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COBOTISATION OF ESS CRYOMODULE ASSEMBLY AT CEA

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Abstract

The assembly of cavity string in the clean room is a tedious work that has noisy and painful steps such as cleaning the taped holes of a part. CEA together with the company INGELIANCE has developed a cobot: a collaborative robot operated by a technician one time and repeating the action without the operator. The cobot can work anytime without any operators: therefore it is working at night, reducing the assembly duration by some hours. The cobot consists of a FANUC CRX10 a 6-axis arm on an Arvis cart. At CEA, the cobot is used to blow the flange holes of the cavities and bellows. This allows to reduce the noisy steps that the technicians are exposed to. The process is also more reproducible since the cobot always does the same steps. The cobot is used on ESS cavity string to clean the coupler and cavity flanges. The development of this new tool is presented.

INTRODUCTION

The use of cobots (COllaborative roBOTS) in activities linked to the SRF accelerators domain appears more and more as a solution to ease the preparation and assembly steps. Most developments have focused on component inspection operations and cleanroom activities, in particular all activities related to component assembly (cavities, valves, etc.) and preparation (high-pressure rinsing, handling, cleaning, etc.). There are two main reasons for this choice. The first one is the criticality of cleanroom operations, induced by particulate contamination due to the numerous movements and operations carried out by operators. The second one is the painful nature of certain cleanroom operations, which can adversely affect the repeatability. In addition to the CEA activities, other laboratories are developing robotization or cobotisation for clean room operations. Among these are KEK (Japan), which has developed a solution for cleaning cavities and assembling components on these cavities [1] or MSU (USA), which has developed a robotized high-pressure rinsing system that optimizes the cleaning process according to cavity geometry [2].

Among the wide range of cleanroom operations, the CEA team chose to focus, as a first step, on the use of the cobot for cleaning activities, due to the painful nature of these tasks. This choice was also motivated by the fact that most of the cleaning steps can be carried out in masked time during lunch or at night, to save time on cavity string assembly. This paper presents the steps involved in deploying cobotisation in the cleanroom assembly phases of the ESS project. From the definition of the specifications, the development of the chosen solution, the commissioning to validate the use of the cobot in the CEA ISO4 cleanroom, to the development and implementation of "cobotised" cleanroom phases. This development was performed in parallel with the assembly of the cryomodules for the ESS project, with the aim of integrating the successful "cobotised" steps into the ESS project's production.

DESCRIPTION

The experience of assembling 100 cryomodules for XFEL has led us to better optimize the assembly of cavity string in the clean room by reducing the number of painful operations for the operators and by gaining time on the overall assembly. The clean room assembly steps are tedious operations where the operators have to remain static (see Fig. 1) with their arms in the horizontal position, meanwhile they are holding the nitrogen gun to blow flange holes and a particle counter detector. Depending on the cleanliness of the flanges, the blowing and checking could last for two hours. Moreover, some flanges with taped and threaded holes could be harder and longer to clean, adding longer painful work.

Figure 1: Manual cleaning operation on coupler to cavity assembly workstation.

To assemble a coupler on a cavity, two flanges are cleaned and, to minimize the contamination, these should be cleaned far from each other and in parallel. The operations are performed in a clean room which has its constraints: low particle emission, close environment with limited space and restricted number of operators. In the industry, cobot are intended for direct human-robot interaction within a shared space, or where humans and cobots are in close proximity. CEA took advantage of the development of cobots as a solution to lower the painful work in a clean room, save time and work in parallel if needed. Cobot are built with lightweight

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construction materials, rounded edges, and inherent limitation of speed and force: the cobot will stop when touching an operator or a component: it will not harm anyone or any components by applying a force while performing its tasks.

DEVELOPMENT

The development started with the CEA cobotic division (DRT/LIST) using a cobot trained by an operator: it could then repeat the blowing of the flange holes with no operator. Then, as described in more details below, a cobot with vision was developed and is now in use. The early development with the DRT/LIST (September 2017 to October 2018) allows to reach a technology readiness assessment level 5 [3]: validation of the technology in the relevant environment (ISO4) with the CEA prototype cobot SYB3. This first step was useful to pursue with the correct technological choices on many topics as ionizing system, axis number requirement, task sequencing. The second step (January 2020 to March 2021) using a commercial cobot provides promising results. Some additional tasks around the main goal have been studied:

- A benchmark of three cobots (SYB3 from Isybot (https://www.isybot.com/), M0617 from Doosan (https://www.doosanrobotics.com/en/Index) and UR10e from Universal Robot (https://www.universal-robots.com/). Reach distance, payload, transparency, price, mobility are the main criteria to evaluate these cobots (see Fig. 2)
- Following the study of the thorough cleaning process transmitted by the IRFU team, the DRT/LIST simulated the process and made with a virtual reality rendering. The goal is to validate the ergonomics of the new semi-automated tool in the ISO4 clean room environment. To help the operator, semi-automatic sequences were set.

