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CW RF OPERATION OF THE FMIT RFQ*

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Summary

The 80-MHz RFQ for the Fusion Materials Irradiation Test Facility prototype accelerator has been rf conditioned for cw operation to the design field level of 17.5 MV/m (1.68 x Kilpatrick limit). Experimental results and operating experience will be discussed.

Introduction

The FMIT RFQ is an 80-MHz device consisting of two resonators: the core tank that contains the four-vane structure, and the manifold tank that is driven by the rf amplifier. The manifold tank surrounds the core tank, and the rf power is coupled between the two tanks by eight 45° slots in the core-tank wall.[1] At present, the RFQ is driven by an amplifier chain that uses an EIMAC 8973 final output stage capable of generating over 600 kW cw.[2] After extensive operating experience and a variety of thermal-related problems with the RFQ (necessitating some minor mechanical modifications), more rf diagnostic capabilities were added to the structure.

Diagnostics

Three rf monitor loops were added to each quadrant of the core tank. These loops were located near the core tank wall along the vane bases of the top and bottom vanes. One loop was located near each end of the vane base and one near the center.

The monitor loop design is shown in Fig. 1. All 12 signals are routed through the upstream end wall through SMA-type feedthrough connectors. Equal-length semirigid coaxial transmission lines connect the 12 monitor loops to two 6-position electrically actuated coax switches. The single output signal from each coax switch is transmitted through an RG-8/U cable to the low-power rf rack. In the rack, the signals are monitored by the facility control computer system.

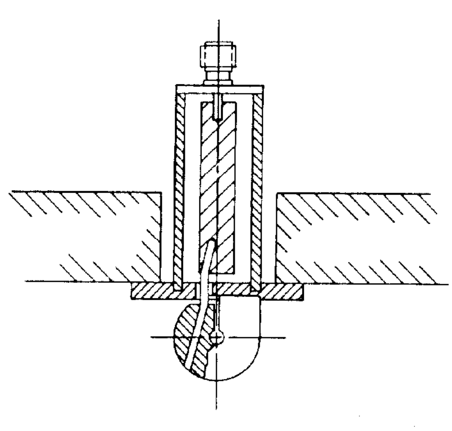

Fig. 1. RFQ monitor loop.

One additional monitor loop is located on the top of the left vane (looking downstream) at the center of the vane base length. This signal also is routed through the end wall but is not switched. It is transmitted through phase-stable, foam-flex cable directly to the low-power rf racks. This signal is used as the feedback signal for the phase and amplitude control systems as well as the reference signal against which all the other loops are compared.

Four electric-field probes are symmetrically positioned (between the four slug tuners) around the circumference of the manifold. These probes are monitored through a third coaxial switch. Two additional monitor loops located along the manifold tank are connected to this switch.

All of the monitored rf signals are routed to the low-power rf racks where they are split several ways. One output of each splitter is detected with a calibrated diode detector for pulsed measurements. Another splitter output is applied to a bolometer-type power meter. Processed signals are then fed to the facility control system computer that logs the information. The computer automatically operates the coaxial switches to obtain the data on the RFQ fields. All of these signals are sampled at 5-min intervals. These signals also can be manually selected and observed on a video monitor. The computer monitors forward and reverse power (from which it calculates VSWR), vane temperature, and frequency. Unprocessed rf signals as well as the diode detector outputs can be monitored with an oscilloscope.

Operating History

The RFQ has logged approximately 600 h of pulsed operation, and 400 h of cw operation at 350 kW. Operation of the rf system is becoming routine as weaknesses in the system are eliminated.

