ENGINEERING ISSUES OF THE MEDIUM ENERGY BEAM TRANSPORT LINE AND SRF LINAC FOR THE LIPAc

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Abstract

The LIPAc (Linear IFMIF Prototype Accelerator) is a 9MeV – 125 mA CW deuteron accelerator [1]. It is designed and manufactured in most parts in Europe and is being installed in Japan. Among its main components, the MEBT (Medium Energy Beam Transport line) [2] will shape the 5 MeV beam before its injection into the SRF Linac that will accelerate it up to its end energy. This paper addresses the engineering issues associated with the integration of the MEBT supplied by CIEMAT and SRF Linac supplied by CEA and CIEMAT at the LIPAc facility. It considers the seismic analysis of the beamline components and the tests and alignment activities performed in Europe prior to shipping the components to Rokkasho.

MOTIVATIONS

The LIPAc project is a collaboration between European and Japanese contributors. The Japanese contributors are mainly responsible for the design, manufacture and installation of the building and conventional facilities, while the European contributors supply most of the accelerator components and several other related equipment. This sharing implies a number of constraints that have to be taken into account for the design and assembly of the machine.

Since the LIPAc will be installed in Japan, seismic analyses are necessary to ensure the integrity of the accelerator in case of earthquake.

Since the machine is being manufactured in Europe, it is highly desirable to assemble and test most of the equipment before shipment to Japan for two main reasons. The first is to maximise the reaction time to resolve technical issue close to the manufacturing site. The second is to avoid delaying the schedule on LIPAc site operations where many other concurrent activities related to installation and commissioning of other equipment are performed [3]. A balance has to be found with the constraints linked to the shipment. The vibrations and accelerations encountered during a sea trip from Europe to Japan are indeed significant. If the equipment cannot sustain then another option is to use air transportation. Nonetheless, if these constraints are still too high for airplane transportation or if the cost is not acceptable, the solution is to ship the components separately and realize the assembly in Japan. Another important constraint is the alignment of the equipment that depends not only on the accuracy of the machining, but also on the tools and methods used during assembly and installation. If possible, it is always better to carry out an alignment campaign during assembly of the equipment and before shipment to Japan. The installation inside the LIPAc building can then be carried out more rapidly using some of the external frame CCR's (Corner Cube Reflector) and re-checking the rest.

MEBT

Seismic Analysis

An RS (response spectrum) analysis was performed to check the behaviour of the MEBT in case of a seismic event. A simplified model prepared from the 3D CAD mock-up was introduced to the Ansys v14.5 – workbench environment. The first six calculated natural modes from the modal analysis fall below 20 Hz, three of them are located in the maximum acceleration range (2-10 Hz) of the excitation spectrum. These modes contribute in great part to the maximum displacements observed in the RS analysis results at the top of the valves linked to the turbo pumps.

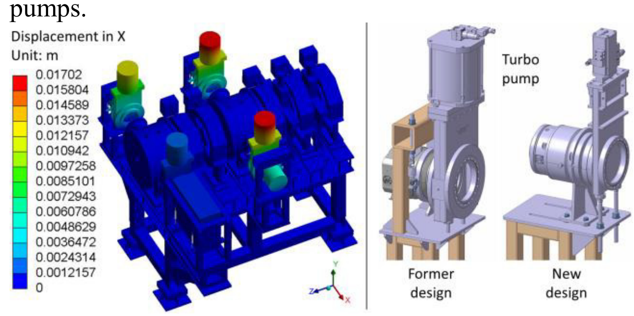

Figure 1: MEBT deformation from RS analysis and turbo pump design change.

As a result of the analysis, the supports were redesigned fixing the turbo pumps rigidly instead of using springs, see Figure 1. The RS analysis did not reveal more points that could be a problem for the MEBT.

