SYSTEM FOR FLAT-TOPPING THE RF VOLTAGE AT TRIUMF

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Summary

The resonator for the RF system of TRIUMF consists of two quarter-wave flattened coaxial stubs ($\lambda/4$ = 325 cm), facing the dee gap as in a conventional two-dee cyclotron, and contained inside the 16 m diameter magnet pole pieces. The dee-to-liner gap has a uniform value of 10 cm from tip to root (shorting plane). Because of this uniform spacing, the frequency of the third mode, f_3, is very close to $3 \times f_1$. Various schemes of regulation of the frequencies have been considered. However, only a slight warping of the liner at either 1/3 or 2/3 of the distance from root to tip (where the f_3 voltage standing wave is maximum or zero, respectively) is sufficient to make $f_3 = 3\ f_1$, precisely. An adjustment range of 2 mm is adequate to accommodate all operating conditions. A test facility for developing the tuning and control systems at full power has been set up in a vacuum chamber using only two resonator segments (out of 80 in TRIUMF). The RF drive consists of two transmitters with outputs of 50 kW at 23 MHz and 10 kW at 69 MHz. Results of the initial measurements which confirm the feasibility of the concept will be described.

Introduction

Operation of the TRIUMF RF system on the fifth harmonic of the ion rotational frequency leads to a resonator of quite simple shape that fits entirely within the magnet gap. Each of the two "dees" consists of a flattened coaxial resonator that is $\lambda/4$ in length. The gap between the dee, or coax centre conductor, and the outer shield is a uniform 10 cm from tip to root. This form suggests the possibility of exciting higher order harmonics for flat-topping the RF voltage. This addition could reduce the phase dependence of orbital motion to permit improvement of either the beam quality or the phase acceptance.[1] Early studies at TRIUMF showed that separated turns could be achieved, energy spread reduced to ~100 keV, and phase acceptance increased by a factor of ~14 with the addition of about 11% third harmonic.[2] Later, it was shown that this energy resolution could be attained even in the presence of such imperfect isochronism that would cause phase oscillations as large as 20°.[3]

The extraction scheme, described at this conference,[4] that is now being developed for TRIUMF requires the addition of a third harmonic. To achieve a total energy uncertainty of only 150 keV in the 450 MeV beam,[5] the tolerances would be:

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

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

Phase difference between fundamental and third

$$\Delta\delta_3 < \pm 0.12°$$

for an initial phase spread of ±6°.
The ratio of V_3 to V_1 would be 1/9.

The system being developed to meet these requirements is described below.

Test Facility

In TRIUMF, each of the two dees in the resonator is made up of 40 segments joined edge to edge to form the coaxial resonator. Thus 20 segments are suspended from the inside top of the vacuum chamber and 20 sit on the floor. Figure 1 shows a view inside TRIUMF on the median plane, but with the top half of the magnet-vacuum chamber-resonator raised about 4 m. Each of the segments is 81 cm wide along the dee gap and ~325 cm long perpendicular to the dee gap ($\lambda/4$ at 23.055 MHz). The cantilevered construction of the hot arms (centre conductor of the coax) requires the heavy aluminum and stainless steel structure shown.

For the test facility to be used in developing the techniques for flat-topping, two of these segments are used (one upper, one lower) plus flux guides (edge pieces) to join the top and bottom segments. Figures 2

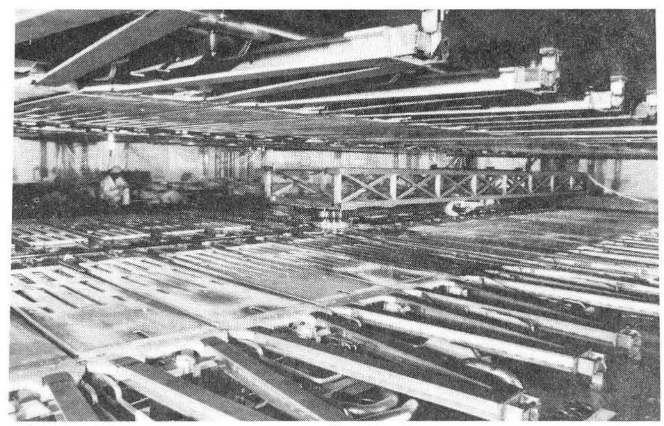

Fig. 1. View into TRIUMF median plane plane region with top raised.

and 3 show the general arrangement. For 100 kV peak tip voltage, the power required for excitation is about 38 kW at 23.055 MHz. A rather conservative 10 kW is available for the third harmonic.

