

DEVELOPMENT, PRODUCTION AND TESTING OF 4500 BEAM LOSS MONITORS

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Abstract

Beam-loss monitoring (BLM) [1] is a key element in the LHC machine protection. 4250 nitrogen filled ionization chambers (IC) and 350 secondary emission monitors (SEM) have been manufactured and tested at the Institute for High Energy Physics (IHEP) in Protvino, Russia, following their development at CERN. Signal speed and robustness against aging were the main design criteria. Each monitor is permanently sealed inside a stainless-steel cylinder. The quality of the welding was a critical aspect during production. The SEMs are requested to hold a vacuum of 10^{-7} bar. Impurity levels from thermal and radiation-induced desorption should remain in the range of parts per million in the ICs. To avoid radiation aging (up to $2 \cdot 10^8$ Gy in 20 years) production of the chambers followed strict UHV requirements. IHEP designed and built the UHV production stand. Due to the required dynamic range of 10^8 , the leakage current of the monitors has to stay below 2 pA. Several tests during and after production were performed at IHEP and CERN. A consistently high quality during the whole production period was achieved and the tight production schedule kept at the same time.

INTRODUCTION

The design of the LHC beam loss monitors is based on the experience gained with the SPS beam loss system. There, nitrogen filled, sealed, parallel plate ionization chambers have been in operation for the last 30 years. The monitors installed in the ring have received a radiation dose of 0.1 to 1 kGy per year; while the ones close to the extraction and injection regions have received 0.1 to 10 MGy per year. The aging of these monitors was assessed by placing a radioactive source Cs137 on the monitors and reading the induced signal with the installed standard BLM electronics. Significant gain variations (Fig. 1) were observed only at the high radiation areas. The relative sigma of the 140 regular ring monitors is below 1%, while the 42 injection/extraction monitors show a gain variation with a relative sigma of approximately 5%. The estimated radiation dose on the monitors in the LHC during 20 years of operation is $2 \cdot 10^8$ Gray in the collimation sections and $2 \cdot 10^4$ Gray at the other locations. Consequently, no gain variations are expected on the LHC BLMs for 20 years of operation, with the possible exception of the collimation regions.

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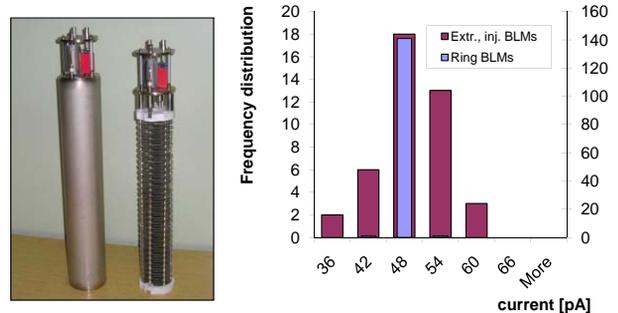


Figure 1: Left: LHC BLM ionization chamber. Right: Gain variations on installed SPS monitors after 30 years of operation.

DESIGN CRITERIA AND SPECIFICATION

Signal speed and robustness against aging were the main design criteria for the detectors. Because of the high dynamic range two types of detectors are used. The standard monitors are ionization chambers with parallel aluminum electrode plates separated by 0.5 cm, as shown in Fig. 1. The detectors are about 50 cm long with a diameter of 9 cm and a sensitive volume of 1.5 liter. The chambers are filled with N_2 at 100 mbar overpressure. At locations with very high (potential) loss rates the ionization chambers are complemented by secondary emission monitors [2]. They are based on the same design, but hold only three electrodes made out of titanium, as its secondary emission coefficient shows better stability as the integrated dose increases. The chamber is 10 cm long, the pressure inside has to stay below 10^{-7} bar. The sensitivity is about a factor of $7 \cdot 10^4$ smaller than in the ionization chamber. Both chambers are operated at 1.5 kV and are equipped with a low pass filter at the high voltage input. To avoid radiation aging (electronegative gases, organic compounds) a strict cleaning procedure for the chambers is followed (including vacuum firing of the steel components for the SEM). No organic material is present, neither in the production process (pumping, baking and filling) of the detectors, nor in the detectors themselves.