RFQ operation consists of turning on the rf system in the pulsed mode and pulsing it high enough in power to get above the multipactoring regime and long enough for the field level to reach a steady-state value in the structure. This procedure results in a pulse of about 150 μs and a power of 200-600 kW. The RFQ amplitude feedback control is adjusted to provide enough overshoot at turn-on to get through multipactoring and to then return to the design field level. The resonant frequency is found by adjusting the frequency of the signal source until a feedback signal is seen in the core tank through the reference monitor loop. Once the approximate resonant frequency is found in this manner, the frequency is further adjusted to find a minimum in the reflected power signal. The pulse width is then slowly increased as RFQ sparking and VSWR conditions allow. The core-tank sparking is observed with a TV camera that views one quadrant and the inter-vane region of the RFQ. When no sparking is observed for 2 min, the rf duty factor is increased by 5%. During the transition from cold to equilibrium cw operation, several factors change. The RFQ vane bases show a several hundred degree Fahrenheit increase in temperature. The RFQ resonant frequency drops approximately 200 kHz. The VSWR typically changes from 1.8 to 2.1, overcoupled, causing the incident rf power to increase noticeably to maintain constant core fields. Once cw operation at the desired field level is achieved, the beam is turned on; 20 mA of beam current causes a 3-kHz decrease in

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frequency and the expected increase in forward power, moderated somewhat by the decrease in VSWR, from about 2.1 to 1.8.

Having monitor loops in the core tank proved to be quite useful during the early operating history of the RFQ. Although the computer was not logging the data in the beginning, we used the computer as a monitor.

As an example, at low-power (less than 100 W) all monitored signals were within 2 dB, and the measurements were repeatable within 0.25 dB. However, after a few hours at 150 kW, only one quadrant remained relatively stable. The signal strength doubled at the upstream end of a second quadrant and dropped to roughly one-fourth the normal level in the remaining two quadrants. Subsequent operation at a lower power showed that the original pattern had been restored, but when high-power operation was again attempted, a similar shift was noted. Shortly thereafter the RFQ was disassembled, and cracking was discovered at the base of the manifold tuning capacitor. After extensively redesigning the tuning capacitor, the structure behaved well, even at twice the power level (300 kW). The data in the following figures, 2 through 7, were taken after this modification to the RFQ.

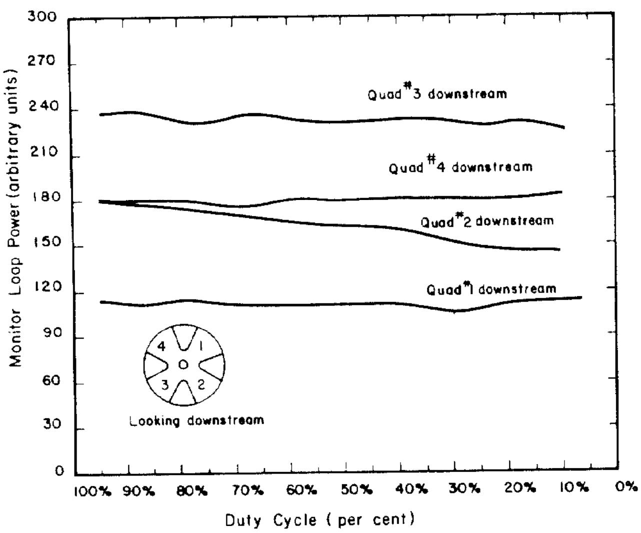

Fig. 2. Downstream monitor loop power signal as a function of rf duty cycle (average power).

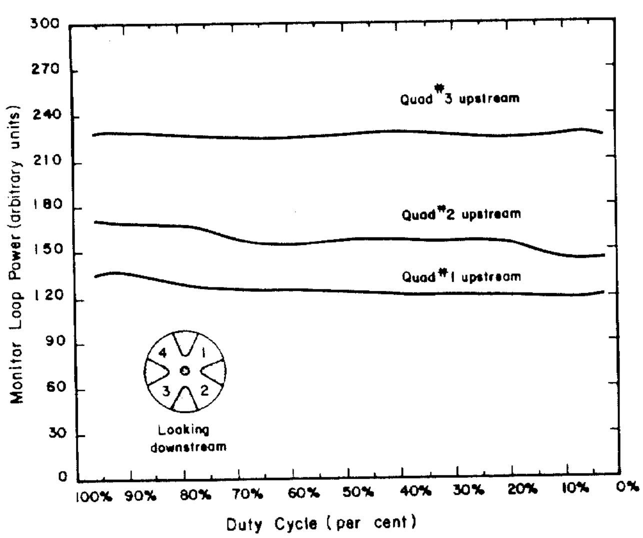

Fig. 3. Upstream monitor loop power signal as a function of rf duty cycle (average power).

