Conditioning of MWPCs *for the LHCb Muon System*

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***Abstract*–We report on the conditioning of the Multi-Wire Proportional Chambers (MWPC) for the LHCb muon system. The MWPCs destined for the inner regions of the muon stations have demanding requirements in terms of rate capability (>100 kHz/cm^2) and ageing properties. Conditioning of the chambers is therefore of utmost importance. After construction, all chambers undergo a conditioning procedure in two steps, resulting in successful cleaning of anode and cathode surfaces. Conditioned chambers show excellent behaviour under working conditions.**

I. The LHCb Muon System

The Large Hadron Collider Beauty experiment (LHCb) is a forward detector at the LHC accelerator at CERN, dedicated to precision measurements of CP-violation and rare decays [1]. Its muon system must provide a fast and robust trigger and muon identification. The muon system is composed of 5 stations, one in front of the calorimeters and four behind, interleaved by iron walls (see Fig. 1). Each station is divided into 4 regions of increasing granularity towards the beam pipe. A total of 1368 MWPCs of 20 different sizes is needed to build the MHCb muon system [2].

II. Design and Construction of the MWPCs

The MWPCs of the LHCb muon system are designed as four-gap chambers, constructed out of 5 panels with a gap size of 5 mm (see Fig.2).

The plane panels are produced in a mould, where polyurethane foam is injected in between two printed circuit boards forming the cathode surface. A mould release agent (ACMOIL36-4600) is used, containing 5-10% silicone. This product is suspected to create patches of insulating film on the cathode surface. However, its use turned out to be unavoidable since other mould release agents containing water were unusable as the foam is very hygroscopic. Although all cathode panels are carefully cleaned by hand with n-hexane, isopropyl alcohol and de-ionized water, especially the border of pads on segmented cathode panels is difficult to clean, and therefore the most susceptible to impurities.

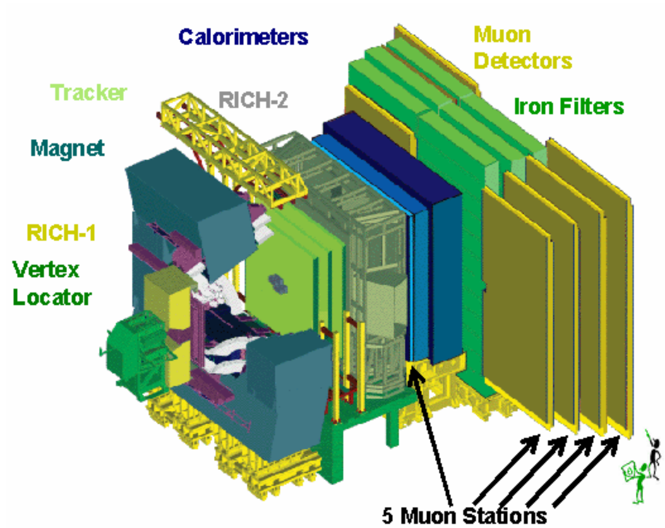

Fig. 1. Schematic view of the LHCb detector. The 5 muon stations are indicated by black arrows. For operation, all chamber stations will be slid into central position, interleaved by the iron filters.

Each wire layer, made of a 30 micrometer gold plated tungsten wires and with a wire pitch of 2 mm, is centered in the gas gap. The design parameters are listed in Table I. Details on the construction can be found in [3].

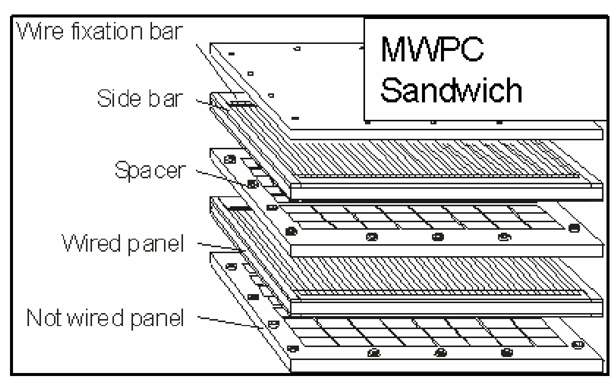

Fig. 2. Construction of a 4 layer MWPC: Two double sided wired panels are placed in between three not wired panels. Bars and spacers define the gas gap size of 2 times 2.5 mm.

