IONIZATION CHAMBERS AS BEAM LOSS MONITORS FOR ESS LINEAR ACCELERATOR

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Abstract

The European Spallation Source (ESS) to be under construction in Lund, Sweden, will provide a highest average intensity beam from a 5 MW superconducting proton linear accelerator to produce spallation neutrons. A serious problem for high current accelerators is the high density of the beam, which is able to destroy the equipment, to make a quench of super conductive magnets.

Loss of even a small fraction of this intense beam would result in high radiation and destruction of the equipment. The Beam Loss Monitor (BLM) system must be sensitive to different level of losses in different accelerator locations. BLM system protection should limit the losses to a level which ensures hands-on-maintenance or intervention. From another side, the BLM system should be sensitive enough to enable machine fine tuning and machine studies with help of BLM signals, including mobile detectors.

The main ESS beam loss detector type is ionization chamber (icBLM). The detector is originally designed for CERN LHC and 4250 monitors were produced in 2006-2008, now widely used in almost all accelerators at CERN (figure 1), in IHEP (Protvino, Russia). In 2014-2017 a new production of 830 icBLM was performed to replenish spares for LHC and to make series for ESS, GSI. The requirements, design, testing and layout for ESS accelerator are presented.

INTRODUCTION

Parallel plate gas ionization chambers developed by CERN for LHC [1] and manufactured and tested at the Institute for High Energy Physics (IHEP) in Protvino, Russia, are chosen as beam loss detectors for the ESS linear accelerator due to their fast response, no gain variation (with possible exception of the target region), the robustness against aging, large dynamic range 10^8 (pA-mA), the little maintenance required.

Figure 1: icBLM at LHC.

The icBLM have a fast reaction time, which implies a detector gas with high ion mobility. The 99.9999 % nitrogen filled at 1.1 bar detector is permanently sealed inside a stainless-steel cylinder. Should a leak occur in a detector and air enter the chamber, the detection properties would not change severely as air consist 79% of nitrogen, therefore not leading to system immediate failure. In systematic system testing with a radioactive source, a lower signal due to lower gas pressure will be detected. The composition of the chambers gas is very important so as this is the only component in the icBLM which is not remotely monitored.

The icBLM is very sturdy, offering a good radiation hardness. The consistent, long-term (20 years of operation) high quality of icBLM requires materials testing and various tests during and after production in IHEP, after reception at CERN and ESS. IHEP designed and built the UHV production stand [2], shown in figure 2.

Figure 2: IHEP production stand.

DETECTORS PRODUCTION

The detectors active zone consists of 61 parallel electrodes with a 5.75 mm distance between electrodes in the ionization chambers produced in 2008 (ic08). The gap between electrodes in the ionization chambers produced in 2017 (ic17) is reduced to 5.71 every 2 electrodes, keeping the same spacer length. The electrodes are indeed made of a 0.5 mm thick aluminium in ic08 and 0.54 mm thick aluminium in ic17 (figure 3). The gap between electrodes is built to reduce the drift path and the recombination probability of the ions and electrons, and hence to get the requested linearity.

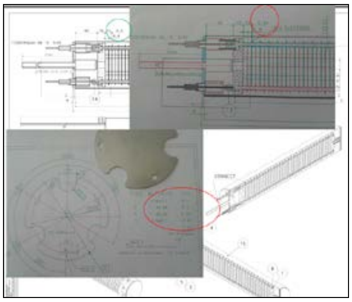


Figure 3: Al electrodes design.

Each signal electrodes are surrounded by two bias electrodes maintained at 1500 V in normal operation. The assembly is attached to the stainless-steel cylinder via two very high resistivity ceramics (Al_2O_3) plates, the electrodes are connected by two ceramics feedthroughs. Feedthroughs testing is done at CERN after reception and in IHEP just before chambers assembly (figure 4). The acceptance criteria for leakage current is set below 1 pA at 2000 V.

Figure 4: Only 15 feedthroughs out of 1700 pieces are not accepted.

The dynamic range of an ionization chamber is defined by its lowest and highest current signals. It is limited by leakage current through the ceramics insulator, which should be less than 1 pA for lowest signals and by saturation due to space charge for highest signals which is the in mA range.

