THE TTF CRYOSTAT . DESIGN REPORT

F.Alessandria (NFN Milano), F.Castagna (on INFN contract), T.Nicol (FNAL), S.Tazzari (Univ.di Roma II & INFN),
L.Catani (INFN-Roma II), M.Ferrario, M.Minestrini (INFN-LNF)

1. Introduction

The aim of the Tesla Test Facility (TTF) is to build and operate a superconducting (SC) linear accelerator, accelerating electrons to an energy of approximately 450 MeV, to establish the technological basis for a TESLA type superconducting linear structure of competitive cost, that should reliably achieve accelerating fields of about 25 MV/m at costs per unit field reduced by a factor of order 20 from those of present relatively small-scale installations.

Factors determining the high cost of present SC cavity installations are their comparatively low accelerating field and the fact that - for various reasons - a single or only a few cavities have been housed in a separate cryostat with its own refrigeration circuit, thus requiring a relatively large number of cold to warm transitions and expensive distribution cold boxes; static losses, proportional to the number of transitions, are a further cost factor.

The TESLA accelerating structure and cryostat design philosophy has thus been to make individual accelerating modules as long as possible and containing as much as possible of the ancillary equipment, and combine them in strings fed by a single cold box, a technique similar to that used for SC magnets in large proton accelerators.

In the TESLA proposal [1], eight individual nine-cell, 1300 MHz SC cavities and their RF equipment (input coupler, HOM couplers, tuners, etc.), a superferric magnetic element (quadrupole doublet plus dipole steering coils) needed to steer and focus the beam along the accelerator, and all diagnostic elements are all combined in a single 12 m long <u>accelerator module</u> (AM), housed in a single <u>cryostat</u>; the assembly consisting of an AM mounted in its cryostat is called <u>cryomodule</u> [1a]. Twelve cryomodules are combined into a 145 m long <u>subsection</u>, individually fed with two-phase He; finally, a separate cryoplant supplies a string of twelve subsections constituting a <u>section</u>.

Cavities are cooled by superfluid two phase helium at 1.8÷2 K°. Quadrupole windings are cooled at 4.5 K°.

The liquid helium (LHe) distribution and cold gas recovery system are incorporated into the cryostat and therefore in the subsection, providing additional savings by reduction of the number of transfer lines and of other hardware on the outside of the cryostat vacuum enclosure.

The TTF accelerating structure will consist of a single string of four TESLA cryomodules.

2. Accelerator Module description

2.1 General remarks

For clarity, a short description is given of the accelerator module, emphasizing aspects connected with the cryostat design.

The TESLA, and TTF cavity production technique has been carefully designed and specified to produce absolutely clean surfaces and to keep them such throughout the whole manufacturing and assembly process; the most significant manufacturing steps are described in ref. [1]. This poses significant constraints on the design and assembly of the cryostat module: eight cavities and the magnetic lens are assembled together in a clean room and have to be inserted in the cryostat as a single UHV tight unit.

Another very significant requirement, deriving from beam dynamics considerations, is that the axes of the eight cavities must stay aligned to the ideal beam axis to within ±0.2 mm and those of quadrupoles to within ±0.1 mm over the entire length of the accelerator; in addition, the vertical midplane of the lens assembly must be aligned to the vertical direction to ≤ ± 0.1 mrad. .

The TESLA design philosophy of very long modules necessarily puts most of the load of keeping such tight alignement tolerances unto the cryostat designer. AM elements and cryomodules are therefore equipped with special survey fixtures: each module carries two pairs of optical target arrays fastened to either side of it ends and other alignement features are incorporated the module supension system. For each element, the target arrays define two axes positioned with respect its ideal axis so that the latter, and the rotation around it, can be optically surveyed.

All targets remain visible from the outside of the vacuum vessel, through appropriate viewing ports, so that the positions of all elements can be surveyed at any time during handling and thermal cycling.

