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DESIGN OF THE ESS DTL MECHANICAL SUPPORTS

P. Mereu†, T. Bencivenga, C. Mingioni, M. Nenni, E. Nicoletti, R. Panero,
INFN-Torino, 10141 Torino, Italy
F. Grespan, A. Baldo, C. Baltador, P. Bottin, A. Pisent, INFN-LNL, 35020 Legnaro, Italy

Abstract

The Drift Tube Linac (DTL) of the European Spallation Source (ESS) is composed of 5 independent Tanks, each of which of 8 t in weight and 8 m in length, is made of 4 Modules and is positioned and aligned to the Nominal Beam Line with 2 mechanical supports. The supports are designed to perform the iso-statical alignment of the Tank, and to allow its longitudinal displacement for the installation and maintenance of the Intertanks.

Presently, 4 of 5 Tanks have been successfully installed and aligned with respect to the Nominal Beam Line, using a laser tracker to monitor the position with a tolerance of 0.1 mm.

This paper details the chosen kinematic configuration, the supports design, the calculation and simulations for design validation, the procedures for regulation and alignment and the achieved results.

SUPPORT DESIGN

Each Tank is independently supported by two mechanical supports with interfaces in Module 1 and Module 4 (Fig. 1), respectively low and high energy with respect to the direction of the beam.

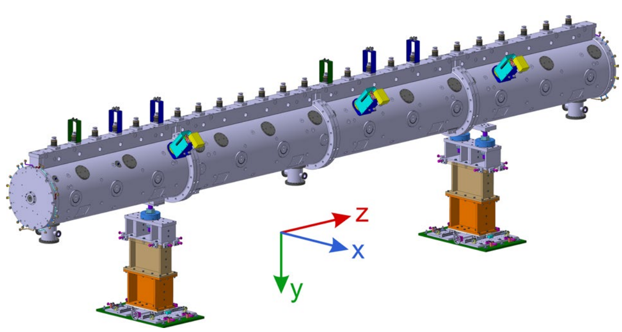

Figure 1: View of the two supports of a Tank, with the directions of regulation x, y and z.

Regulation Requirements

The support allows a continuous regulation of at least ±40 mm in each direction, used for Tank alignment on the Nominal Beam Line. The range in each direction is divided in a coarse and a fine regulation, as described in Table 1, which are done in independent sub-assemblies of the support.

The value of the coarse regulation on z is needed for longitudinal displacement of the Tank during the installation on the beam line, as well as for the installation, vacuum sealing and maintenance of the Intertanks [1].

Table 1: Coarse and Fine Regulation Ranges

	x [mm]	y [mm]	z [mm]
Coarse	± 30	-	± 210
Fine	± 15	± 40	± 30

Kinematic Coupling

During the regulation the Tank support is in isostatic configuration, thus allowing a direct adjustment in any direction.

Given the weight of each Tank, it is very hard to realize a theoretical Kelvin or Maxwell isostatic scheme, as the resulting stress on the contact points of the coupling would be unacceptable.

The isostatic scheme adopted in this case is shown in Fig. 2.

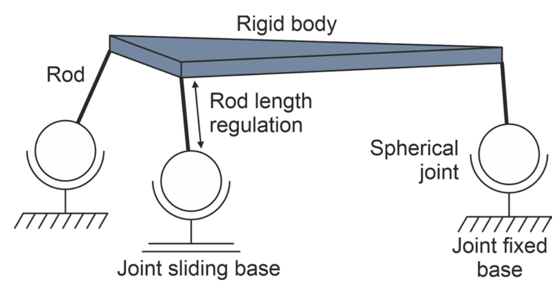

Figure 2: Isostatic scheme adopted for Tank support.

The Tank is supported on three points, two on the high energy support and one on the low energy support. In each supporting point there is a rod rigidly fixed to the Tank, on the upper part, and connected to the support through a spherical joint on the lower part. The base of the spherical joint can be left free to move in the x-z plane, or it can be fixed. By fixing two of the three spherical joint bases, leaving the other free, the 6 degrees of freedom of the Tank are locked and the support is in isostatic configuration.

The spherical joint significantly reduces contact stresses compared to sphere/V-groove or sphere/plane contacts used in classic isostatic configurations.

The yaw-pitch-roll angles and the elevation of the Tank can be adjusted by changing the length of the rod in each supporting point. The isostatic configuration is guaranteed during the adjustment because during the vertical regulation of the rod the corresponding spherical joint base is left free in the x-z plane.

