# DEVELOPMENT OF A TEST BENCH TO PREPARE THE ASSEMBLY OF THE IFMIF LIPAC CAVITY STRING

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*Abstract*

The IFMIF LIPAc cryomodule, whose final design and fabrication status is presented in [1], houses eight half-wave resonators and eight solenoids which will be assembled on a support frame in clean room. Due to the short lattice defined by beam dynamics constraints, there is not much room between two elements for the operators' hands to connect them. In order to test, optimize and validate the clean room assembly procedures and the associated tools, a test bench, consisting of a frame, a little bigger than one eight of the final support has been manufactured. In order to start the tests before the delivery of the actual key components of the cryomodule, a dummy cavity, solenoid and coupler were manufactured and will be used to perform tests outside and inside the clean room to validate the assembly procedure and the tools. The mock-up will then be used to train the operators for the assembly of the whole string.

## THE IFMIF LIPAC CAVITY STRING

The cavity string of the IFMIF LIPAc cryomodule, which is depicted in Figure 1, is made of eight 176 MHz half-wave resonators with their power couplers, eight focusing solenoids - each equipped with beam position monitors (BPMs) - two warm/cold transitions with beam valves, and a pumping line connected to the two central cavities [2]. Due to their size and weight, the couplers are mounted vertically and connected to each cavity at their mid-plane. In order to meet the beam dynamics constraints [3], the cryomodule has been designed to be as short as possible: 400 mm space is allowed for the solenoid package – i.e the focusing solenoid, the BPMs and one bellows on each side [4] – and 280 mm for the cavity equipped with its tuning system. This one is a compression mechanical tuner attached to pads welded to the helium tank of the cavity [5]. These pads are close to the cavity / solenoid interface flange and could hinder operators' hands for the connection.

All the elements of the cavity string are placed on a frame made of titanium. Because of the thermal shrinking of the 5.5 meter long frame during the cool down of the cryomodule - about 8.4 mm – it is not possible to directly attach the cavities and the solenoids on this one in order to be compatible with the couplers which are in interface with the vacuum vessel.

To leave the cavities and solenoids longitudinal position independent from the titanium frame, C-shaped elements with needle rollers similar to the ones presented in [6] are used. Each cavity and solenoid is fixed on an invar rod which is attached to the frame in its centre. Because of the low thermal expansion coefficient of invar (0.4 mm/m between ambient temperature and liquid helium temperature to compare to 1.5 mm/m for titanium), this invar rod fixture determines the longitudinal positions of the couplers.

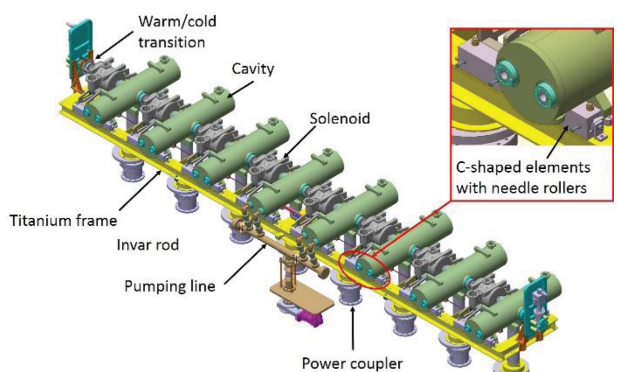


Figure 1: The IFMIF LIPAc cavity string.

The C-shaped elements also assure a fine alignment of the cavities and solenoids around the beam axis with accuracy of ±1 mm and ±10 mrad for the solenoids and of ±2 mm and ±20 mrad for the cavities. The cavity alignment is particularly critical because of its long power coupler. The coupler is connected to the vacuum tank through a flexible bellow and to a RF line. A bellow deformation or a small force in the RF line connection could drive to a resulting moment of rotation, which could perturb the cavity alignment. The spring washer package has been calculated to balance this resulting moment and to keep the cavity alignment.

## PRINCIPLES IN THE CAVITY STRING ASSEMBLY

The beam line is a critical part as it must be free of any pollution for the good performance of the SRF Linac. It means that all the components of the beam line – cavities, solenoids, couplers and accessories – must be assembled in an environment free of dust, an ISO 5 clean room.

### *The Support Frame*

Because the titanium frame is a critical part of the alignment system of the cavity string and is used as a reference for the assembly in clean room, it is made of I-

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beams and plates whose surfaces will be machined before welding in order to have a good surface finish. After welding, the top surface of the frame is precisely machined to respect the flatness requirement of 0.1 mm/m.

