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Remote Disconnection System for the beam dump of the LIPAc accelerator

F. Arranz[a], O. Nomen[b], B. Brañas[a], J. Castellanos[a], J. Molla[a], D. Gutierrez[c]

[a]CIEMAT. Avda. Complutense 40. 28040 Madrid. Spain.
[b]IREC, Jardins de les Dones de Negre, 1, 2ª, 08930, Sant Adrià de Besòs. Spain
[c]The Vacuum Projects. Vellluters, 17. 46988 Paterna. Spain

ABSTRACT

The International Fusion Materials Irradiation Facility (IFMIF), will be a test facility in which candidate materials for the use in fusion reactors can be fully qualified. The LIPAc (Linear IFMIF Prototype Accelerator) is a prototype of one of the two IFMIF accelerators that is currently being built in Rokkasho (Japan). There is a beam dump made of copper at the end of the accelerator to stop the deuterons. The connection of the beam dump with the rest of the accelerator is the object of this article.

The requirements imposed on the connection include radiation levels in that section, vacuum and leak tightness, alignment capabilities of the system, dimensions compatible with the beam stay clear and disconnection of the system from outside the shielding.

The characteristics, functions and layout of the different elements of the mechanical system are explained in this article.

Keywords: LIPAc, IFMIF, Remote handling, Beam dump.

1. Introduction

The International Fusion Materials Irradiation Facility (IFMIF), will be a test facility in which candidate materials for the use in fusion reactors can be fully qualified [1]. The LIPAc (Linear IFMIF Prototype Accelerator) is a prototype of one of the two IFMIF accelerators [2]. Its objective is to validate the low energy part (9 MeV) of the IFMIF linacs (40 MeV, 125 mA of D^+ beam in continuous wave). It will not have a target and hence a dump is needed to stop the deuteron beam.

The LIPAc BD (Beam Dump) which stops the deuterons, consists of a cone made of copper, whose inner surface absorbs a power of 1.12 MW, with up to 2.5 MW/m^2 peak power density in nominal conditions, [3] . The cone is assembled inside a cylinder closed at the rear by a flange with the inlet and outlet pipes for the cooling water.

The RDS (Remote Disconnection System) includes the articulated collar that allows remote disconnection, the two adjacent bellows one at each side of the collar, and the support and mechanisms to align and operate the disconnection system, see Fig. 1.

One of the bellows connects to the BD, the other to a conical tube passing through the shielding wall (700 mm thick). The conical tube ends up on a chamber with the Lead Shutter that defines the end of the HEBT (High Energy Beam Transport Line). The lead shutter is closed for beam off phases in order to avoid the gamma ray streaming to the vault, allowing therefore hands on maintenance on the beam line.

The assembly of the cone with the cylinder is called BD cartridge and it is enclosed by a shielding. The inner layer of the shielding is a neutron barrier including water tanks in the middle and polyethylene rings at the front and rear areas. The outer layer of the shielding is made of steel providing a barrier for gamma rays. More details of the shielding can be found in [4].

The interaction of the beam deuterons with the beam dump lead to the activation of the copper. This activation is dominated by Zn 65 with a half-life of 249 days. Once the accelerator has been running over 5.5 days (integrated time) at 1% duty cycle, doses due to Zn65 coming from the cartridge and computed at the bellows zone will be over 250 microSv/h preventing any hands on maintenance on the RDS, therefore this system has been designed maintenance free.

At the end of the life cycle of the accelerator, for the decommissioning phase, it will be necessary to separate the BD cartridge and introduce it in a container with the required shielding, without direct handling. Therefore a disconnection system that can be operated from outside the shielding was required. After such disconnection the remote opening of the shielding and the extraction of the cartridge with an electromagnet would follow, using the bridge crane for such operations.

As it is shown in the article (sections 2 and 3), the design of the LIPAc RDS system faces challenging space restrictions which requires bespoke solutions to provide the necessary movements for disconnection.

author's email: fernando.arranz@ciemat.es

Similar systems have been used for remote disconnection in J-Parc [5],[6], and SNS [7], allowing a flexible connection and a disconnection system that prevents the close proximity of the workers to the area with higher radiation.

In contrast with the LIPAc RDS system, other remote handling designs require the possibility of reinstalling the components and a retrieval system or carrying out operations such as welding ([8], [9], [10]), which makes those systems more complex.