The ideal axis is appropriately and permanently materialised on the outside of the cryostat vacuum vessel so that the various cryomodules can eventually be aligned to each other to ≤ ± 0.2 mm.

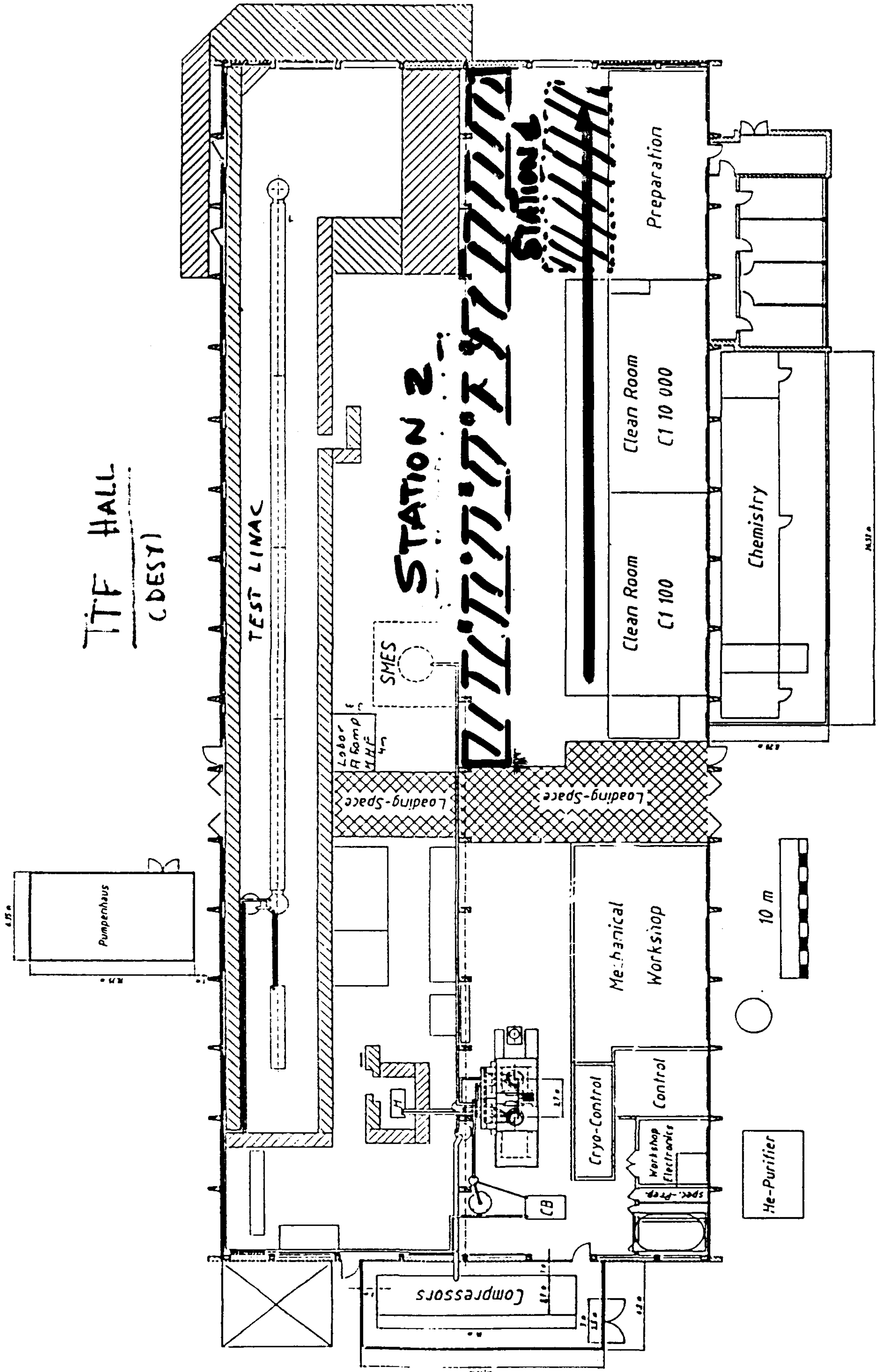

Fig. 1 - Plan of the TTF Hall at DESY

2.2 The cavity

The TESLA superconducting cavity is described in [1] and [2]. It is made of high purity solid Niobium and enclosed in a ss He containment vessel to which the 1.8 °K LHe feed line is directly attached. The tuner is actuated by stepping motors operating in vacuum at low temperature. All flange connections, for main and HOM couplers and an RF pickup, are outside the vessel, on the cavity necks, to save cost of penetrations and to eliminate the risk of superfluid He leaking through flanges into the beam vacuum enclosure. The cavity necks are kept cool by thermal conduction. A high magnetic permeability liner on the inside wall of the vessel is provided to shield the cavity from unwanted stray magnetic fields to the level of ≈ 10 mGauss. Further study of the magnetic shielding is in progress.

Each cavity is powered through a main coupler of flexible design [3]. The innermost coupler section connected to the cavity vacuum is assembled on the cavity in the clean room. The outer part of the coupler is mounted after installation of the cavities in the cryostat. With the proposed cryomodule layout the coupler has to allow for a displacement between the cavities and the outer cryostat vacuum vessel that can be as large as 15 mm.

Several thermoresistors are fastened to the He vessel and to parts of the main and HOM couplers.

2.3 The quadrupolar lens

The quadrupolar lens (or quadrupole) assembly [4], consists of a superferric quadrupole doublet powered in series; the ensemble is enclosed in a stainless steel vessel and cooled by 4 K LHe. Two pairs of additional dipole windings that fit inside the quadrupole yoke bore, provide horizontal and vertical steerers. A RF beam position monitor (BPM) consisting of a 'pillbox' RF cavity, is also rigidly connected to the quadrupole yoke.

The stainless steel beam pipe through the magnet bore is also used to damp HOMs leaking out from the cavities: a cooling sleeve is therefore provided around it in which 70 °K gas is circulated;

