

STATUS REPORT ON FMIT

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Summary

The Fusion Materials Irradiation Test (FMIT) Facility will use a 35-MeV deuteron beam and molten lithium target to generate 14-MeV neutrons for materials damage studies. Operation of the 2-MeV accelerator began in May 1983 and lasted until November. RFQ operation using pulsed rf power demonstrated the basic integrity of the design by producing a 2-MeV beam with acceptable transmission efficiency. In the evolution towards cw operation, a few areas with inadequate thermal characteristics were identified. During the 3-month period following November, the RFQ was disassembled to replace an overheated O-ring that had led to a loss of vacuum integrity in November and to make minor improvements that will enhance the thermal stability of the RFQ. Improved methods for tuning both the manifold and core tanks were developed. Resumption of testing began in March 1984.

The design of the components required to extend the accelerator to 5-MeV is complete. The design of the linac tanks for the 35-MeV accelerator is complete. Procurement of these tanks and the design and procurement of the remaining 35-MeV components will be initiated as soon as funding becomes available.

Introduction

Starting in late May 1983, a series of tests was conducted to demonstrate the performance of the FMIT RFQ. Using a cw beam from the injector and pulsing the rf at 3.5% duty factor (7 ms at 5 Hz) the beam was accelerated to 2 MeV with transmission efficiency $\approx 70\%$. Difficulties in pulsing the injector beam led to this mode of operation and also prevented proper matching of the beam to the RFQ; hence, the transmission efficiency was low. In July the testing program was redirected towards obtaining cw operation at the 350-kW design rf power level. The program was terminated in November by a vacuum leak at the end closure of the manifold tank. During this period the average power was increased to 150-kW cw rf operation. Increase of the average power was limited by outgassing and by thermal overheating of some components. Sparking in the RFQ was a problem, only following increases in power level, and quickly subsided in a manner similar to the rf conditioning of other structures. Sparking was at no time a limiting factor in the conditioning process.

Repair of the vacuum seal required removal of the RFQ from the beamline and at least partial disassembly; therefore, an extensive inspection of all internal surfaces was performed, especially for those regions known to be overheating. This inspection resulted in the following observations:

- The gold wire used for the rf joint on the end closure for the manifold tank was melted in the area of the access boxes used to connect water cooling to the vanes. The resultant overheating of the Viton O-ring and its exposure to the rf fields caused its destruction and the loss of vacuum integrity.
- The tuning straps on the ends of the vanes, which were used to obtain the proper operating frequency and field configuration required for the RFQ, had severely overheated. One strap had melted through.
- Discolorations in the form of narrow circumferential bands in corresponding locations on both the core tank and manifold tank apparently are due to single-surface multipactoring. The bands are near

the rf coupling slots in the core tank where the rf current is a maximum and the electric field passes through a node.

- In general, the condition of the four slug-tuners was good; however, some overheating of the current shunting straps was evident on one of the tuners. These straps were installed during the test program to shunt rf current from the stainless steel bellows in the mechanical movement mechanism, which had been overheating.
- Because of the overheating of the vane tuning straps, some of the nylon pins that were used as retainers for the gold-wire rf seal during installation had carbonized. This carbonization undoubtedly contributed to the outgas rate and is consistent with the data from the residual gas analyzer that had shown evidence of organic decomposition in the RFQ during the conditioning process.

Each of the observations above has led to modest redesigns. The basis for each improvement incorporated into the RFQ is described below.

Manifold Tank

The overheating of both the gold rf seal and the Viton O-ring led to the vacuum failure, forcing cessation of the conditioning program. During the tests, an external map of the RFQ's surface temperature had located this problem. It was correctly hypothesized at that time that the effect was related to the perturbation caused by the vane cooling access boxes in the manifold tank at the low-energy end of the RFQ. Further, these boxes were cooled only by conduction through contact with the outer wall of the core tank.

Overheating during conditioning had extruded a section of the gold-wire rf seal under one of the box cover plates in such a way that it shorted the box to the adjacent capacitor plate and detuned the manifold. Removing this section of the gold wire restored the manifold-tank tuning and allowed some further testing until the O-ring failed.

A thorough SUPERFISH analysis of the manifold tank has been made. Such study is difficult and somewhat indirect because this is a three-dimensional problem, but our codes are only two dimensional and assume certain basic symmetry characteristics in the calculations. These studies revealed a power density peak between the access box corners and the manifold-tank wall, well above the design value. The original access boxes were replaced with an improved design of minimal profile. A factor-of-5 reduction in peak surface power is expected from this improvement. In addition, the cover plates are directly cooled by circulating of water through new cooling tubes attached to them.

One other improvement in the manifold tank was made. The parallel-plate tuning capacitor (one plate attached to the manifold tank, the other to the core tank) was replaced with a coaxial design. This improvement permits the three sections of the manifold tank to be welded into a single continuous cylinder and allows the manifold tank to be installed over the core tank as a single unit, not only easing the assembly, but also eliminating the four gold-wire rf seals that were required to mount the capacitor plate to the manifold. The parallel-plate capacitor also had acoustic mechanical modes of oscillations that were excited in pulsed rf operation. These oscillations were observed

as 5- to 8-ms variations in the RFQ resonant frequency. The rigidity of the cylindrical capacitor should eliminate this effect.

