCR design has been improved by: (i) increasing the joint diameter to decrease the current density; (ii) using a tin-silver solder (Mattisol-E) instead of the lower-temperature, 50/50 tin-lead solder; (iii) copper-plating the soldered joints (using a brush-plating technique) to lower surface resistance; and (iv) increasing the VCR to end-tuner-post gap to decrease the current due to the capacitance coupling. The improved VCR joints have been in service for over a year with no sign of deterioration.

RFQ1 "Racetrack" Seals

Racetrack-shaped gaskets, made from 1.5 mm thick OFHC copper, are compressed against sealing edges at the bottom of the vanes and on the tank, to make rf and vacuum joints.[4] They are cooled by conduction to cooling channels in the vanes, tank and clamps. Overheating of the gasket at the end of the vane is still a factor limiting the cw operating power on RFQ1. Recent MAFIA calculations have confirmed that overheating is due to field enhancement in the vane-end region, which was not accounted for in the original cooling design of the tank and vanes. The predicted power density at the bottom-end corner of the vane and on adjacent surfaces of the copper gasket is a factor of 5 higher than anticipated in the original design. The racetrack-shaped gaskets have thus proven they are able to withstand much higher temperatures and thermal gradients than expected.

Since replacement of the vane seals in early 1989, there has been only a minor vacuum leak at the high-energy end of one of the vanes. Torquing the three bolts nearest the end of the vane an additional 5% cured the leak and there have been no reoccurrences in the past year.

Discussion And Conclusions

RFQ1 has proven to be a valuable test bed for high-power cw RFQ components. Detailed designs for dynamic tuners, rf drive loops, VCR's and racetrack-shaped copper seals have been developed, tested and improved for cw operation up to 150 kW, 10% above design power. Although recent problems with the operation of the drive loop have interrupted operation of the facility, we are gaining a better understanding of this critical component and are establishing the utility of the SEAFISH code for rf component design and analysis.

Acknowledgments

Special acknowledgment to R.M. Hutcheon, J.C. Brown and J.Y. Sheikh for their support in rf design, to M.S. de Jong for his support in rf computer simulation, to E.C. Douglas for his assistance in mechanical design, to L.F. Birney, A.D. Davidson and B.H. Smith, who assembled, tested, and maintain the facility, and to the staff in the Accelerator Physics machine shop who built, repaired and modified the components.

References

1) G.E. McMichael, G.M. Arbique, J.C. Brown, B.G. Chidley, R.M. Hutcheon, M.S. de Jong and J.Y. Sheikh, "Exploring the Beam Parameter Space of a CW RFQ Proton Accelerator", Proc. 1989 IEEE Part. Acc. Conf., 2, 980, 1989.

2) B.G. Chidley, G.M. Arbique, R.M. Hutcheon, G.E. McMicheal and J.Y. Sheikh, "RF Tuning and Initial CW Operation of RFQ1", European Particle Accelerator Conference, Rome, Italy, June 1988.

3) M.S. de Jong, private communication.

4) G.E. McMichael, B.G. Chidley, R.M. Hutcheon and T. Tran-Ngoc, "RFQ1 Fabrication and Low Power RF Tuning", Proc. 1987 IEEE Part. Acc. Conf., 3, 1875 (1987).