Online aging study of a high rate MRPC *

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Abstract: With the constant increase of accelerator luminosity, the rate requirements of MRPC detectors have become very important, and the aging characteristics of the detector have to be studied meticulously. An online aging test system has been set up in our lab, and in this paper the setup of the system is described and the performance stability of a high-rate MRPC studied over a long running time under a high luminosity environment. The high rate MRPC was irradiated by X-rays for 36 days and the accumulated charge density reached 0.1 C/cm^2. No obvious performance degradation was observed for the detector.

Keywords: high rate MRPC, aging test, current, counting rate

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1 Introduction

The multi-gap resistive plate chamber (MRPC) is a type of gas detector developed at CERN in the late 1990s [1, 2]. Due to its properties of excellent time resolution, high efficiency, low cost and easy production of large area, the MRPC is widely used in the construction of time of flight (TOF) systems in particle physics and nuclear physics experiments such as STAR at RHIC [3, 4] and ALICE at the LHC [5]. The University of Science and Technology of China (USTC) and Tsinghua University designed an MRPC prototype and constructed a TOF system for STAR, and the TOF system plays an important role in STAR physics analysis such as the observation of antihelium-4 [6]. MRPCs are usually assembled with float glass and their efficiency drops fast when the incident particle rate exceeds a few hundred Hz/cm^2. The Compressed Baryonic Matter (CBM) experiment at the Facility for Antiproton and Ion Research (FAIR) is a high luminosity experiment to study QCD performance and equation of state, and an MRPC-based high rate TOF will be constructed for this experiment [7]. In order to meet the rate requirement of the CBM-TOF (~25 kHz/cm^2 in the central area), this kind of MRPC will be assembled with low resistive glass developed by Tsinghua University [8, 9]. This is the first time for a high rate MRPC to be used in a large experiment and it is essential to test its aging performance. An online aging test system has been established in our lab. The system consists of an X-ray source, cosmic ray telescope, VME DAQ system and monitoring system. The high rate MRPC can be irradiated with X-rays, and at the same time its efficiency and time resolution can be tested with a cosmic ray system and other performance characteristics such as working current and signal counting rate can also be recorded. This irradiation test is very similar to the detector test on the Gama Irradiation Facility (GIF) at CERN [10].

2 Experimental apparatus and test environment

A pad readout MRPC designed by Tsinghua University, intended for the central area of the CBM TOF, was tested. The structure of the module is shown in Fig. 1. This double stacked module consists of ten gaps and the width of each gap is 0.22 mm. There are 12 readout pads and the dimensions of the pad are 2 cm ×2 cm.

In order to study how the detector performance changes with irradiation dosage, the counting rate and working current are recorded online with an Agilent 34410A Digital Multi-meter. Figure 2 shows the structure of the performance monitoring system. The MRPC signal from pad3 was sent to the meter, which was recorded by a computer. The working current from the high-voltage source (CAEN N471)was connected to the other meter. A Spellman XRB80 X-ray source was used to irradiate the detector and the signal rate and working current were sampled every 30 seconds.

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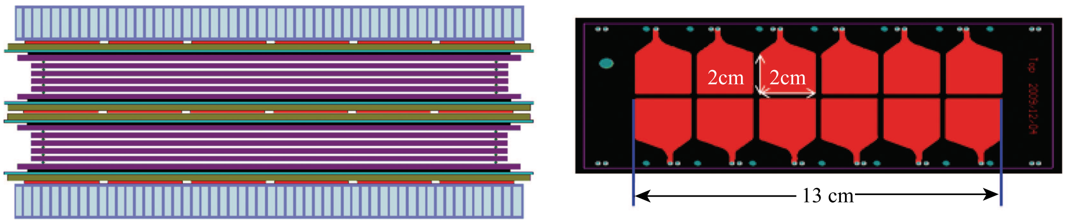

Fig. 1. (color online) Structure of high rate MRPC module.

