Robotisation of cavity string assembly at CEA

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Abstract. Since 2017, CEA has been developing the use of collaborative robots (cobot) to carry out the steps required to assemble superconducting cavities strings. This development is based on two mains objectives. The first is to reduce the tediousness for operators of certain stages of component cleaning by blowing, so that they can focus on higher value-added tasks. The second is to improve assembly quality by keeping operators, the main sources of particle contamination in cleanrooms, away from open critical RF surfaces. The integration of component cleaning (flange, inter-cavity bellows, etc.) in the cleanroom by the cobot was carried out on the production of ESS cryomodules cavity strings. For future projects, CEA is currently working on the cobotisation of component assembly steps to meet the second objective.

1 Introduction

Cavity string assembly in the cleanroom involves tedious and noisy processes, such as cleaning the taped holes of parts. Human operators are known to be the biggest source of particulate contamination during these sensitive cleanroom operations. Collaborative robots (cobots) can operate independently, even overnight, reducing tedious tasks and decreasing assembly time by several hours. Cavity string components are well-defined and immobile, and the assembly phase is highly repetitive, making cobot integration ideal. The inherent variability of human performance can be eliminated, leading to better consistency and quality in cleanroom operations. In addition to CEA's initiatives [1], various other laboratories are advancing robotization and cobotization for cleanroom operations. For example, Michigan State University (MSU) in the USA has developed a robotized high-pressure rinsing system that enhances the cleaning process by adjusting to the cavity's geometry [2]. Similarly, KEK in Japan is developing a system for cleaning cavities and assembling components [3].

2 CEA OBJECTIVES FOR COBOTISATION

CEA's ultimate goal is the assembly of cavity strings using a cobot. This can be divided into two sub-objectives: cleaning and component assembly, with assembly being the most challenging. CEA began by focusing on cleaning components with nitrogen blowing. The assembly process, during which beam vacuum surfaces are exposed to the cleanroom environment, has a more significant impact on quality and is now a priority. The cleaning of parts

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by cobots has already been implemented during the assembly of ESS cryomodules [4]. All the development discussed here required multiple steps of modeling and programming. CEA uses FANUC cobots, and the programming is done with Roboguide. This software enables the cobot to be programmed without disrupting its use in production, and simulates all the cobot's actions to identify problems and areas for optimization. The preliminary work involves path programming and vision-based localization of parts, allowing the cobot to adapt the pre-programmed paths. Since the ESS project, CEA has introduced tool changers to allow for cleaning parts that require different End-of-Arm Tools (EOAT) or for inserting intermediate cleaning steps during assembly. The tool changers are supplied by WINGMAN, with electrical and compressed air pass-through interfaces tailored to the EOAT's needs.

3 CLEANING OF COMPONENTS

The first step is the cleaning of the following component:

- Environment of cavities
- Flanges and their holes
- Gasket groove in between flanges
- Inter-cavity bellows (most critical parts at last)
- Power couplers (most critical parts at last)

The cleaning is performed going from the dirtier parts or areas to the cleaner, such as environment of cavities then flanges and their holes and at the end the cavity-to-cavity bellows (see fig.1). Operators always install the objects to be cleaned and remove the screws and studs from the flanges to be cleaned. The cleaning is realized by blowing ionized and filtered air (6.5 bar). The cleaning efficiency is validated by particle counting performed by the cobot monitoring a particle airborne counter (28,3L per flange's hole).

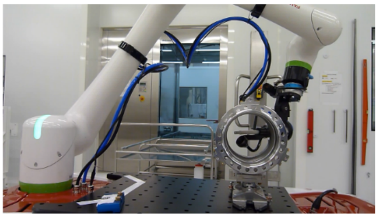

Figure 1. Cobot CRX-10iA cleaning an inter-cavity bellows

Since May 2022, a CRX-10iA cobot has been cleaning components for the ESS project. So far, it has been used to prepare 17 cryomodules (out of 24 delivered). Cobots and operators can work independently or in parallel, saving around one-fourth of the assembly time for ESS strings in the cleanroom. The cleaning process is highly efficient and fully meets ESS specifications. Based on the number of cleaned components, CEA has gained considerable experience in developing and implementing cobot-based cleaning steps.

4 ASSEMBLY OF COMPONENTS

Following the success of the cleaning phase in the ESS project, CEA decided to continue developing cobot capabilities. The new objective is the assembly of critical components in the cavity string (such as inter-cavity bellows and power couplers). Operators are still responsible for roughly positioning components near the cobot and removing or installing screws on the components.

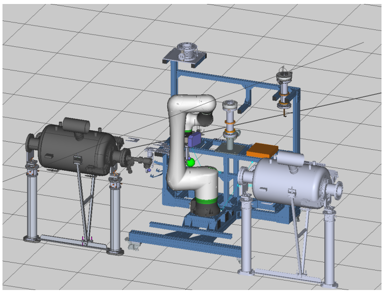

Figure 2. 3D model of the future assembly workstation with the CRX-25iA cobot in the clean room.