The LHCb muon trigger requires a coincidence of the 5 stations in a time window given by the LHC bunch crossing

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rate (40 MHz). In order to achieve a muon trigger efficiency of at least 95%, the efficiency of each station has to be higher than 99% and requires a time resolution of 4 ns, which is achieved by OR-ing pairs of layers to double-gaps. For a p_T resolution of 20%, the required spatial resolution of the MWPCs in the bending plane is of the order of 1-10 cm, depending on the chamber distance to the LHC beam pipe. This is achieved by reading out cathode pads and/or groups of wires.

The innermost chambers must handle a rate of up to 200 kHz/cm^2 at the LHCb peak luminosity of L= $5x10^{32}$ $cm^{-2}s^{-1}$. This demands an aging resistance of up to 1C/cm of accumulated charge over 10 years on the wire.

TABLE I
DESIGN PARAMETERS OF THE WMPCS

gap size	5 mm
gas mixture	$Ar/CO_2/CF_4$ (40:55:5)
wire	gold-plated tungsten
wire diameter	30 micrometer
wire length	250 – 310 mm
wire spacing	2 mm
mechanical tension on wire	65 grams
high voltage working point	2650 kV
field on wires	262 kV/cm
field on cathode	6.2 kV/cm
gas gain	~ 50000

III. MWPC CONDITIONING

Even though chamber assembly is taking place in a clean environment, impurities on anode wires and cathode panel surfaces can not be fully avoided. The application of positive High Voltage (HV) to the anode wires in a new MWPC results in high currents, which can damage the electrodes due to discharges. Chamber conditioning therefore is needed.

A conditioning method in two steps was elaborated, to clean both anode and cathode surfaces. The result is a successful application of up to 2900 V, which is well above the nominal HV of 2650 V, with a normal dark current response at the level of 1-2 nA.

A. Step1: Conditioning under Inversed High Voltage

In the first step of the conditioning procedure, negative HV up to -2300 V is applied to the sense wires. At this voltage level only a weak avalanche effect occurs, thus allowing for a safe chamber treatment. Both, electron emission from tip-like dirt on the wire as well as ion and electron bombardment on the electrodes are expected to have positive impact on surface cleaning.

At each step of incrementing HV a fast current reduction from the level of microamperes to the level of 10 nA is observed within the first 10 minutes. At -2300 V delta-like current pulses of up to 10 microamperes amplitude occur. After an average conditioning time of 48.5 hours, the number of delta-like current pulses decreases and the observed average rest current is well below 10 nA.

After this conditioning step with inversed HV, positive HV of up to 2900 V can easily be applied to the sense wires, and a dark current level is documented.

B. Step 2: Conditioning under High Gamma Irradiation

All chambers of the inner regions are exposed to high gamma irradiation at the Gamma Irradiation Facility (GIF) at CERN. 660 keV photons of a ~600 GBq ^{137}Cs source provide conditions similar to the background irradiation in the LHCb environment. At the same time the cathode quality is tested and the chambers are conditioned.

During this high irradiation test Malter-like thin film field emission [4] was observed in about 20% of all tested gaps: A thin insulator film on the cathode surface gets charged up by positive ions. The resulting high electric field then starts electron emission through the thin film.

The mould release agent used for panel production, as mentioned in section II, is a most probable candidate for creating patches of insulating film on the cathode surface. Fig.3 shows the observation for 2 MWPCs (8 gas gaps): Nominal HV was applied to the chamber. When the radioactive source was switched on, the measured current of each gap rose to different levels from 6 to 10 microamperes. At a certain point however, 3 out of the 8 gaps show an onset of a higher current level (building-up effect). A self-sustained current, equal to the building up effect, remains even when the radioactive source is switched off (see Fig.3).

