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Alignment strategy for IFMIF-DONES facility

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A R T I C L E I N F O

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A B S T R A C T

This article addresses the challenges associated with the alignment of the equipment within the IFMIF DONES installation and presents the strategy devised to achieve acceptable levels of uncertainty. The primary obstacles stem from the need to align equipment located in different rooms, some of which are inaccessible for manual operations. Additionally, the elevated radiation levels in certain areas impose restrictions on the fiducials that can be employed.

The article details the outcomes of implementing the proposed alignment procedure, including the specific equipment used and the achieved levels of uncertainty.

Acronym	Room	Acronym	Equipment
AC	Access Cell	CP	Control Points
AV	Accelerator Vault	HFTM	High Flux Test Module
TC	Test Cell	STUMM	Start Up Monitoring Module
TIR	Target Interface Room	TAA	Target Assembly

1. Introduction

IFMIF-DONES (International Fusion Materials-Irradiation Facility-DEMO Oriented Early Neutron source) is a facility for irradiating materials and qualifying them for the construction of DEMO and other fusion reactors. The need for the facility is recognized in the Eurofusion Roadmap [1]. The facility is divided into systems [2], of which, the accelerator, the lithium systems and the test systems, have plant equipment that must be aligned in order to meet the irradiation requirements in the test specimens to be irradiated. Proper alignment also minimizes beam losses and hence, components activation, ensuring the safe operation of the machine.

The alignment strategy is a great challenge since some plant equipment is located in rooms with radiation levels that do not allow operators access at any time. A description of the equipment that uses remote handling for its maintenance can be found in [3].

In addition, certain plant equipment receives high doses of radiation that would impair standard targets that must be left permanently installed. Estimated values of radiation levels can be found in [4].

In the next sections, the defined strategy and the uncertainty values obtained through simulation will be explained. These values were confirmed by performing tests with actual metrology instruments.

The reference points installed on the walls and on the floor to create a network for alignment will be named in this article as Control Points (CP), although in the literature they are also called monuments or nests.

2. Layout of equipment requiring alignment

The main line of the accelerator includes different elements in which magnetic fields keep the particles confined and progresively increase

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their energy level. More details of this equipment can be found in [5]. Both the equipment that generates the electromagnetic fields and the diagnostics that measure the position and other characteristics of the beam must be placed in their nominal position with a very low uncertainty, the target value for equipment in Accelerator Vault (AV) is 0.1 mm and for the equipment in Target Inteface Room (TIR) and Test Cell is 0.2 mm. Similar values were determined for the alignment for the components of the main line of the LIPAc accelerator [6,7].

In Fig. 1, a plant view is shown with part of the main building of the facility. Beam line equipment of the accelerator appears inside the AV room, from the injector to the so-called RIR module. During the beam-stop of the accelerator for maintenance, it will be possible to enter the AV for performing metrology work manually.

On the right-hand side of Fig. 1, is the TIR, where the TIR modules can be seen [8]. It is a room that is separated by a wall from AV. The beam tube passes through the wall to allow the accelerated particles to go forward towards the target. The same happens with the equipment located in the TC room, where again there is a separation wall with TIR, which is crossed by the tube that transports the particle beam, in order to reach the target.

In the TC room there are two very relevant pieces of equipment that require precise positioning. One of them is the Target Assembly (TAA), within which the particles of the beam reach a curtain of liquid lithium and create the desired neutron flux. The TAA is part of the Lithium systems, whose more detailed description can be found in [9].

The other relevant piece of equipment within TC is the High Flux Test Module (HFTM), which contains the samples of the material to be irradiated. This equipment belongs to the Test Systems whose description can be found in section 1.5 of [10]. During starting up of the facility, instead of the HFTM, the Start Up Monitoring Module (STUMM) will be used, with instrumentation that will allow proper characterization of the neutron flux. The STUMM will have the same alignment features and restrictions as the HFTM.