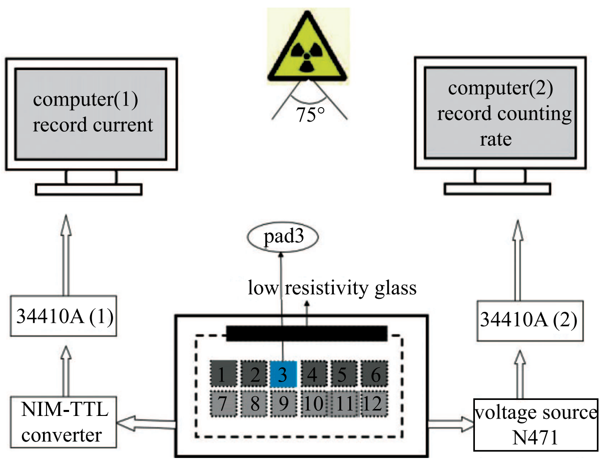

Fig. 2. (color online) Schematic diagram of the monitoring system.

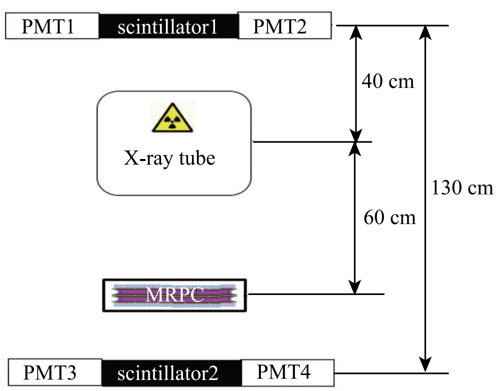

Fig. 3. (color online) Layout of the irradiation system.

The experimental setup is shown in Fig. 3. Two scintillators were placed 1.1 m apart, and the distance from the X-ray source to the MRPC was 60 cm. The voltage of the X-ray source was set at 60 kV and the current at 0.4 mA. According to simulation [11, 12], the irradiation is nearly uniform in each gap of the MRPC. The working gas consisted of 90% freon, 5% iso-butane and 5%SF6, and the working voltage was ±6.2 kV. The temperature in the room was kept at 24℃ by an air conditioner. A network camera was put in front of the gas mixture to monitor the flow rate of the working gas. During the experiment, the X-ray source had to be powered off for about 30 minutes every five days and we could check the noise rate and dark current in this interval.

3 Test results

For CBM-TOF, the normal radiation tolerance is about 0.1 C per year, which corresponds to the detector being irradiated by X-rays for 36 days. When the MRPC was irradiated by the X-ray source, the current was around 1.4 μA and the signal counting rate was around 13 kHz/cm^2. In order to compare the performance, the efficiency was scanned before and after irradiation and the efficiency plateau is shown in Fig. 4. It can be seen that the efficiency becomes lower after irradiation when the working voltage is lower than 6 kV, but at the plateau, the efficiency is nearly the same.

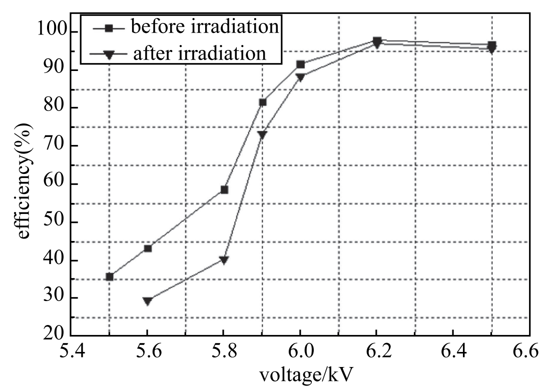

Fig. 4. Efficiency as a function of high voltage before and after irradiation.

