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CONSTRUCTION OF A MOBILE IRRADIATION INSTRUMENT FOR THE VERIFICATION OF THE CERN LHC BEAM LOSS MONITORING SYSTEM

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Abstract

The strategy for machine protection and quench prevention of the super-conducting elements of the Large Hadron Collider (LHC) at the European Organisation for Nuclear Research (CERN) is heavily reliant on its beam loss monitoring (BLM) system. This is one of the most complex and large-scale beam instrumentation systems deployed anywhere in the world.

In order to augment the system's dependability and verify the correct connection of each of the approximately 4000 detectors distributed around the 27 km LHC ring to its assigned channel in the electronic system, a mobile irradiation instrument has been designed and built. This instrument can be easily and safely transported along the LHC tunnel and imitate a localised beam loss at each BLM detector.

This paper describes the concept of the instrument, its engineering design, the safety measures included and recent upgrades. Possible future improvements of the device are also considered.

INTRODUCTION

There are approximately 4000 beam loss detectors using the ionization chamber principle installed next to areas where losses can take place in the LHC [1]. It is necessary to periodically verify the connection to the corresponding channels of the electronic system and the signal quality of all detectors. The purpose of the mobile irradiation device is to mimic a beam loss at a given detector using a ^{137}Cs radioactive source, and in so doing verify the complete detection chain for that particular channel. The instrument described here is designed to safely transport the ^{137}Cs radioactive source along the tunnel inside a lead safety container and then to perform the required tests. The equipment functions by pushing the compact radioactive source out from its lead safety container towards a defined end position located several millimetres from an ionization chamber and then to pull it back into the container after the tests are complete. The operators manipulate the device remotely, always remaining at least 5 meters from the radioactive source such that the dose rate does not exceed 1.5 µSv/h. The instruments currently used for BLM system validation have several reliability and safety issues related to the electromechanical system that lead to an increased risk of unnecessary radiation exposure for operators. The new device is therefore designed to be highly reliable during operation to avoid any requirement for human intervention close to the radioactive source

As this validation process is normally conducted as close as possible to the end of machine shutdowns, the transportation and manipulation of the source should be fast and easy.

ELECTRO-MECHANICAL DESIGN

The instrument consists of a metal box trolley with dimensions 1000 mm x 600 mm x 800 mm with all the equipment located inside for safe transportation along the tunnel, that can be towed by a standard LHC electric car. Figure 1 shows the general view of the instrument (opened). In order to safely transport the radioactive source a lead safety container is required. The thickness of the lead must be at least 100 mm to provide sufficient shielding from the source to the outer surface of the container, such that the dose rate on the surface does not exceed 2.5 µSv/h [2]. The radioactive source is attached to the end of a long, ny-

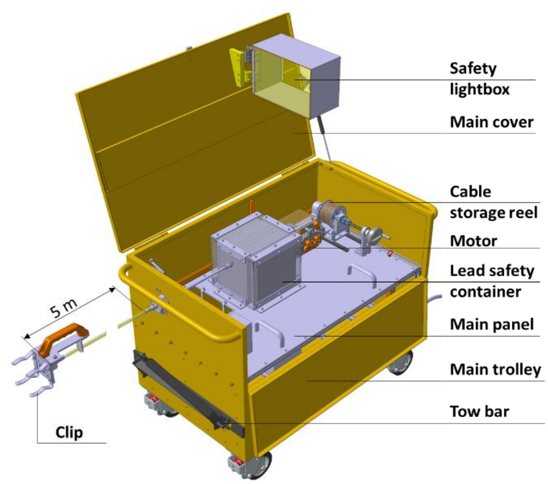

Figure 1: General view of the mobile irradiation instrument.

lon-coated steel cable stored on a reel. This cable is pushed by electric motor rollers through a 5 m long hose. Nylon coating helps to reduce friction between the cable and the hose to ensure low motor loads. It also protects the cable from possible mechanical damage. The hose is connected at one end to the lead safety container and at the other to a clip which is clamped on the detector under verification. When the source arrives at its end position inside the clip it activates an end-switch and the motor stops automatically. It is not then possible to push the source further. When the source is retracted to its home position it activates another end-switch located outside the lead safety container, again automatically stopping the motor.

The cable is stored on a compact reel that houses up to 5.6 m of cable. The reel has an auto-return spring mechanism that will retract the source back into the lead safety container in case of electric motor failure.

