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DEVELOPMENT OF FLAT-TOPPED RF VOLTAGE FOR TRIUMF

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Summary

A Test Facility with operating characteristics equivalent to the TRIUMF RF system was used to generate a flat-topped RF dee voltage at full operating values. The fundamental at 23 MHz, and the third harmonic at 69 MHz were combined in the single resonator. No difficulty was encountered with multipactoring in the addition of the third harmonic when the fundamental voltage was on at the level of a few kilovolts. Since the TRIUMF dees are flattened coaxial λ/4 lines with uniform dee-to-liner spacing, the natural frequencies f_1 and f_3 fall quite near a 3/1 ratio. Only a slight warping of the resonator in two locations that affect f_1 and f_3 differently is required to tune for a given f_1 and for $f_3 = 3f_1$, precisely. With the two high power signals (1800 kW at 23 MHz and ~100 kW at 69 MHz in TRIUMF; 45 kW and ~4 kW in the Test Facility) combined in one resonator, rather large filters in addition to the impedance matching networks are required in each drive line for isolation of the transmitters. The results of the tests and the physical layout will be described as well as the control systems for auto-tuning and for amplitude and phase of the two voltages.

Introduction

This paper describes the progress in the development of a system to simultaneously achieve resonance in the TRIUMF dee structure[1] at both the fundamental and third harmonic. Thus an accelerating voltage with a flat top can be realized leading to increased phase acceptance and more precise turn and energy resolution. Since the TRIUMF operating system cannot be used for development, a test facility that has operating characteristics equivalent to those of TRIUMF is used.

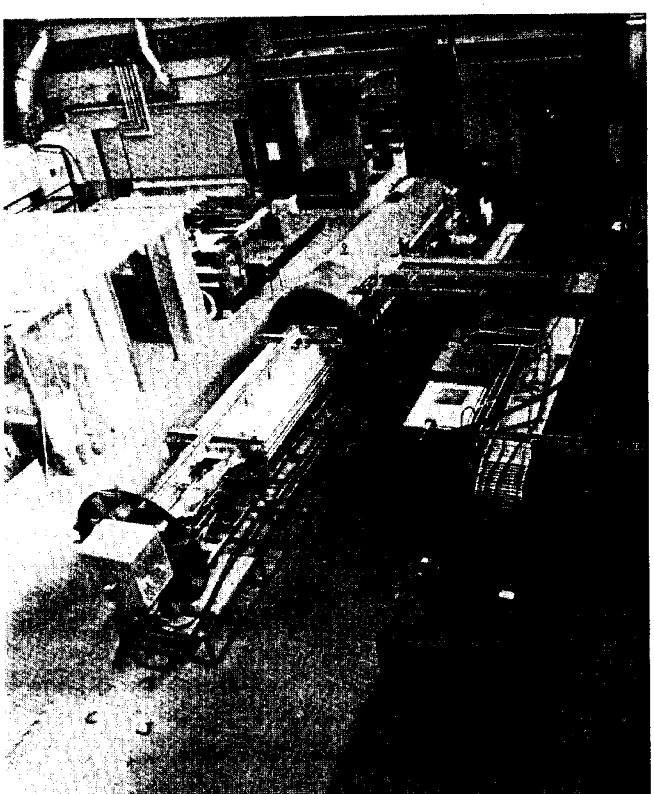

Fig. 1. Photograph of test stand.

Test Facility

The test facility consists of two resonator segments as used in the TRIUMF Dees.[2] With the addition of fluxguides a λ/4 flattened coaxial cavity is formed. A photograph of the test stand and a cross-section of the cavity are shown in Figs. 1 and 2 respectively. Because of the tip capacitance the resonant frequency of the third mode, f_3, is not exactly three times that of the fundamental, f_1. Cavity tuning to achieve a 3:1 frequency ratio is accomplished through tip and swayback deflection as shown in Fig. 2. Swayback deflection refers to the ground arm deflection at L_D. This deflection, where the third harmonic voltage standing wave goes through zero, $L_D=2/3L_T$, acts to raise f_3 while lowering f_1. An example of cavity tuning as a function of tip and swayback deflection is shown in Fig. 3, where $L_D=L_T/3$.