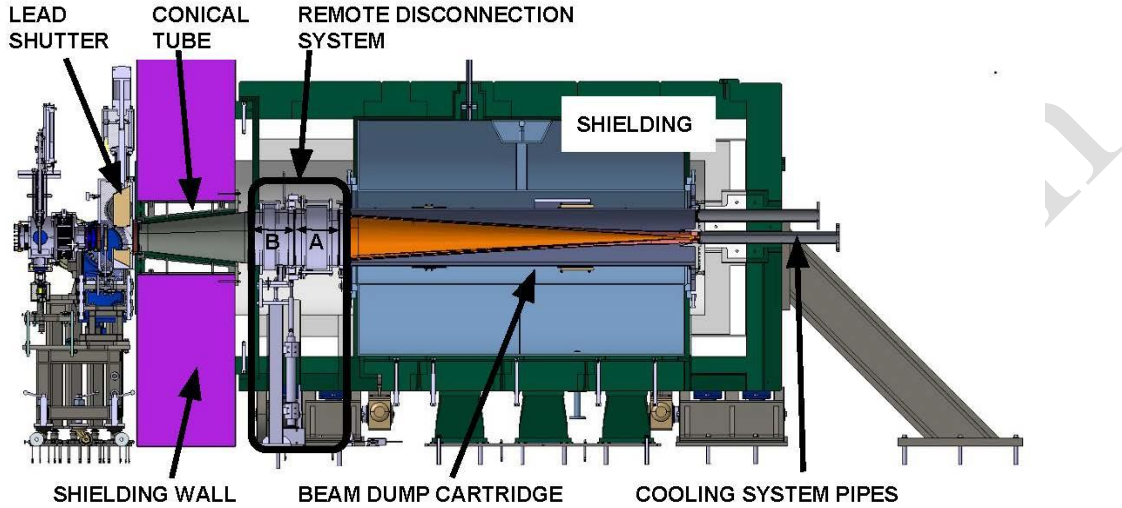

Fig. 1. Remote Disconnection System and adjacent systems. “A” cartridge side. “B” wall side.

2. Requisites for the Remote Disconnection System

The main requirement of the RDS system is to provide a means of disconnection of the BD cartridge from the rest of the beam line from outside of the shielding, such disconnection is possible through an articulated collar shown in figure 2. Other requisites including radiation, vacuum and alignment have been taken into account for the design.

The prompt dose requirement in the vault is fulfilled with the designed shielding, which provides values below 12.5 μSv/h outside the vault and below 0.5 μSv/h outside the fence boundary of the accelerator building [11].

The dose inside the shielding, at the zone where the RDS is placed, is over 1×10^{4} μSv/h, with beam off and after 6 months operation full power, therefore any operation to be performed by removing part of the shielding should be remote.

Concerning vacuum requirements, pressure values in the vicinity of the BD will be in the order of 1×10^{-5} to 1×10^{-4} mbar, therefore the RDS has a requisite in the vacuum forces to be balanced in the bellows as well as the allowable leak rate in the system (welds and leaktightness of the o-rings). The gas rate produced in the BD is in the order of the 1.5×10^{-2} mbar·l/s coming from the deuteron beam converted in deuterium gas by neutralisation and recombination on the cartridge surface. The requisite imposed to the RDS is a He leak rate smaller than 1×10^{-8} mbar·l/s .

With regard to alignment requirements, the RDS includes two bellows that provide the required flexibility to compensate manufacturing and assembly deviations in the elements connecting the lead shutter chamber with the BD cartridge.

Concerning the elements connected to the bellows of the RDS, the total allowed deviations of the manufactured pieces with respect to the nominal values are: 4.5 mm lack of coaxiality, 5 mm accumulated axial deviation and 0.6º angular deviation.

Fig. 2. Articulated collar for disconnection.

The inner diameter for the elements that make up the RDS is limited by the Beam Stay Clear (BSC) defined in that section. Those elements have been chosen with a minimum inner diameter of 400 mm, this allows us to assure that no losses are present in the transport line, even considering alignment and power supply errors. As the beam is divergent, only in the second bellows, closer to the beam dump, some beam losses (lower than 100 W) could take place during the startup and tuning of the accelerator.

3. Design of Remote Disconnection system

The RDS is divided into two main parts:

- Elements of the wall side, Fig. 3.
- Elements of the cartridge side, Fig. 4.

