Measurements of Crowbar Performance of the 20 kV 130 A dc Power Supply of the TRIUMF rf System

A.K. Mitra
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C., Canada V6T 2A3

Abstract

The TRIUMF rf system operates at a fixed frequency of 23.06 MHz with a power capability of 1800 kW. The dc plate power for the four push-pull power amplifiers is provided by a single dc power supply at 20 kV, 130 A and the amplifiers are protected by a single ignitron crowbar circuit. In the case of voltage breakdown outside the tube, the triggering of the crowbar circuit relies on the voltage developed across a low resistance shunt in the return path of the common dc power supply. Frequent failure of the crowbar ignitrons, following an external dc voltage breakdown, led to the investigation of the crowbar performance. Current transformers have been installed in the common B^+ line to the power amplifiers and the anode circuit of the ignitron crowbar in order to measure amplitude, duration and time delay of various dc currents under fault conditions. Similar current transformers were installed in the individual anode circuits of the power amplifiers to provide protection to the complete system in case of an external dc voltage breakdown. The results of these measurements and recommended solutions for operations are reported.

I. Introduction

The eight power amplifiers which constitute the main rf system of the TRIUMF cyclotron [1,2] are protected by a single ignitron crowbar circuit. The purpose of the crowbar is to provide a fast short circuit on the output of the 20 kV dc power supply to direct the stored energy in the filter capacitors away from the fault should any of the eight amplifiers arc internally or high voltage breakdowns occur in the circuitry outside the tubes. The firing signal for the crowbar circuit is obtained from voltage developed across a series resistance in the cathode circuit of each amplifier and a low resistance shunt in the return path of the power supply. The ignitron crowbar is thus triggered by any of the nine signals or combination of them. Frequent crowbar firing and failure of some of the ignitrons led to this investigation of crowbar performance.

Four current transformers using low μ NiZn ferrite of 8" o.d. and 5" i.d. and a single layer winding of 8 turns, have been placed at appropriate locations in the dc power supply for measurement of fault currents and evaluation of the crowbar performance. The units are enclosed in shielded boxes and have been tested at 45 kV without any breakdown. Two more transformers are planned to be installed in the near future.

II. System Description

The basic schematic of the 20 kV dc power supply is shown in Figure 1 where PA1 to PA4 are the four push-pull power amplifiers. The sensing resistors in the cathode circuit of PA1–PA4 and the dc shunt 50 mV/150 A have been used to sense and trigger the ignitron crowbar. The current transformers CT1 to CT4 are the recently installed components in the dc power supply. Two commercially available Pearson 301X transformers have also been mounted next to CT1 and CT2 for calibration and initial measurements.

The current transformer CT1 senses ignitron current only when it fires. CT2 measures the dc operating current (approx. 80 A) when rf is switched on/off and also responds to the instantaneous short circuit currents should any of the anode supply lines to the power amplifiers short. Hence, the output of CT2 can be used to trigger the ignitron crowbar under the above fault condition. Current transformers CT3 and CT4 are to be used only for monitoring the fault condition of the power amplifiers although they can be utilised to trigger the crowbar if needed.

III. Calibration and Measurement

The current transformers have been calibrated against the Pearson which has a sensitivity of 0.01 V/A with 1 MΩ termination. Figure 2 shows the voltage outputs of the Pearson and CT1 when rf drive is switched off. The measured sensitivity of the current transformer is 0.023 V/A.

Short circuit current measurements from the dc shunt and the Pearson transformer (location CT1) are shown in Figures 3 and 4 respectively. The test was carried out by firing the ignitron from the crowbar logic circuit. The voltage developed across the shunt gives a short circuit current of 3960 A whereas the Pearson output leads to a short circuit current of 2200 A. The higher current from the shunt measurement is due to the presence of rf noise. A PSPICE simulation of the power supply circuit with a single phase star-delta configuration and full wave rectifiers, yields a peak short circuit current of 3000 A.

The total charge/minute for the ignitron computed from

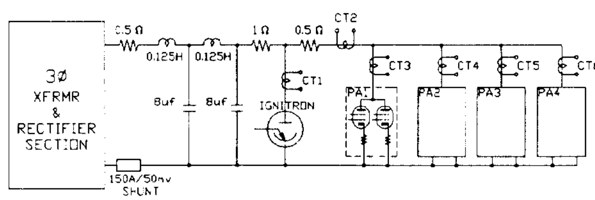

Figure 1. Schematic drawing of the dc power supply.