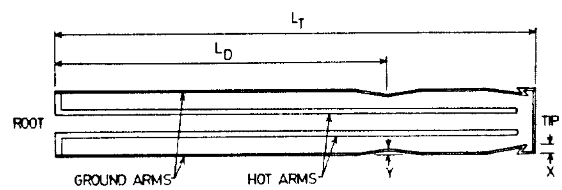

Fig. 2. Cross section of RF test stand resonant cavity showing positions where ground arms are deflected.

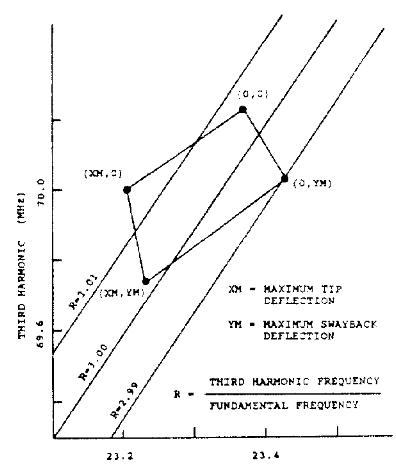

Fig. 3. Tuning of RF test stand. Position of swayback deflection is approximately $L_D=L_T/3$ in this case.

RF Power Test Setup

A block diagram of the RF test setup is shown in Fig. 4, including the feedback system. The RF source consists of a frequency synthesizer for the fundamental and a frequency tripler to provide the third harmonic frequency. This then feeds the 23 MHz and 69 MHz amplifier chains.

Initial tests at low power using a network analyzer revealed the effects of multipactoring. Figure 5 shows frequency scans at the fundamental frequency for

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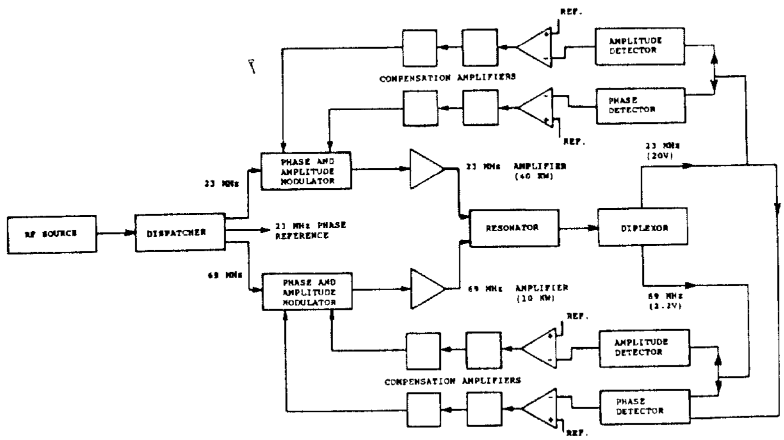

Fig. 4. Block diagram of RF and phase and amplitude control system.

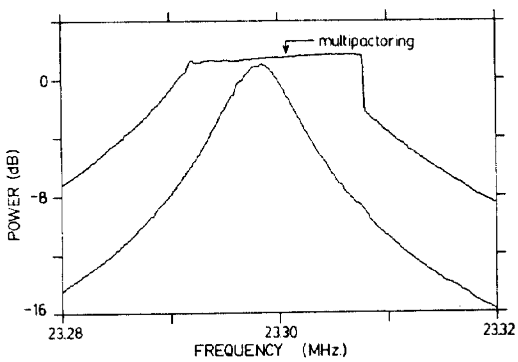

Fig. 5. Multipactoring at the fundamental resonant frequency. Input powers for traces showing multipactoring and no multipactoring are .25 watt and .002 watt respectively.

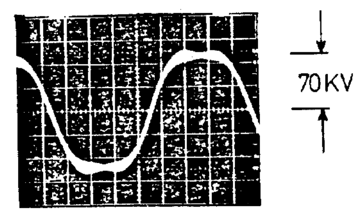

Fig. 6. Dee voltage showing flat-topped waveform.