Tuning

A cross section of the resonant cavity is shown in Fig. 4. Measurements indicate that the ground arms vary from a parallel position by a maximm of 0.050 in. for each ground arm. Frequency tuning of the cavity to obtain the ratio $f_3/f_1 = 3$ is achieved by inward deflection of the ground arms at the tips and at some point between the tip and root. If the initial value of f_3/f_1 is greater than 3 the ground arms are deflected at the tip and at position $L_D = L_T/3$. If the initial value of f_3/f_1 is less than 3 the ground arms are deflected at the tip and at $L_D = 2/3\ L_T$. Measurements taken of tuning at these two positions are shown in Figs. 5 and 6. Comparison between water pressure and no water pressure is shown. The maximum tip deflection was $X_M = 0.25$ in. The maximum deflection at the tuning point between the tip and root was $Y_M = 0.10$ in.

In the test facility tip, tuning is accomplished by motor drives similar to that used in TRIUMF to adjust the position of the dee gap end of the ground panels. For tuning the f_3/f_1 ratio, a wedge-roller was built to push inward the ground panel as described

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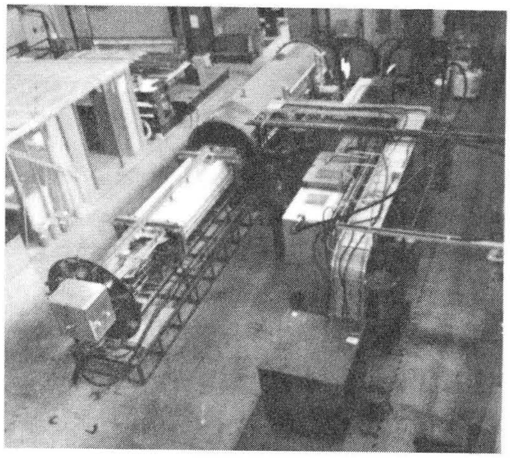

Fig. 2. Test facility overview.

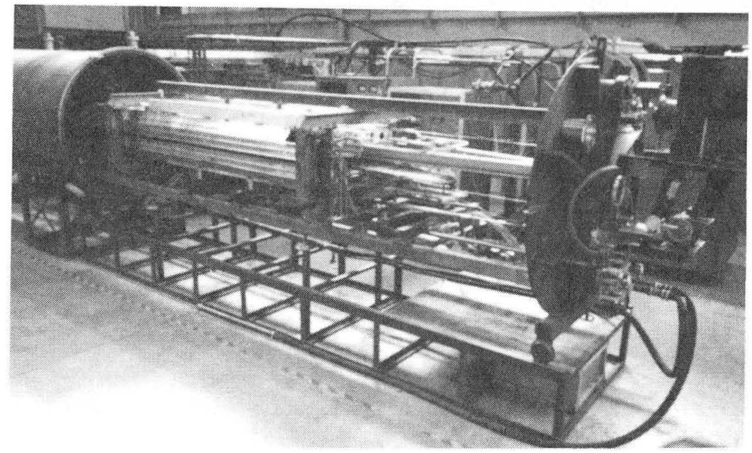

Fig. 3. Test facility resonator and vacuum chamber.

above. The wedge, shown in Fig. 7, has a possible travel of 60 mm which causes the panel to be deflected inward up to 6 mm. The overall thickness of the ground panel is 20 mm; the wedge had to be designed to fit in that space.

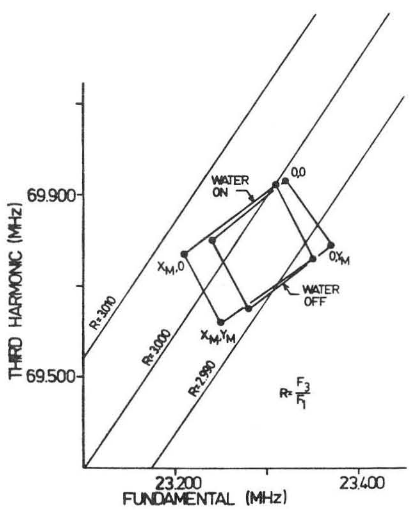

Fig. 5. Tuning of RF test stand resonant cavity at tip and at $L_D = 0.74\ L_T$, $X_M = 6.4$ mm, $Y_M = 2.5$ mm.

