REDUCTION OF MULTIPACTORING EFFECTS IN THE TRIUMF CYCLOTRON

V. Pacak, D. Dohan, K. Fong, R. Worsham and G. Dutto
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3

ABSTRACT

The reduction of rf leakage into the accelerating chamber has been one of the main development tasks at TRIUMF for the past few years. Rf leakage seriously limits the use and operation of diagnostic devices and is the driving force behind a resonant multipactoring discharge that occurs in the beam space. This in turn causes many problems in performance and reliability of the whole rf system. Two major problems were: 1) the excessive heating of the mechanical dee-support structures that warps individual resonator segments, 2) instabilities in resonant frequency caused by erratic behaviour of the multipactoring discharge. By improving the rf gap alignment, and by adjusting the distances between dees and ground panels to compensate for electrical asymmetries, a leakage reduction of 20 dB was achieved, bringing the maximum operating temperature on the resonator strongbacks down from ≮150° C to ≮80° C. Also the signal-to-noise ratio on various probes was greatly improved, and multipactoring frequency shifts were practically eliminated.

INTRODUCTION

The design of the rf resonator of the TRIUMF cyclotron is quite unique since it consists of a conceptually simple electrical and mechanical dee structure that gives about 400 keV/turn energy gain and, yet, has the structure completely enclosed within the magnetic field with its major dimension barely larger than the 500 MeV beam orbit diameter. To accomplish this task, it was necessary to operate the resonator on a higher harmonic, in this case the fifth, of the orbital frequency[1]. However this meant that the vacuum chamber would have a diameter about three times the half-wavelength of the rf and, hence, resonant-cavity modes could exist in the chamber that would be driven at the operating frequency of the dee system.

As a result of measurements from voltage probes located in the beam space of the dees and from studies in a 1/10 scale model of the resonator those modes with frequencies close enough to the operating frequency (23.06 MHz) to be excited significantly were identified as the TM_{310} and TM_{410}[2]. Analytical and model studies reported at the Tokyo Conference[3] also showed that the resonant frequencies of these modes could be shifted to affect their excitation, and, most important, that the adjustment of the dee tip-to-ground spacings along the dee lips could be used to greatly reduce the coupling between the accelerating rf field space and the beam volume.

Also reported[4] was the replacement of eight of the eighty segments comprising the resonator structure with ones of a new design. The new structure is mechanically stiffer, has thermally isolated, cooled panels on the beam side, and is less subject to vibration.

OPERATIONAL EXPERIENCE

As a result of tests with a new segment in the cyclotron, it was possible to isolate the water cooling to its beam side panel and to measure precisely the power loss caused by the leakage. This value of 1200 watts, dwarfing the maximum of 100 watts that could be attributed to RF surface currents, led to the realization that the source of heat came mainly from multipactoring. Analysis shows that first order multipactoring in the beam gap occurs when the leakage voltage is between 170 and 680 volts[3].

By this time further measurements with both the cyclotron and the model, along with further analysis, confirmed that tip alignment can be quite an effective tool in controlling leakage. Along with installation of the segments of the new design and the increase in understanding of the leakage phenomenon, on-line displays of the leakage voltages, tip voltages, and temperatures throughout the resonator plus remotelycontrolled motor drives on forty of the eighty dee ground arms were added.

Initially, the leakage was reduced in the south dee only (the only one with probes and thermocouples) to a level near or below the limit of 170 volts for first-order multipactoring.[5] The maxiumum temperature in the south dee was cut from ~150°C to ~80°C; frequency drift and warm-up time were cut by a large margin; vacuum improved (less rf heating of cryopanels); probe measurements were possible that had been impossible previously (because of improved S/N ratio). A fact not fully appreciated at first was that the leakage fields in the two halves of the resonator were almost independent. That is, the leakage into the south dee was affected strongly by alignment of the south dee but much less so by the north dee. And vice-versa.

A new phenomenon appeared with operation in this low leakage mode - that of frequency jumping. It had been observed on a small scale previously, but now became a significant problem. During normal, steady operation, and with no detectable warning, the resonator frequency would suddenly jump as much as 25 kHz. Since the range of automatic tuning in the cyclotron is at most 4 kHz, the beam would be lost and the system would have to be retuned. The explanation for this phenomenon was the switching on and off of regions of multipactoring, which seemed to occur most frequently when the system operated with leakage voltages near minimum values. This idea was supported by temperature shifts that occurred simultaneously in a small region. The multipactoring acted, apparently, as a reactive as well as resistive load on the resonator, pulling the frequency.

To cure the jumping problem, the system was returned to the arrangement used previously for operation with higher leakage. Meanwhile, the instrumentation in the north dee and 24 more motor drives on the tips were added. A computer-controlled servo system was added to simplify motor control.

