Proof of Concept Experience in the SPES Experiment: First Solutions for Potentiometers Replacement in System Maintenance

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Abstract. SPES (Selective Production of Exotic Species) is a large facility, currently under advanced construction at the INFN-LNL (Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro) for the production of Radioactive Ion Beams (RIBs). Coordinated efforts are being dedicated to the development and upgrading of both the accelerator complex and the up-to-date experimental set-ups. This paper describes a work of upgrading as far as the inspection and maintenance of the system is concerned, and it deals with human-centered design methods to reduce the time spent in the radioactive environment of the facility during ordinary maintenance operations and to simplify them, also considering stress conditions of the operator and the mandatory wearable radiation protection devices (such as tracksuit, gloves, oxygen tank mask) which make simple operations difficult.

Keywords: Proof of concept · Human-centered design · Functional design · Ergonomics · Design methods

1 Introduction

SPES (Selective Production of Exotic Species) is a large facility, currently under advanced construction at the INFN-LNL (Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro) for the production of Radioactive Ion Beams (RIBs). Coordinated efforts are being dedicated to the development and upgrading of both the accelerator complex and the up-to-date experimental set-ups [1, 2].

Studies [3], such as the one presented in Fig. 1, have been performed to give indications about radiation exposure of operators who have to maintain the facility. In particular, Fig. 1 shows the results of a simulation to calculate the residual activation near the most radioactive components of the facility, in terms of ambient dose equivalent rate. The black circles correspond to locations where the operator is supposed to stand still in order to accomplish the ordinary and extraordinary maintenance operations.

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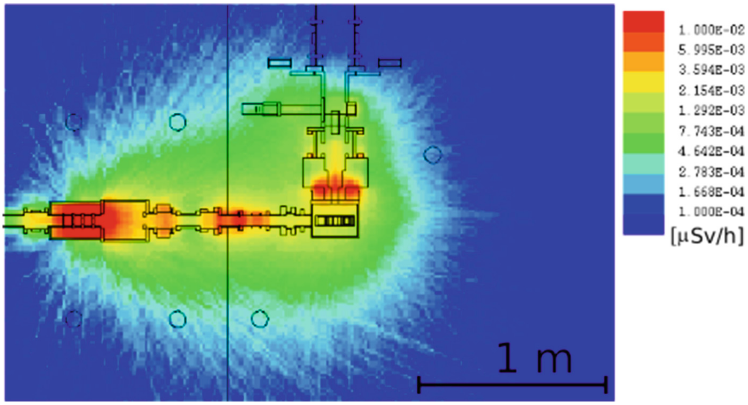

Fig. 1. Results of radiation exposure simulations.

The foreseen period of activity of the SPES facility, before the total or partial substitution of system structural components, is in the order of years. Component activation and consequent ambient equivalent rate progressively increase, due to the accumulation of medium-long lifetime isotopes.

Operator need to complete maintenance operations in stress conditions, due to the knowledge that the environment is potentially dangerous, that they are equipped with a tracksuit, two pairs of gloves, an oxygen tank mask, a helmet, and that the room is initially dark, and operators have to bring light with themselves. Moreover, operators know that they need to minimize the time they stay in the chamber, in order to minimize their exposure to dangerous radiations. All these conditions contribute to make simple operations difficult [4–6].

To minimize maintenance operation time, a sequence of simple operations is required, together with the reduction of tools.

The current inspection and maintenance plan presents some critical aspects, which need to be upgraded. In particular, this works analyzes the current mechanical solution for what concerns some diagnostics components and their substitution during ordinary maintenance operations. Critical aspects of the current solution are taken into account and possible human-centered designed solutions are proposed to simply operations, to reduce the stress conditions of the operators and to minimize the time for these operations. A human-centered designed proof of concept device of these possible solutions has been realized [7].

2 Case Study: Replacement of Potentiometers

To diagnostics purposes, on the SPES facility are assembled different components, such as the ones shown in Fig. 2. In these figures linear motors, potentiometers and limit switches are presented: these components are located in many parts of the facility and need ordinary maintenance, because they are useful and important to know and to make the right positioning of the crucial component of the facility. As is visible from the figures, some of these components are mounted on the system in positions which are critical to reach, or in which there is a small space to operate.

