TEMPERATURE STABILITY OF THE TRIUMF CYCLOTRON RF CONTROLS

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Abstract

Factors which contribute to ambient temperature sensitivity in the TRIUMF cyclotron RF control system are examined and characterized. Seasonal temperature variations together with air conditioning system limitations can give rise to unwanted temperature variations in the rack space housing the control system. If these are large enough, they can cause excursions in the cyclotron accelerating voltage. The critical components responsible are characterized and some possible remedies outlined.

INTRODUCTION

The current cyclotron control system has been in operation for a number of years [1]. The megawatt or so of power circulating in the resonators is controlled using a feedback signal from two centrally located voltage probes. A network of monitoring probes is used to fine tune individual resonators, and can also be summed and averaged to give a dee voltage reference reading that is independent of the control system. Recently, some discrepancies have been noted between the voltage reported by the control system and that given by these voltage probes.

In an attempt to shed some light on the causes of these discrepancies, both the rf control system and the voltage probe monitoring system were investigated in some detail. The results of those investigations form the subject of this paper.

CYCLOTRON VOLTAGE PROBES

Since these probes were being used as a reference, and no performance data on them was available, a closer examination was undertaken. There are 60 of these probes distributed across all four quadrants of the cyclotron. These lead to the bank of detectors shown in Fig. 1. Approximately 2-3 watts of power is drawn from each probe, which must be dissipated by the detector electronics. Finned aluminium extrusions are used. It may be noted that these are located horizontally, and spaced quite close together, which somewhat reduces their efficiency.

To get a picture of the temperature gradients experienced at the detectors, measurements were taken at each end of the heatsink serving a bank of eight detectors. These measurements, which were taken at an ambient temperature of 22.7 degrees, are summarized in Table 1. A range of temperatures spanning 7.5 degrees can be observed, with the coolest temperatures at the detectors located at the bottom of the array, and the warmest in the upper central region.

Figure 1: Cyclotron voltage probe detectors.

Table 1: Detector Temperatures (degrees C)

Detector	Left	Right
Upper Q1	44.4	44.5
Upper Q2	47.9	47.1
Upper Q3	49	47.7
Upper Q4	47.1	47.1
Lower Q1	47.1	46.5
Lower Q2	46.5	43.6
Lower Q3	45.9	43.9
Lower Q4	43.5	41.5

To determine if these temperature variations as well as potential ambient temperature variations were significant, information on the temperature sensitivity of the detector circuit was required. Since this was not available, the detector circuit was examined in more detail. A photo of the detector circuit is shown in Fig. 2. The circuit used is a conventional half wave diode detector. The heat sink mounted 50 ohm terminating resistor is visible, as is the detector diode, low pass filter, and an output clamp diode.

To determine the temperature sensitivity without a proper environmental chamber, the heatsink was insulated, and self heating used to gradually raise the temperature of the detector. This limited the temperature range to 10-15 degrees C or so, but this covers the observed operating range of the detector array, and also leaves room for some ambient temperature variation.

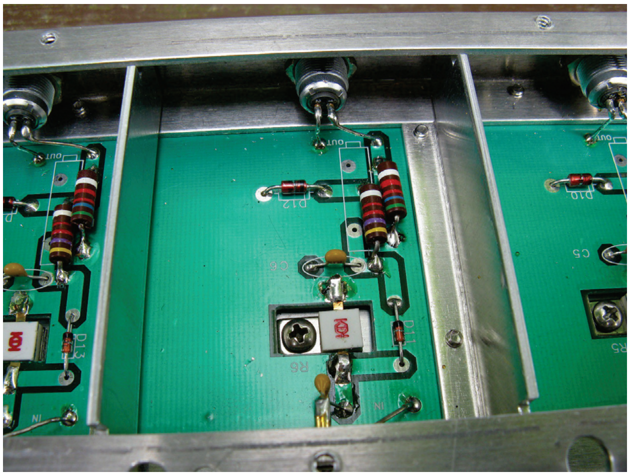

Figure 2: Voltage probe detector circuit.

