TRIUMF CYCLOTRON RF SYSTEM RELIABILITY ENHANCEMENT

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This paper presents recent RF system improvements related to the cyclotron resonators, RF amplifiers, and transmission lines. Although the program is not complete, the downtime due to rf sparking has already been reduced by a factor of 5.

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1. INTRODUCTION

The TRIUMF cyclotron [1] is powered by a 23.06 MHz, 2 MW multistage amplifier. The final stage is based on 8 EIMAC 4CW250000B tubes arranged in 4 power amplifiers (PA) running in parallel. The output power is obtained through 3 combiners. There is another accelerating cavity [2] operating at the 4th harmonic of fundamental frequency that boosts the energy gain per turn at the outer radii. The rf system causes two types of downtime, due to rf sparking in the cavity and hardware failures. Considerable effort was devoted to improve equipment reliability and to reduce sparking.

2. HARDWARE SERVICING AND UPGRADE

The cyclotron operation does not leave much time for detailed tests, troubleshooting, and upgrades of the RF system. Basically, the system is available for service for about 2 months a year.

In the past we experienced a few failures due to water leaks in different locations, for example in the transmission line section containing water-cooled capacitors. In some cases the problem was traced to the aggressive behavior of the low conductivity water with respect to copper components. Solutions were applied: gold plating of rf contacts exposed to water; an introduction of electrochemically active (zinc) dummy electrodes and improved water connections. We have changed the design for all 3 capacitor stations in the matching section. The new modular approach allows fast access to the capacitors for visual inspection and high voltage tests.

Another major activity in the rf refurbishing program was related to the redesign of 3 powerful (up to 1 MW) combiners. The original units required a substantial effort to suppress parasitic oscillations, and were difficult to maintain and adjust. Two new combiners were fabricated and commissioned at full power. The third is scheduled for installation this autumn.

A substantial effort was dedicated to a 500 kW resistive load development. This is an essential tool for high power testing of rf combiners and PA tuning and troubleshooting. The load was commissioned in 2002 at full power. Next year we plan to install an rf switch at the output of the final combiner. This will allow a prompt switch from the cyclotron resonator to the dummy load for diagnostic purposes and eventually will permit 2 PA operation in emergency situations, while 2 others can be serviced. The device is being commissioned.

The output circuit of the Intermediate Power Amplifier (IPA) was recently equipped with two directional couplers and a 100 kW resistive load that provides easy IPA tuning and matching to the following RF power splitter, simplifying system troubleshooting.

So far, power metering between amplifier stages, as well as in the rf splitter and in the combiner branches, has been performed manually. This summer an automatic data acquisition system was developed. In addition to monitoring the power balance, it will feature a watchdog function to prevent operation under high reverse power conditions in any section of the transmission lines between PA's and combiners. To improve troubleshooting efficiency, we have also built a first event detector system. It receives rf signals from as many as 24 voltage pickups and resolves which one drops out first, in the case of sparking. This allows us to localize a hardware failure in the rf chain from the frequency synthesizer to the cyclotron cavity, and to log it for a post-mortem analysis. The system resolution between two subsequent signals is 0.1 μs.

The original copper chore pads installed in the cyclotron tank to dampen the mechanical vibrations of the bellows in the resonator cooling circuit gave trouble on at least 3 recent occasions. Typically, they cause an rf arc, punching a hole in the stainless steel bellow. Resonator panel removal from the tank was required to fix the leak, with considerable time and effort. We are in the middle of a program to replace copper pads with fiberglass ones. The total number of locations is about 160. The work will progress gradually over a few shutdowns.

3. REDUCTION OF SPARKING EVENTS

Operational rf gradients in the rf cavity do not normally ignite vacuum breakdowns. However, theoretical studies and model measurements [3] show, that in the cyclotron vacuum chamber there are parasitic resonant modes other than the fundamental. Some oscillate at frequencies relatively close to the operational mode and at voltages that could enhance multipactoring events. The TM_{310} and TM_{410} modes are the closest ones. Rf field propagation in the beam gap was found to be associated mostly with these modes. Multipactoring in the cyclotron was observed indirectly from the load of the main rf field and the vacuum deterioration connected to the leakage. Evidence of secondary electron emission discharge could also be observed from discolorations on the resonator panels. Some areas are particularly vulnerable to multipactoring. Therefore a lot of effort was put into leakage field measurement and adjustment. The leakage field amplitude is measured with 36 capacitive