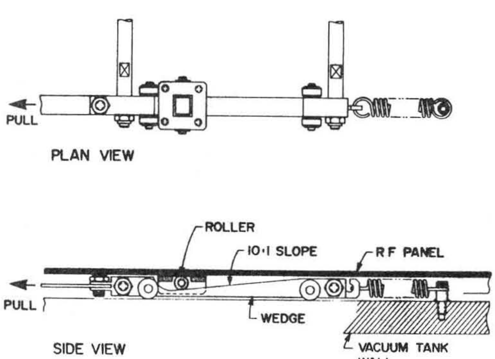

Fig. 7. Wedge for deflection ground panel.

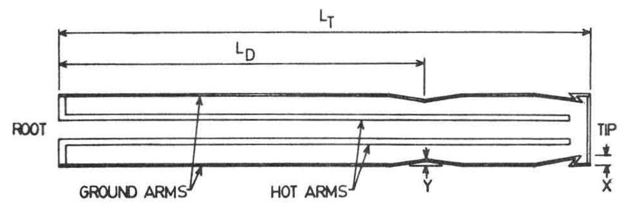

Fig. 4. Cross section of RF test stand resonant cavity showing positions where ground arms are deflected.

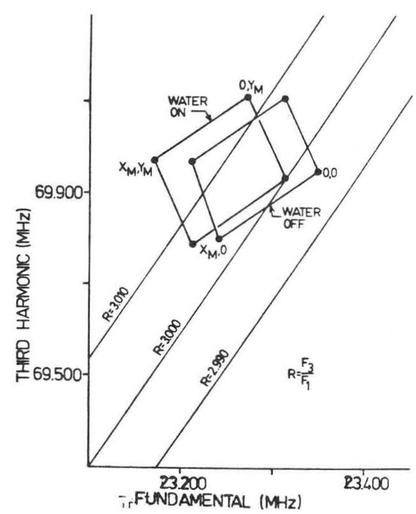

Fig. 6. Tuning of RF test stand resonant cavity at tip and at $L_D = 0.3\ L_T$, $X_M = 6.4$ mm, $Y_M = 2.5$ mm.

RF Coupling

The configuration for exciting the cavity with third harmonic power is shown in Fig. 8. The filter and matching section will be constructed from shunt connected coaxial lines with movable short circuit terminations. The matching section will consist of two tuning stubs. The cavity will be excited from a loop of length 3 in. and diameter 0.625 in. The impedance of a test loop of these dimensions was measured in the cavity. Using this value for the loop impedance allowed estimation of the lengths of the stubs of the matching section and the distance between them.

Measuring the impedance of the third harmonic loop at fundamental frequency allowed estimation of the fundamental power coupled into the third harmonic transmission line. It is estimated that after filtering by the matching section approximately 4 W of fundamental power remain. This power can be further reduced by the high pass filter shown in Fig. 9 consisting of three stubs. The lengths of the stubs and the distances between them are initially derived from consideration of the three-element Chebyshev prototype. The dimensions are then adjusted to achieve acceptable VSWR over the tuning range of the third harmonic. The responses of three and five stub filters are shown in Fig. 10.

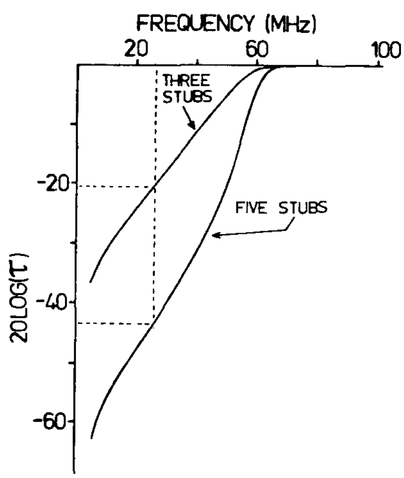

Fig. 10a. Frequency response of three stub and five stub filters τ = [Power transmitted/Power incident]$^{1/2}$.