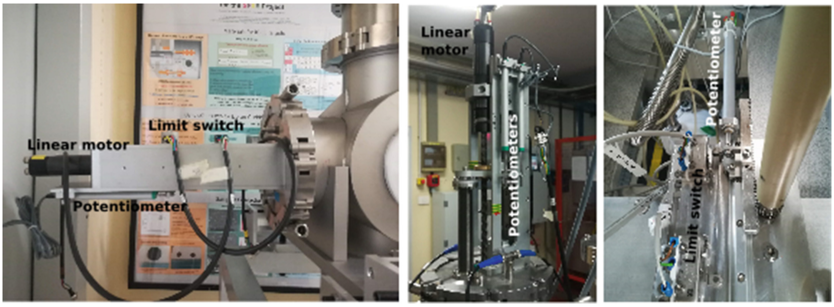

Fig. 2. Some ordinary components necessary as diagnostics: their maintenance is critical due to their current mounting and to their positions, near the most radioactive zones of the facility.

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In the study presented in this paper, the focus is on the maintenance of the potentiometers. These potentiometers are mounted in a lot of positions in the facility and they are supplied with all the measurement and alignment components of the system. Potentiometers have a passive role, but they are important for diagnostics.

The existing solution was analyzed to identify the parameters for a new project, in order to simplify the operation of potentiometers substitution.

The considered parameters were (i) the number and (ii) shape of the holding parts, (iii) the number and (iv) complexity of human operations for substitution, (v) the need for tools, (vi) the need of blocking degrees of freedom. In particular, the current holding system is based on a screw clamping ring which holds the body of the potentiometer and a hold on the sliding carriage for the threaded head of shaft of the potentiometer.

Figure 3 shows that, in order to assemble the potentiometer, the operator needs to align the body to the clamping ring, and then make it slide through the holding and keep it in position with one hand while the other tightens the screws using a key.

The next step is to align the shaft's head to the positioning hole, slide through it and fix it with an M3 nut tightened with a key.

The holding system is strong and fixes both axial movements and rotation of the body, but longitudinal alignment depends only on operator.

To mount the potentiometer in the considered system, a sequence of operations is required, two keys are needed, the nut is hard to handle with two gloves on each hand and aligning and sliding operations are not easy both for position of the holding ring and for

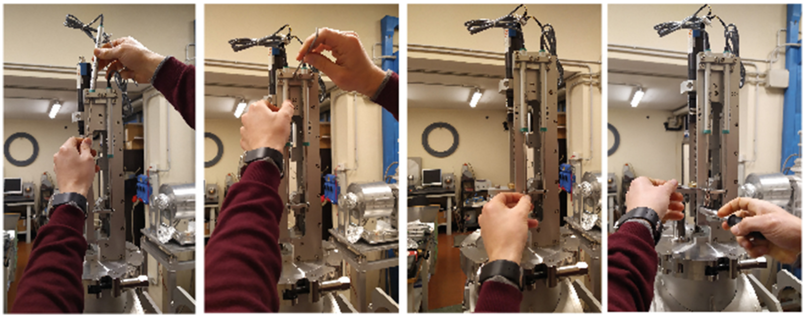

Fig. 3. Current potentiometer assembly.

the needed space to mount, which has to be double than the length of the potentiometer (not all the potentiometers in the facility are so easy to reach).

Operator's stress condition must also be considered.

The aim of the new solution was therefore identified as fixing both parts of the potentiometer (body and shaft) in one phase without using tools and without need to take manually care of alignment (Fig. 4).

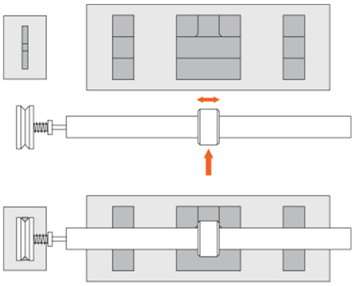

Fig. 4. Degrees of freedom of the potentiometers.

The method is based on the functional simplification of the system holding the potentiometers by splitting it in more parts, each of them both guide operator movements and block one degree of freedom shown in, and on the fact that screw and nut locks can be substituted by spring based locks, commercial latch clamps or gravity-based blocking parts.

Two proofs of concept have been developed and are shown in Fig. 5(a) and in Fig. 5(b):

- to correctly mount the sliding shaft, both the solutions are based on a couple of discs, held together by a spring, which is screwed on the head (before maintenance operation) and get mounted on an open slot on the sliding carriage as a clip. Choosing a spring stiffer than the force needed to make the shaft of the potentiometer slide is enough. Chamfering of all the corners makes easier the insertion.