After the regulation, during normal operation of the DTL, all three spherical joint bases are fixed, making the support a hyperstatic configuration, with the result to increases the stiffness of the supports and therefore the stability to accidental loads.

† paolo.mereu@to.infn.it

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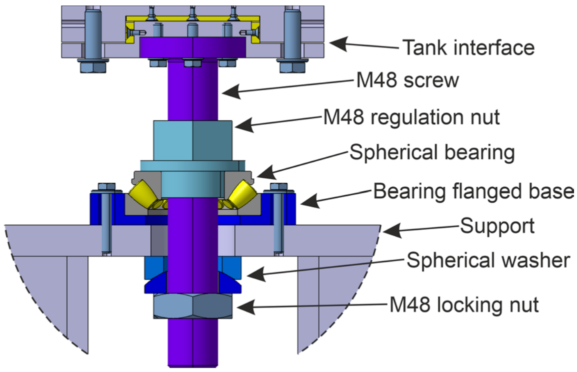

Figure 3: Section of the vertical regulation block, with the spherical joint, M48 screw and nut.

The support scheme above described is implemented with a rod that is an M48 screw and a spherical joint that is a spherical roller thrust bearing (Fig. 3). The external ring of the bearing is flanged to the support; by losing the clamping screw of the flange, the flange of the bearing can be alternatively left free or fixed according to the regulation procedure.

The length of the rod is regulated by acting on the corresponding nut.

Mechanical Design

The support modular design simplifies the assembly and installation phase, since each block can be mounted independently and in parallel with the others.

Each support weights about 400 kg, with a nominal height of 1210 mm and a footprint maximum transversal dimension of 570×970 mm.

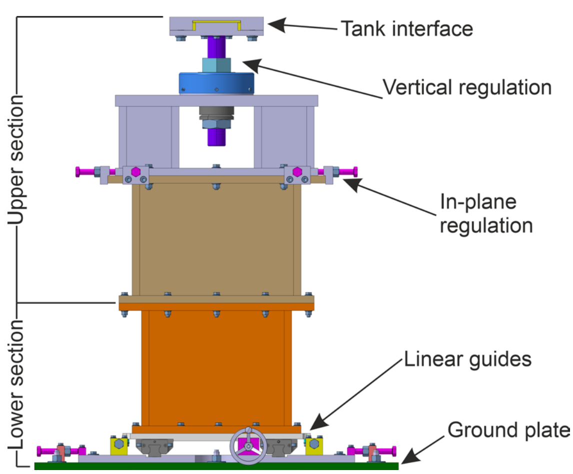

Figure 4: Main blocks of a DTL support.

Each support is made by:

- a lower section, placed at the nominal installation position in the accelerator tunnel before Tank installation, which allows the coarse regulation in x-z plane;
- an upper section, pre-assembled to the Tank, for the 3-axis fine regulation.

The coupling of the two sections is done during the final phase of the installation of the Tank on the Nominal Beam Line and it is compatible with the handling equipment for the transport and installation of the Tank.

The lower section is the same for the two supports and it is composed as described in Fig. 4. The floor interface allows a translation of the support on the horizontal plane; regulation on x direction is done with regulating screws while on z direction is done with two linear guides, parallel to the Nominal Beam Line, and with a manoeuvring screw.

The upper section is described in Fig. 4, and it has a different design for the two supports (i.e., single or double point) required by the chosen kinematic coupling. The fine regulation on the x-z plane is done with regulating screws. The regulation of vertical position and yaw-pitch-roll angles is done with custom M48 screw and nut, with a spherical roller thrust bearing. Figure 5 shows the vertical regulation assembly and a fully assembled support under its Tank in the accelerator tunnel.

The Tank thermal expansion, due to the Radio Frequency thermal load, is allowed by the support system; the high energy support is fixed, while the low energy support has a prismatic guide which allow the sliding of the Tank over the support.

The M48 screws and its nut are made of Steel 39NiCrMo3 because of the high yielding stress limit. The sliding interfaces are done with a surface of AISI 304L Stainless Steel, and the other one of aluminium alloy with a hard anodization treatment. This coupling provides a reasonably low friction factor without deformations due to the high loads. All the other components are made of structural steel with protective powder coating.

Figure 5: The vertical regulation block installed on the double version of the column (left). A Tank installed in the tunnel on its support (right).

DESIGN VALIDATION

The support design has been verified with analytical calculations and Finite Element Method (FEM) simulations, with the purpose to ensure static stability and regulation functionality.

FEM simulations verified stress and strain distribution and were performed independently on the sub-assemblies of the support to reduce the complexity of the analysis.