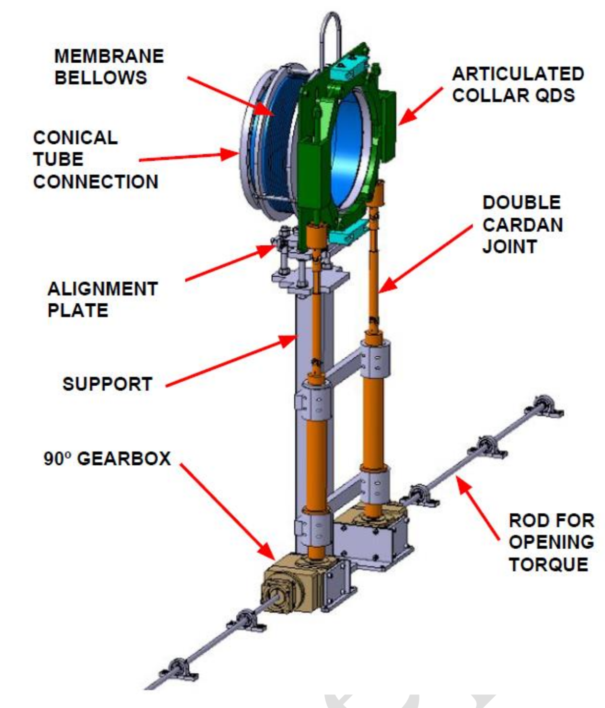

Fig. 3. Elements of the wall side.

3.1 Elements of the wall side

These elements will remain in place when the cartridge is removed during the decommissioning phase.

The bellows connecting the conical tube (at the section of the wall and HEBT connection), is a membrane or edge welded bellows. It has been chosen membrane type because its high flexibility in a small space, facilitating thereby the assembly and compensating for the deviations from the nominal of manufactured pieces. The size of the beam in this section is smaller and it is consequently further away from the beam tube surface.

The articulated collar of the Quick Disconnection System (QDS) is operated with only two bolts, see Fig. 3. The assembly process can be carried out hands-on, nevertheless the final opening process at the decommissioning phase should be done remotely from outside of the shielding.

The required torque to rotate the screws of the QDS is transmitted by two sliding double cardan joints. This type of joint is needed to allow the alignment of the system above the alignment plate.

The torque reaches the cardan joints through 90° gearboxes with a reduction coefficient of i = 90.79. The gearboxes are anchored to the floor and they are connected to horizontal rods that get out of the shielding guided on ball bearings.

The input torque at the end of the horizontal rods is 2.8 N·m and will be applied manually as it is expected to be operated only once at the end of the life of the accelerator. It would be possible, however, to couple a motor for the operation.

3.2 Elements of the cartridge side

The bellows for the BD connection is a hydroformed bellows that allows axial compression up to 47 mm, it is bolted to the BD cartridge flange. It has been chosen hydroformed for its robustness given that it is in a section where the beam is wider and therefore the probability of some ions reaching the beam tube inner surface is higher.

During normal operation vacuum forces tend to compress the bellows, therefore four rods are installed to balance these forces that will hold 2673 N in total, see Fig. 4.

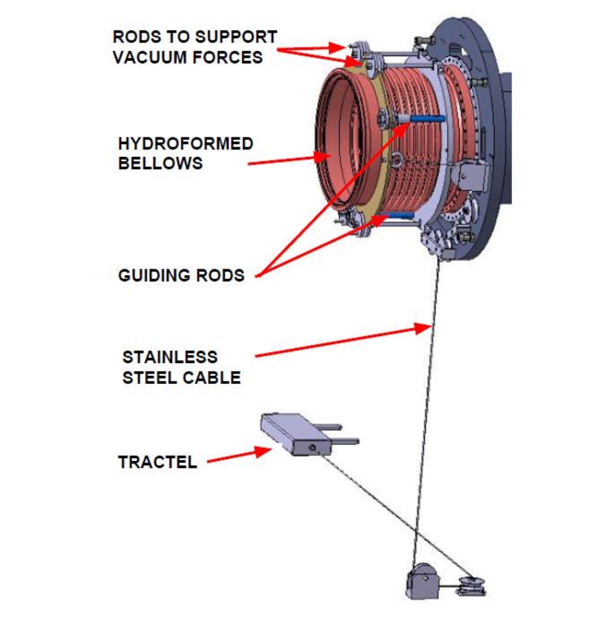

Fig. 4. Elements of the cartridge side.