Assembly Test of ACCT

Due to the reduced space at the interface between the RFQ (Radio Frequency Quadrupole) and the MEBT where the ACCT (AC Current Transformer) is located, it was decided to perform an assembly test of the ACCT

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mounting, see Fig. 2. This operation requires dismounting the upper half of the first MEBT magnet in order to access to the ACCT screws. The difficulty is that these screws, that are accessible only by inserting a tool through the ACCT, have to be tightened alternatively by a quarter turn while the ACCT is displaced progressively. This is due to the presence of threaded holes on both side of the assembly, the ones on RFQ side having a chucking function whereas the ones on ACCT side are present to prevent the screws from falling into the ACCT. A first test showed that it was not possible to install the ACCT without the use of special tooling. A dedicated temporary support for the ACCT was designed, manufactured and used during a second assembly test. Notwithstanding the remaining poor accessibility, the test was successful and validated the assembly sequence.

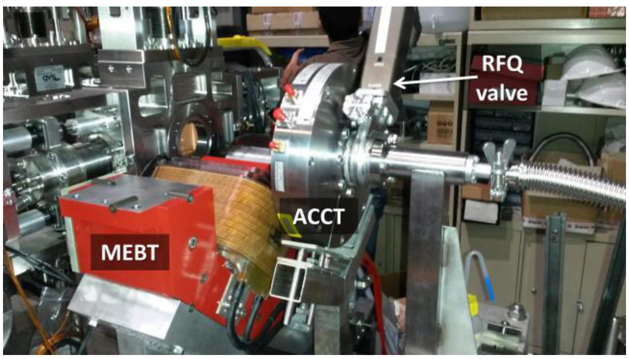

Figure 2: Assembly test of the ACCT.

Alignment Campaign

Since the MEBT tolerates sea shipment, all the main components (five quadrupoles, two scrapers, two bunchers, the beamline with four Beam Position Monitors and three turbo pumps) were assembled on the MEBT frame. An alignment survey was performed on all the MEBT components except of the second buncher, see Figure 3.

The assembly table of the MEBT incorporates specific features defining the assembly coordinate frame. These features have been surveyed in the first step of the assembly and a best fit process has been launched to find the best match between the coordinate of the surveyed features and the nominal coordinates as defined in the reference CAD model. This process implicitly guarantees the best coincidence between the CAD coordinate frame and the assembly bench. The second phase of the assembly consisted in the characterization of the components to be installed. In this phase, each part of the MEBT has been measured and a proper set of offset distances has been defined to take into account the differences between the mechanical and magnetic axis of each part. On the basis of these preliminary activities the proper assembly of the MEBT started. Two Hexagon Laser Trackers have been used simultaneously to drive the operators to lock the part under installation in its final position. Each tracker was put on continuous measuring mode such as to produce in real time a simplified window showing the difference between measured and target points. The procedure proved to be very useful and time saving. Alignment was considered satisfactory only when the difference between target point coordinates and measured point coordinates was less than the global uncertainty of the measuring process. For the adopted process and layout, this uncertainty was not higher than 20 microns with a confidence level of 95%.

The last phase of the assembly was the full survey of the fiducial supports of the MEBT. More than 80 fiducial nests have been surveyed many times realizing a database of more than 500 measurements. These coordinates will be used to assess dilations due to transportation to Rokkasho and, if necessary, to re-align the components after the delivery.

Figure 3: Two laser trackers and watch windows during MEBT alignment campaign.

SRF LINAC

Seismic Analysis

Similarly to the MEBT, RS analyses were performed for the SRF Linac to examine its behaviour during a seismic event. The cold mass includes a frame supporting the cavities, solenoids, couplers and He phase separator, and hangs from the top of the vacuum vessel by ten vertical Ti alloy rods and four horizontal ones in lateral direction. The first analysis revealed a potential problem at the interface between the cold mass and its support. The analysis results show that the cold mass would move nearly 10 mm longitudinally, which could damage its supporting structures. The problem was solved by adding two locking systems in the middle of the cold mass frame, thereby reducing the longitudinal displacement.

