ISBN: 978-3-95450-219-6 ISSN: 2226-0366 doi: 10.18429/JACoW-LINAC2024-THPB011

COBOTISATION FOR SRF CRYOMODULES AT CEA: FOCUS ON ESS AND FUTURE PROSPECTS

S. Berry†, A. Bouygues, J. Drant, A. Gonzalez-Moreau, C. Servouin, C. Madec, A. Madur
Université Paris-Saclay, CEA, Département des Accélérateurs,
de la Cryogénie et du Magnétisme, Gif-sur-Yvette, France

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 operator: Therefore, it is working at night reducing the assembly duration by several hours. The cobot consists of a *FANUC* CRX-10iA a 6-axis arm on an Arvis cart. At CEA, the cobot is used to blow the flange of the cavities and the bellows inside. This allows to reduce the noisy steps that the technicians are exposed to. The process is also more reproducible since the cobot does always the same steps. The cobot is used on ESS cavity string assembly to clean flanges but also beam vacuum surface as inter-cavity bellows. Our activities, results and technical choices for next development will be presented in this article.

INTRODUCTION

Laboratories beyond CEA [1] are advancing robotization and cobotization for clean room operations. 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]. KEK in Japan is developing a system for cleaning cavities and assembling components [3]. Cavity string assembly in the clean room is a tedious work that has noisy and painful steps such as cleaning the taped holes of a part. It is recognized that humans are the biggest source of particulate contamination during assembly operations on sensitive components in cleanrooms.

A COllaborative roBOT (hereafter cobot) can work anytime with or without operators including overnight, reducing painful work and assembly duration by several hours. The use of cobot is also motivated by the fact that cavity string components are well defined, immobile and the assembly phase remains identical during the production.

The repeatability is an issue for operators, whereas it is an important advantage and objective for a cobot. The quality of cleanroom operations could be improved by limiting the inherent variability of human operators.

CEA OBJECTIVES FOR COBOTISATION

CEA's final objective is the assembly of cavity strings with a cobot. This objective contains two sub-efforts: cleaning and assembly of components (the latter being the most difficult). CEA initially cleaned parts under blowing nitrogen. However, assembling with the vacuum surfaces exposed to the cleanroom environment has more impact on the quality (i.e. cavity specifications) and is now being addressed as a priority. The cleaning of parts with the cobot have been reported for ESS cryomodules assembly [4].

All the development presented hereafter required several steps of modeling and programming. The cobot used at CEA comes from *FANUC* and the programs are realized with Roboguide. The preparatory work consists of path programming, vision-based localization of parts, then the cobot will adapt the recorded paths. All cobot actions can be prepared in advance. The small change in our strategy since ESS experience is the introduction of the tool changer in order to be able to clean parts which requires different End-of-Arm tools (EOAT) or to insert intermediate cleaning steps during assembly. The tool changer is from *WINGMAN* company, electrical and compress air Pass-through interface depends on the need of the EOAT.

CLEANING OF COMPONENTS

The first step is the cleaning of following component:

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

The cleaning is performed going from the dirtier part to the cleaner such as environment of cavities, then flanges and their holes, then the cavity-to-cavity bellows (as shown in 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 air borne counter (28,3L per flange's hole).

The cleaning of components is implemented since May 2022 in ESS project with a CRX-10iA. Up to now, it has been used for 17 cryomodules preparation (24 cryomodules delivered). Cobot and operators can work independently in parallel or cobot works at night, it's a time-saver for ESS string assembly in the clean room: ~1/4 of assembly time. Cleaning is very efficient and meets perfectly ESS cleaning specifications.

Table 1 summarizes the statistics of the last particle counting performed by the cobot for the 17 ESS cryomodules assembled up to now. About 68 flanges of each type (coupler flanges, beam flanges with right angles valve and beam port with blind flanges) are taken into consideration.

† stephane.berry@cea.fr.

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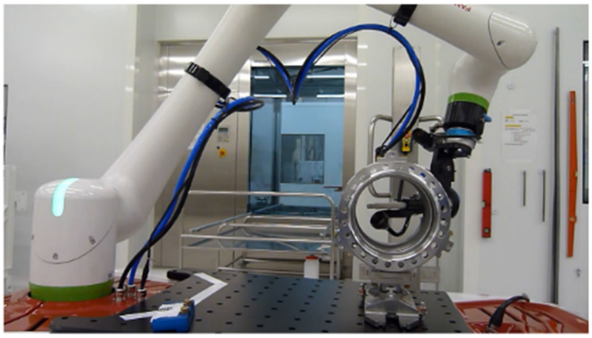

Figure 1: Cobot CRX-10iA cleaning inter-cavity bellows.

