AN AUTOMATED CONDITIONING SYSTEM FOR THE MUCOOL EXPERIMENTS AT FERMILAB

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Abstract

The MUCOOL project aims to study RF cavities for the Neutrino Factory and the Muon Collider. The large emittance muon beams in these accelerators require high-gradient RF cavities at low-frequencies and they need to operate in the presence of relatively strong magnetic fields. MUCOOL is conducting a number of tests on 805MHz and 201 MHz cavities in order to develop a technology that can meet all of these requirements.

An automated conditioning system was developed for the 805MHz test program for MUCOOL. This system was designed to replicate the logic a human operator would use when conditioning an RF cavity and to provide automated logging of the conditioning process. This paper describes the hardware and software of the system developed.

INTRODUCTION

Lattice designs for the ionization cooling sections of the Neutrino Factory and the Muon Collider utilise RF cavities that operate at 201 MHz. These cavities need to have a relatively high gradient, due to the short lifetime of the muon, and they need to operate within the fringe fields of solenoids. The MUCOOL [1] project aims to test the RF cavity technology required for these lattices and determine whether the required operating gradients can be achieved. The main factor restricting the operating gradient is high-voltage breakdown, which is mainly influenced by the surface material, surface preparation techniques and the way the cavity has been manufactured.

The first time a new cavity is operated it needs to undergo a process called conditioning whereby the RF power is slowly increased in steps up to the operating gradient. This process improves the vacuum in the cavity and the surface condition of the cavity. During the conditioning process breakdowns may occur, leading to localised surface damage and sharp increases in the vacuum pressure. When this happens the voltage in the cavity is reduced for some time and then slowly increased again. A maximum operating gradient can be define as the gradient where the breakdown rate is very small and beyond which large breakdowns will occur requiring reconditioning of the cavity.

One set of experiments being done at the MUCOOL Test Area (MTA) at Fermilab aims to study the effects of surface material using an 805 MHz cavity that allows buttons of different material to be placed in the middle of the cavity and tested within the bore of a 5 T solenoid. The button tests at the MTA measured the maximum operating gradient as a function of material and applied solenoid field [2]. Other tests are planned at the MTA to study the effect of surface preparation [3].

The original experimental setup for performing the button tests required an operator to be present throughout the tests and manually log the conditioning process. The Automated Conditioning System (ACS) was developed to automate the conditioning process for the button tests. This allows a faster turn-around time for testing buttons (since the system could operate 24 hours a day) and automatic logging of the way each button is conditioned. Even though this system was originally developed for the button tests, its capabilities have been extended to suit the needs of other tests at the MTA such as the high-pressure gas filled cavity tests [4] and the box-cavity tests [5].

PREVIOUS EXPERIMENTAL SETUP

Figure 1 shows a schematic drawing of the experimental apparatus used to obtain the results given in [2]. Here the operator uses the signal generator to set the frequency and magnitude of the RF power in the cavity. The resonant frequency, for a particular RF power, is determined by maximising the pickup voltage signal read from the analog oscilloscope. This voltage is then recorded in a log book as the voltage in the cavity at that frequency. The RF power is slowly increased and the vacuum level in the cavity is monitored to determine when breakdowns occur. A sharp rise in the pressure in the cavity indicates a breakdown and the operator would then reduce the RF power and wait some time before increasing the power again. Hardware controls monitoring the reflected power signal are used to trip the klystron's modulator if multiple breakdowns are detected or if the vacuum level is too high.

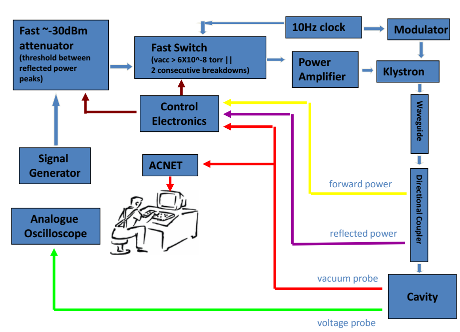

Figure 1: Schematic of the old experimental setup showing the hardware used and the signals used to monitor the cavity.

The precise lengths of time required for each step in the conditioning process, e.g. the time to wait after a breakdown has happened before increasing the RF power again, comes from the experience of the operator and prior knowledge of the cavity and button. Without a precisely defined procedure for the conditioning process it is possible for a button could be conditioned differently depending on which operator was present.