In order to align the pieces of equipment that are in TIR and TC, it is necessary to remove some concrete slab shields located on the ceiling of the rooms. Then, remote handling equipment can access from the room above named Access Cell (AC).

Even during shutdown for maintenance, the residual dose levels in TIR and TC prevent an operator from entering to carry out maintenance work, thus these operations must be performed with remote handling equipment, which is described in [3].

The relative positions of the rooms involved in the alignment process can be seen in Fig. 2. The AV room where the alignment is done manually will have a CP network distributed throughout its walls. Likewise, the AC room will have a CP network distributed on its walls and floor, which will be used to align the equipment that is inside TIR and TC. The fiducials of the equipment will be visible once the concrete slabs that act as shields have been removed.

These fiducials, placed on the TIR and TC equipment, must remain installed during the operation of the beam, since they cannot be placed manually during shutdown for maintenance. Therefore, they must withstand high neutron radiation. The solution that has been chosen as a baseline, is to use stainless steel balls, whose geometry is read by a laser radar during the alignment process.

In the next section, an explanation is given about how both CP networks are connected, such that all the devices are positioned with respect to the same Global Coordinate System.

3. Connection of networks of control points

The main building of the facility is 158.5 m long and it is built in reinforced concrete. Some areas have very thick concrete walls to provide the necessary radiological shielding. These characteristics of the building can lead to differential ground settlements, which in turn lead to deformations in the order of a few units of millimeters. In [11], the alignment of a similar scientific facility is described, in which 3 mm of relative displacement due to differential settlement of the ground was measured. Also shrinkage effect of concrete structures will modify relative positioning of equipment during the early years after construction.

Therefore, it is considered essential to perform a periodic calibration and establish a connection method for the two CP networks, the first one in AV and the second in AC.

The solution adopted is the use of three holes that connect both rooms (AV and AC), through which the beam of a laser can pass. This solution has been successfully used in the CNAO facility (INFN-Frascati) [12].

In Fig. 3, the lines of sight of the laser tracker can be seen, they are used to connect both rooms.

During normal irradiation operation, the holes connecting AV and AC will be closed with shielding plugs with a labyrinth shape, to prevent the passage of radiation. In addition, the holes will be covered with a blind flange with a sealing gasket to keep the environments of both rooms separated.

During a long shutdown for maintenance, the blind flanges and shielding plugs of the holes will be removed for the time necessary to connect the two CP networks with laser tracker, and then they will be installed again.

The complete sequence of connection of CP networks and equipment alignment can be expressed in a simplified way by means of the following steps:

1. The beam of particles stops.
2. With a laser tracker on the floor of AV, manually, the coordinates of the CP network on the AV walls are measured.
3. Shielding plugs separating AV and AC are removed.
4. Using a laser tracker on the AV side, manually connect the AV network with some points on the eastern AC wall Fig. 3. Afterwards, with the laser tracker installed on the AC floor, connect some points on the AC walls and floor with the AV network, looking through the holes of the wall.
5. The shielding plugs that separate AV and AC are installed again in their usual position.

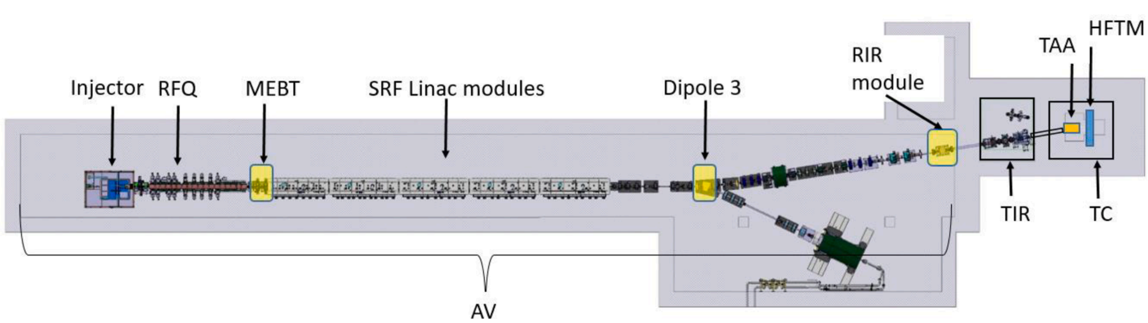

Fig. 1. Plant view with equipment requiring alignment.

