ANALYSIS OF HIGH-POWER CONDITIONING FOR ACCELERATOR CAVITIES USING A SIX-PORT REFLECTOMETER*

G. O. Bolme, P. M. Denney, W. D. Gutscher, S. P. Jachim, K. F. Johnson, C. K. Little, R. D. Patton, A. H. Regan, and O. R. Sander
Los Alamos National Laboratory, MS H818
Los Alamos, NM 87545

Abstract

An rf structure's capability to sustain high-power rf operation without sparking is one measure of the conditioned state of an rf accelerating cavity. High-power impedance measurements from a six-port reflectometer developed for the Ground Test Accelerator (GTA) program now provide additional information on the rf drive line and accelerating cavities relevant to the conditioning and reconditioning process. The information provided has been particularly useful in understanding unexpected power consumptions and decreases in coupling during rf conditioning and operations and in identifying multipacting power bands.

Introduction

The conditioned state of an rf accelerating structure is normally measured and quantified by the peak-power capacity of the cavity, by the tendency of the cavity to multipactor, and by the ability of the cavity to resist high-voltage spark breakdown. Because of the limited viewing access to the cavity's interior and the limited accuracy of rf power measurements, visual observations and rf power measurements provide only limited indications of field-induced effects. Diagnostics that help quantify high-power operation would be useful to measure the conditioned state of an rf structure and could provide indications of the root causes for high-power rf anomalies.

The recent development of a six-port reflectometer [1] for the Ground Test Accelerator (GTA) provides an additional diagnostic tool useful for analyzing the performance of a resonant rf structure at high power. While operating at high power, the six-port reflectometer measures the complex impedance of the resonant rf accelerating structure. The impedance information from the six-port reflectometer complements the conventional power information for understanding the resonant structures at operational field levels.

Application

The six-port reflectometer measures and resolves both the real and imaginary components of the rf line and rf load attached to the reflectometer. As an rf diagnostic for the GTA program, it provides rf structure coupling data for the beam experiments, and it provides the data used in the feedback control of the rf structure tuners.

During high-power conditioning and operation of the rf structures, the impedance data from the six-port reflectometer has also been very useful in determining abnormal or unexpected response to the rf power. Using the six-port reflectometer data along with the system power measurements, gives a much better understanding of rf structure behavior. For the GTA rf structures, this understanding of anomalous behavior was very useful in the applications discussed below.

Identifying a Well-Conditioned Radio-Frequency Quadrupole (RFQ)

After each vacuum and temperature cycle of the RFQ, it is reconditioned back to a state in which it will maintain the design field levels at pulse lengths on the order of 500 μs. For the GTA RFQ, the design-field level is reached at a peak-power level of 63 kW; however, as a matter of practice, the reconditioning is done up to a peak-power level of 85 kW to accommodate various accelerator experiments. During the first reconditioning subsequent to vacuum and temperature cycling, we have observed that the measured cavity fields will not exceed levels corresponding to ~75 kW of consumed power, even though excess incident power (forward power minus reflected power) is applied. Under conventional conditions, excess incident power will result in high-voltage spark breakdown; however, during this reconditioning, there is the appearance of a saturation of cavity signal with no apparent sparking. As a result, there is an unexpected power loss mechanism during the initial reconditioning.

Within an hour of the initial reconditioning, the RFQ accepts power levels exceeding 85 kW, and very little evidence of the power loss mechanism remains. At this point, the RFQ is considered well conditioned and ready for beam experiments. Figure 1 depicts the RFQ response to incident rf power at 15 minutes following the initial reconditioning and after the rf structure is well conditioned.

A more complete view of the RFQ power response during reconditioning is obtained from the six-port reflectometer impedance measurement. Figures 2 and 3 show impedance after 15 minutes and 30 hours of reconditioning, respectively. From Fig. 2 we can see that there is the onset of a reactive impedance component at ~65 kW RFQ cavity power that increases through the saturation power levels. After the RFQ is well conditioned, we see from Fig. 3 that the onset of this reactive impedance component is pushed back to ~85 kW.

