SPARKING RATE STUDIES AND SPARK BREAKDOWN PROTECTION STUDIES WITH A CW RADIO FREQUENCY QUADRUPOLE LINAC*

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Abstract

A high-current, cw linear accelerator has been proposed as a spallation neutron source driver for tritium production. Key features of this accelerator are high current (100 mA), low emittance-growth beam propagation, cw operation, high efficiency, and minimal downtime. A 268 MHz, cw radio frequency quadrupole (RFQ) LINAC section and klystrode based rf system was obtained from the Chalk River Laboratories and was recommissioned at LANL to support systems development and advanced studies in support of cw, proton accelerators. System protections were previously installed to preclude damage to the RFQ at the large stored energies, high field levels, and intense powers sustained under cw operation. An rf power blanking system has proven effective in quenching the damaging, sustained arcs following structure sparkdowns. A detailed study of the sparking rate and the rf blanking parameters has demonstrated that a cw RFQ can be maintained under almost continuous operation with minimal interruptions from spark induced transients or shutdowns.

1 INTRODUCTION

The **C**halk **R**iver **I**njector **T**est **S**tand (CRITS) was the LANL designation given to a proton accelerator designed, built, and originally commissioned at the **C**halk **R**iver **L**aboratories (CRL) in Canada under the RFQ1 program [1]. The rf structure for this accelerator, shown in Figure 1, is a 1.25 MeV, 268 MHz RFQ LINAC designed to operate at 1.75 times the Kilpatrick field level. During commissioning of the rf structure, it was discovered that sparks inside the vacuum region of the RFQ system developed into arcs which were sustained by the cw power. These sustained arcs sputtered the copper in the driveline resulting in damage to the vacuum window. It was learned at CRL that providing a momentary power interruption quenched the arc and protected the system from damage.

In cooperation with the CRL commissioning team, an rf blanking module was developed at LANL which interrupted power upon the detection of high VSWR (reflected power) and provided a ramped turn-on after system recovery. This module provided the necessary rf structure protections to facilitate the commissioning of the accelerator at CRL.

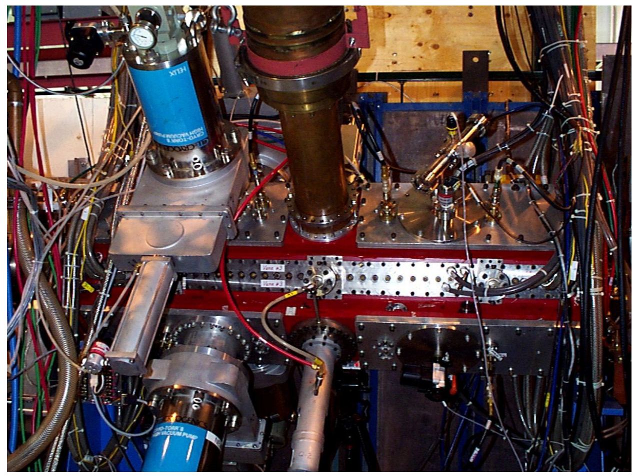

Figure 1: The CRITS RFQ accelerating structure.

In 1983, the accelerator and supporting systems were shipped from CRL and reassembled at LANL to support accelerator technology development programs. During the following years, the CRITS related programs have supported high-power rf operations studies [2], injector development studies [3], cw proton beam studies [4,5,6,7], and this study of sparking rates and spark breakdown protection.

2 THE RF BLANKING MODULE

The rf blanking module not only provided the system protection from sustained arcs but also provided the logical signal for the counting of sparkdown rates. Key features of this module were the detection of the high VSWR, a response feature providing a brief rf OFF period, and a ramped restoration of rf power to minimize repeat sparks. Through the use of this module, power could be restored to the RFQ within 100 μsec, a desirable feature for high-intensity cw accelerators dependent upon uninterrupted operation for rf structure stability and other

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target related considerations. Because this module protected against system damage, a key design requirement was a no-deadtime response, allowing it to protect against repetitive sparks.

During the evaluation of this module at CRL, it was determined that the optimal configuration blanked the analog amplitude setpoint rather than attenuating the rf signal between the low-level rf amplifier and the intermediate drive amplifier. The blanking function was then integrated into an amplitude setpoint control within the module for overall control of the low-level rf drive.

An RFQ cavity spark is identified by an increase in reflected power as shown in Figure 2. Figure 3 displays the setpoint response and the subsequent ramped demand signal for rf turn-on. Figures 4 and 5 show the response of the forward power and cavity field signals respectively. The gradual power increase following the sparkdown reduces reflected power, and the cavity field rises more slowly than the forward power due to the cavity fill time. As a result, the field response following a spark is gentler allowing additional cavity recovery time.