MONITOR PRODUCTION

All components for one vacuum stand production batch (with the exception of ceramics components) are cleaned in IHEP [3] shortly before assembly, following the CERN standard for UHV requirements. The stainless steel com-

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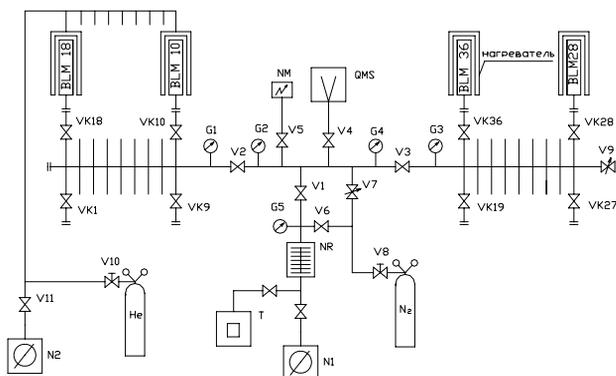


Figure 2: Layout of the IHEP vacuum production stand.

ponents are cleaned in an UHV ultrasonic bath with NGL (NGL 17.40 SP ALU, NGL Cleaning Technology S.A. Nyon, Switzerland) (20 g/l) in distilled water at 65 °C during 30 minutes. After that, they are rinsed in distilled water at room temperature and again in an UHV ultrasonic bath during 5 minutes. The last step of the cleaning procedure is baking at 150 °C in air. The aluminum electrodes are cleaned in the UHV ultrasonic bath with NGL (10 g/l) in distilled water at 65 °C during 20 minutes, rinsed in distilled water at room temperature and in an UHV ultrasonic bath during 10 minutes and finally baked at 150 °C in air. After the cleaning, all components are transferred to the clean room for assembly with closed packing. Standardized test samples analyzed at CERN periodically helped to check the cleaning performance. The vacuum production stand (Fig. 2) was designed and built in IHEP. It consists of: a) the ultra-high-vacuum pumping part (pre-vacuum pump, two turbo-molecular pumps - TMP56 and TMP170, and an ion molecular pump); b) the vacuum gauges (two PKR261, three APR262, and one Prisma QMS 200F2 mass-spectrometer); and c) two manifolds for 18 chambers each.

The welds have been executed by TIG (tungsten inert gas) arc welding under argon shielding without a filler material and with 100% penetration of the welds. Several different tests were performed at IHEP before, during and after the production to verify the quality of chambers. For example, quality of the cleaning of the components, recording of the vacuum stand data, the dark current measurements of feedthroughs, of the “heads” after welding and of the monitors after filling and immediately before shipping to CERN. All of these data were written into the equipment MTF (Manufacturing and Test Folders) database. All welds were He leak tested. Before heating, the outgassing of the chambers and the stand was measured to estimate the quality of the component cleaning. The same procedure was repeated after heating. The temperature of each chamber on the vacuum stand (“Agilent 34970A”) and the pressure measurements (“Pfeiffer TPG256A”) were recorded automatically during the cycle and displayed online.

Ionization Chambers

Heating of the chambers started after the pressure had reached $2 \cdot 10^{-5}$ mbar. The temperature of the chambers was increased at a rate of 50 °C per hour and kept at 220 °C for 6 hours. Then, the heating was switched off and at about 100 °C and a pressure of $5 \cdot 10^{-6}$ mbar the ion molecular pump was switched on and kept pumping during 20 hours to further reduce the pressure to a final value of 10^{-8} mbar before filling. Chambers were filled with 99.999% nitrogen at 1.1 bar at a temperature of 20 °C. After pinch-off (annealed Cu-tube) and removal of the chambers from the vacuum stand, the nitrogen is pumped from the stand during one hour (test of the tightness of all pinch-offs remaining on the stand). To control the purity of the nitrogen, the composition and residual gas pressure was measured. Analysis of the residual gas spectrum shows a typical spectrum for this type of vacuum stand and gives evidence of the absence of additional pollution from the nitrogen gas. After transport of the monitors to CERN by lorry, reception tests were performed at CERNs gamma irradiation facility (GIF). For the IC they consisted of a) leakage current measurements and b) measurements of the signal induced by the radioactive source. 15 monitors were placed in a special support at 1.4 m transverse to the flux of the radioactive source ^{137}Cs (98 GBq, 4.7 mSv/h), the geometry leading to a difference in flux of +/- 5% between the 15 monitors. The measurements are recorded in the MTF equipment database. Fig. 3 summarizes the reception tests. Out of 4259 IC arriving at CERN only 20 did not pass the reception tests.

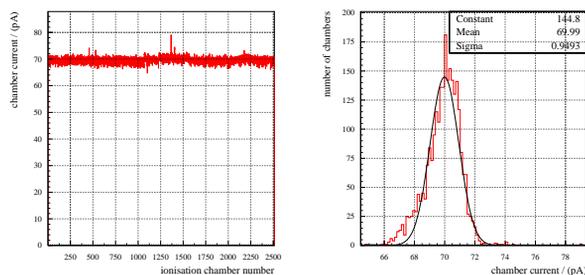


Figure 3: Gain of the ICs measured in the GIF facility, partly corrected for systematic effects.