RFQ Core-Tank Tuning

The severe overheating of the tuning straps used in the original tuning of the RFQ core tank dictated either an improved method of cooling the straps or the development of an alternative method of tuning. Although direct water-cooling of the straps is possible, the mechanical engineering is complex. Further, installation of the straps also prevents additional vane adjustment. Perturbation measurements showed the compression of the magnetic flux by the straps to result in a power density at the vane ends about five times higher than the corresponding regions between the vanes.

Because the straps have so many disadvantages, alternative methods of tuning the RFQ were examined. The RFQ's resonant frequency was already below 80 MHz, and most tuning mechanisms tend to lower the frequency further. Hence, to raise the frequency, it was necessary to increase the vane separation by 0.4 mm from the theoretical position. Extrapolations based on the performance of the proof-of-principle RFQ indicate that this method has a negligible effect on beam quality and RFQ performance and raises the resonant frequency of the RFQ above 80 MHz and opened the door for several alternative tuning schemes, two of which were identified as promising.

It was discovered, through discussion with another RFQ development group, that cylindrical slugs mounted on the RFQ end flanges would be effective in redistributing the rf fields. If these slugs were placed in the magnetic field's radial maxima, the field tilt could be controlled nearly independently of the frequency because the frequency shifts of each type of tuning (inductive and capacitive) are opposite in sign.

During experimentation with these tuning slugs, it also became evident that overall movement of the vanes was effective in tuning the structure. Vane movements (in-out and tilt) of only 0.2 mm or less are effective in achieving the proper quadrupole field and longitudinal field distributions. The adjustment screws were redesigned, and the vanes were modified to allow easier adjustment. Tuning was accomplished by moving the vanes instead of adding tuning straps or slugs.

Multipactoring

Multipactoring was not a serious problem during the initial test program. Multipactor effects were observed only during operation below 100 kW. Break-through was achieved by overshooting the rf power during the start of the pulse. The evidence of single-surface multipactoring on the circumferences of both the core and manifold tanks, mentioned above, probably is the source of the phenomena observed below 100 kW. Titanium nitride coating of rf surfaces has been shown to be very effective in eliminating multipactoring. All surfaces of the FMIT RFQ were so coated. An ancillary effect should be a significant reduction in the outgas rate.

Slug Tuners

In addition to the minor slug-tuner problems mentioned above, heating of the steel mounting plate had occurred during the tests. The mounting plates were plated on both surfaces with about 0.5 mm of copper to decrease the electrical resistance and increase thermal conductivity. During the final tuning of the RFQ in March 1984, it was discovered that the braided copper straps (that had been installed to prevent overheating of the slug-tuner bellows) introduced an undesirable rf mode of oscillation. For a position of the slug

tuner, the volume behind the tuner resonated very strongly--close to the 80-MHz operating frequency. The short braided straps were replaced with long flat strips of beryllium/copper, which lowered the mode frequency well below 80 MHz.

Outgassing Considerations

Outgassing was the major limiting factor in the rf conditioning. Undoubtedly, some of the gas evolution was due to overheating the tuning straps and overheating near the manifold tank vane-cooling access boxes. In addition, three of the slug tuners and the high-energy end closure for the core tank were fabricated, using hydrogen furnace brazing. Because the residual gas analyzer showed hydrogen to be the predominant component (~99% during conditioning), the slug tuners and end closure were furnace baked at 400°C for 24 h to eliminate the absorbed hydrogen.

Miscellaneous Enhancements

Even though the thermal analyses show the vane bases to be adequately cooled by thermal conduction, our experience with the tuning straps has convinced us to enhance thermal stability of this critical area by attaching copper water-cooling tubes to the inner surfaces.

Six rf monitor loops are also being installed on each of two opposing vane bases. The three loops on each side (located at the center and near each end) will allow direct determination of the rf field levels inside the RFQ. In addition, four penetrations were made in the manifold tank located azimuthally between the slug tuners to allow electric field sensing of the manifold fields. These monitors will be used to ensure that the slug tuners are positioned to give cylindrically symmetric fields in the manifold.

Conclusions

The data from the test program and the detailed inspection indicate that the basic engineering design of the RFQ is sound, and that the performance was close to that expected. The thermal difficulties, although dramatic in consequences, require only minor configuration alterations to correct. The configuration of the injector system and control system has been described before.¹ Except for the inability of the injector to provide a pulsed beam, both systems functioned well. In particular, the control system was invaluable in monitoring the accelerator status and in providing a data log of selected accelerator parameters.

The time-of-flight energy-measurement system provided a measure of the beam energy that agreed very closely with an independent measure of the beam energy using a magnetic deflection method. The light from beam-induced excitations of the residual gas provided a relative measure of the transmission efficiency as a function of input rf power. Some improvements in the beam-position monitor systems and in the beam-current transformer electronics were indicated by the tests; these improvements are now being implemented.

In general, the rf power system functioned very well. Operation in the pulsed mode ranged from 100- to 400-kW with pulse lengths from a few tens of microseconds to 12 ms. Operation in the cw mode was limited by the RFQ structure to 160 kW.

Reference

1. D. D. Armstrong, "The FMIT Accelerator", Proc. 1983 Particle Accelerator Conf. May 21-23, 1983, Santa Fe, New Mexico, IEEE Trans. Nucl. Sci. **30** 2965 (1983).