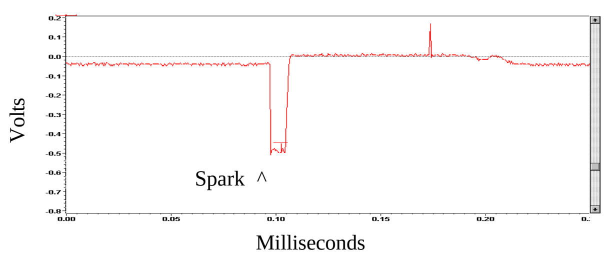

Figure 2: Rectified rf reflected power signal (negative signal) during a sparkdown.

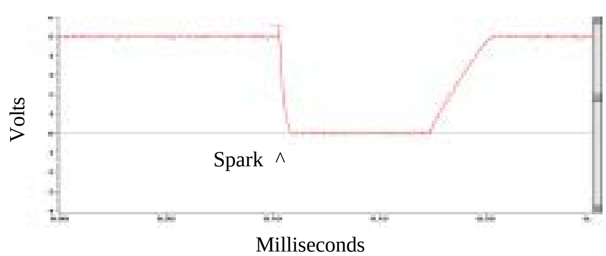

Figure 3: Setpoint signal during a sparkdown.

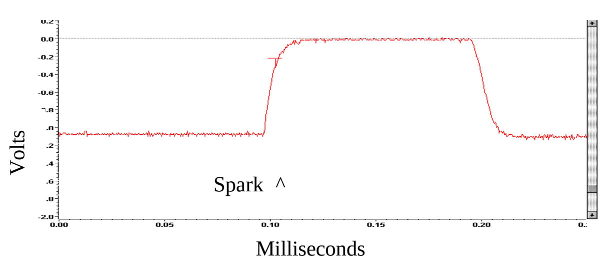

Figure 4: Rectified rf forward power signal (negative signal) during a sparkdown.

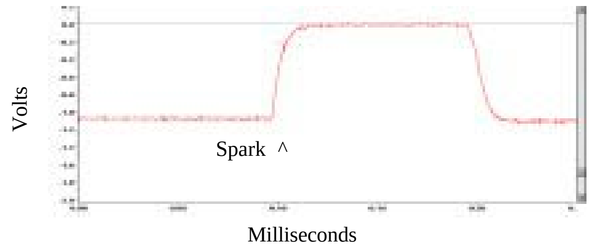

Figure 5: Rectified RFQ cavity signal (negative signal) during a sparkdown.

3 SPARK RATE ANALYSIS

During the CRITS RFQ operation, the total number of sparks was systematically measured and stored each second. At one minute intervals, the raw number of sparks as well as the number of seconds with at least one spark (spark-seconds) was stored. In fact, this last information is more relevant since spark avalanches do not bias it. Corresponding with the spark rates, the forward, reflected, and cavity rf power levels were also recorded along with the residual vacuum pressure. Figure 6 displays a representative data set.

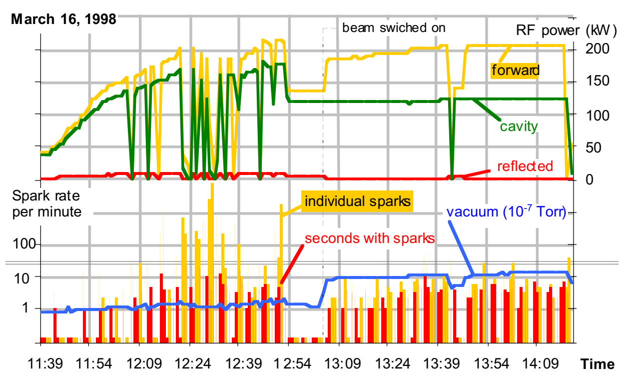

Figure 6: Example of archived rf power operations.

Long data, sets of continuous operation (between 22 and 163 minutes) have been extracted for count rate analysis - 34 runs without beam and 24 with beam. For each run, the average rate of spark-seconds was computed. As some runs yielded no sparks at all, one spark has been added arbitrarily to each data point in order to be able to plot the zero-spark points on a log scale (Figure 7).

Without beam, the rate is typically 0.3 spark-seconds per minute at the design field (77.4 kV intervane voltage), i.e. the average time between two bunches of sparks is two minutes. The slope shows that a 0.22 Kilpatrick decrement in the electric field lowers the sparking tendency by an order of magnitude.