Although the source of the power consumption mechanism and the corresponding impedance change is unknown, the impedance measurements of the six-port reflectometer give a very clear view of the conditioned level of the RFQ.

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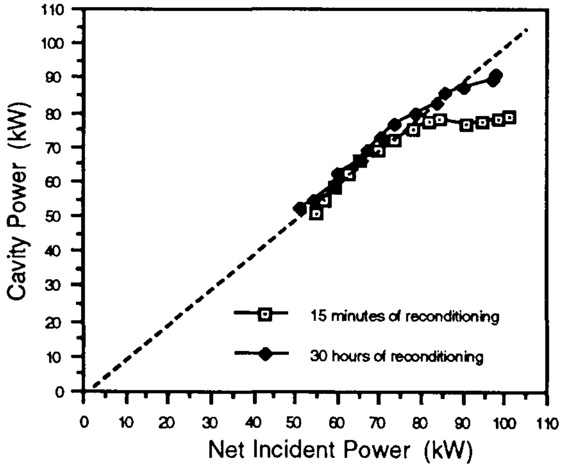

Fig. 1. GTA RFQ power response during reconditioning.

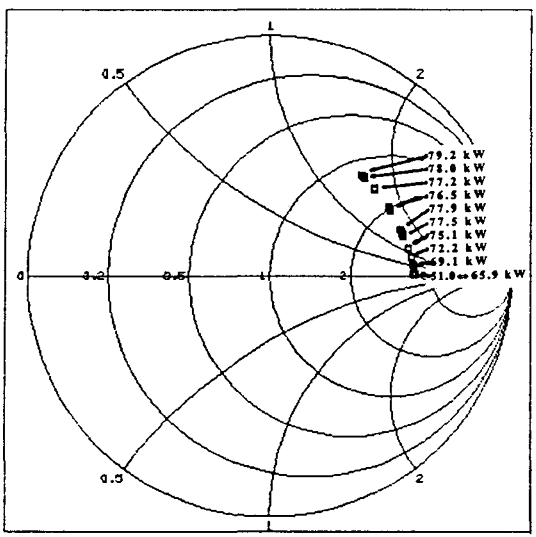

Fig. 2. RFQ impedance response after 15 minutes of reconditioning.

Identifying a Multipacting Power Band for the RFQ

During operation of the GTA RFQ, we have observed a power band over which the rf structure tends to undergo multipacting. During both initial and daily reconditioning, it is necessary to break through this multipacting band with peak powers that exceed 40 kW. After the RFQ is conditioned to accept high power, the multipacting breakdown can be conditioned away by extended pulse-length operation through the RFQ cavity power band of 8-40 kW. It is interesting that once the multipacting breakdown is conditioned away, it returns after overnight shutdowns with no temperature or vacuum cycling.

After conditioning away the breakdown in the multipacting power band, there remains an impedance response to the power band from 8-40 kW. Figure 4 displays the six-port reflectometer measurement of the drive-line coupling (β) across the multipacting band. The indication of a power response to the multipacting power band even after the multipacting breakdown is conditioned away proves the tendency of this phenomenon to recur.

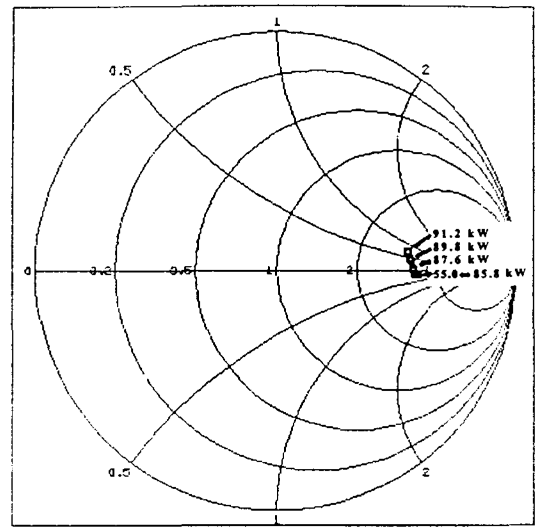

Fig. 3. RFQ impedance response after 30 hours of reconditioning.

