A MICRO-CHANNEL PLATE BASED RFA ELECTRON CLOUD MONITOR FOR THE ISIS PROTON SYNCHROTRON

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Abstract

Electron clouds produced inside a particle accelerator vacuum chamber by the passage of the beam can compromise the operation of the accelerator. The build up of electron clouds can produce strong transverse and longitudinal beam instabilities which, in turn, can lead to high levels of beam loss often requiring the accelerator to be run below its design specification. To study the phenomena of electron clouds at the ISIS Proton Synchrotron, a Micro-Channel Plate (MCP) based electron cloud detector has been developed. The detector is based on the Retarding Field Analyser (RFA) design and consists of a retarding grid, which provides energy analysis of the electron signal, and a MCP assembly placed in front of the collector plate. In this paper, we describe the lab based experiment used to test our detector using a low energy electron gun. Results from our MCP based detector installed in the ISIS accelerator ring are discussed and compared to a RFA detector, installed at the same location, which has no MCP fitted.

INTRODUCTION

ISIS is the UK's spallation neutron (and muon) source located at the Rutherford Appleton Laboratory in Oxfordshire. Operation centres on a 50Hz proton synchrotron which accelerates ~3E13 ppp (protons per pulse) from the Linac output energy of 70Mev to an extraction energy of 800MeV. There has never been any evidence of beam instabilities that have been directly associated with the production of electron clouds. Based on the proposed ISIS mega-watt upgrade plans [1] a decision was made to design and build detectors that could look for signs of electron cloud build-up and beam instabilities.

Electrons clouds are formed from electrons that are liberated though interactions of the particle beam with the residual gas, and from interactions of the beam with the vacuum chamber walls [2]. If the electron cloud density becomes large enough, this will lead to a strong transverse mode coupling between the proton beam and the electrons, in turn leading to beam instability and beam emittance growth and beam loss [3] [4].

Theoretical studies of the electron cloud phenomena based on the present ISIS accelerator and different ISIS upgrades [5] have been conducted. Although as stated ISIS has never knowingly suffered from electron cloud beam instabilities, these studies have indicated that for an upgraded ISIS, with higher beam intensities, that electron clouds could become a problem and directly affect the performance of the ISIS accelerator[6].

In an attempt to complement the theoretical study of the phenomena of electron clouds, at the ISIS Proton Synchrotron, two Retarding Field Analyser (RFA) based detectors were designed and installed into the 800MeV accelerator ring [7]. However, results from these two RFA detectors showed no evidence of electron cloud activity. At the time this lack of electron cloud signal was considered to be due to the low level of the electron cloud signal combined with the high level of beam induced noise picked up by the RFA detectors themselves.

In order to overcome these two challenges, a Micro-Channel Plate (MCP) based electron cloud detector was developed. The detector is of a standard RFA design, consisting of a negative potential retarding grid, which is used to provide energy analysis of the electron signal, and a MCP assembly placed in front of a graphite collector plate. The MCP assembly provides a current gain over the range 300 to 25K, thereby increasing the signal to noise ratio and dynamic range of the electron cloud measurements.

PRE-INSTALLATION TESTS

Detector Assembly

The new ISIS Electron Cloud Monitor detector assembly is shown in Fig. 1. The schematic diagram of the laboratory set up used to characterise the RFA detector, MCP and amplifier prior to installation is shown in Fig 2.

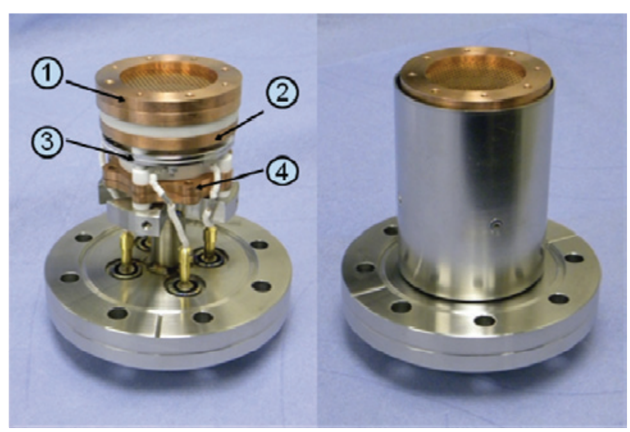


Figure 1: Details of the ISIS Electron Cloud Monitor. On the right hand side, the detector is shown with the mu metal shield in position.