The irradiation instrument clip can be easily attached to the BLM thanks to spring-type clamps. These clamps pro-

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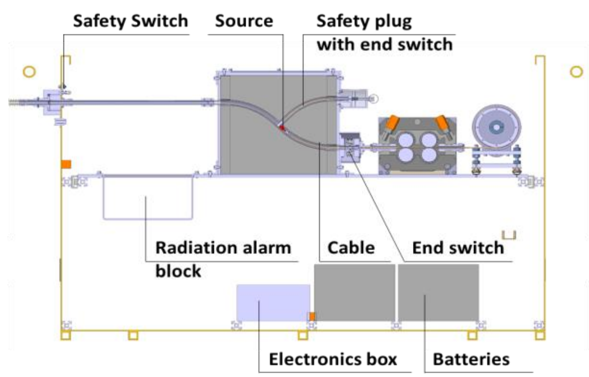

Figure 3: Irradiation instrument cross-section. The batteries and electronics box are located below the main panel. This panel can be extracted for battery replacement or electronic system maintenance.

vide a reliable fixation of the clip on the detector and a precise orientation of the source towards the detector's central axis.

As some detectors are mounted in unusual orientations or positions, the clip can revolve around the hose axis thanks to a swivel connection (Figure 2), to allow comfortable handling of the clip in case of difficult access.

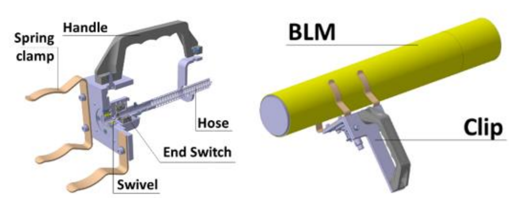

Figure 2: Detailed view of clip (left) and clip fixed on BLM (right).

There are several safety measures included to avoid unsafe extraction of the radioactive source from the lead safety container:

- A safety lightbox with an illuminated sign "IRRADIATION IN PROGRESS. LEAVE IMMEDIATELY" switches on when the main cover is opened to signal that the intervention involving the radioactive source is ongoing.
- A safety plug creates a physical block in case of accidental activation of the system. This device is shown in Figure 3. It is extracted manually by the operator before launching the test. After the test is finished and the source back in the lead container the plug is re-inserted.
- A safety switch on the side of the metal box trolley creates an interlock when the hose is not connected to the pipe coming from the lead safety container. The remote control is blocked and the user cannot operate the instrument if this interlock is active.
- An electrical wire connecting the clip end-switches and to the electronics box is fixed on the hose. The end connector of this wire needs to be plugged into the connector on the trolley to activate the control panel.
- An audible radiation alarm is activated when the source is out of the lead safety container.

DESCRIPTION OF OPERATION

The BLM system validation (Figure 4) is performed as follows:

- The box trolley is parked close to the detector under test
- The main cover of the trolley is opened
- The clip is fixed on the detector
- All safety switches are deactivated
    - Hose is connected to the container; electrical wire on the hose is connected to the electronics box
    - Safety plug is extracted
- The operator moves a minimum of 5 m away from the detector with the remote control panel
- The motor is activated and the source moves through the hose towards the BLM
- An audible radiation alarm is activated indicating that the operator should stay at a safe distance from the source.
- The source generates an ionisation current in the detector which the detector transforms into an electrical signal
- The signal is read by the operator in the control room and system levels and interconnections are verified
- The source is moved back to the lead safety container.
- The audible radiation alarm stops several second after the source is safely in its container, indicating that the operator can approach the trolley.
- The safety plug is re-inserted and the main cover closed.
- The trolley is moved to the next BLM

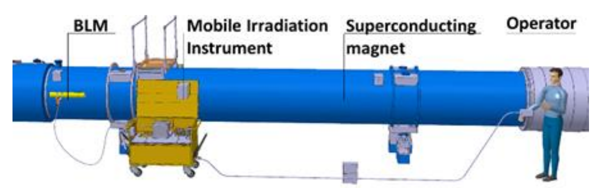

Figure 4: Instrument in operation.

RESULTS OF ELECTROMECHANICAL TESTS WITHOUT RADIOACTIVE SOURCE

To minimise human exposure to radiation it is very important to avoid mechanical problems when the radioactive source is outside its lead safety container. To reduce the time required for the interventions it is also important to avoid mechanical problems during the transport of the mobile irradiation instrument through the tunnel or when setting-up the device. Dedicated testing has therefore been performed in order to debug the mechanism and verify its reliability. Tests were performed using a dummy part with the same geometry as the radioactive source.