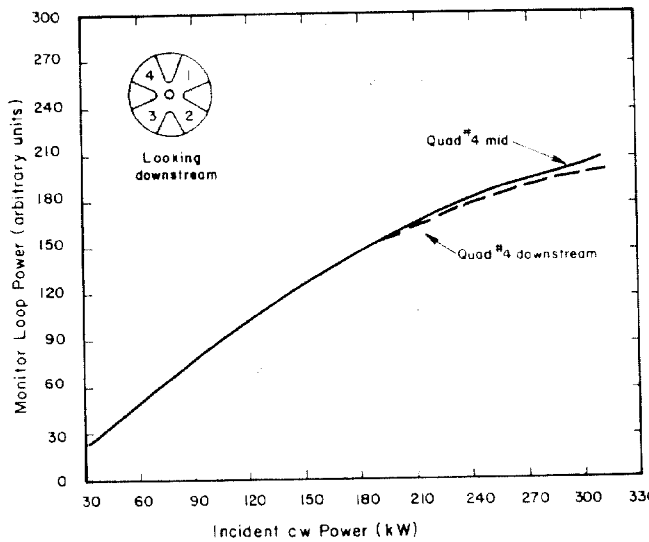

Fig. 4. Monitor loop power signals in quadrant #4 as a function of cw power level.

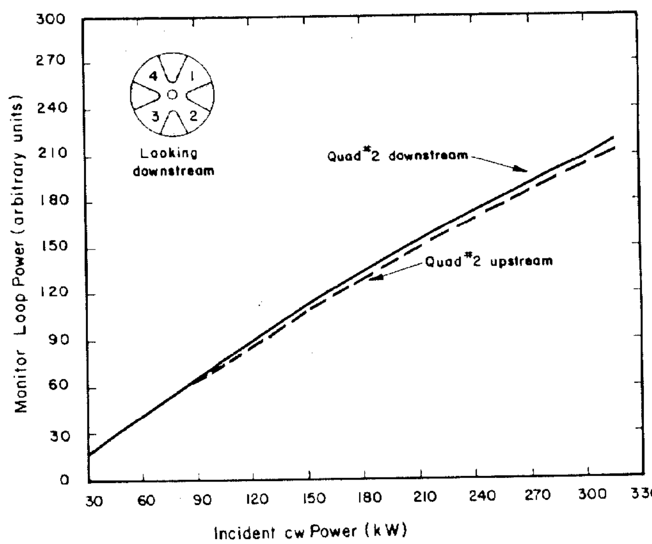

Fig. 5. Monitor loop power signals in quadrant #2 as a function of cw power level.

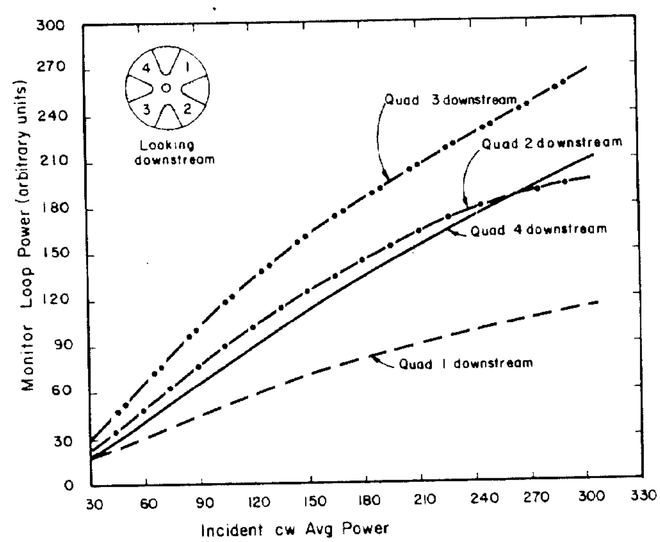

Fig. 6. Downstream monitor loop power signals as a function of cw power level.