At the front of the detector shown in Fig. 1 there is a 40mm diameter grounded grid (1) with a transmission efficiency of 20%. This grid acts as a substitute for the pipe wall so as to not interfere with the multipacting process, while at the same time allowing through a sample of electrons from the cloud [8]. Next, there is a 40mm diameter retarding grid (2) with a transmission efficiency of 85% connected to a negative power supply whose voltage output can be adjusted remotely for measurements of the energy spectrum of the incoming electrons. The MCP assembly (3) is located between the retarding grid and the collector plate (4). The front plate of the MCP is grounded to the body of the detector and the back plate is connected to a positive bias supply. The collector assembly consists of a 55 mm diameter graphite disk sandwiched inside a copper frame. Graphite was chosen as the collector material due to its low secondary emission coefficient. The whole detector is surrounded by a low mu metal shield grounded to reduce the electromagnetic interference.

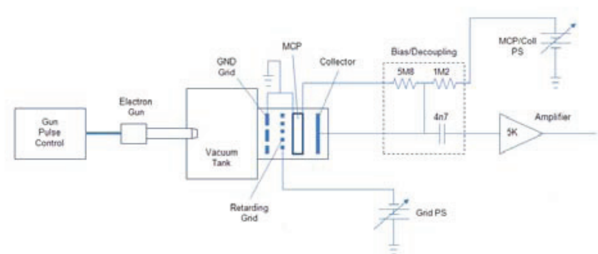


Figure 2: A schematic diagram of the detector characterization setup.

Amplifier

The amplifier used is a custom design d.c. coupled trans-impedance amplifier with a gain of 5 Kohms and a bandwidth of 20 MHz. The input impedance is 100 ohms and the output impedance 50 ohms. Because of the input a.c. coupling capacitor (Fig. 2), the whole system has a band- pass response with cut-off frequencies of 330 KHz and 20 MHz.

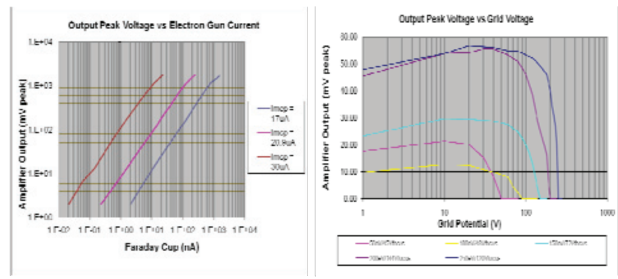
Electron Gun and Diagnostics Used to Test the RFA Detector

The electron cloud detector is installed inside the test vacuum tank with an electron gun located opposite to it to provide a customised electron beam for the laboratory tests detailed below. The gun is an EFG-7F-6017 model from Kimball Physics [9], capable of providing variable d.c. beam or a pulsed beam. The gun is fitted with a retractable faraday cup which is used to measure the total output charge. Focusing of the electron beam was made with the help of a retractable phosphor screen.

Laboratory Tests Results

To obtain precise values of the electron cloud intensity in the ISIS accelerator, the RFA detector, MCP and amplifier had to first be characterised by laboratory based measurements. This was achieved using a purpose built vacuum chamber and electron gun as a signal source. All tests were done using a pulsed electron beam.

The first test carried out provides the transfer function of the whole system (detector and amplifier) for three sets of MCP bias current values. This allows a good input dynamic range within the MCP linear region, ranging from 50pA up to 500nA. The obtained results are shown in Fig. 3.



Figures 3 and 4: Left: Full system (detector and amplifier) transfer functions corresponding to three different MCP gains. Right: Graph showing the amplifier output signal versus retarding grid potential for five different electron energies at a constant beam current.