A plot of the resulting temperature measurements is shown in Fig. 3. Eliminating a few points at the low end where the circuit had not reached thermal equilibrium, the plot shows a negative temperature coefficient. Averaging the curves yields a variation of about 0.18V aver a temperature span of 11 degrees C. This works out to be 0.19% of the 9.39V sensor voltage and yields a temperature coefficient of about -0.017%/degree C. This should not be a concern, as the discrepancies in voltage of concern were in excess of 1%.

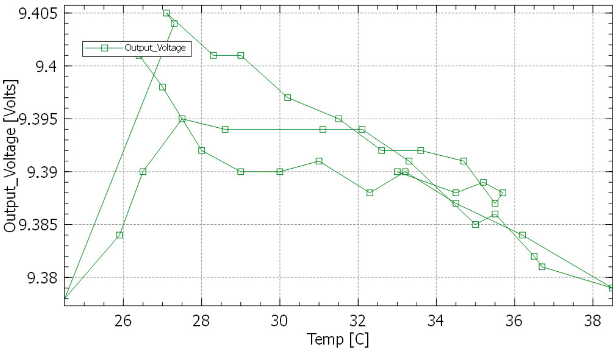

Figure 3: Voltage probe output vs. temperature.

RF CONTROL SYSTEM FEEDBACK PATH

A block diagram of the rf control system feedback path is shown in Fig. 4. As mentioned, two voltage probes are used. In the event one probe should fail, a switching circuit will switch control to the remaining functioning probe. In normal operation, the two probe outputs are summed and used together. The feedback path includes a pair of 20 dB couplers which provide diagnostic signals, followed by 20 dB power attenuators to reduce the signal to less than one watt. The signal then enters the rf interface box, which contains a bandpass filter and a multi-turn variable attenuator for fine setting of the feedback level. This is followed by a 15 dB coupler to provide a scope monitor signal, and a phase shifter on the "B" probe signal to allow exact tuning of the differential phase before the inputs are summed.

The signals then go to the amplifier module which contains a video multiplexer, a combiner, a bandpass filter, an amplifier, and a variable phase shifter. The multiplexer and associated logic provide the aforementioned fail-safe function. From this module the combined feedback signal then goes through another 15 dB diagnostic directional coupler to the rf modem module. Here the signal is split, one path going through a variable phase shifter, while the second goes through a 48 dB limiter. An analog multiplier followed by a low pass filter then completes the synchronous detector function. The signal then passes to the DSP module (not shown) where it is digitized, and a PID program generates the control output.

Temperature Sensitivity

From previous measurements, the rf interface box has a temperature sensitivity of 0.7 KV for a temperature rise of 20°C at the 81 KV level. At the same level, the sensitivity of the rf amplifier and rf modem modules is about 1.4 KV for a 10°C rise. Taken together, they account for a 1.75 KV change over 10°C. At the 81 KV level, this amounts to a change of 1.75/81 = 2.2%, for a temperature coefficient of +0.22%/°C. While this is potentially significant, it only becomes a problem if the temperature in the rf room fluctuates by more than a few degrees. To help determine if this was happening, the temperature at the rf control chassis air intake was monitored over a nine day period.

The temperature data from this period, together with the outside air temperature (from weather data) is plotted in Fig. 5. It can be seen that the average temperature fluctuation over most of the time period is about 0.5 °C peak to peak. These peaks track the outside air daily cycle, as might be expected.