During beam operations, the RFQ was run about 10% below the design field because of a peak rf power limitation. The rate jumped to 3.0 per minute, independent of the beam current (20 to 80 mA) and the field (1.5 to 1.7 Kilpatrick tested). This is about 6 times more than without beam at 1.75 Kilpatrick. It was established that the spark rate has some influence on vacuum, but there is no evidence of any reciprocal effect.

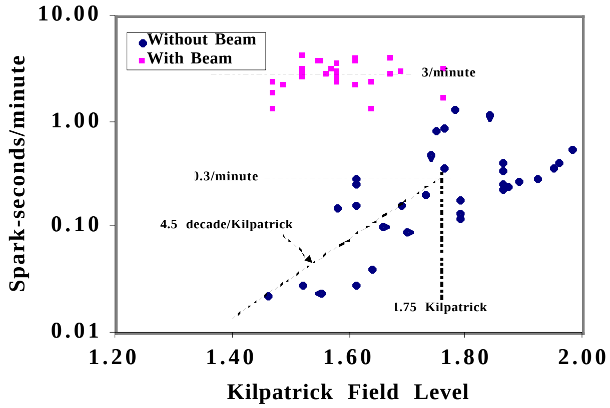

Figure 7: Spark rates during long runs.

4 BLANKING PARAMETER STUDY

Since the interruption of rf power was essential for extinguishing arcs which could damage the RFQ, it was of interest to determine whether the blanking parameters, rf-off duration and rf turn-on ramp time, would have any effect on the sparking rate. Throughout the high-power studies and the proton beam operations, the blanking module adequately protected the RFQ with blanking module settings resulting in an rf-off time of 64 μsec and a turn-on ramping time of 29 μsec. After the beam studies were complete, a test program was commenced to evaluate the effects of these parameters.

The test sequence involved conditioning the RFQ at the beginning of each day at 1.75 Kilpatrick until stable operation was sustained for at least 15 minutes. A single parameter, blanking width or turn-on ramp, was changed and the spark rates measured for run times of 30 minutes or greater. These measurements were taken throughout the day at different parameter settings; and, at the end of each testing day, another measurement was made at the nominal settings. The blanking parameters were adjusted from settings near the fill time of the cavity up to several times that of the nominal settings. The spark rates and spark-second rates for the blanking width parameter study are shown in Figures 8 and 9, respectively.

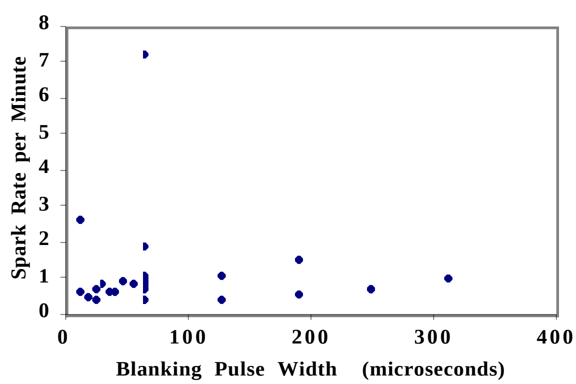

Figure 8: Spark rates as a function of blanking width.

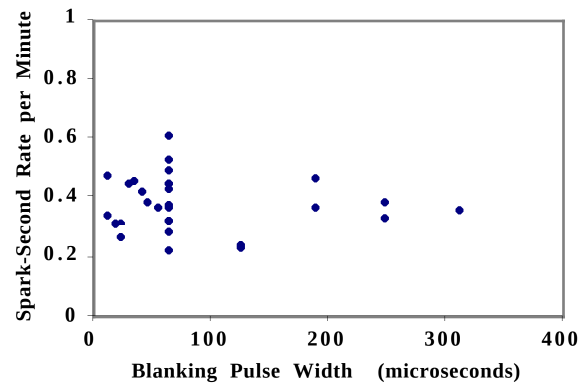

Figure 9: Spark-second rates as a function of blanking width.

Although the rates vary from measurement to measurement, there was no systematic variation observed across a large span of blanking width times. The same was observed from those measurements in which the turn-on ramping time was varied. From this study, we have concluded that it is essential only to interrupt the rf power to extinguish the arc, and varying the blanking time parameters does not reduce the sparking for the RFQ.

5 ACKNOWLEDGMENTS

We would like to thank the personnel of the Chalk River Laboratories who developed the understanding and concepts of operation necessary to protect rf structures under cw, high-power operation. Their initial studies in the operation of this RFQ has been the groundwork for our present cw accelerator program at LANL.

6 REFERENCES

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