It is assumed a design weight of 10 t. Simulations also verified the transversal stiffness during a seismic event: it is assumed, as per requirements, a peak horizontal acceleration of 0.4 g, largely conservative if compared to the seismic hazard maps of the installation site.

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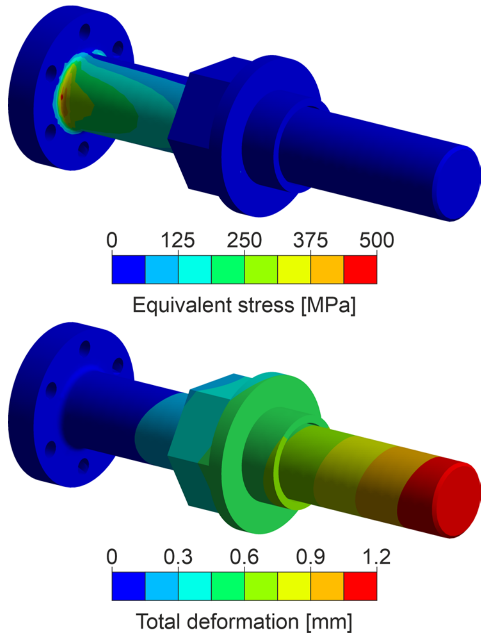

Figure 6: Equivalent von-Mises stress (top) and strain (bottom) distribution in the vertical M48 screw.

In Fig. 6 are shown the stress and displacement distributions on the fully extended vertical screw in the single support, which is the most demanding configuration.

It is assumed a combined load of compression (half of the total weight, 50 kN), bending (due to a transversal seismic load of 20 kN) and torsion (due to the torque required to move the screw, estimated by analytical calculation as 350 Nm). Results are coherent with analytical calculation and safe compared to the material yielding stress of 740 MPa.

All the other blocks were checked with FEM simulations, showing very low stress and strain distributions.

The thermal expansion has been verified with a FEM thermo-structural simulation, in which the Radio Frequency thermal load and the water cooling are considered. The maximum Tank thermal deformation along beam axis is about 2 mm and the interface module-support is consequently dimensioned to allow this elongation.

ALIGNMENT AND REGULATION PROCEDURE

After a Tank is assembled, it is characterized with a local coordinate system: the z axis (Tank beam axis) is obtained from the interpolation of the centres of all Drift Tubes with a Permanent Magnets Quadrupole, going from low to high energy; the y axis is vertical, going from top to bottom. Once installed on the supports, the goal is to align the Tank to the Nominal Beam Line, according to the following criteria:

- the z axis shall be aligned along the Nominal Beam Line, within a cylinder with a diameter of 0.1 mm;
- the y-z plane shall be aligned with the corresponding plane in the tunnel coordinate system within an angle error of ±1 mrad;
- the longitudinal position of the Tank shall be aligned with the theoretical one within an error of ±0.5 mm.

To do that, the Tank relative position in the tunnel is measured using a laser tracker, with an accepted error of 50 µm. Acting on the supports regulating system, the position of the Tank is adjusted up to the Nominal Beam Line.

The first step of the procedure involves the lower section of the support, before the Tank installation. Coarse regulation is made in the plane x-z by acting on the driving screws to reach the parallelism of the linear guides on the two supports; the regulation is monitored with the laser tracker. Then the Tank is placed on its support and translated along the linear guides, in a range ±0.5 mm respect to the nominal position. Once the rough regulation is done, the screws and the guides are locked.

The second step is the fine regulation, which involves the upper section of the supports, the one fixed on the Tank. The regulation procedure is made acting on each block iteratively: first a regulation on y-axis and on yaw-pitch-roll angles is made, for the Tank axis to be parallel and at the same height of the Nominal Beam Line; then a regulation on the x-z plane is made for the two axes to be coincident.

Regulation of y-axis yaw-pitch-roll angles is made acting on the vertical regulation blocks, one at a time. Then, the position on x-z plane is regulated. Once the position is reached, eventually after some iterations, all regulation screws and M48 nuts are tightened.

Finally, the interface plate on the high energy support is loosened to allow thermal dilatation as previously described.

ALIGNMENT RESULTS

Presently, Tanks 1, 2, 3 and 4 have been aligned in the accelerator tunnel [2]. Measures with laser tracker confirms that, for each Tank, the axis position is within the described alignment requirements.

The assembly of Tank 5 has been completed, and bid-pulling is currently being carried out. Tank 5 will be transported in the accelerator tunnel, and thus aligned, by the end of 2023.

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