### *The Auxiliary Linear Guides*

Once qualified, each element will be prepared for the clean room assembly. For the cavities and the power couplers, only the external envelope shall be cleaned before assembling a coupler on a cavity. For the solenoid package, a high pressure rinsing of the beam tube and the two bellows shall be performed before mounting the buttons of the beam position monitors.

Because of the strengthening bars of the support frame and the size of the coupler flange, the positioning of the coupler / cavity sub-assembly on the frame must be done in two steps: first a vertical motion, and then an horizontal motion. The second step is delicate as it corresponds to the connection of a cavity to a solenoid. Ideally, this should be done using the C-shaped elements which support the components on the frame. But the small longitudinal displacement allowed by these elements – a few millimeters – is not sufficient for assembling a solenoid to a cavity, about five centimeters are needed to check the good positioning of the interface flanges. Furthermore, these ones cannot be used in the clean room due to the difficulty to clean them up.

Auxiliary linear guides compliant with the use in a clean room are used. The company Igus® manufactures such devices: Drylin® is a range of maintenance-free and lubricant-free linear bearings fulfilling the corresponding air cleanliness specifications in accordance with ISO-14644-1 [7]. Two Drylin® T type guide rails are fixed on the top surface of the titanium frame and due to the weight of the coupler / cavity assembly, four carriages are used for each element: two with fixed bearings on one rail, two with floating bearings on the other as recommended by the manufacturer for automatic adjustment of parallelism errors.

### *Alignment Strategy*

Performing a dust-free assembly is the main goal of the clean room operations. Another goal is to make sure that all the components of the string can be connected together with the minimum stress on the inter-components bellows and the minimum vertical tilt of the power coupler. Moreover, the operators must ensure that the C-shaped elements could be mounted around the pads of the cavities and the solenoids once the cavity string is taken out the clean room to continue the cold mass assembly. Indeed, one of the first operations outside the clean room is to transfer the weight of the cavity string from the carriages to the C-shaped elements.

In order to ease the assembly and to minimize the manufacturing errors on the flanges, mitigation actions were taken during the design phase. Due to the compact design of the cryomodule, the cavity beam flanges have threated blind holes and the solenoid flanges are not rotatable. So the solenoid flange has Ø10 mm slotted holes for M8 screws and the positions of the holes are precisely defined on the drawings and will be checked after the manufacturing.

To ensure a good alignment, the surfaces of the support pads of the components of the cavity string are precisely machined relatively to the beam axis. Nevertheless, errors could occur during the manufacturing. To avoid a difficulty to connect all the elements of the beam line, a positioning adjustment system is mounted on each carriage allowing to adjust the vertical and lateral position of each element but also the tilt around the beam axis and the vertical axis of the power coupler (Figure 2).

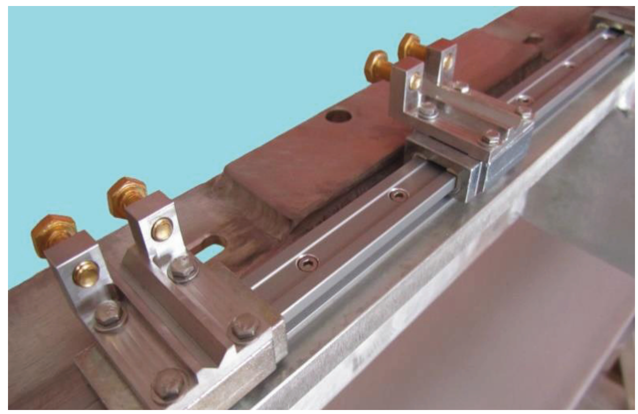

Figure 2: auxiliary linear guide assembled on the support frame with two carriages partially equipped with the positioning adjustment system.

## THE TEST BENCH

A test bench was developed to test, optimize and validate the use of the linear guides in the clean room, the tools and the way to connect the elements together. A piece of frame, a little bit longer than one eighth of the real support frame, and equipped with the linear guides, and a trolley were manufactured.

So as to start the tests before the delivery of the actual key components of the cryomodule, a dummy cavity, solenoid and coupler were manufactured (Figure 3).

The dummy cavity is made of stainless steel and has the same outer shape and the main interfaces than the niobium cavity with its helium tank. There is no need to have the complex shape of half-wave resonator. A simple tube connected between the two beam flanges is sufficient for the validation test. The coupler port is closed with a disc. All the welds are helium tight.

The dummy solenoid vessel is very similar to the one which will be installed in the cryomodule. Only the coils are not installed in the dummy. The manufacturing of this mock-up was a way to check the feasibility of the weld preparation and the mechanical tolerances after assembly and welding before launching the manufacturing of the series.