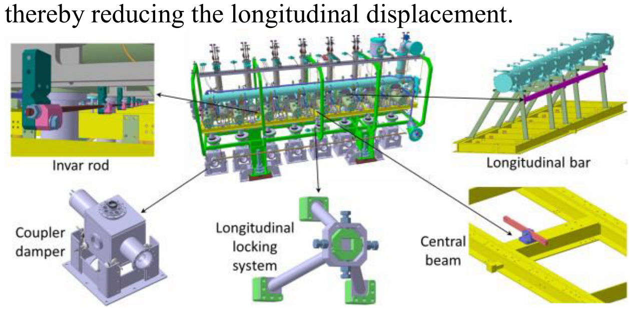

Figure 4: SRF Linac design optimisation following seismic analyses.

A second analysis highlighted a further swinging motion of the cavities and couplers (again nearly 10 mm in the longitudinal direction), and also on the He phase separator (around 2 mm). The central beam located in the middle of the cold mass frame, and to which all the cavities/solenoids are fixed via invar rods, was too flexible (7 mm of the 10 mm deformation mentioned previously). In addition, the stresses observed in the invar rods were above the yield limit of this material. Four modifications were applied to the design in order to improve the SRF Linac seismic behaviour, see Figure 4. The central beam was reinforced by changing its geometry. The invar rod diameter was increased from 8 to 12 mm and its fixing system to the central beam modified. Dampers were fixed to the base of the vacuum vessel to limit the displacement of the couplers and as a result the cavities and solenoids. A longitudinal bar linking all He phase separator supports was added. A third RS analysis showed that the implemented changes were sufficient to reduce the displacements of all the components (see Figure 5) and validate the design from a seismic perspective.

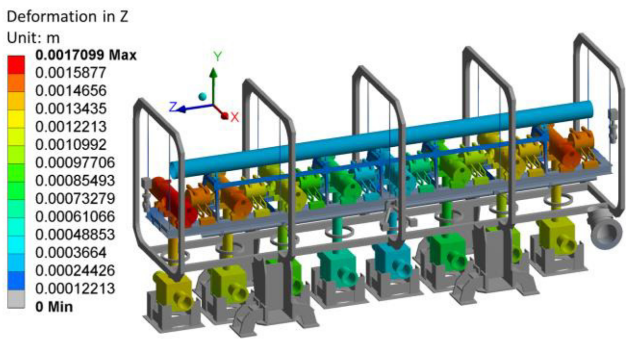

Figure 5: SRF Linac deformation after design optimization.

Assembly and Shipment

The assembly of the SRF Linac beam line (cavities, solenoids, couplers) was initially planned in the premises of CEA at Saclay prior to shipment to Rokkasho [4]. A risk analysis was performed to assess the viability of this solution. As a result the decision was taken to carry out the assembly task in Rokkasho under the full responsibility of F4E (Fusion for Energy). A first reason was linked to the weakness of the ceramic coupler windows. These fragile components support the RF antennas located inside the beam tube volume and for which no clamping tool for transport can be installed once the assembly is complete. Any failure of the ceramic window, which is also a beam vacuum barrier, would result in dust contamination of the beam vacuum. In this case it would be necessary to disassemble the complete SRF Linac in order to clean the cavities / solenoids / couplers in ultra sound baths following strict procedures and reassemble the SRF Linac in a clean room. This is why handling operations of the SRF Linac after assembly have to be minimized. A second reason was related to the road transport of the whole SRF Linac. Studies were required to design and manufacture a special transport frame able to damp the vibrations and protect the integrity of the equipment. This could be avoided in the case of an assembly on site and an opportunity to build a clean room was identified. The cost of an appropriate clean room for the cavity string assembly is comparable to cost difference between air and sea shipment.

The SRF Linac components manufactured in Europe will be shipped separately to Japan [5]. The assembly will be performed in an ISO5 clean room located in a building adjacent to the LIPAc building.

CONCLUSION

The seismic analysis of MEBT led to an alternative design in order to improve its mechanical behaviour in case of earthquake. The alignment of MEBT was successfully performed in Europe. The assembled MEBT was shipped by sea to Japan and will be installed during 2016. The SRF Linac components are currently being manufacturing in Europe and will be shipped to Japan for final assembly in 2017.

DISCLAIMER

This publication reflects the views only of several of the authors, and Fusion for Energy cannot be held responsible for any use which may be made of the information contained therein.

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