Recently in the shutdown of November 1988, a sufficient period of time was set aside to rework the segments as required to insure reliable contacts at all tips and to make the gaps uniform in both upper and lower parts of both dees. A series of periscope measurements to determine the effects on the dee-liner gaps of the magnetic field (negligible), vacuum, and raising of the upper half of the vacuum chamber and magnet for access were required. The latter is required since the segment adjustments must be made with vacuum chamber fully open. With the system back under vacuum, measurements at signal level of the effects of each set of segments, or combinations, on the coupling between the field in the dee to the leakage field were completed. The effects as a function of tuning individual segments were, considering the large size and structures of the sheet-metal panels, reasonably linear and repeatable.

Holding to a symmetrical pattern to keep the natural frequencies of the two dees as equal as possible, the ground arms were adjusted by trial-and-error to lower values of leakage. Similar results were achieved on both north and south sides. Only in two regions (north dee, quadrant 1, segment 7 and in the south dee, quadrant 4, segments 6 - 9) was the leakage high enough to support multipactoring. Typical examples of the leakage fields and the temperatures of the segment strongbacks are shown in Figures 1 and 2. The maximum operating temperature was typically about 80°C in the region where some multipactoring still existed. The frequency jumping almost disappeared - occasional jumps, but within the 4kHz range for auto-tuning, were observed.

During the period from the November shutdown up to the following March shutdown the system operated with no tip tuning required at all. Further, the frequency drift in the periods of rf off were further cut markedly reducing the time delay in warming up the system. The downtime in this interval attributed to "resonator instability" was cut by a factor of two to four.

PLANS

The above successful period, achieved after major efforts in re-work and alignment of the resonator, demonstrates the potential for improvement in cyclotron stability and reliability. For easy reproduction and control of dee tip alignment and stable low leakage plans call for new segments of the new design (stiffer, cooled beam-side panel, hinged ground arms) to go into positions Nos. 8, 6, and possibly 10. The results with the new segments in No. 4 indicate that the mechanical dee tip stability will be greatly improved (by a factor up to three) with this arrangement; existing older units could be retained in intermediate positions. Coating of the surfaces with Acquadag or Ti-N will be tested to reduce multipactoring effects even further. In addition, a system of active feedback to excite the TM_{310} and TM_{410} modes that would allow precise balance of the leakage components at low levels will be investigated.

REFERENCES

1) Erdman, K., et al., Proc. 6th Int. Conf. on Cyclotrons, AIPCP#9 (AIP, New York, 1972), 444.

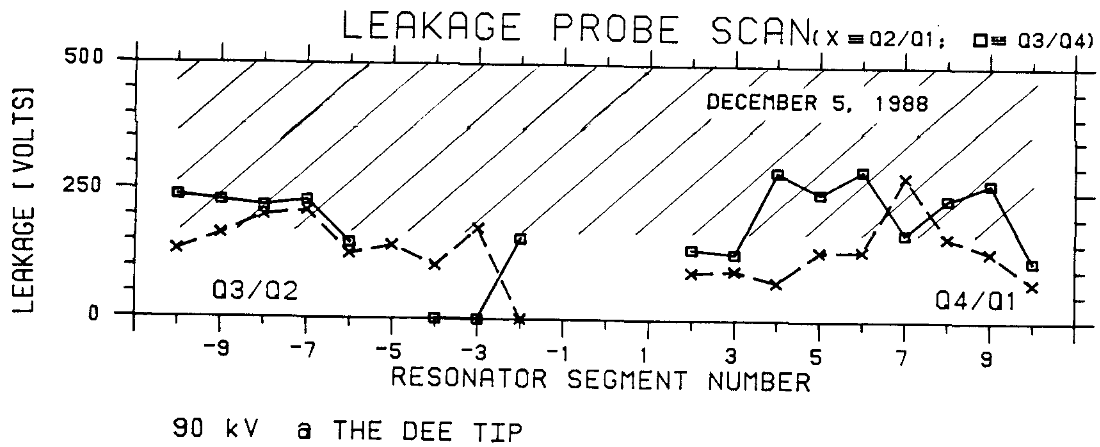
2) Poirier, R., et al., IEEE Trans. Nucl. Sci. NS-30(4), 3514 (1983).

3) Dohan, D., et al., Proc. 11th Int. Conf. on Cyclotrons and their Applications, Tokyo, October, 1986, 345.

4) Worsham, R., et al., Proc. 11th Int. Conf. on Cyclotrons and their Applications, Tokyo, October, 1986, 353.

5) Worsham, R., et al., IEEE 87CH2387-9, Particle Accelerator Conf., Washington, March 1987, 1839.

Fig 1. Typical values of leakage after the November 1988 alignment of the resonator.
Solid lines - south dee, quadrants 3,4
Dashed lines - north dee, quadrants 1,2



Note: quadrant 3, segments 3,4 were inoperative

Fig 2. Temperatures (°C) measured for the leakage pattern shown in Fig 1.
Note the maximum temperatures of 78°C are in quadrant 1, segment 7 and quadrant 4, segment 9. The 91°C thermocouple in quadrant 4, segment 1 is on the vertical flag grazing the beam. The water cooling in the rf panels of the segments reads about 32°C.