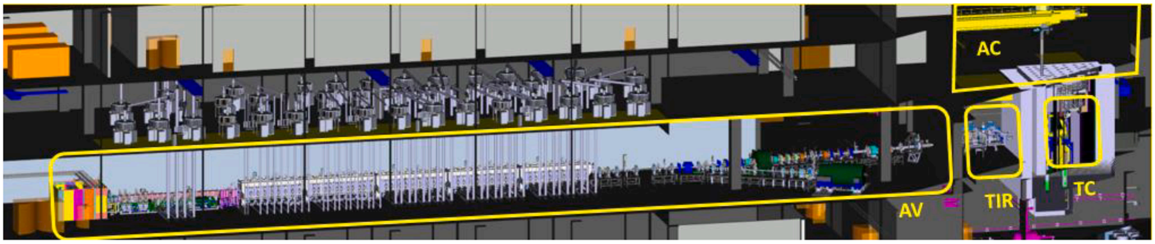

Fig. 2. Rooms involved in alignment (AV, TIR, TC and AC).

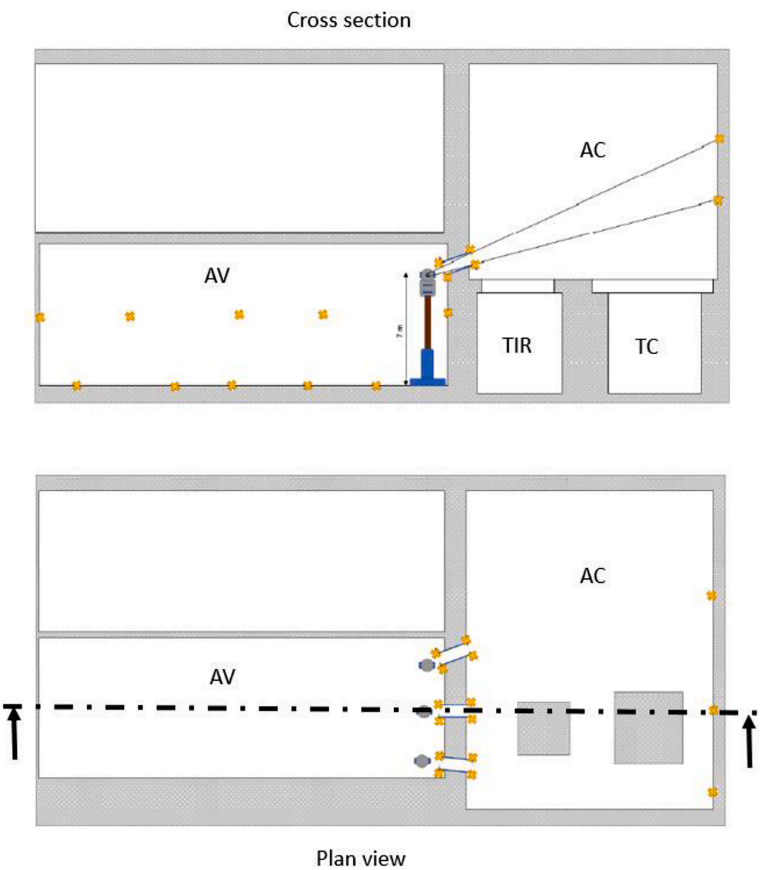

Fig. 3. Holes connecting networks of CP in AV and AC.

