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ROBOTIC SOLUTION FOR BLM DETECTOR MAINTENANCE IN HIGH RADIATION AREAS

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Abstract

CERN's Beam Loss Monitoring (BLM) system is essential for the protection of machine elements against energy deposition due to beam losses. The protection function relies on approximately 5000 ionisation chamber type detectors installed along all of CERN's accelerators. Some of the areas where the detectors are installed have a high background dose (above 2 mSv/h). Installation and maintenance times must be minimised to ensure personnel safety. For this reason, a new solution was designed that allows the manipulation of detectors and their supports by robotic action. Every aspect of the solution has been designed to reduce intervention time, using a rapid locking mechanism and the possibility of transporting the material by robot. The paper presents the design, prototype characterisation results, identified issues, and mitigation methods developed for the automated manipulation of these detectors.

INTRODUCTION

At the CERN Accelerator Complex, machine protection and optimization are critically dependent on the Beam Loss Monitoring (BLM) systems [1]. These systems are essential for providing continuous and highly reliable loss measurement histories, capturing data with a dynamic range spanning up to ten orders of magnitude at microsecond-level resolution [2, 3]. This capability is vital for ensuring the safe and efficient operation of the accelerator. The standard BLM detectors, which are based on ionisation chambers, are connected using coaxial bayonet connectors. While effective, the manual connection and disconnection of these components expose personnel to significant risks. The time required for tasks like installation, testing, and maintenance directly increases personnel radiation exposure. To mitigate this occupational hazard, a more efficient and safer solution is needed for a rapid installation system for the stand itself, as well as the detector and interconnections.

CERN has developed an extensive robotic service to support maintenance and inspection tasks in hazardous environments across its accelerator complex [4, 5]. Over the past decade, several robotic platforms, such as the CERNBot, the Train Inspection Monorail, and various robotic tool changers, have been developed to serve operational needs. The present work builds upon this experience by creating a dedicated mechanical interface compatible with robotic manipulation for BLM detector interventions.

The BLM support and detector, designed for robotic transport and installation, must also allow manual installation in at least ten times less time, i.e. in a couple of minutes, compared to the traditional solution in which detectors, equipped with bayonet connectors, fixed to a pole and anchored to the floor require. To design the new solution to be compatible with both robotic and manual handling, several key requirements were defined such as: the support must fix to an independent ground-anchored base installed during long shutdowns; the support pole must be lightweight, i.e. < 5 kg, to allow use of a smaller and more accessible robot; the interconnection between the detector and the harness must be simple and reliable; and the system must use high radiation resistant material, including those for connector isolation.

DESIGN OF THE BLM SUPPORT AND THE DETECTOR ASSEMBLY

The elements that make up the BLM support and the detector assembly are shown in Fig. 1 (left). Once the ground-anchored base is in place, the robot can transport the support pole together with the sliding cylinder, the electrical insulator, the detector guide and the electromechanical interconnection cup with the interconnection cables. The latter consist of special high-radiation resistant coaxial cables designed for use in highly radiative areas of CERN. The total weight of the holder assembly with everything needed for the interconnection of the BLM detector is less than 5 kg. The BLM detector, highlighted in yellow in Fig. 1, also complies with the under 5 kg rule. The solution presented consists of three independent assemblies: a base anchored to the ground, a complete stand, and a detector.

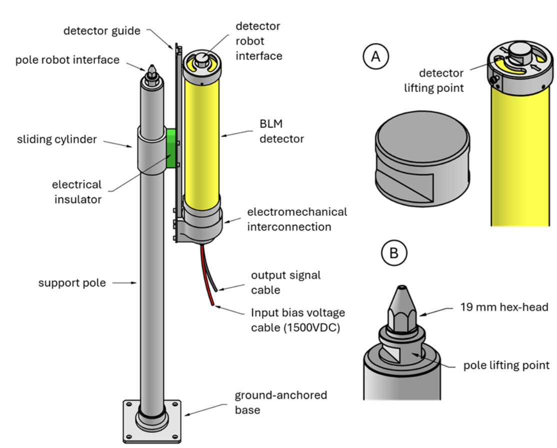

Figure 1: BLM support (left), Lifting points for the detector assembly and support pole (right).

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As shown in Fig. 1 (right), both the support and the detector are equipped with a lifting system compatible with the robotic arm. In addition, the pole head is equipped with a hexagonal head that allows the support pole to be fixed to the base by means of cordless screwdriver on the robotic arm. The shape of the lifting point was defined to ensure a robust and reliable robotic interface and to help during the process of aligning the detector on the support holder. The process of inserting the detector, shown in Fig. 2, into its supporting interface, shown in Fig. 3, consists of four basic steps: inserting the detector guide pins into the guide, inserting the detector head into the support cup, final alignment via the detector groove, and the electrical pins interconnection. Figure 2 highlights the guide pins mounted on the detector body. They provide an initial approximate alignment of the detector within the guide shown in Fig. 3 (A). Once the detector begins to be inserted into the support cup, the final alignment groove created on the detector head shown in Fig. 3 (B) slides on a calibrated pin located on the support cup.