THE AUTOMATED CONDITIONING SYSTEM

The ACS was developed to improve the turn-around time for testing buttons and to automatically log the way in which each button is conditioned. The main requirements of the system was to replicate the logic used by the operator to automatically perform the button tests in a systematic way; determine breakdowns with 100% efficiency; log every step in the conditioning process; measure breakdown rates and maintain hardware failsafe controls. Other secondary requirements were to display real-time and historical data of the conditioning process and provide a user-friendly interface.

This system needed to be working in the shortest time possible so it was decided to use as much of the existing hardware as possible and to minimise software development time. In addition to the hardware in Figure 1, a 4-channel Techtronix digital oscilloscope and a PC running Windows Xp was available. A NI-5105-PCI DAQ card was purchased from National Instruments and was used as a fast digitizer for additional signals from the directional coupler and the second voltage pickup probe in the cavity. The digital oscilloscope and signal generator was interfaced to the PC using a NI-GPIB-PCI card. Figure 2 shows the modified apparatus and the additional signals used. Labview was used to create the control and logging software as it required the least development time.

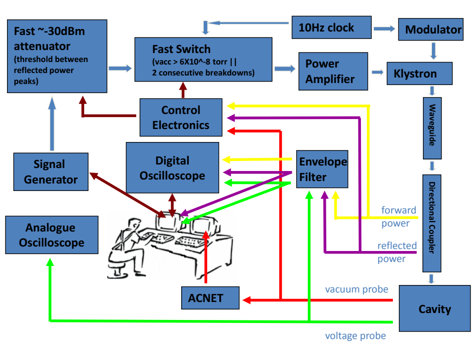

Figure 2: Schematic of the new experimental setup showing the hardware used and the signals used to control the power input to the cavity.

All signals being fed to the PC (via the DAQ card) have an envelope filter applied to remove the 805 MHz modulations. The digital oscilloscope is primarily used to save fast signals (including the 805 MHz modulations) when triggered by the ACS. This is particularly useful for the high-pressure gas filled RF cavity tests where information about gas-breakdown processes can be extracted. Figure 3 shows the reflected power signal from the directional coupler and the pickup probe signal both after applying envelope filters.

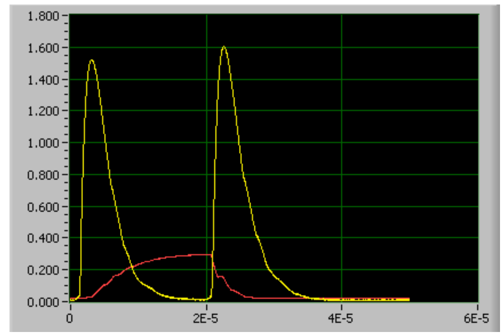

Figure 3: Reflected power (yellow) and pickup probe (red) signal after the envelope filter has been applied.

RF power to the cavity is pulsed by a 20 μs long square-wave signal, typically at 10 Hz. Thus the reflected power signal shows two peaks corresponding to power being stored in the cavity and power being dissipated by the cavity. The rising edge of the first peak of the reflected power signal is used to trigger the DAQ card. When a breakdown occurs power is removed from the cavity before the end of the 20 μs pulse. Thus, a breakdown can be identified when the measured time between the two peaks in the reflected power signal is less than 20 μs. The frequency of the signal generator is set to match the resonant frequency of the cavity. The ACS determines the resonant frequency by adjusting the frequency of the signal generator to maximise the pickup probe signal.

Conditioning was performed manually at low power levels for a new test. This is mainly due to a technical problem with the pickup signal being too low to use at low power. When the ACS is activated, it first sets parameters on the digital oscilloscope, DAQ card and signal generator. The average (mode) of the time difference between the peaks of the reflected power signal is measured for a number of consecutive RF pulses. This is then used, together with an error margin, to set the threshold below which a breakdown is assumed to have occurred.