The space charge effect is caused by the large number of positive ions, which drift to the signal electrode much slower then electrons. At a given dose rate, the field created by these ions is so high, that it starts screening the bias voltage between the electrodes and a gap without field is created. The ions located in the gap are usually lost by recombination or diffusion, which lowers the response of the detector (saturation). It should be noted that the ionization chambers in the LHC BLM system will not have signal filters, so the input of the electronics will be saturated before the space charge effects could occur.

The ceramics insulator is the key component of icBLM, limiting the lower end of its dynamic range. In ic08 monitors, ceramics insulators are from SCT, France. No degradation has been observed over 10 years of operation at LHC. In ic17, ceramics insulators are from Friatec Germany. Various investigations on ic17 ceramics insulators include vacuum, chemical, electrical, cleaning, heating tests (figure 5). These tests lead to improve the quality of the ceramics from a first “red” type to a “white” type. Both material types are used in ic17 detectors.

Figure 5: Ceramics test in vacuum.

The thickness of the stainless steel outer cylinder is 2 mm, its length is 483 mm. In ic17 monitors the cylinders are cut by 1.5 mm on both sides. The bottom and the top cover are 5 mm thick. The covers, feedthroughs and the copper pumping tube are welded in argon inert atmosphere (TIG). The quality of the welding is a critical aspect during production, it is therefore tested in vacuum.

Aging depends on the quality of materials to high radiation (ceramics, feedthroughs). To avoid radiation aging (electronegative gases, organic compounds), a strict cleaning procedure for the chambers is followed. Impurity levels due to thermal and radiation induced desorption are estimated to stay in the ppm range. No organic material is present, neither in the production process (pumping, baking, filling) of the detectors, not in the detectors themselves. Standardized test samples analysed at CERN periodically helped to check the cleaning performance. For example, the conclusions of X-ray photoelectron spectroscopy (XPS) from 2016-12-13 is following: “From the point of view of carbon contamination, the stainless steel and aluminum samples are considered UHV compatible. But high amount of Si is observed on all the samples. The latter is very likely coming from NGL 17/40 which contains sodium metasilicates. Probably rinsing was insufficient to eliminate the silicates from the cleaning detergent bath”.

The various tests were performed at IHEP before, during and after the production to verify the quality of chambers. All welds including heads are He leak tested (figure 6).

Figure 6: “Head” after welding.

Additional tests have been performed on ic17 chambers, including the test of each ceramics insulators before assembly. The quality of the production has been continuously controlled and recorded from the vacuum stand, from the leakage current measurements of the components, from the tests of the assembled monitors. All data was logged into CERN's Manufacturing and Test Folders database [3], shown in figure 7.

Figure 7: Data for each icBLM in MTF.

To stabilize the high voltage a low pass filter, R=1 MOhm and C=0.047 μF is mounted on the HV input (figure 8).

Figure 8: HV low pass filter.

The icBLM connectors are 5 kV HV, series SHV and coaxial, series BNC. The connectors insulating material is chosen to resist to an ionizing dose of up to 10 mGy. The insulator in ic08 chambers is PEEK, the one in ic17 is Polystyrene. The 2 insulators have similar properties in radioactive dose, the only difference is temperature limit.

After transport of the monitors to CERN by lorry, reception and calibration tests were performed at CERNs gamma irradiation facility GIF++ (figure 9).

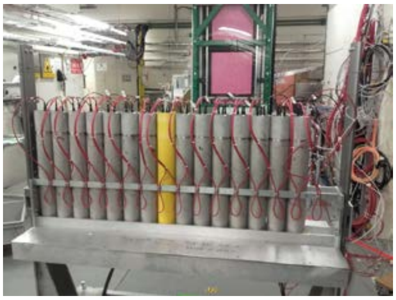


Figure 9: Test set-up at GIF++.

For each ic17 detector the tests consisted of leakage current and radioactive source induced signal measurements (figure 10). 14 tested monitors were placed in a special support at 2.8 m transverse to the flux of the radioactive source, the geometry leading to a difference in flux of +/- 5% between the 14 monitors. One ic08 monitor is in the centre of the set-up as a reference during the measurements.