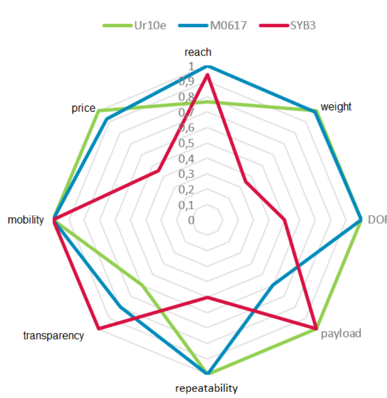

Figure 2: Cobot benchmark result during 2020 study.

The demonstrator is based on the integration of a cleaning effector especially designed for this project. The effector includes the SIMCO Air Ionizing Cartridge (MODEL 6110A), a CMM-type sensing probe and an isokinetic probe for particle counting. The development of a program was performed on the selected robot: DOOSAN M0617. The 6 degrees of freedom arm is fixed to the cart. DRT/LIST also developed a master application to control the robot by implementing a state machine. This master application is used to manage the cleaning program selected for the relevant flange. The program was organized in several separate stages; among them, a probing phase to recalculate the frame of the part to be cleaned and adapt the recorded pathways. The TRL at this step was level 7. During the clean room DOOSAN cobot commissioning, particulates generation checks were performed in particular at the junctions. The cobot M0617 (6 kg payload, 1.7 m reach) can be used in ISO4 even though it is not certified for. This second step with DRT/LIST validates that this type of cobot can be operated in clean room for mass production assembly.

CEA/Irfu place a contract in January 2022 to Ingéliance company to program, integrate and commission a ARVIS cart holding a FANUC 6 axis arm cobot. ARVIS is a cart designed by Ingeliance. The arm is a CRX-10iA/L with 10 kg payload and 1.4 m reach (see Fig. 3). The development lasts 4 months, the installation and commissioning took 15 days, and the ESS cryomodules production plans to use the cobot for about 2 years.

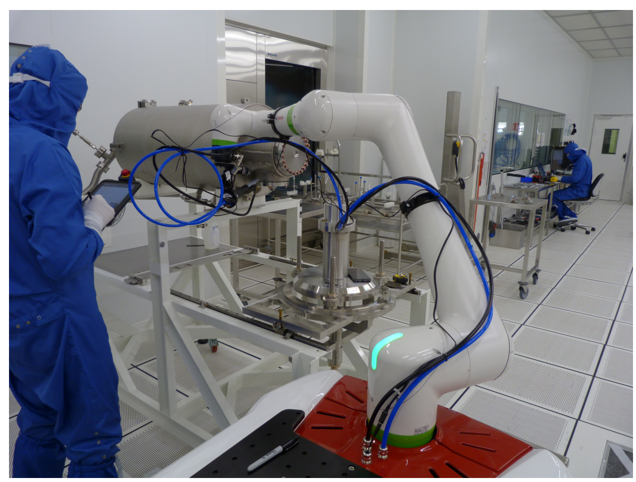

Figure 3: Operator programming the pathway of the effector to the coupler flange of the cavity while the coupler is pre-align.

COMMISSIONING

Both Arvis cart and Fanuc arm went through a cleanroom validation with respect to particles generation in ISO4 after a preliminary cleaning. The cobot blows ionized and filtered air (6.5 bar), the effector and the tool quick changer have a total weight of 1.7 kg. A vision system replaces the probing phase. It consists of a 2D camera (Kowa SC130E B/W). The initial goal was to localize the part to clean through its shape detection. The program actually integrates a localization phase where the camera pictures a target temporarily fixed to the part to clean. This picture allows adjusting the robot frame to the part frame: localization of X0, Y0 and rotation

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of horizontal plane around Z (along gravity). Even if the cobot repeatability specification is ± 0.04 mm, we reach 1 mm repeatability due to not fully corrected part frame. The machine architecture is simplified with only one human machine interface: the cobot teach-pendant containing all programs. The coupler to cavity assembly program validation is performed with the coupler already pre-aligned with the cavity flange. The TRL at this step was level 9.

COBOT USE ON ESS CRYOMODULES PRODUCTION

After a period of training and development between the CEA and B&S, the company in charge of cryomodules production, B&S operators started to use the cobot daily on the different workstations in the clean room ISO 4. The cobot is in operation since May 2022 whereas the production started in January 2019. 15 cryomodules have been shipped to ESS and the cobot was in operation for eight cryomodules. Before using this cobot, clean room operators were static in an uncomfortable position for long periods, sometimes 1.5 hour, until all the holes of a flange were clean with the ESS cleaning specifications (less than 10 particles of 0.3 µm/min) (see Fig. 1). Today, after different fast steps of flange preparation and position configuration of the cobot, a cleaning run can be launched. The cobot and operators can work independently. Operators can realize tasks on other workstation; they can also launch a run for breaks or nights. The cobot spends two hours per flange to reach the ESS cleaning specifications.