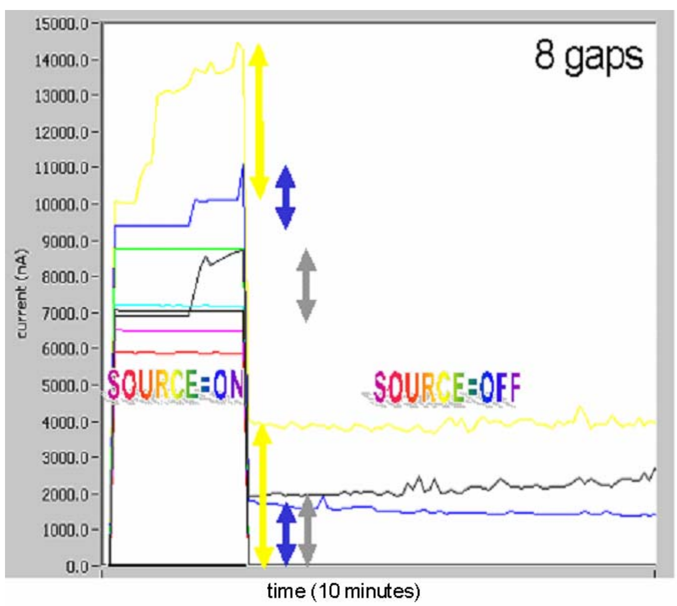

Fig. 3. Current response of 8 gas gaps to irradiation with a ^{137}Cs source. Each gap is plotted in a different color. Three of the 8 gaps show a sudden onset of Malter-like emission, seen as a high current level, which is self-sustained, even after closing the source.

If Malter-like emission has been detected, positive HV is applied in small steps of 50-100 V for the range of 2200 –

2750 V. High gamma irradiation leads to the creation of many positive ions. The result of the treatment is an exponential current reduction to the level of the nominal dark current level. The conditioning time for this step can last up to 70 hours of treatment.

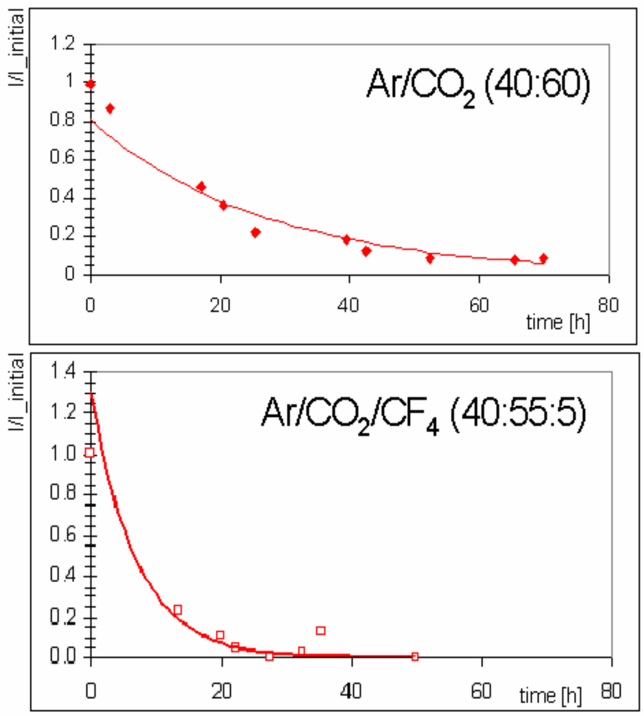

Fig. 4. Comparison of MWPC conditioning with 2 gas mixtures: The upper plot shows the observed current reduction with a gas mixture without CF_4, whereas for the lower plot a gas mixture containing 5% CF_4 was used. Both measurements were performed on the same chamber. The current reduction is much faster and more efficient, when CF_4 is added.

A comparison on conditioning with different gas mixtures, one without and one with 5% CF_4, has been performed. Fig.4 shows the result. Without CF_4 the current decreases with a slower time constant, and the final current saturates still in the range of microamperes. Adding 5% CF_4 to the gas mixture leads to a faster current reduction down to the nominal dark current level. This is due to the fluorine radicals produced from the 5 % CF_4 in the gas mixture. Silicon may be removed by creating SiF_4 molecules that are volatile and are removed by the gas flux.