Once the operation of the accelerator is finished, the cartridge has to be disengaged from the beam line, with the following process:

1) The system is vented and there are no vacuum forces. Open the articulated collar of the QDS (as explained in section 3.1). The opening movement pushes the links outwards releasing the tabs of the rods that were supporting the vacuum forces, Fig. 5.

2). The bellows is compressed by means of a stainless steel cable, driven by a hand operated pulling equipment (tractel). The operator has to apply 121 N on the tractel, whereas the force reaching the bellows is 2520 N. The cable is guided by pulleys on the front of the cartridge and on the floor.

3) There are three guiding rods that provide an even motion during the compression movement and, once a compression of 30 mm has been achieved, a locking system of spring-loaded balls retains the bellows in that position.

Concerning the sealing rings in the three flanged joints (with conical tube, in the articulated collar and with the BD cartridge),they are the elastic metallic type Helicoflex delta model with the outer lining made of OFE copper. They are compatible with the radiation environment and the required compression for vacuum tightness (240 kN) is small compared to conventional sealing rings, which is very convenient for such big diameters (400 mm). The sealing rings are the model HNV200 manufactured by Technetics, with inner diameter 420.0 mm and a torus diameter 4.64 mm. The compression force in the sealing ring is obtained by applying 254 Nm torque to the two bolts on the sides of the articulated collar.

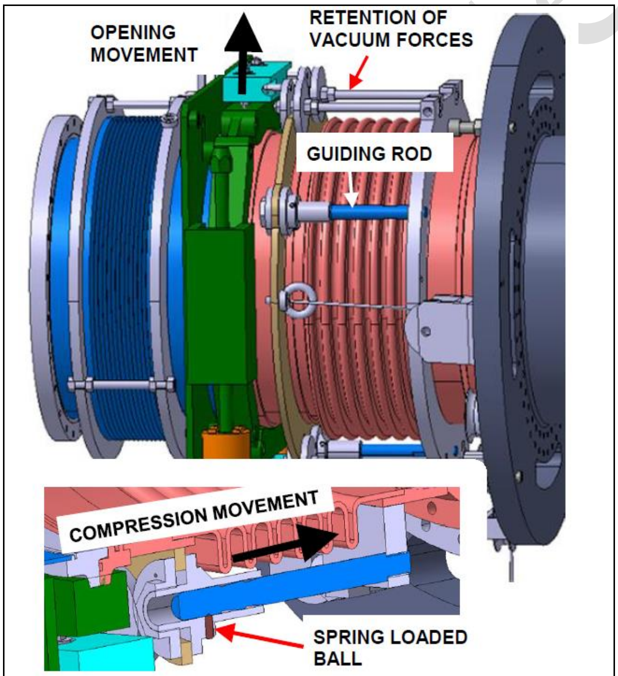

Fig. 5. Assembled system (up). Cross section detail (down). Note: Compression forces are applied symmetrically on both sides of the bellows.

4. Manufacturing process

The manufacturing requirements on materials exclude the use of any non-metallic piece for compatibility with the radiation level in this area.

Most parts inside the shielding are made of stainless steel, whereas outside the shielding, the gearboxes have cast iron casings and metal seals, and the oil has been substituted by solid grease.

The flanges and the parts connected to them are machined within 0.05 mm deviation margin which leads to the required concentricity tolerances.

The manufacturing process to joint parts for vacuum boundary elements is TIG welding, requiring auxiliary tools in order to achieve the required accuracy concerning dimensional and geometrical tolerances.

After manufacturing completion, cleaning of the parts with vacuum requirements was done in an ultrasound bath with hot water and detergent, hot water rinsing and drying with compressed air.

Acceptance tests of the system include dimensional checking with a measurement arm, and He leak test with an acceptance threshold of 1×10^{-8} mbar·l/s .Finally a functionality test was carried out, mounting the whole system and checking the opening of the articulated collar and the compression of the hydroformed bellows and its retention system.

5. Conclusions

A connection system between the BD and HEBT has been devised that allows the disconnection of the BD at decommissioning phase. This disconnection is performed from the outside of the shield and can therefore be done manually.

The system compensates manufacturing deviations from nominal design and allows the alignment of the system.

Radiation, vacuum, dimensional and functional requirements have been taken into account.

Acknowledgments

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