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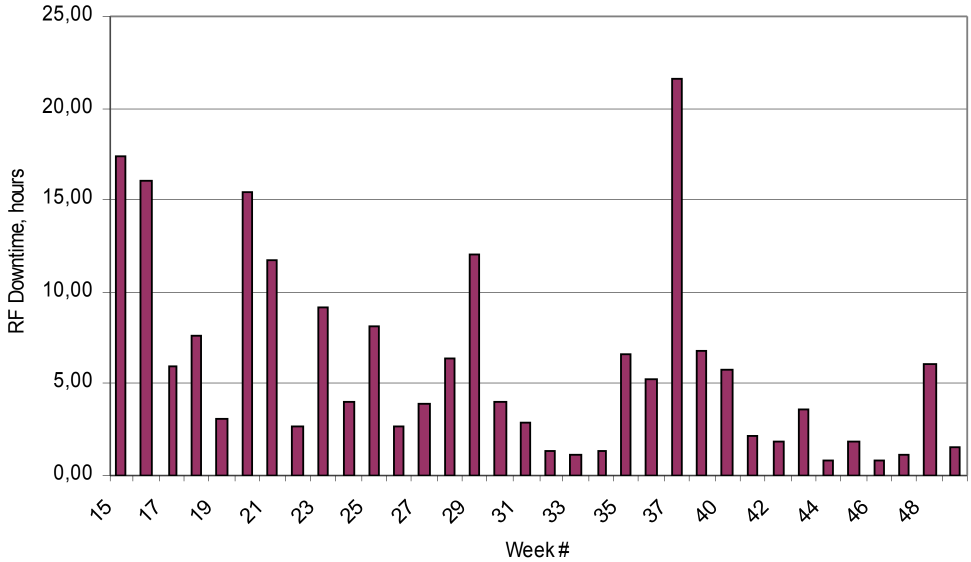
probes, installed on the resonator panels. So the leakage field level can be adjusted and minimized by varying the rf gap between ground arms and hot arms. After the new refurbished control system for the ground arm tip (GAT) position was installed, we performed extensive tip tuning to reduce the leakage field. As a result, the cyclotron downtime due to sparking was lowered by a factor of 5. The weekly downtime graph is presented in Figure.



Year 2002 weekly rf downtime graph. GAT system was upgraded on week 41

It was also noticed that sparking itself does not necessarily have to cause significant interruptions as long as the rf power is automatically turned off at every spark. In the old system, within a few seconds delay, the control system automatically started ramping up the voltage. In total it took about 15 seconds before voltage came back to the nominal value. However, by that time the cyclotron thermal balance was lost because of the substantial rf power removed from the structure by efficient cooling. Temperature variations will affect the resonant frequency. In the operational mode, automatic control of the resonant frequency is performed by varying the cooling water pressure. This system is very efficient, but works within a very limited tuning range of about 3 kHz. Thermal unbalance due to the above recovery time caused cyclotron frequency shifts above 10 kHz, requiring about 3 minutes for the system to come back to the driven mode. Beam restart added 10-20 seconds. So a total spark recovery used to cause 4-5 minutes of machine downtime. The new procedure is as follows. Spark detection is based on voltage drop analysis. When the drop rate exceeds 10 kV/µs, the event is recognized as a spark. At this point the rf drive turns off for 300 ms to allow the ions migrate away from the arc channel. The rf drive then instantly comes back to its original value and automatic amplitude and phase regulation are turned on. The only thing left is to switch the system back to the driven mode, which is done manually by the cyclotron operator. In such a scenario the rf resonators return to operational conditions right away and typically the spark recovery downtime shrinks to 10...20 seconds.

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ПОВЫШЕНИЕ НАДЁЖНОСТИ ВЧ-СИСТЕМЫ ЦИКЛОТРОНА ТРИУМФ

Ю. Былинский, С. Калик, Р. Пуарье, К. Фонг

Обсуждаются усовершенствования ВЧ-системы: резонаторов циклотрона, ВЧ-генераторов, питающего волновода. Часть работ к настоящему времени завершена, что привело к уменьшению простоев из-за ВЧ-пробоев в 5 раз.

ПІДВИЩЕННЯ НАДІЙНОСТІ ВЧ-СИСТЕМИ ЦИКЛОТРОНА ТРІУМФ

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Обговорюються удосконалення ВЧ-системи: резонаторів циклотрона, ВЧ-генераторів, що живить хвилевід. Частина робіт вже виконана, що дало зменшення простоїв через ВЧ-пробої у 5 разів.