Table 1: Statistics of the last particle counting by the cobot for the different flanges holes for the 17 ESS cryomodules

About 68 flanges of each type	max.	mean	std. dev.
couplers flanges (16 holes each)	10	0.38	1.36
flanges with right angle valve (24 holes each)	4	0.03	0.30
blind flanges (24 holes each)	6	0.12	0.56

The validation criterium for the cobot is set at 10 particles or less. Particles of size bigger than 0.3 μm are counted for one minute. Note that the number of holes per flange is detailed in Table 1. Based on the number of cleaned components and the statistics reported in Table 1, CEA has now a solid experience in developing and implementing cleaning steps using a cobot.

ASSEMBLY OF COMPONENTS

Following the success of the cobotisation steps on the ESS project, it has been decided to continue its development. The new objective is the assembly of the critical components on the cavity string (inter-cavity bellows and power couplers). Rough positioning of components near the cobot, removal or installation of screws on components remain the responsibility of operators.

A new cobot, the CRX-25iA mounted on a work frame, is being purchased to increase the handling and assembly capacity (see Fig. 2). To achieve the goal of assembling parts with the cobot, several actions have been identified and are in development:

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

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

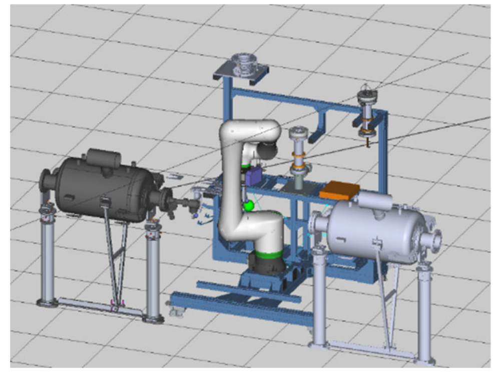

Figure 2: the 3D model of the future assembly workstation with the CRX-25iA cobot in the clean room.

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 pixel),
- Ease of locating component (measurement area should fit the part).

Tests have been performed with ESS flanges, starting with two flanges at unknown positions and orientations. The cobot with 3D camera is programmed to grab one flange and adjust its position with respect the other flange with enough accuracy to insert the 24 screws in their holes without misalignment.

COMPONENT CLEANING EXTENSION

The cleaning phases of 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 including details.

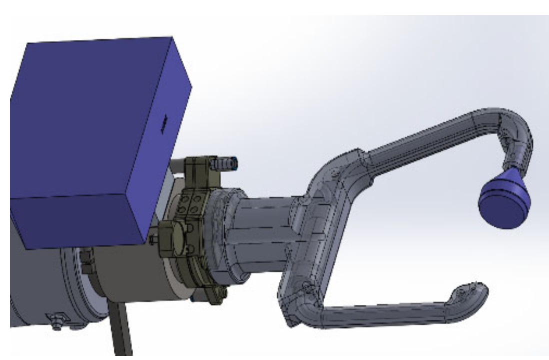

Figure 3: the 3D model of one cleaning extension with the future CRX-25iA cobot. The 3D camera (blue box) is fixed to the cobot end of arm. The tool changer (dark grey) is inserted between the end of arm and the cleaning extension. The extension includes the particle counter sensor head.

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The cleaning will be performed with filtered compressed air (0.01 µm, filtration efficiency 99.99 %, max rate 100 L/m). Validation of the cleanliness of the cleaned surfaces will be still qualified by particle counting performed by the cobot monitoring a Solair 3100 (*LIGHTHOUSE*) airborne particle counter (typically zero particles of size bigger than 0.3 µm on a sampling volume of 28.3 L).

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, either powered electrically, hydraulically, mechanically or pneumatically.

The technical solutions under investigation at CEA are electric gripper (brand *SCHUNK*, model: EGU 60-MB-M-SD) or 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). 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.

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 on 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 have been performed with success at CEA with 3D printed interface part connected to the electrical gripper. To meet both requirements, it appeared appropriate to design an interface to be attached to the components rather than using a gripper.

CLEANLINESS OF ASSEMBLING PARTS WITH THE COBOT CRX-10

One of the most expected improvement from the cobot is the particle reduction during assembly of parts. Experiment have been performed to evaluate the impact of parts assembly with a cobot by measuring the particle inside the cavity. This has fostered worse case scenarios rather than more likely ones. A difficult condition is the shutdown of the nitrogen flushing inside of the beam pipe (to protect against particle intrusion). We also assembled and disassembled twice the parts without recleaning the studs maintaining the clamps.

The sequence under particle counting with ESS flange and bellows is as follow (particle count outside of the assembly is indicated in brackets):

- Grab the tool changer on the flange: 24 counts for 1 min;
- Remove clamps: 866 counts on 1 min;
- Remove the blind flange: 0 count on 30 sec;
- Change the tool by operator far from the counter;
- Assemble the bellows:
  a) Approach the bellows: 0 count on 30 sec;
  b) Connect the bellows: 128 counts on 1.5 min.

The most interesting measurement is given by the particle counter which was installed inside the beam pipe near the flange. The two samples of 3 minutes recorded zero particles of diameter 0.3 µm or bigger.

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.

ACKNOWLEDGEMENTS

The authors would like to thank all our colleagues FNAL, KEK and CEA involved in the regular international meetings on robotics for SRF.

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