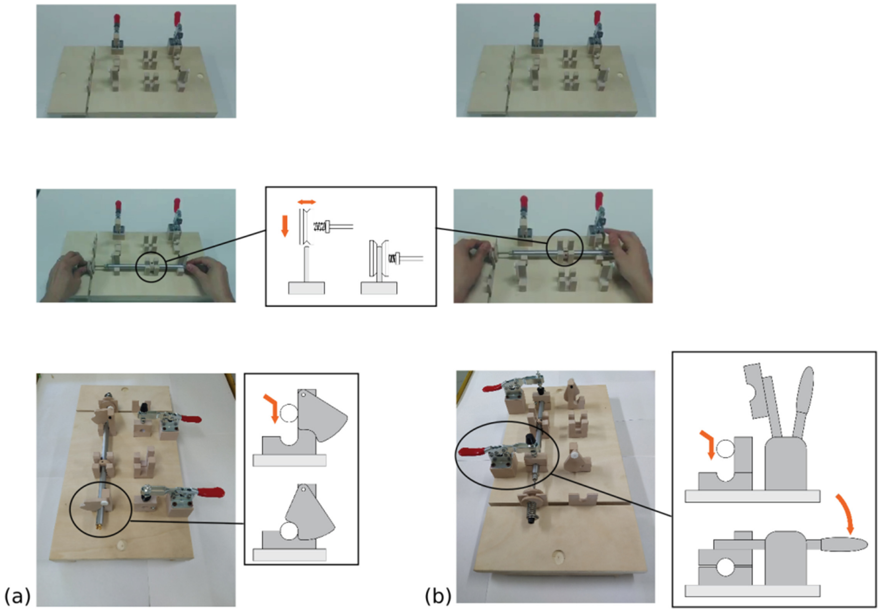

Fig. 5. A human-centered designed Proof of concept device has been realized for both the two proposed solutions assembly. (a) First proposed solution; (b) second proposed solution.

- To fix the body, both solutions are based on a screw clamping ring which is mounted on the potentiometer prior to maintenance operations. This part will provide exact aligning avoiding operator errors and block longitudinal degree of freedom.
- Holding parts are shaped in order to guide operator's movement and fix one degree of freedom at a time, being longitudinal alignment the fundamental, transversals secondary and rotation not so significant for potentiometer functioning.
- All corners were chamfered if needed to simplify positioning.
- Blocking the body is obtained by hanging mobile parts which are pushed away by potentiometer body during insertion and return to their position by gravity after the component reaches its final position blocking it, in the solution showed in Fig. 5(a), and by commercial latch clamps in the solution showed in Fig. 5(b).
- Both solutions are tools-free and allow operator to manage the potentiometer with two hands and mount it with one movement.

A first discussion about the two solutions with SPES staff underlined that, despite of being based on one movement for both placing and blocking the potentiometer, the solution in Fig. 5(a) is perceived as less safe than the one based on the clamp, which need two movements (placing and blocking). This makes us add safety perception as an additional parameter to consider in the next phase of the project, which includes tests on users. A test desk for solutions comparison (existing one and both new solutions) is under construction to allow tests on a larger number of users.

3 Conclusions

Critical aspects of the design of the diagnostics system have been studied, and typical mechanical solutions, which are adequate in a common workshop, have been upgraded with other mechanical solutions which don't need tools and that allow for a simpler sequence of operations.

A human-centered designed proof of concept device has been realized for both the proposed solutions. Tests to objectively confirm the goodness of the proposed solutions and to compare these upgrades with the previous solutions need to be performed and have been already planned.

References

1. Gramegna, F., et al.: The SPES exotic beam ISOL facility: status of the project, technical challenges, instrumentation, scientific program. Il nuovo cimento C **41**, 195–201 (2018)
2. Bisoffi, G., et al.: Progress in the realization and commissioning of the exotic beam facility SPES at INFN-LNL. J. Phys. Conf. Ser. **1067**, 052017 (2018)
3. Donzella, A., et al.: Shielding analysis of the SPES targets handling system and storage area using the Monte Carlo code FLUKA. Nucl. Inst. Methods Phys. Res. B **463**, 169–172 (2020)
4. Sonora, A., et al.: The impact of stress on surgical performance: a systematic review of the literature. Surgery **147**(3), 318–330 (2010)
5. Prabhu, A., et al.: Increased stress levels may explain the incomplete transfer of simulator-acquired skill to the operating room. Surgery **147**(5), 640–645 (2010)
6. Wetzel, C.M., et al.: The effects of stress on surgical performance. Am. J. Surg. **191**, 5–10 (2006)
7. Paderno, D., Bodini, I., Villa, V.: Proof of concept as a multidisciplinary design-based approach. In: Design Tools and Methods in Industrial Engineering, pp. 625–636 (2020)