A typical measurement of current against applied voltage is plotted in Fig.5. The measured current is electron emission multiplied by the gas gain. Expressing the same data in a Fowler-Nordheim plot [5], [6], generally used to describe field emission from metals, a straight line can be fitted to the data with a slope inversely proportional to the local electric field. By repeating the measurements after several hours of treatment, the line rotates, indicating a reduction of the electric field due to the conditioning (see Fig.6).

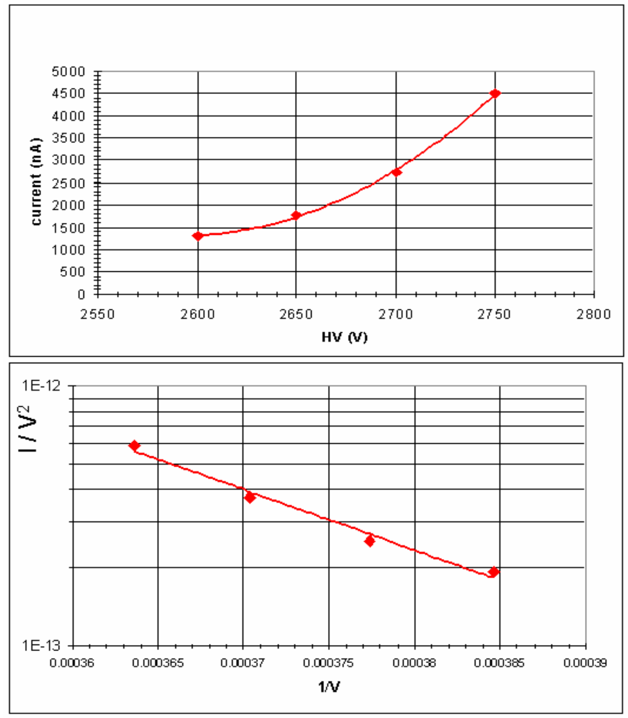

Fig. 5. Upper plot shows measurements of current versus applied voltage. The lower plot expresses the same data in form of a Fowler-Nordheim plot. The slope of the fitted line is inversely proportional to the local electric field.

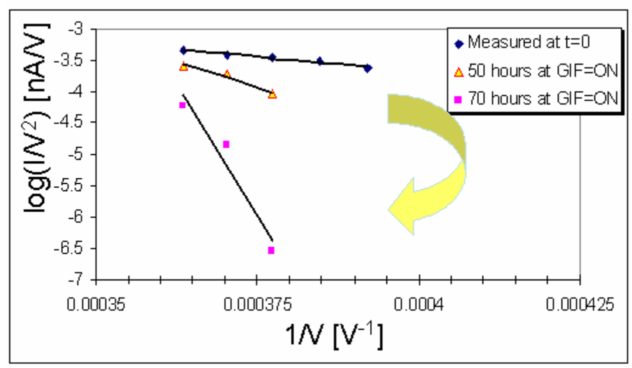

Fig. 6. Repeated measurements result in a rotation of the fitted line, indicating the reduction of the electric field.

IV. Summary and Conclusion

A fast and efficient cleaning and conditioning procedure for the MWPCs for the LHCb muon system has been found, which is performed in 2 steps. In the first step, inversed HV is applied to the sense wires and slowly incremented to a level of -2300 V. Electron emission from the sense wires and ion and electron bombardment on the electrodes are the most prominent effects for chamber cleaning. In the second step, positive HV on the sense wires is incremented in steps of 50 – 100 V for the range of 2200 – 2750 V, while exposing the chamber to a high gamma ray source (^{137}Cs, ~600 GBq). Patches of thin insulator film, which may exist on cathode surfaces, get charged up by ions and lead to electron emission. After up to 70 hours of treatment under the fully open source, the current level reaches the nominal value of the dark current level of 1-2 nA.

We conclude, that a successful anode wire and cathode surface cleaning and conditioning can be achieved following the 2-step method presented here.

Furthermore, we can assume that the observed anomalous currents are self-suppressed during MWPC operation at LHC, due to the high background radiation in the experimental environment. Therefore we are confident, that the long term operation of the LHCb muon system is guaranteed.

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