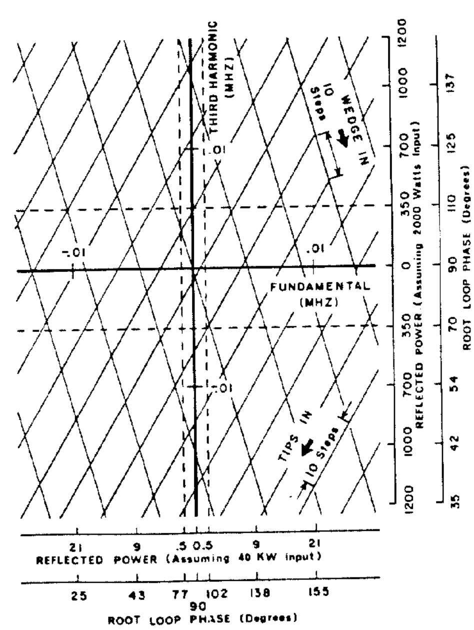

Fig. 7. Expanded version of tuning diagram showing deadband regions for first and third harmonic.

input powers of .002 watts and .25 watt. For the very low power case the normal resonance curve is seen. As the input power is increased to .25 watts a severe flattening of the resonance curve is seen. As the input power is increased there is little corresponding increase in dee voltage. Similar measurements exist at 69 MHz.

At the fundamental frequency the effect of multipactoring is overcome by using standard pulsing techniques. At this point with the fundamental on it was not known if the third harmonic could be brought on directly or if pulsing would be required. With just the fundamental on, the system was allowed to warm up and stabilize. The third harmonic was then brought on in CW mode. With the fundamental on it was possible to bring up the third harmonic voltage to the desired level without encountering any detectable effect of multipactoring. The fields due to the fundamental frequency bias the cavity such as to prevent multipactoring currents from building up with introduction of the third harmonic.

The flattopped dee voltage is shown in Fig. 6. The amplitude and phase noise present in the waveform is due to panel vibrations.

Automatic Tuning System

An expanded version of the tuning diagram is shown in Fig. 7. The grid structure shows lines of constant wedge (swayback) and tip displacements. The desired resonant frequencies have been chosen, in this example, to be 23.3 MHz and 69.9 MHz. The deadband regions (i.e. regions in which the reflected power is below accepted limits) are indicated by the dotted lines. The function of the automatic tuning system is to place the resonant frequencies of the first and third harmonic in the central rectangular region. This is done by first measuring the root-loop phase of both the fundamental and third harmonic to determine present tuning status. Depending on where the system is, an iterative scheme is embarked upon involving moving either the wedge or tips until the deadband region is entered.

Phase and Amplitude Control

A block diagram of the phase and amplitude control system was shown above in Fig. 4. The specifications[3] for the control system are:

Fundamental voltage $\frac{\Delta V_1}{V_1} < \pm 8 \times 10^{-5}$

Third harmonic voltage $\frac{\Delta V_3}{V_3} < \pm 6.6 \times 10^{-4}$

Phases difference between fundamental and third harmonic

$$\Delta\delta_3 < \pm 0.12°$$

for an initial phase spread of ±6° (fundamental).

The ratio of V_3 to V_1 should be 1/9. These values must be attained with an average beam current of 100 μA pulsed as required for operation of the proposed Kaon Factory synchrotrons.

There are four control loops in the system: one each for the 23 MHz phase and amplitude and, similarly, for 69 MHz phase and amplitude. The signal that is to be regulated is derived from a resonator tip voltage probe. This signal has both fundamental and third harmonic signal components. These components are separated in the filter unit. This filter should provide flat amplitude characteristics in the passband region, equal group delays for the fundamental and third harmonic frequencies and present a low input VSWR (<1.01). The phases and amplitudes of the resulting signals are then detected and used as inputs to the control system. The compensation amplifiers consist of two similar proportional integral stages. The signals from the compensation amplifiers control the phase and amplitude modulators. The gains of the compensation amplifiers and the operating points for the phase and amplitude modulators are set by the microprocessor unit which updates these values using an optimization algorithm.

First measurements on the RF test facility show a possible control bandwidth of 25 kHz with adequate stability margin.

References

[1] R.E. Worsham, T. Enegren, D. Dohan, L. Durieu and Roger Poirier; Tenth International Conference on Cyclotrons and their Applications, East Lansing, April 1984, p.360.
[2] R.L. Poirier and M. Zach; TRIUMF RF System, IEEE Trans. on Nucl. Sci. NS-22, No.3, 1253, June 1975.
[3] G.H. Mackenzie et al., Plans for the Extraction of Intense Beams of H^- Ions from TRIUMF, Tenth International Conference on Cyclotrons and their application, East Lansing, April 1984, p.233.