Figure 4 shows a screen snapshot of the ACSs interface whilst running. The plot on the top left shows the reflected power signal and the pickup probe signal for the current pulse; the plot on the top right shows the history of the measured pulse width where values less than 19.5 μs are breakdowns; the middle left plot shows the history of the frequency of the cavity; the middle right plot shows the history of the probe voltage; the bottom plot shows the history of the breakdown fractions for the short and long intervals. A copy of the log, which is saved to a file, is displayed on the bottom right of the screen. Parameters for the various breakdown conditions can be set at the top of the screen.

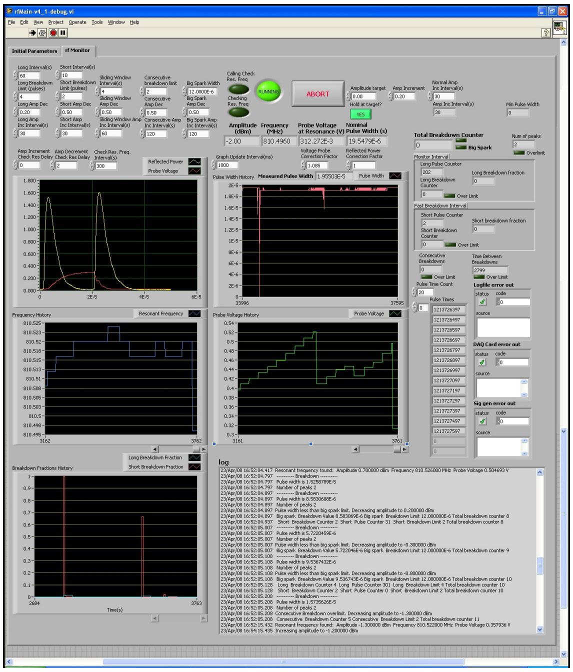

Figure 4: Snapshot of the ACS interface whilst running.

CONDITIONING ALGORITHM

The ACS controls the amplitude and frequency of the signal generator and steadily increases the amplitude until one of the breakdown conditions are met. The amplitude is then decreased and increased again only after a certain period has passed. Figure 5 shows how the signal generator amplitude may vary as a function of time. The values for A and t_1 are fixed whereas the values for D and t_2 are set by the most severe breakdown condition that was met. The breakdown conditions that are monitored by the ACS, in order of severity, are

Big Spark Width
Where the breakdown happens near the end of the breakdown pulse thereby potentially causing more damage due to the higher stored energy in the cavity.

Consecutive Breakdowns
When the number of consecutive pulses that had a breakdown exceeds the limit.

Short Interval Limit
When the number of breakdowns within the specified short time interval exceeds the limit.

Sliding Window Interval
When the time since the previous breakdown is less than the specified interval.

Long Interval Limit
When the number of breakdowns within the specified long time interval exceeds the limit.

Default values for these parameters were set based upon prior experience of the operators.

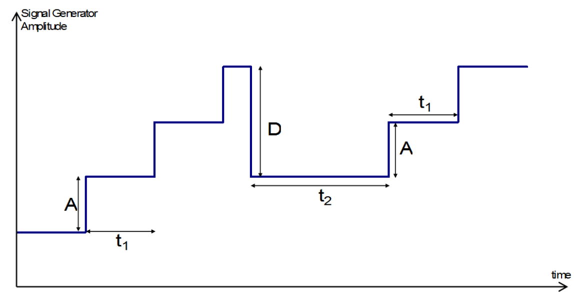

Figure 5: Graph showing how the ACS might vary the signal generator amplitude as a function of time. A is the fixed increment of the amplitude and t_1 is the time between amplitude increments. D is the amplitude decrement and t_2 is the time interval before the next increment, both of which are determined by the breakdown condition that was exceeded.

SUMMARY

An automated conditioning system was developed for the tests at the MTA in Fermilab. The system replicates the logic used by an operator and performs systematic conditioning of the cavity and automatically logs the conditioning procedure. A number of breakdown conditions have been defined to allow flexibility in the way power in the cavity is decreased (e.g. smaller decrements can be used for less severe breakdown conditions) and the time intervals waited before increasing the power again in the cavity.

The interface for the ACS has been designed in such a way as to provide the user control over the way in which the conditioning procedure is carried out. The interface also provides relevant real-time information, historical data for the current run and displays the contents of the log file. The ACS has been successfully tested for the box cavity tests and the high pressure gas filled cavity tests.

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