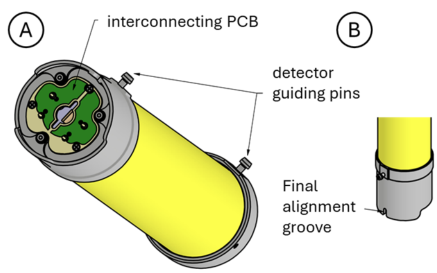

Figure 2: (A) Detector assembly; (B) Detector head zoom.

The 3D section shown in Fig. 3 (B) shows the interconnection area inside the support cup. The electrical interconnection is provided by two printed circuit boards, one with male pins on the detector side and the other with female pins on the holder side. Underneath the support board is an area equipped with grommets and used for the passage and housing of the coaxial cable.

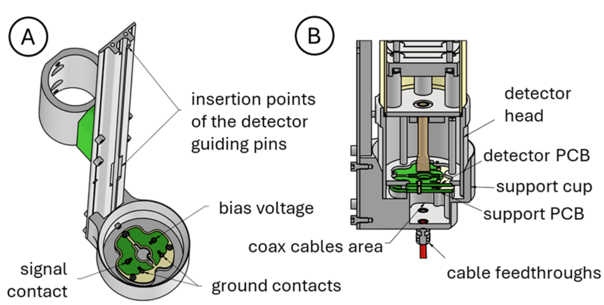

Figure 3: (A) Detector guide; (B) Interconnection details.

DESIGN OF THE ROBOTIC LIFTING AND FASTENING TOOL

The tool for handling the support pole and BLM consists of two parts. The BLM support pole screwdriver unit for fastening the pole to the base and a lifting fork designed to handle the support pole and the detector. Figure 4 illustrates the full assembly and cross-section that comprise the BLM detector assembly lifting and screwdriver tool. To achieve a low tool weight while maintaining rigidity for handling and fastening the detector and support pole, all metal components (besides the socket holder) are manufactured from Aluminium 6061 and the housing parts are made from 3D-printed polymer.

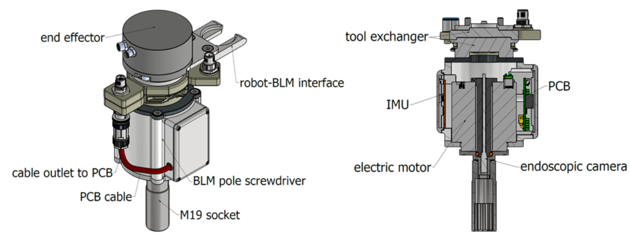

Figure 4: Full assembly (left) and cross-section (right) of the pole screwdriver and lifting tool.

To not exceed the 5 kg maximum payload of the robotic arm, the screwdriver tool will be detached and stored on the robot platform before lifting the BLM-pole with the lifting fork. For this purpose, the screwdriver is mounted on the Wingman WM1, a remotely actuated tool changer system that enables the robot to autonomously connect to the screwdriver interface. The WM1 is equipped with modular connection interfaces, one of which houses a M12-12 connector used to establish communication with the embedded devices within the screwdriver. The robot-BLM interface is connected to the tool exchanger via the end effector attachment plate. This plate sits between the end effector and the tool exchanger and is always attached to the robot.

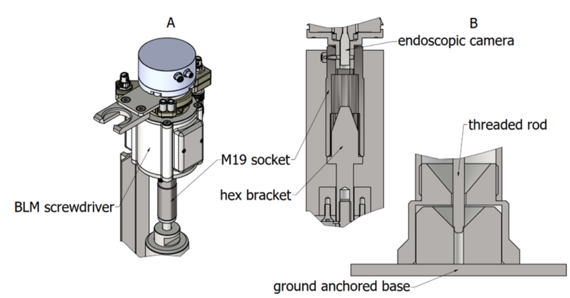

Figure 5: Pole fastening (A); detailed views (B).