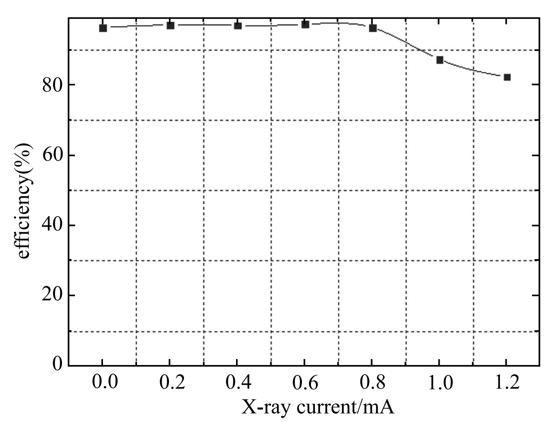

Fig. 5. Efficiency with varying X-ray current.

We also checked how the efficiency changes with the X-ray current. The results are shown in Fig. 5. With the increase of current of the X-ray source, an obvious decrease of efficiency of the MRPC is observed when the current increased to 0.8 mA. We therefore conclude that 0.8 mA is the maximum irradiation current. This level is very high compared with what the detector would experience in the real experiment radiation environment. For the safety of the MRPC, the working current of the X-ray source is set at 0.4 mA and the irradiation is at half of the maximum strength.

Figure 6 shows the relationship of working current and counting rate of the MRPC with the X-ray source current. The current and counting rate of the MRPC increas linearly with the source current. When the source current is 0.4 mA, the current of the MRPC is 1.4 μA and the counting rate is 13 kHz/cm^2.

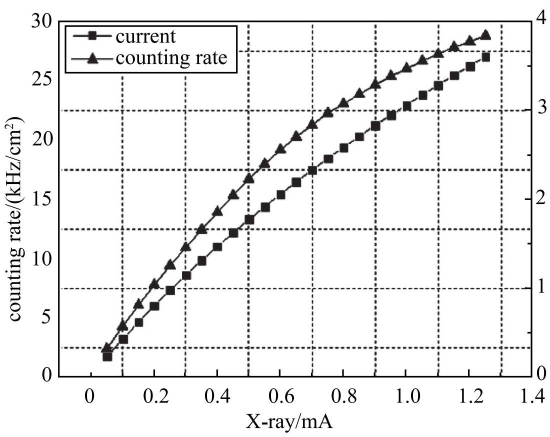

Fig. 6. Variation of current and counting rate with X-ray strength.

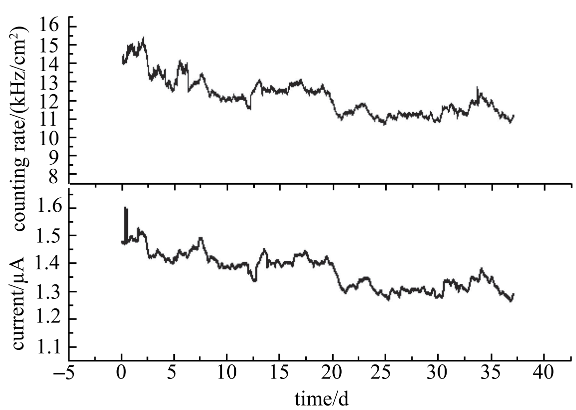

Fig. 7. Variation of current and counting rate with irradiation time.

To monitor the performance of the MRPC, the working current and counting rate were recorded every 30 seconds. Figure 7 shows the change of working current and counting rate with irradiation time. It can be seen the working current and signal counting rate remain stable throughout the whole process. However, it is hard to say because there is no indication of what the uncertainty on the measurement is. The slight fluctuations may be caused by the X-ray current fluctuation. The irradiated area is about 43 cm^2, so the integrated charge 0.1 C/cm^2 can be calculated from the following formula:

$$Q = 1.4\times10^{-6}\times36\times24\times3600/43 = 0.1\,\mathrm{C/cm^2}$$

The efficiency, cluster size and noise are important parameters indicating the performance of the MRPC. We can get from Fig. 8 that these three parameters remain almost constant during the irradiation process. There is some minor fluctuation. For example, the efficiency changes from 90% to 95% and the cluster size from 1.15 to 1.2. The noise stays at around 5 Hz/cm^2 before irradiation and after a few hours of irradiation, the noise increased sharply to tens of Hz/cm^2 between 40–70 Hz/cm^2, before gradually decreasing over the rest of the process.