This new tool is a great time-saver for ESS string assembly in the clean room and operators because they had to prepare and clean 32 flanges with 16 to 24 holes for each flange. With the different programs developed by CEA, the cobot can clean 18 of the 32 flanges that are on the beam line; saving 18 hours to 27 hours of work.

Five programs have been developed during the commissioning process:

- A program is used for the cleaning of the coupler flange of the cavity (see Fig. 4) before the assembly of the coupler to the cavity.
- Another program is used for cavity flanges that will be connected to a bellows (see Fig. 5). For this program, the cobot is placed between two cavities and cleans the upstream flange of one cavity and the downstream flange of the other cavity.
- Two programs are used for cleaning the most upstream and downstream flanges of the cavity string, seating at the extremity of the string.
- In addition, CEA develops a last program for cleaning the bellows between cavities. For this, the bellows is placed on the cobot cart. The cobot cleaned the two flanges, the entire outside surface but also the inside surface of the bellows as shown on Fig. 6.

Figure 4: Cobot cleaning the cavity coupler in the clean room.

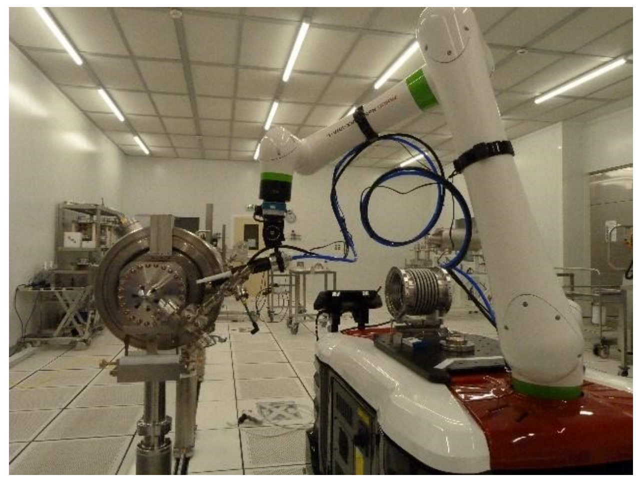

Figure 5: Cobot cleaning a cavity flange and a bellow ready to be cleaned on the cart.

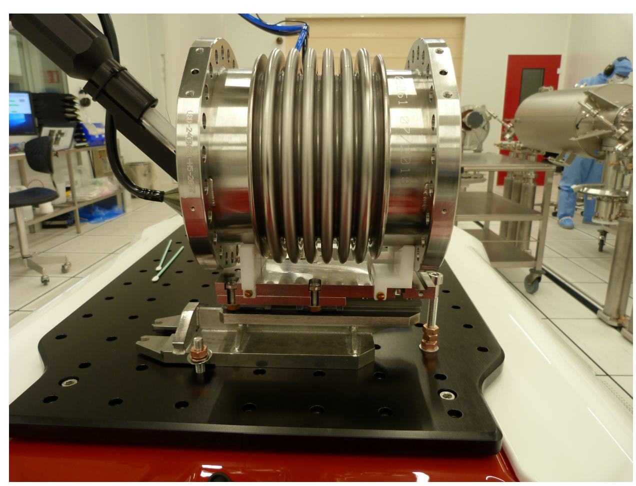

Figure 6: Cobot cleaning the inside surface of a bellows.

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The cleaning is very efficient and answers perfectly ESS cleaning specifications. The cobot records a log file of the last particle count of each cleaned flange. Nevertheless, after a cleaning run by the cobot, the operator checked manually the particle counts for 2 or 3 minutes, save the results in traveler, and validate them before continuing the assembly.

In addition, the operators fell less tired by long and heavy cleaning operations. They can focus more on the demanding assemblies.

NEW DEVELOPMENTS FOR THE COBOT USE

CEA with B&S are also working on the other ESS components. Soon the cleaning of the flanges of the coupler on the coupler box, beam valves, and transition flanges will be carried out by the cobot. The cobot will be available to clean all 32 flanges of the cryomodule cavity string.

In addition to the cleaning phases described above, CEA is currently developing the use of the cobot for component assembly on the cavity string. These developments are primarily intended for use in the production phase of future laboratory projects (PIP-II, etc.). The aim is to target the most critical assemblies in terms of particulate contamination. The cobot will be used from the alignment phase of the components to be assembled, through to placement of these components on the cavity. The operator then installs the screws to finalize and validate the assembly. Thus, the assembly of inter-cavity bellows on cavities is being developed using a controlled gripper mounted on the cobot's arm to handle the bellows. CEA is also working on the assembly of couplers on cavities and the removal of cavity flanges.

The aim of these developments is to carry out all the phases involved in assembly: from the cleaning of the components to be assembled, to the removal of the flanges, to the assembly of the components on the cavities.

CONCLUSION

The cobot has been implemented in the clean room and is used daily for ESS string assembly. It helps to reduce the assembly time by 26 hours per cryomodule. After the first development to reach the above goal, CEA continues the deployment of the cobot on the components assembly.

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