Mitigating Temperature Sensitivity

The observed temperature variations of about 0.5°C would only account for a variation of about 0.11% in dee

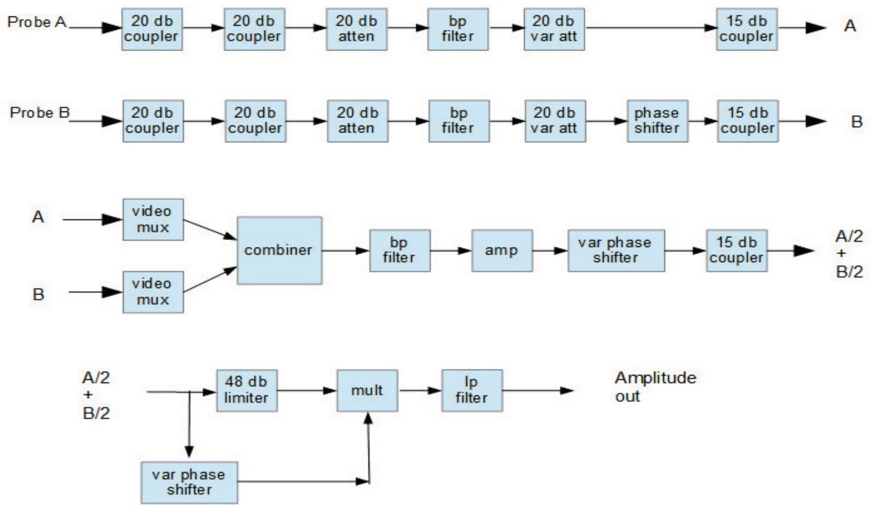

Figure 4: Cyclotron Feedback Path Block Diagram.

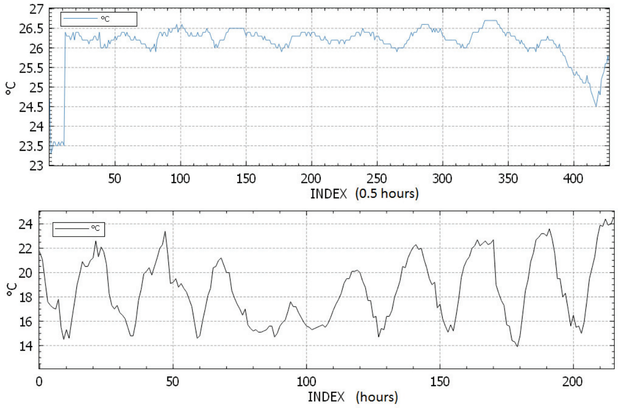

Figure 5: RF room and outdoor temperatures.

voltage. While this is not a major concern, it is obviously an area with room for improvement. A simple solution would be to replace some of the attenuation in the feedback path with temperature compensated attenuators. These can be sized to neutralize the observed positive temperature coefficient. The optimum coefficient would be about -0.19 db/°C. A commercial compensated attenuator is available with a negative temperature coefficient of 0.006db/db/°C. A 3db attenuator with this specification would yield -0.18db/°C, which is very close to the desired number.

CONCLUSION

Since no data was available on the performance of the voltage probes, these were examined in some detail. They were found to perform satisfactorily in the temperature range of interest (less than a fifth of a percent variation over a ten degree temperature range). The rf control system had been tested previously and was known to have a degree of sensitivity to ambient temperature (0.22%/°C). What was not known was how much the ambient temperature was fluctuating in normal operation. This variation proved to be quite small – about 0.5°C, which did not explain the discrepancy between the control system and voltage probe readings. It is possible that other factors may have produced larger ambient temperature swings than those measured here. It is also possible that beam heating in the vicinity of the feedback probes, or some other factor than the control system electronics, is causing the observed variations. In any event, if the temperature performance of the electronics can be easily improved, this would seem to be a goal worth pursuing.

REFERENCES

[1] K. Fong, M. Laverty, S. Fang, “RF Control System Upgrade at TRIUMF,” EPAC’94, London, June 1994, pp. 1842-4 (1994); http://accelconf.web.cern.ch/AccelConf/e94/PDF/EPAC1994_1842.PDF.

[2] K. Fong, M. Laverty, S. Fang, “Operating Experience with the New TRIUMF RF Control System,” PAC'95, Dallas, May 1995, MPR16, pp.2273-5, (1995).http://accelconf.web.cern.ch/AccelConf/p95/ARTICLES/MPR/MPR16.PDF