Transmitters

The two transmitters to drive the test resonator at the fundamental and at the third harmonic are shown in Fig. 11. The 23 and 69 MHz signals are derived from the frequency synthesizer-dispatcher described below. Solid-state broadband amplifiers raise the power levels to 12 to 14 W maximum, followed by tuned stages that drive the final 4CX20,000 A tubes in each transmitter. The 23 MHz amplifier, running with a grounded cathode, is capable of 50 kW output, while the 69 MHz amplifier, running in a grounded-grid circuit, can provide up to 10 kW output. In Fig. 12, the 23 MHz transmitter can be seen in the three centre racks, while the 69 MHz one is shown in the two racks closest to the camera. These transmitters were designed and constructed in collaboration with HN Engineering of Burnaby, B.C.

Controls

The RF control system for TRIUMF, which is in the process of being redesigned to satisfy the insertion of the third harmonic, will be checked out initially on the RF test facility. At the same time, this new system must meet the stringent resolution and stability constraints setup by the requested single turn extraction mode. The block diagram of the proposed new system is shown in Fig. 13.

The principal disturbances known are related either to the resonator panel mechanical vibrations (frequency range up to 20 Hz) or to variable beam load-

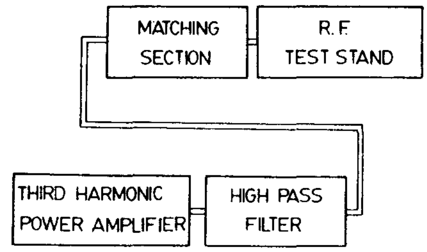

Fig. 8. Configuration for third harmonic excitation of RF test stand.

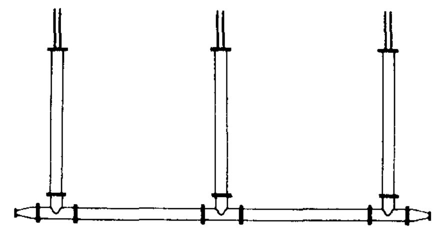

Fig. 9. Three stub high pass filter.

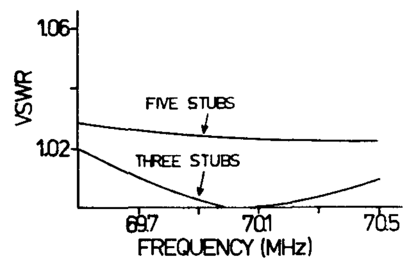

Fig. 10b. VSWR of three stub and five stub filters over tuning range of interest.

ing in the machine. This last perturbation is generated by the beam pulsing mechanism that was originally introduced to gain an insight into the beam characteristics. The normal operation of the machine now heavily relies on diagnostic information gathered by this tool. Unfortunately, this technique introduces a fairly significant energy dispersion caused by variation of the power distribution between the beam and the resonator.

This last effect requires that the usable bandwidth of the RF control system be extended close to the maximum allowed by stability considerations. These various constraints, when put together, explain the route chosen: the system will be built as a collection of modules and functions using both analog and digital elements. The analog subsystem allows for the resolution, absence of quantization noise and wide bandwidth at minimum cost and complexity. The digital subsystem using modern microprocessor techniques allows for versatility in mode definitions and ease of implementation of such chores as starting up, interlocks, diagnostics, and operator communication.

The system will have to control the amplitude of both accelerating voltage components, along with their relative phase under very stringent specifications. At