CEA has acquired a new CRX-25iA cobot mounted on a work frame to increase handling and assembly capacity due to its higher payload and range. Several actions are being developed to meet the goal of assembling parts using cobot:

- Improving vision
- Component cleaning extension
- Handling flanges for removal
- Handling/alignment of components to be assembled

5 IMPROVING VISION

The assembly steps require greater precision than cleaning phases previously implemented. The 2D camera used on ESS project will be updated to a 3D camera (the 3DV/200 VISION SENSOR from FANUC). We choose this model according to:

- its measurement area (between 124 x 124 @ 302 mm and 219 x 199 @ 492 mm) which fits to the flange diameter
- Greater precision (1060 x 950 pixels)
- Ease of locating component (measurement area should fit the part)

Tests have been conducted with ESS flanges. Starting with two flanges in unknown positions and orientations, the cobot with the 3D camera successfully grabbed one flange and adjusted its position with respect to the other flange, inserting all 24 screws without misalignment.

6 COMPONENT CLEANING EXTENSION

The cleaning phases of the component continue to be improved. The cobot needs to handle all cleaning phases prior to component assembly:

- Environment of components
- Flanges/holes cleaning
- Coupler antenna

• Inter-cavity bellows

Optimization of blowing needs cleaning tools that adapt to different component geometries. Figure 3 presents one example, details are in the figure caption. These new cleaning tools are used to perform the same types of cleaning operations as those carried out on the ESS project, as presented at Figure 4.

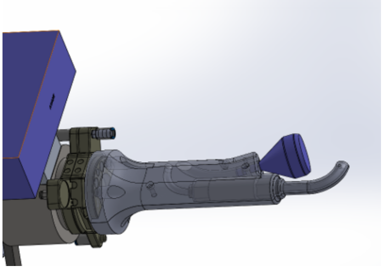

Figure 3. 3D model of one cleaning extension with the future CRX-25iA cobot. The 3D camera (blue box) is fixed to the cobot end of the arm. The tool changer (dark grey) is inserted between the end of the arm and the cleaning extension. The extension includes the particle counter sensor head.

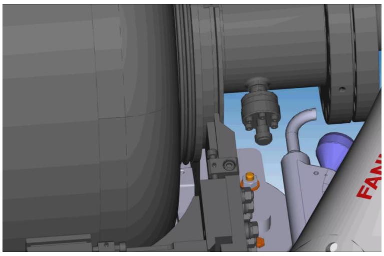

Figure 4. 3D model of a cleaning extension, cleaning flange holes in preparation for assembly.

The cleaning will be performed with filtered com-pressed air (0.01 µm, filtration efficiency 99.99%, max rate 100L/m). Validation of the cleanliness of the cleaned surfaces will be still qualified by particle counting per-formed by the cobot monitoring a Solair 3100 (LIGHT-HOUSE) airborne particle counter (typically 0 particle of size bigger than 0.3 µm on a sampling volume of 28.3 L).

7 HANDLING FLANGES FOR REMOVAL

To perform the assembly steps on the cavity strings, the cobot must be able to handle objects less critical than inter-cavity bellows or power couplers. The focus is on the closing flanges on the cavities to be assembled. The use of grippers appears to be a good solution to handle these flanges. There are many different types of EOAT grippers. They are powered electrically, hydraulically, mechanically or pneumatically. The technical solutions under investigation at CEA are an electric gripper (brand SCHUNK, model: EGU 60-MB-M-SD) or a suction gripper (brand SCHMALZ). The suction gripper consists of a compact ejector with integrated air saving control and a flat suction cup for very dynamic handling of smooth parts (ejector: SCPS 15 G02 NC M12-5 PNP, suction cup: SAF 30 NBR-60 G1/4-IG). They can be adapted to the different diameters and configurations of flanges to be handled, so both grippers seem appropriate for our cleanroom application. The study is still on going and these solutions are well mastered and quite easy to integrate.

8 HANDLING/ALIGNMENT OF COMPONENTS TO BE ASSEMBLED

The cobot's complete autonomy of handling is not targeted, as operators will always be present during these operations. The handling of critical components (power couplers, inter-cavity bellows) must meet several constraints:

- Safe gripping and handling of components not designed to be handled by a cobot
- Ensure precise alignment of components with each other

Some assembly tests of a bellow to a mock-up cavity has been performed with success at CEA with 3D printed interface part connected to the electrical gripper. To meet both requirements, it seemed appropriate, for the time being, to design an interface installed on the component to be handled, to which the cobot will attach itself, rather than using a gripper. The operators will install them on the components before the cleaning process and disassembly them after the operation. These interfaces must guarantee precise, repeatable positioning of the component to be assembled on the cobot, to ensure accurate positioning of the component as it is assembled on the cavity. By way of example, the gripping interface of an inter-cavity bellows is shown in Figure 5.

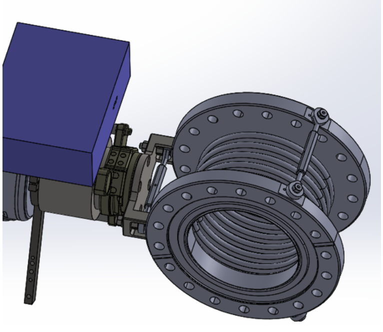

Figure 5. 3D model of gripping interface of an inter-cavity bellows

9 CONCLUSION

The development of cobotisation continues at CEA. The aim remains to limit the number of tedious tasks performed by operators in cleanrooms, and to focus more attention on high value-added tasks. After validation on mockups and on R&D's cavities in the FJPPN framework, the goal is to deploy the assembly of power couplers and beam pipe bellows on PIP-II. A gain in productivity and assembly quality is expected. Several prospects for improvement are currently being studied, to facilitate assembly preparation tasks and extend the range of components that can be assembled by a cobot.

References

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