Secondary Emission Monitors

The SEM monitor [2] requires for its proper functioning a very high vacuum to keep the internal ionization signal level safely below the secondary electron emission. All the materials were chosen according to the UHV standards, as the outgassing needs to be strictly minimized for being able to achieve the lifetime of 20 years in a very high radiation environment. During the design and production, an effort was made in order to assure the cleanliness of all the surfaces and the minimization of possible unpumped gas volumes or leaks. All the steel components (without threads) were vacuum fired at 950 °C and the Ti electrodes at 750 °C

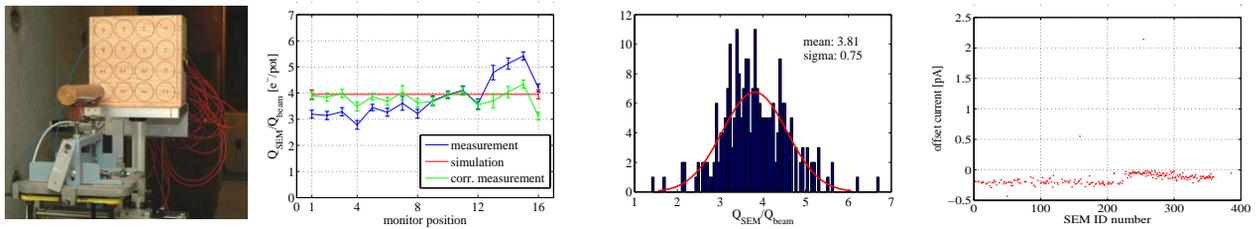


Figure 5: From left to right: A) Test beam setup with a 20cm Cu target and a container with 16 SEMs on a movable table. B) Response of the SEM detectors for each of the 16 positions in the sample holder. C) Calibration of 250 SEM detectors in a mixed radiation field corrected for systematic position errors. The simulation result was 3.95 ± 0.17 e-/proton on target. D) Leakage current of the 250 tested SEM monitors. The bias voltage was set to 1.5 kV.

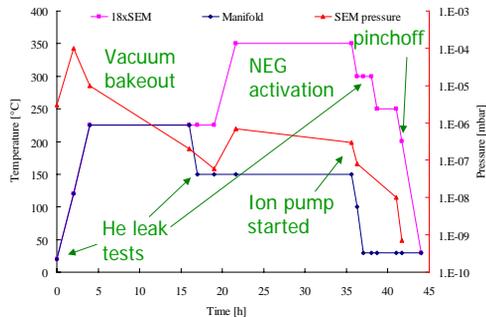


Figure 4: Cycle of the vacuum stand for the SEM production.

to outgass the H_2 dissolved in the bulk during the production of the metal. A similar procedure was put in place for the electrode holders during the brazing with the ceramics.

A very high sensitivity outgassing test was performed at CERN to estimate the thermal desorption rate of the detector. The results indicated a very slow pumping of the Ti, thus the thermal outgassing could be compensated by this effect. Nevertheless, the radiation induced desorption has a potential to degrade the vacuum considerably, so an additional pumping was needed. A stripe of a high capacity Non Evaporable Getter (NEG) ST707 was therefore inserted in the chamber. The total available surface (170 cm^2) of the NEG has a potential to adsorb the quantity of gas equivalent to one mono-layer covering all the detectors' inner surfaces. The NEG has to be activated by heating at the temperature of 350°C for 14 hours, so the pumping cycle of the SEM is extended compared to the IC (Fig. 4). The He leak testing is performed additionally after the activation and the final pressure before the pinch-off is below 10^{-10} mbar.

A dedicated fixed target setup was installed in the H4 secondary beam line to verify the SEM production in a mixed radiation field for possible gas contents. A 300 GeV proton beam was shot on a 20 cm copper target, behind which a box with 16 SEM detectors was installed on a movable table (see Fig. 5). All the chambers were connected in series to a HV power supply. The signal outputs of the SEMs were connected to a custom designed switch array. The switch was connected by a low noise 10 m long triaxial Keithley cable. The resulting charge was integrated by the Keithley 6517A Electrometer and the beam intensity was measured by an air filled precision ionization chamber

(PIC) placed in the beam. There was a systematic offset for each row of the detectors observed. The SEMs located closest to the aluminum plate of the table had the highest response apparently due to the additional backscattering of secondary particles. The mean response per position was calculated and the difference from the total mean was subtracted as a systematic error. The response before and after correction as well as the result of the Geant4 [4] simulation are presented on the Fig. 5. Only one chamber had a too high leakage current (above 2 pA) otherwise it stayed below 0.5 pA. The sensitivity of the measurement was estimated to $4.4 \cdot 10^{-2}$ mbar and all the tested SEMs have a residual pressure below this level.

SUMMARY

4250 nitrogen filled ionization chambers and 350 secondary emission monitors have been produced at IHEP for the LHC beam loss monitoring system, following their development at CERN. The various tests allowed a good control of production and shipping of these delicate devices. A tight production schedule was kept and the very strict tolerance for cleanliness and leakage current were successfully met.

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