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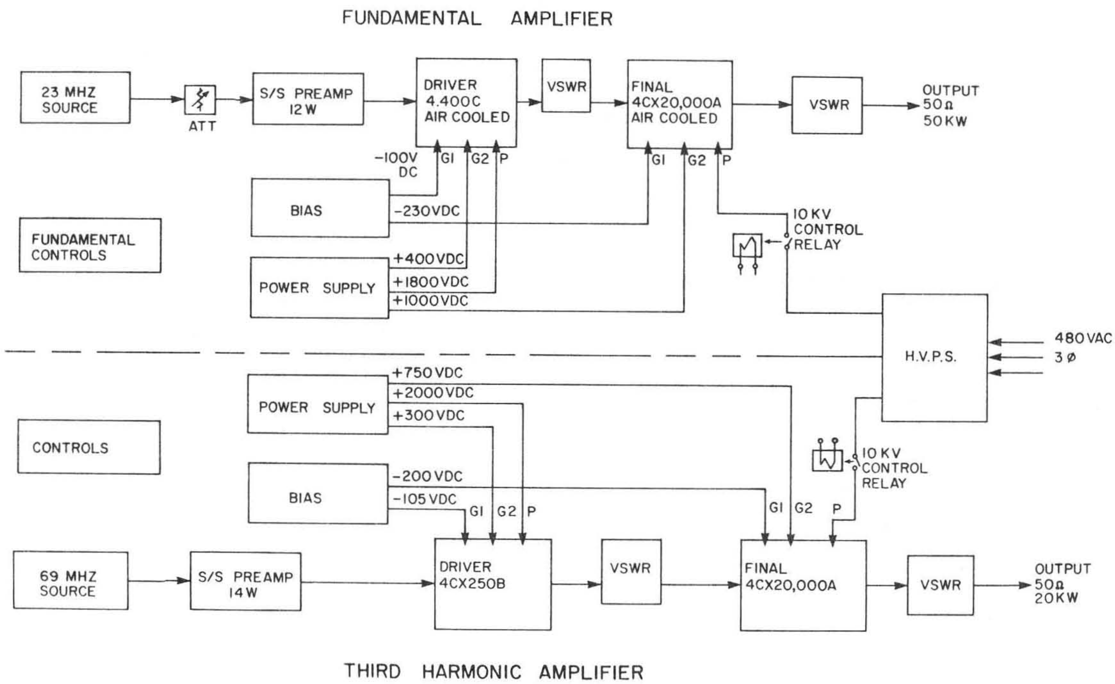

Fig. 11. Block diagram: 23 and 69 MHz transmitters.

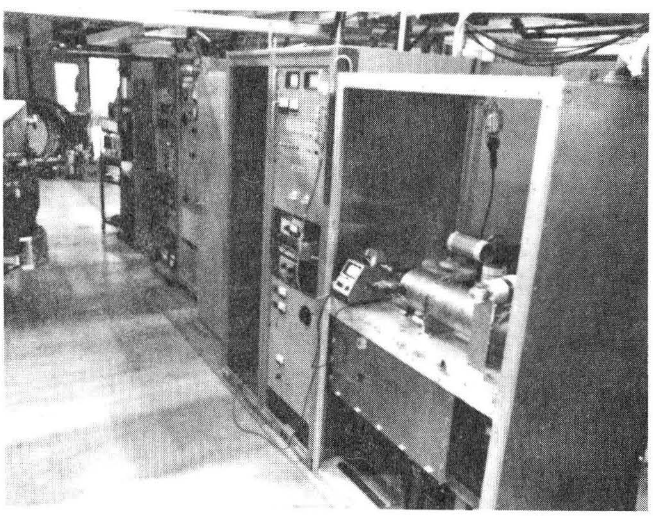

Fig. 12. Transmitter installation.

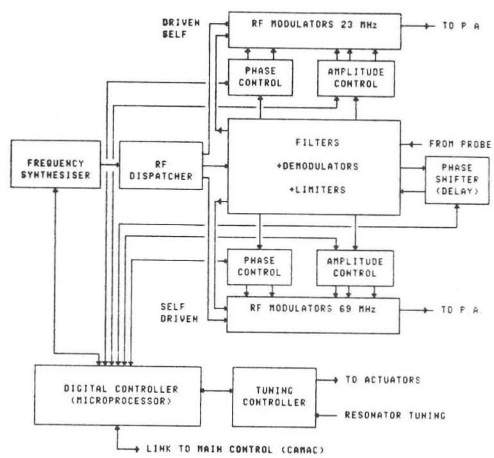

Fig. 13. Frequency generator and control block diagram

the same time, the resonator must be kept tuned at both frequencies. Analysis of the system dynamic behaviour indicates that it should meet the required energy dispersion constraints with a bandwidth of 625 Hz for both amplitudes and their relative phase. The total residual phase noise of the fundamental reference should be kept at a fraction of a degree for a bandwidth of 4.5 MHz each side of the carrier excluding the ±200 Hz centre band. A low phase noise synthesizer is required.

At a later stage, some beam-related information may be needed in order to achieve long-term stability and to reduce any RF correctable effect not apparent in the RF parameters. The necessary entry points have been built into the system for this implementation.

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