In the second test a graph has been produced for the MCP gain versus different values of bias current. This data can be used to optimise the dynamic range of the MCP when looking for electron cloud signals in the ISIS accelerator ring.

The third laboratory test provides the curves for the amplifier output signal against the retarding grid potential at different electron gun beam energies. The data shows the stopping efficiency of the grid at different electron energy levels. The current output of the electron gun was fixed at 4.9nA (Fig. 4).

EXPERIMENTAL RESULTS

Location

The electron cloud monitor is positioned on the inside of the accelerator ring looking along the horizontal plane of the beam (Fig. 5). At the same location there are the two original RFA type detectors without MCP assemblies. One of these RFA's is located on the opposite side to the MCP version, therefore again looking along the horizontal plane of the beam. The second non-MCP RFA detector is situated on top of the beam pipe looking down onto the beam path.

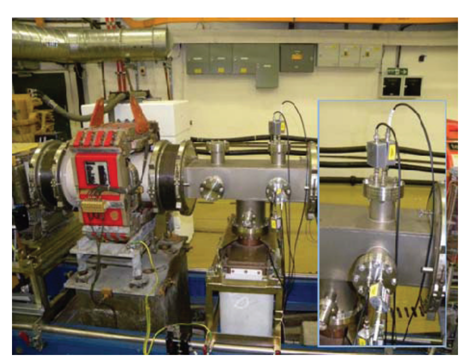


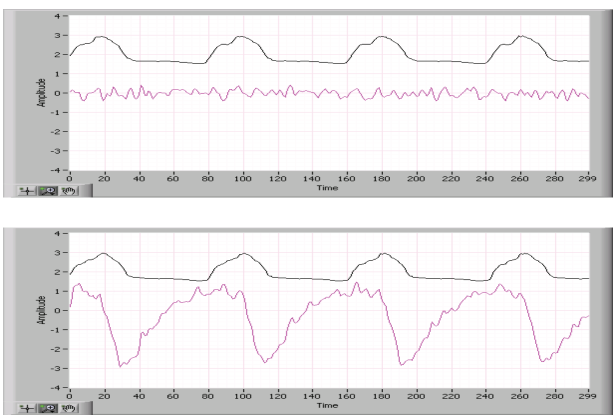
Figure 5: Detail of the installed detectors at the ISIS straight 5 location.

The synchronisation of the data acquisition with the proton bunches is achieved by using the output signal of a position sum monitor located 10m downstream of the electron cloud detector.

Electron Cloud Measurements

As previously mentioned, the two non-MCP RFA units were installed and tested with different amplifiers, but no electron data could be obtained from the signal, due to the large amount of beam induced noise picked up by the detectors. With the new version of the detector, the measurements signal to noise ratio has been greatly improved, due to the extra gain provided by the MCP for the electron signal and the smaller beam induced noise signal, because of the reduced gain of the amplifier.

Figures 6 and 7 show the output signal of the amplifier with and without retarding grid voltage applied. The electron cloud signal is now clearly visible and can be neutralised by applying a potential to the retarding grid. The MCP gain selected for these captures is 7.5K and a potential of 200V at the retarding grid.



Figures 6 and 7: MCP version detector signals. The screenshot on the top was taken with 200V applied to the retarding grid and the one on the bottom without any potential applied. The black trace is the beam position monitor sum signal and the purple one is the electron cloud signal with a vertical scale of 10mV/div.

SUMMARY

The results obtained with the MCP based electron cloud detector have marked a successful transition between the simulation work that was originally carried out on electrons clouds at ISIS and the experimental work reported here. The electron cloud monitor promises to be a valuable piece of diagnostics to be used for present and future upgrade programs for ISIS. Possible improvements to the detector system are:

- D.c. amplifier for build up effect measurements.
- Built in calibration system (e.g. electron gun).

It is intended that this electron cloud detector will eventually be used in conjunction with a strip line monitor and fast feed-back system which is currently under development. Once all these systems are operative, it would then be possible to observe beam instabilities with the strip line monitor and correlate them with the electron cloud signal [10].

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