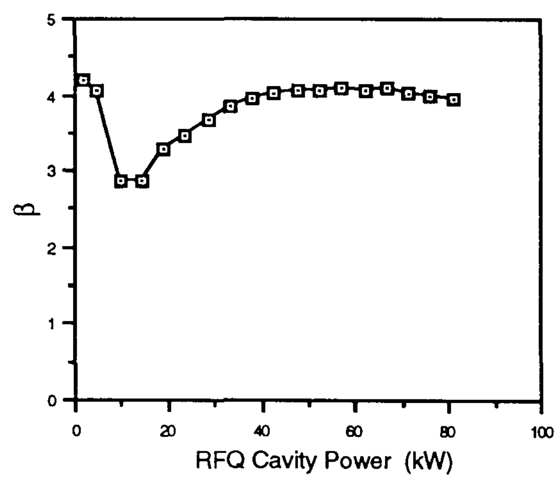

Fig. 4. GTA RFQ drive-line coupling as a function of cavity power.

Quantifying an Unusual Power Consumption Mechanism for the IMS Bunchers

An unexpected power consumption mechanism for the GTA IMS bunchers occurs above cavity powers of ~8 kW. The nonlinearity of the power measurements for the second buncher, IMS buncher B, is shown in Fig. 5.

The six-port reflectometer measurements of drive-line coupling (β) and the cavity impedance for the same buncher are displayed in Figs. 6 and 7, respectively. Because the additional power consumption is primarily resistive and corresponds to a drop in β, the loss mechanism could be either an emission power loading or a drop in Q from increased surface resistivity.

Although the unexplained power loss and its character is known, we have yet to identify the root source.

Measure System Degradation Over Time for an IMS Buncher

During a recent GTA experimental cycle, we observed that IMS buncher B required additional power to

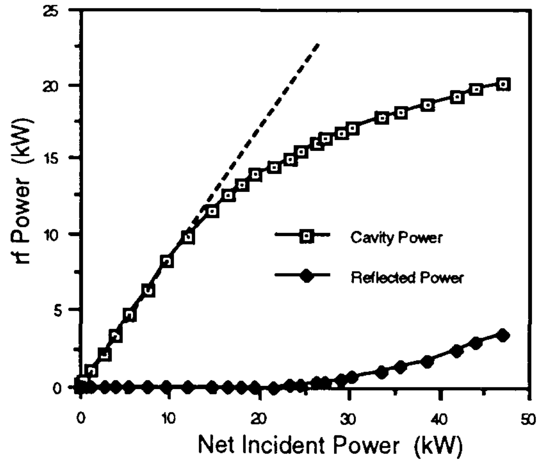

Fig. 5. GTA IMS Buncher B cavity and reflected-power response.

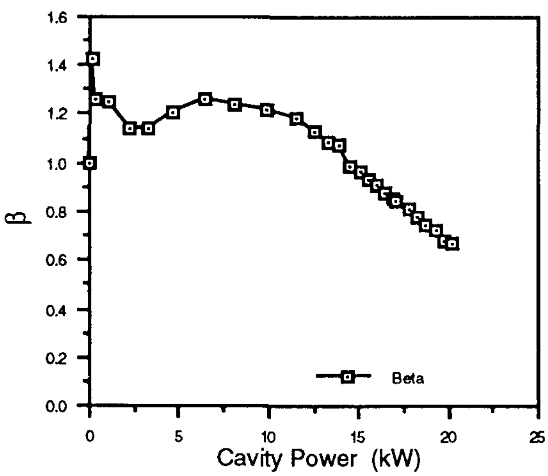

Fig. 6. GTA IMS Buncher B drive-line coupling (β) power response.