Figure 4 (right) shows a cross-section view of the screwdriver tool. The screwdriver shown in Fig. 5 is equipped with an eRob 70H hollow-shaft motor featuring a harmonic gear, integrated driver, and absolute encoder. It delivers a peak torque of 23 Nm, with a continuous allowable torque under average load of 9 Nm. A 0.5 inch square drive is mounted in the motor's output flange, enabling engagement with the 19 mm bi-hex socket required to fasten the pole. An endoscopic camera, aligned with the tool axis, is mounted to the motor housing and inserted through the hollow shaft via a dedicated camera holder. This configuration assists with precise hex-head alignment while minimizing parallax errors caused by off-axis perspectives. Additionally, a Gable IMU SE01, integrating an accelerometer and gyroscope, is enclosed within the screwdriver housing.

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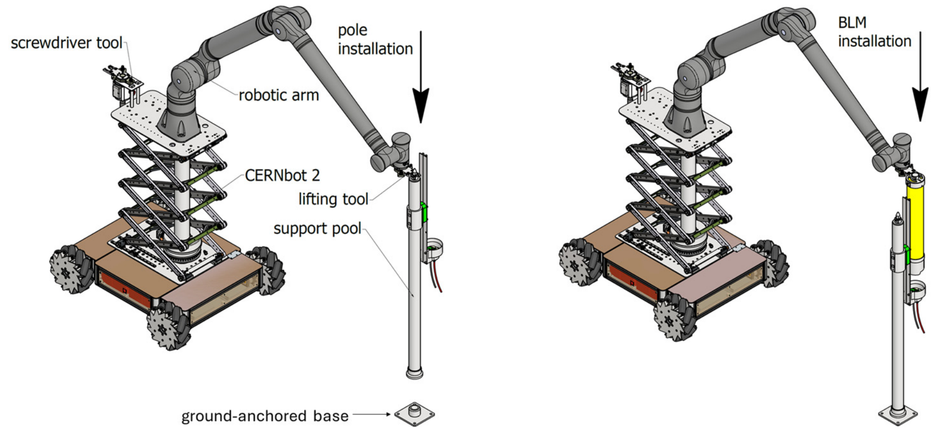

Figure 6: Full robot assembly for the pole setting intervention (left) and the BLM detector assembly insertion (right).

This sensor assists the robot operator in keeping the tool perpendicular to the ground, ensuring correct pole fastening and maintaining the detector alignment parallel to the pole during rail insertion.

INTERVENTION

The full robotic operations for the pole installation and the BLM detector assembly insertion can be seen in Fig. 6. For ground-anchored bases positioned behind large obstacles and magnets, the CERNBot2 can be extended to 1.6 m in elevation. The robotic arm has a maximum reach of 1.8 m from its base. In this way, the robot can accomplish remote handling of difficult-to-reach locations.

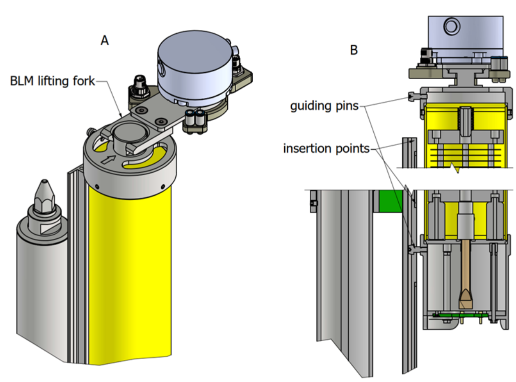

Figure 7: BLM insertion (A); guide pins setting (B).

When the pole is set remotely, the lifting fork must be attached to the lifting point of the support pole, located below the hex bracket. When the BLM support pole is set on the ground-anchored base, the robot arm attaches the screwdriver tool and moves it over the hex bracket. The endoscopic camera is implemented inside the M19 socket for remote precision manoeuvring of the tool. The threaded rod will be fastened to the ground-anchored base with a torque of 7.4 Nm to ensure the yield strength of the aluminium rod is not exceeded.

The detector assembly is lifted onto the pole and inserted into the guide rail with the guide pins, and then until the interconnecting PCB is attached to the bottom plate. To lift the BLM and set it into the guide rail of the support pole, the lifting fork needs to be inserted into the detector lifting point (Fig. 7). Then follow the four steps for the detector assembly insertion mentioned earlier.

CONCLUSION

A robot-compatible interface was developed to enable safe, efficient, and repeatable installation and removal of the Beam Loss Monitoring system's detectors and supports placed in high-radiation environments. The design prioritises modularity, robustness, and dual compatibility with robotic and manual operations. Key components include a ground-anchored base, a lightweight support pole, and a gravity-assisted electromechanical connection, all within a 5 kg payload limit and built with radiation-tolerant materials. Tailored robotic tools with visual and inertial sensors ensure precise alignment and reliable handling. Features such as a hexagonal drive head, guide rails, and pin-based connectors reduce intervention time and improve mounting accuracy. The system is currently undergoing validation and is expected to be deployed in future shutdowns.

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