6. The complete network of CP in AC is created manually with laser tracker (based on the points measured in step 4).
7. The AV plant equipment is manually aligned with laser tracker.
8. TIR and TC concrete slab shieldings are removed and the plant equipment is aligned in these rooms with laser radar, using remote handling equipment to apply the required adjustments in position.
9. The TIR and TC concrete slab shieldings are placed in its operative position again, closing the ceiling of the rooms.
10. All the metrology equipment is removed and the alignment operation is terminated.

In this way, it is possible to compensate for the deformation of the building and connect the two CP networks periodically, while maintaining isolation in terms of radiation and contamination during normal plant operation.

The uncertainty values calculated in a simulation with Spatial Analyzer software gave acceptable values for both AV and AC. The laser tacker model used was FARO Vantage S6 Max. The laser radar model used was Nikon APDIS MV4 × 0.

In the AV, fiftysix CP have been considered distributed on the walls of the room at two heights, 1 m and 3.2 m from the floor, respectively. Fourteen different positions have been considered for the laser tracker, such that the distance to the fiducials and to some CP points is always less than 5 m. With these hypothesis, the position uncertainty of the plant equipment in AV is in the order of 0.077 mm, which is a value compliant with the requirements.

The uncertainty values in the TIR and TC equipment, are relatively high because it has been necessary to pass through the three holes that connect AV and AC, which implies long distances. Then it was necessary to create a CP network on the AC walls and floor. Finally, to measure the fiducials on the equipment that are in TIR and TC, we use a laser radar. The distance between fiducials and laser radar in this case is large due to the geometry of the problem. All these factors mean that the maximum uncertainty calculated in this case is around 0.220 mm. This value is still acceptable although it is a bit over the desirable value set initially of 0.2 mm.

Fig. 4 shows the laser radar in the measurement position of the TIR

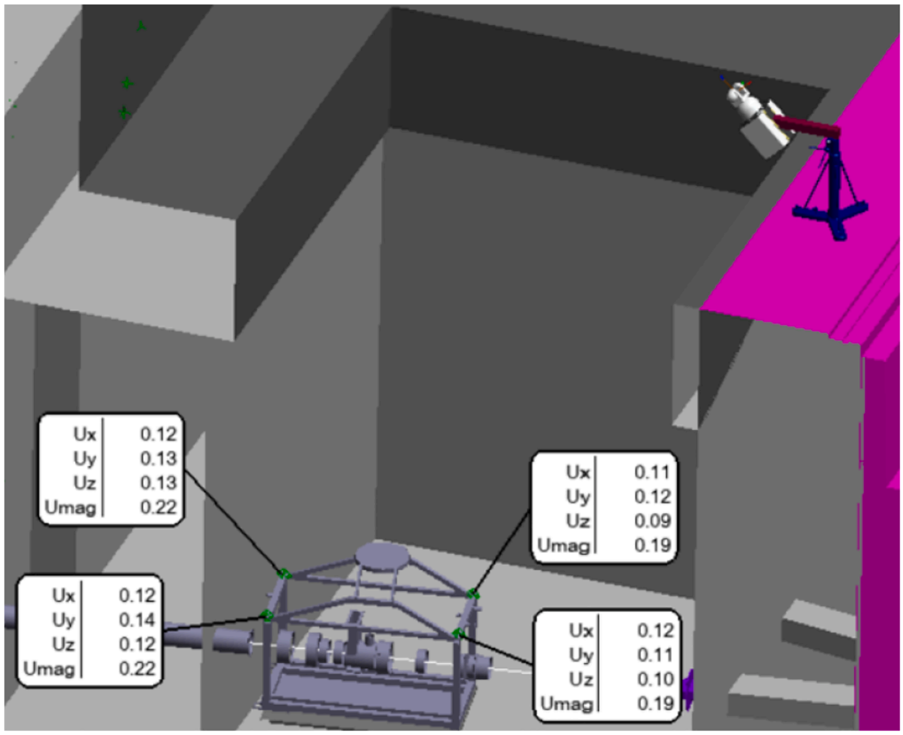

Fig. 4. Uncertainties for TIR equipment with laser radar.

equipment, and the uncertainty values of four fiducials belonging to one of the TIR modules. The laser radar is placed on a tripod, with an inclination such that it can see the fiducials within the range of angles indicated by the manufacturer.