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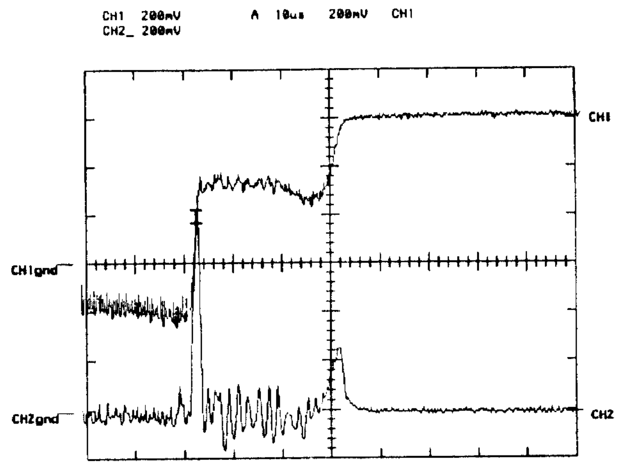

Figure 2. On-line calibration of current transformer. Ch1 - Pearson output. Ch2 - CT1 output.

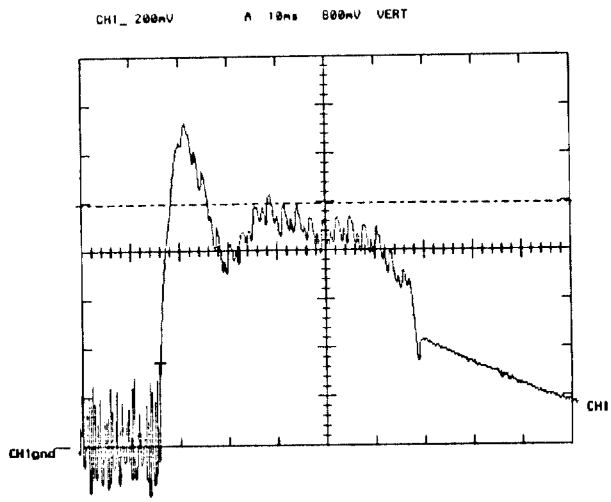

Figure 3. Voltage output across dc shunt.

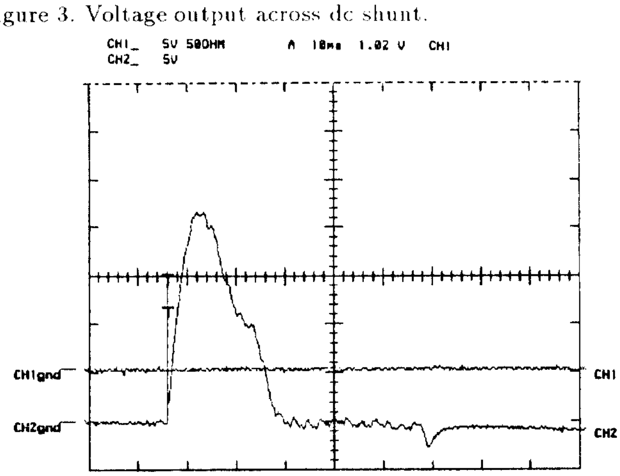

Figure 4. Voltage output from the Pearson transformer.

the above current measurement is 1.1 Coulomb and the duration of the ignitron current is 53 msec (~3 1/2 cycle).

IV. Summary of Measurements

The following results can be summarised from the measurements:

1. The peak instantaneous anode current through the ignitron is 2200 A
2. The duration of ignitron anode current is 53 msec.
3. The main circuit breaker is opening in 3 1/2 cycles.
4. The total charge/minute is 1.1 Coulombs for the ignitron.
5. The delay between fault and ignitron firing is 1.4 μsec.

V. Discussion

In the present configuration of the crowbar circuit, reflected power due to momentary sparks in the resonator system, arcs in the power combiners, and spurious rf noise etc. cause the ignitron to fire falsely when it is sufficient to switch off the rf drive without switching off the dc power supply. Output from the current transformers, which are rf shielded, can be employed to trigger the crowbar circuit only when the instantaneous dc current exceeds a certain pre-set value.In this way, with fewer ignitron firings, longer life of ignitrons can be achieved. It is rather easy to stay within the maximum voltage or current rating of a particular ignitron, however, exceeding one key factor, i.e. the current energy transfer per minute in Coulombs, has an adverse effect on the life of the ignitron tube due to anode heating. Exceeding the current pulse duration also gives rise to side-wall erosion, causing further reduction of tube life.

VI. Future Scope

It is evident that a reliable crowbar firing scheme has to be developed employing current transformers as outlined in this paper. Fiber optic links can be incorporated between the output of the transformers and crowbar firing circuit to enable implementation of these transformers in the existing protection circuit of the complete system. Voltages developed across resistive shunts can be filtered adequately with RLC networks but can still be utilised in the crowbar firing circuit with slower response time.

VII. Acknowledgements

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VIII. References

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