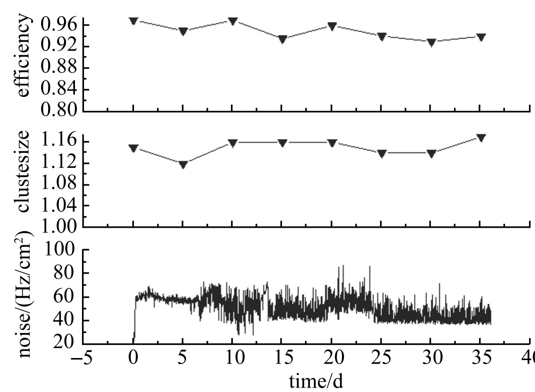

Fig. 8. Variation of efficiency, cluster size and noise with irradiation time.

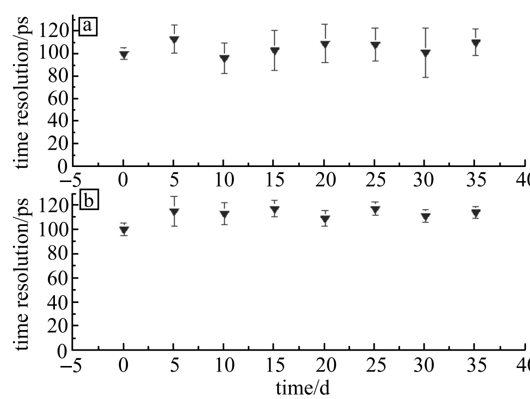

Fig. 9. Variation of time resolution with irradiation time.

Figure 9 shows the time resolution measured over the whole irradiation process. Because of statistical problems, the time resolution is analyzed by two methods. In the first method, it is analyzed every five days and only events (about 500) in these five days are used for analysis. The results are shown in Fig. 9(a). In the second method, the time resolution is also analyzed every five days, but the events are total events obtained from the beginning. The results are shown in Fig. 9(b). It can be seen that the fluctuation and error bars are all smaller in Fig. 9(b). The time performance remains stable during the 36 days.

The charge spectra are shown in Fig. 10 and it can be seen the average charge decreases slightly with time. This is mainly caused by the space charge effect.

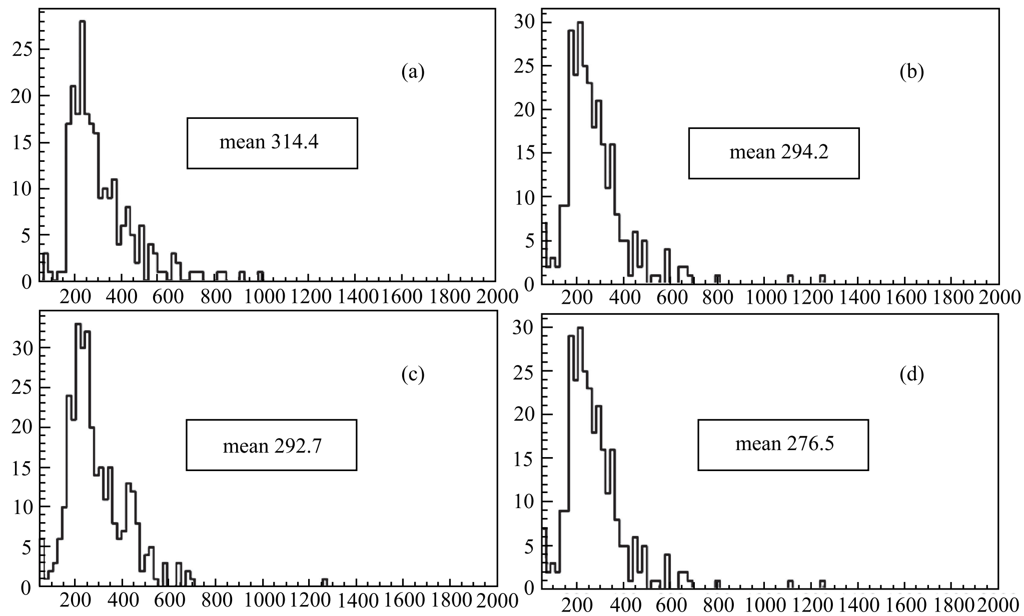

Fig. 10. The charge spectrum at different stages: (a) before irradiation, (b) after ten days' irradiation, (c) after twenty days' irradiation and (d) after thirty days'irradiation.