The software of the laser radar is operated with a personal computer from remote distance. It allows the use of cameras built-in the laser radar. Such cameras are used to search for the next fiducial to be measured and then scan it and acquire the geometry. In this way, the operator who manages the personal computer will be located outside the AC room, during the period that the concrete slab shieldings are removed and, therefore, the radiation levels in AC are high.

Once the measurement and alignment are finished, the concrete shielding slabs are reinstalled on top of the RIR and TC, thus reducing AC radiation levels and allowing access to an operator to manually remove the tripod with the laser radar.

An alternative method to connect the CP networks in AV and AC has been analyzed, using paths through corridors, elevator shafts, doors and other rooms, using temporary CP points, but given the great lengths to travel, the uncertainty values would be inadmissible. Nevertheless it could be used as a support method.

Similarly, the use of photogrammetry to measure TIR and TC equipment has been analyzed, since there are photogrammetry targets made of ceramic materials that could withstand radiation. Nevertheless, the geometry of the problem is not suitable for this technique. It would be necessary to place photogrammetry targets with inconvenient orientations in order to be able to connect the CP network outside the rooms and, moreover, it would also require the introduction of calibration bars. In a test carried out with photogrammetry equipment, the results were that uncertainties were significantly bigger than those obtained with laser tracker and laser radar. Therefore, in this case, photogrammetry could only be used to support the baseline proposal.

4. Conclusions and future developments

The IFMIF DONES facility has some peculiarities that make alignment a challenging process: (1) plant equipment that are located in separate rooms have to be aligned, (2) some plant equipment (in TIR and TC) must maintain fiducials during operation which must resist neutron radiation and (3) the position of the fiducials of some plant equipment (in TIR and TC) must be acquired by operating the measurement instruments remotely.

The proposed alignment strategy allows to solve these challenges, obtaining acceptable uncertainties, although by a narrow margin in some cases.

There are still some difficult issues to resolve in the alignment of the plant equipment, especially those located in TIR and TC:

- Deformation of equipment due to temperatures and pressures during operation. These deformations can reach values of a few units of millimeters, so the alignment at ambient temperature and pressure must take these deformations into account.
- Positioning of fiducials. A detailed study must be made to place the fiducials on the plant equipment, so that they can be seen from the high positions of TIR and TC, even when all services, such as signal cables, power cables and connection pipes, are installed.
- Means to adjust equipment position in TIR and TC. Some clever mechaninsm must be provided to move the components to be aligned and reach its nominal position, with remote handling tools, which only have access from the top of the rooms.

CRediT authorship contribution statement

Fernando Arranz: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **Santiago Becerril:** Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Davide Bernardi:** Formal analysis, Investigation, Supervision, Writing – review & editing. **Tamas Dezsi:** Formal analysis, Investigation, Supervision, Writing – review & editing. **Javier Gutierrez:** Formal analysis, Investigation, Supervision, Writing – review & editing. **Mario Garcia:** . **Jorge Maestre:** Formal analysis, Investigation, Supervision, Writing – review & editing. **Ivan Podadera:** Formal analysis, Investigation, Supervision, Writing – review & editing. **Cayetano Prieto:** Formal analysis, Investigation, Supervision, Writing – review & editing. **Urszula Wiacek:** Formal analysis, Investigation, Supervision, Writing – review & editing. **Daniel Sanchez-Herranz:** Formal analysis, Investigation, Supervision, Writing – review & editing. **David Beltran:** Conceptualization, Formal analysis, Investigation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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