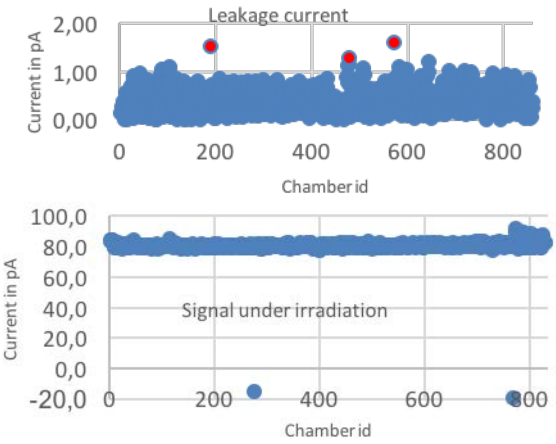


Figure 10: 830 icBLM tests results.

Calibration tests are performed in mixed fields at HiRadMat in order to obtain irradiation conditions as close as possible to operational accelerator dose. These tests allow a comparison between ic08 and ic17 chambers, for which tests are ongoing (figure 11).

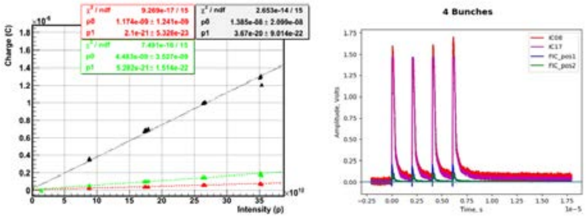


Figure 11: HiRadMat calibration results, 2015 (ic08) and 2017 (ic08 and ic17).

After acceptance test at GIF++ each accepted detector was insulated and shipped to ESS and GSI (figure 12).

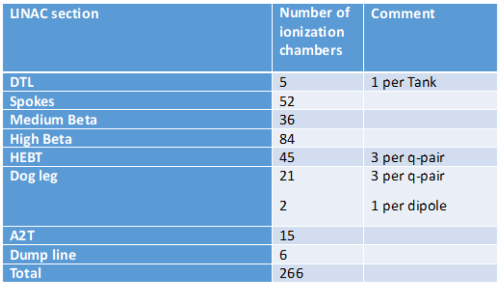
Figure 12: Insulation of icBLM.

icBLM at ESS

285 detectors were received at ESS in July 2017 and are now under reception and calibration tests (figure 13).

Figure 13: icBLM at ESS.

icBLM detectors positions in the ESS LINAC are chosen in accordance with maximum beam loss locations, to minimize crosstalk and to allow full coverage without blind spots. For diagnostic use, the detector layout (figure 14) should also allow determination of the loss origin [4].



LINAC section	Number of ionization chambers	Comment
DTL	5	1 per Tank
Spokes	52	
Medium Beta	36	
High Beta	84	
HEBT	45	3 per q-pair
Dog leg	21 2	3 per q-pair 1 per dipole
A2T	15	
Dump line	6	
Total	266	

Figure 14: icBLM layout at ESS

Detectors will be installed outside cryostats and will have a mounting flexibility option (figure 15).
Normal operational 1 W/m proton beam loss was considered in the detectors locations determination. This was derived from hands-on maintenance criteria for high intensity proton machines and was adopted at ESS as a maximum allowable operational beam loss.

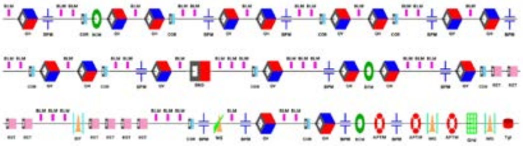


Figure 15: Synoptic installation layout, ESS LINAC A2T sector.

CONCLUSION

830 nitrogen filled ionization chambers have been produced in 2014-2017 at IHEP for the ESS, GSI and LHC beam loss monitoring system, following a first production in 2006-2008 with modifications. These chambers are the main beam loss detector for ESS linear accelerator but need further tests, analysis and simulation.

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