One phenomenon observed is that the performance recovery speed becomes slower after irradiation, and this can be seen in Fig. 11 and Fig. 12. The black solid dots are experimental data and the red curves are fitted lines. Figure 11 shows the current recovery after one day of irradiation and Fig. 11 the recovery after 36 days of irradiation. The current recovery curve can be fitted with an exponential function such as:

$$C=a^*\exp(-x/b)+C_0,$$

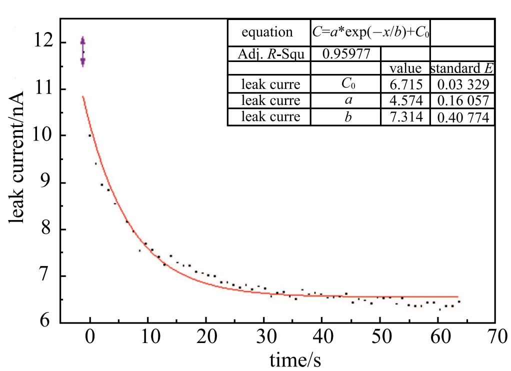

Fig. 11. (color online) Current recovery curve after one day of irradiation.

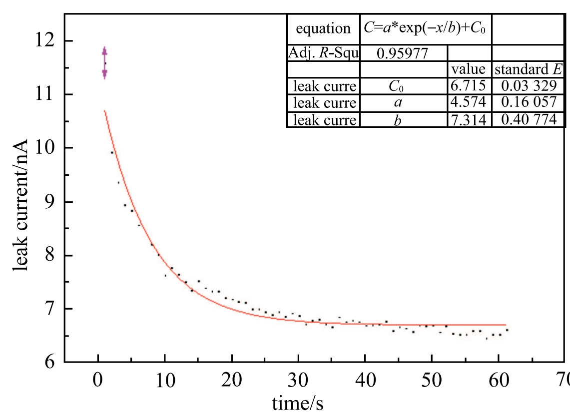

Fig. 12. (color online) Current recovery curve after 36 days of irradiation.

where C represents the current, x is time, and A, b and C_0 are constants. The parameter b is 7.3 seconds and 13 hours in Fig. 11 and Fig. 12 respectively. The noise rate of the detector has the same tendency as dark current. It can be seen the performance recovery speed is greatly affected by irradiation. This phenomenon has been observed in the RHIC-STAR Muon Telescope Detector (MTD)system [13] and it is mainly caused by a gas pollution effect. Gas pollution means the ionized gas is not exchanged in time, which affects the MRPC performance. A lot of studies have to be done to improve the gas exchange efficiency.

4 Conclusions

The application of high rate MRPCs is very important in high luminosity hadron physics experiments. A kind of low resistive glass has been developed at Tsinghua University and the rate capability of our high rate MRPC can reach 70 kHz/cm^2. In order to measure the long term stability of high rate MRPCs, an online aging test system has been set up in our lab. Our high rate MRPC has been irradiated by X-rays for 36 days and the accumulated charge density reached 0.1 C/cm^2, which corresponds to the radiation tolerance of one year of operation for CBM-TOF. The working current and counting rate were monitored throughout the whole irradiation process. Other performance characteristics such as efficiency, time resolution and cluster size were analyzed periodically. No obvious performance degradation was observed for working current, noise rate, time resolution and cluster size, but there was an obvious degradation of recovery speed after irradiation. The test results show that the high rate MRPC can meet the requirements of CBM-TOF, but to be sure of the detector stability over a longer time (more than five years) running, we need to do further studies. For our next step, the detector will be irradiated at GIF++ at CERN for a long time.

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