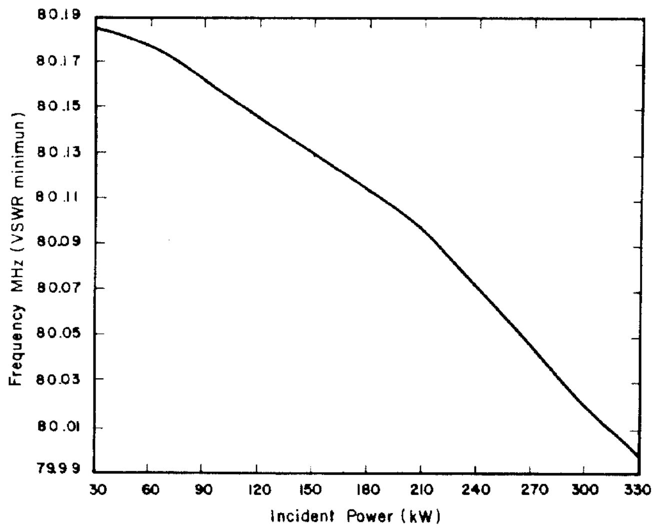

Fig. 7. RFQ resonant frequency as a function of cw power level.

Having the field monitor loops in the RFQ enabled us to observe rf field behavior in the structure as input power level was changed. We could calibrate the monitor loops at low power, then observe how the fields shifted in the structure as average power was increased. In the first test run, the RFQ initially was run at full cw power. The duty factor was then reduced in 10% increments by reducing pulse width while maintaining peak power. At each duty factor setting, the computer logged the monitor-loop power signals from both the upstream and downstream ends of the RFQ. Data from the downstream end are shown in Fig. 2 and from the upstream end in Fig. 3. In this test run, the core-tank field was held constant by the amplitude control system employing the unswitched monitor loop in the center of the RFQ as the feedback reference.

Core-tank quadrants are numbered 1 through 4 moving clockwise from vertical, looking downstream. Figure 3 has only three curves because the upstream loop in Quadrant 4 did not function. It should be observed that the upstream and downstream ends of the same quadrants tracked each other well as the duty factor was changed. Power in Quadrant 2 appeared to decrease relative to the other three as the duty factor was reduced (while maintaining the same peak power), perhaps indicating a change in tuning caused by reduced or asymmetric thermal loading.

Another test run was made with the rf operated cw, but with the rf input power stepped from 30 to 330 kW. The fields along each quadrant were observed, as well as the quadrant-to-quadrant power balance. Figure 4 shows the monitor-loop signal power level for Quadrant 4, and Fig. 5 shows the results for Quadrant 2. The field level in a given quadrant stayed very uniform throughout the range of input powers. Note that the slopes of the curves in Figs. 4 and 5 are slightly different. The significance of this slope difference is seen in Fig. 6 where the monitor-loop signals at the downstream end of each quadrant are plotted. All signal levels increase monotonically with increasing input power level, but there is actually a crossover between signals from Quadrants 2 and 4. This behavior is consistent with the data in Fig. 3 that show Quadrant 2's power level dropping relative to the other three as average power was reduced. This measurement has been verified several times. Figure 7 shows the decrease in operating frequency of 200 kHz as the average power level increases from 30 to 350 kW. It should be noted that the slope of the frequency versus power curve changes considerably, by a factor of approximately 2.5 over this power range. There are two distinct points of inflection on this curve. We cannot make a definitive statement about the cause of this behavior except that the RFQ is a very complex resonant structure with two interacting cavities: the core and the manifold. The RFQ also has a complex cooling system. Both the rf and thermal characteristics interact to produce the complex frequency behavior we see in Fig. 7.

Conclusion

The FMIT RFQ is being routinely operated at a full cw power level of 350 kW. Diagnostics that have been incorporated into the design have been very helpful in dealing with the problems encountered during the rf commissioning of the structure.

Acknowledgment

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References

1. D. D. Armstrong, "The FMIT Accelerator," IEEE Trans. Nucl. Sci. 30 (4) August 1983, 2965.

2. R. F. Nylander, M. V. Fazio, F. F. Bacci, and J. D. Rogers, "Performance Tests of the 600 kW CW, 80 MHz, Radio-Frequency Systems for the FMIT Accelerator," IEEE Trans. Nucl. Sci. 30 (4) August 1983, 3438.