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As two irradiation instruments are planned to be used in parallel for the entire BLM system validation in the LHC it was necessary to prove that each mechanism can perform a specified 2500 full cycles without maintenance or failure (corresponding to over half the total number of BLMs) to ensure complete system validation without instrument maintenance. A special test bench was built in order to make continuous, automatic, in-out tests. 4000 cycles were performed without any mechanical or operational issues.

RESULTS OF TESTS WITH RADIOACTIVE SOURCE

The test set-up with source is shown in Figure 5.

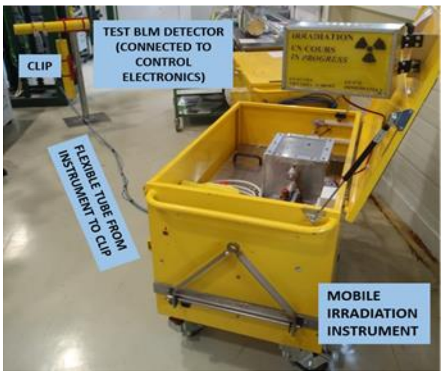

Figure 5: Test set-up with radioactive source.

These tests showed that the source could be brought to the same position with good repeatability with signal variations of less than 4% during 30 in-out cycles. The signal obtained during the test exceeded the intentionally injected electronic offset current of ~10 pA (used to ensure that the electronics chain is always functional) by a factor of 3, hence giving a clear loss signal [3] and allowing the complete detector chain to be considered operational. The radiation level in the area of the instrument operator remained acceptable at below ~0.8 μSv/h.

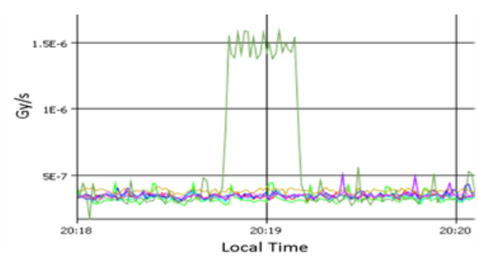

Figure 6: Signal profile showing that the BLM detector is fully operational.

A graphical representation of the signal obtained by the BLM detector in real time is shown in Figure 6. The operators should observe the signal during approximately 25 s to conclude that the monitor fully functional.

FUTURE IMPROVEMENTS OF THE INSTRUMENT AND PROCEDURE

The mobile irradiation of BLM monitors in the LHC involves human operators that have to work in the vicinity of a dangerous ^{137}Cs radioactive source. The average time required to check 1 detector from arrival of the trolley to departure is about 4 minutes. It is therefore quite time consuming to check all the 4000 LHC BLMs using this push-pull cable solution. In addition, the instrument requires regular maintenance of the electromechanical system.

The LHC tunnel is equipped with a monorail system, that could also be used for transporting a mobile radioactive source using a robotic train. Such a train already exists for remote observation and survey in the LHC [4].

A two degrees of freedom manipulator installed on the monorail module could in future house a radioactive source, allowing the BLM detectors to be inspected one-by-one fully remotely from the main LHC control room. This would allow the entire system check to be performed without any human presence in the tunnel hence reducing the integrated dose to operators. The concept of such a system is shown in Figure 7. The telescopic arm in its retracted state is compact enough to allow the train pass throughout the LHC tunnel, while the extended arm would allow validation of BLM detectors on both sides of the magnet cryostats.

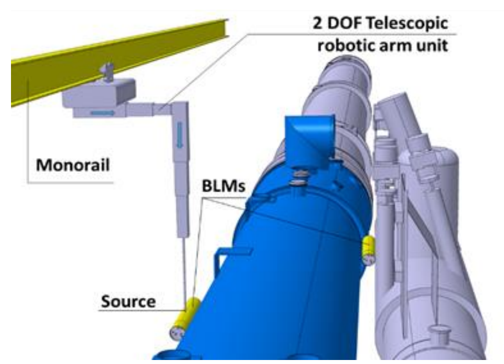

Figure 7 : Possible monorail mobile irradiation instrument.

SUMMARY

A mobile irradiation instrument for validating the LHC BLM system has been designed, produced, assembled and successfully tested. All the electromechanical problems that existed in previous generations of such instruments have been resolved. In addition, several new safety measures have been implemented to significantly reduce the risks of accidental radiation exposure for operators.

New design features have also been added to simplify the manipulation of the instrument components, so reducing the overall time necessary for BLM system validation.

The considered irradiation instrument fulfils all requirements and be used for all future BLM system validation. An alternative, fully remote solution, further reducing the risk of accidental exposure and reducing intervention times is being considered as a future upgrade.

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