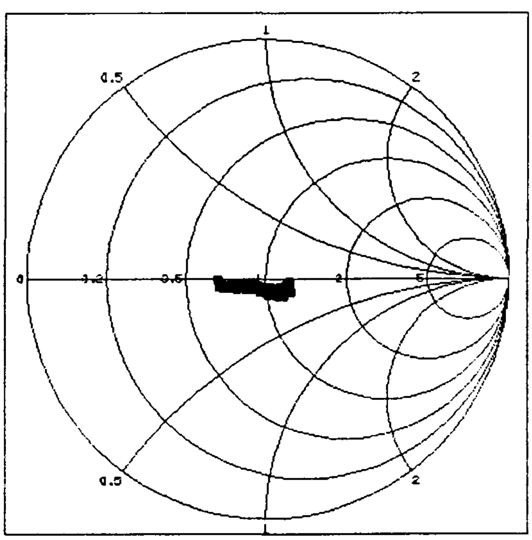

Fig. 7. IMS buncher B impedance from 0 to 20 Kilowatts.

maintain the operational field level as the experiment progressed over several weeks. The buncher's power response to net incident power is displayed in Fig. 8 for two separate days during the experiment.

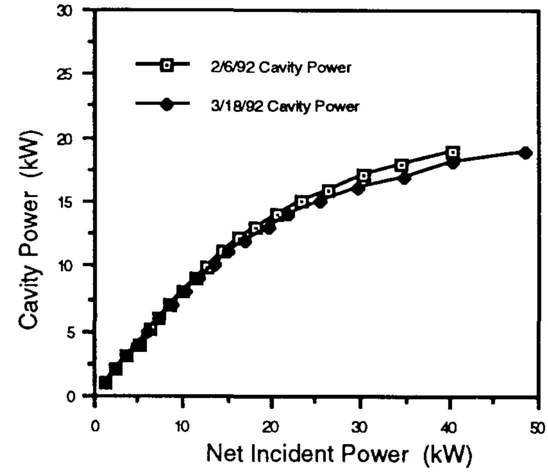

Fig. 8. GTA IMS buncher B cavity power response for two separate days.

The six-port reflectometer drive-line coupling (β) measurements for the same incident powers are displayed in Fig. 9, and the corresponding decrease in β is evident. This decrease confirmed a degradation in the buncher performance.

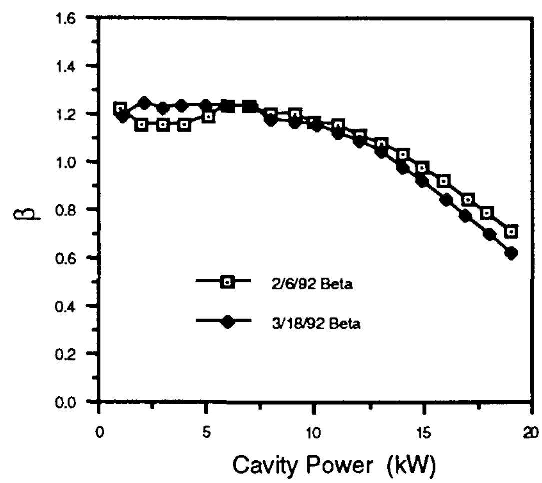

Fig. 9. GTA IMS Buncher B drive-line coupling on separate days.

Following the experiment, we removed the drive line and an inspection was completed of the buncher's interior and the drive-line components. Resistive tracking was discovered on a teflon stand-off in the coaxial drive line.

Conclusion

Data provided by the six-port reflectometer has increased our understanding of rf structure performance at high-power levels. It also has provided a useful tool for measuring the conditioned state of an rf structure and has augmented other data for increasing our understanding of anomalous rf structure behavior at high power.

References

1. S. P. Jachim, "Some New Methods of RF Control," Proc. Linear Accelerator Conference, September 1990, pp 573-577.