The dummy coupler is made of three stainless steel parts: a first tube which represents the outer conductor with a flange which connects to the coupler port of the cavity. One end of the tube is closed with a disk to ease the cleaning. The other end is welded to a closed tube with a bigger diameter. This one represents the warm part of the power coupler with the diagnostics. The third part represents the interface flange of the power coupler with the vacuum vessel. Unlike the real power coupler, the dummy coupler has no bellows.

Figure 3: the test bench with a dummy cavity and solenoid.

First, tests were performed outside the clean room to validate the linear guides, the positioning system, the tools and the reference scenario.

### *Reference Scenario and Tools*

The first step of the reference scenario is to adjust the position of the frame. As the top surface is precisely machined to get a flatness of 0.1 mm/m, this one is the reference surface for positioning the elements of the cavity string. For this step, a dedicated tool has been developed [8] (Figure 4): it consists of a plate with three ball end pins fitting in the V groove of three carriages which can move all along the linear guides. A level is placed on the reference surface of the plate, and the four feet of the trolley are adjusted until the frame is perfectly horizontal (Figure 4, top left).

The same tool is used to control the horizontal position of the cavity once this one is placed on the frame. The plate is set on the two upper reference surfaces of the cavity and the pins fit inside counter bores drilled in these reference surfaces. A second plate, which can slide along the linear guides and which leans on the tuner pads of the cavity, is used to control the tilt of the element with respect to the beam axis (Figure 4, top right). To control the position of the cavity and check if the C-shaped elements could be mounted around the pads of the cavities and the solenoids once the cavity string is moved outside the clean room, a C-shaped template and calibrated gauges are used. When the template is placed around the pads, the calibrated gauge shall fit in the free space (Figure 4, bottom left).

Then a solenoid is placed on the frame. To adjust the position of this element, the tools are similar to the ones used in the previous step. But the operators have also to check that the holes of the beam flange of the solenoid are in front of the threated holes of the cavity beam flange. Because the cavity shall be opened to air the shortest possible time to avoid dust contamination, special blank flanges are installed on the beam ports of the elements: the blank flange on the cavity beam port has two precisely machined counter bores; the one on the solenoid beam port has two pins. When one element is well positioned relatively to the other, the pins perfectly fit in the counter bores (Figure 4, bottom right).

The last step is to connect the solenoid to the cavity. First the solenoid is moved away the cavity and the blank flanges are carefully removed. Then a gasket is placed inside the groove of the cavity beam flange and the solenoid is slowly approached until the seal touches the solenoid beam flanges. Finally the screws are tightened.

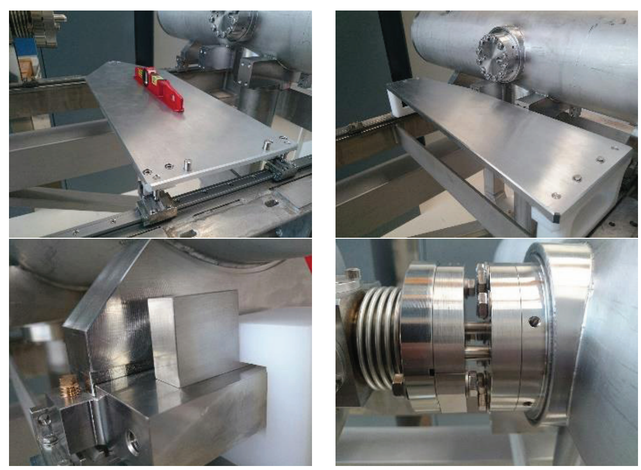

Figure 4: some of the tools.

## SUMMARY AND OUTLOOK

Minor changes will be performed before next tests: a finest thread will be used on all the screws of the positioning adjustment system. And the screws of the lateral positioning system, with flat end, will be replaced by screws with ball end to lower the friction with the pads of the cavities and solenoids. And because reading the bubble can be awkward and difficult, a digital inclinometer will be supplied.

Then, tests will be performed in clean room. Thanks to the leak tight welds of the dummy elements, it will be possible to check the leak tightness of the gasket between the dummy cavity, the dummy solenoid and the dummy coupler.

Developing this test bench is an important mitigation measure to prevent a critical event during the assembly of the cavity string. The assembly tools are being tested and improved as well will be the procedures. Moreover these




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mock-ups will be used to train the operators for the assembly of the whole string.

In parallel a tool is being developed for the assembly of the power coupler on the cavity. The qualification of this tool will be performed during the SATHORI test [9, 10], which consists in characterizing a jacketed and fully dressed cavity with its coupler and tuner in a dedicated test cryostat.

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