The 8 current leads powering the quadrupole lenses and the dipole steering coils are passed through a special pipe that runs from the LHe vessel to a flange on the cryostat vacuum vessel, and cooled by cold He gas. At the end nearest to the quadrupole the pipe terminates in a connection box where connections to the windings are performed.

The quadrupole coil is equipped with temperature monitoring thermoresistors; their wiring and a voltage-tap pair of wires are passed through a separate uncooled pipe also running from the He vessel to a flange on the cryostat vacuum vessel. Two additional thermoresistors on the beam pipe and two accelerometers on the He vessel are also part of the instrumentation .

2.4. String assembly procedure

The AM manufacturing and assembly process takes place in a special assembly hall being set up at DESY (Fig.1). In the final assembly cycle all AM elements are connected to each other, hermetically sealed-off and prealigned to the required accuracy on a special carriage on rails that then moves the sealed and prealigned string into an adjacent area (station 1), for assembly into the cryostat.

Special tooling, briefly described in § 4, is needed to pick-up the AM, perform all necessary final alignment operations, complete the assembly of the cold mass and insert it into the cryostat vessel.

3. The Cryostat

3.1 Basic design choices

The design solution presented here has been chosen for its simplicity and ease of assembly. It has the disadvantage of requiring the cavity input couplers to be flexible (see below); however, preliminary data on flexible couplers realised at FNAL and DESY [3] have not so far evidenced any serious problem in making them perform to specification. To minimise costs it has also been excluded to perform any machining on large items such as the vacuum vessel and the He gas return pipe (see below).

The cryostat outer vacuum vessel is of carbon steel and is evacuated to a pressure of $\leq 10^{-6}$ mbar; its design critical external overpressure is 1.25 bar (which gives a maximum allowed internal overpressure of > 7.5 bar) . To minimize the number of warm-cold transitions and avoid external transfer lines, all refrigeration piping runs inside it. The vacuum vessel is supported on two adjustable supports resting on the floor.

A schematic view of the cryostat is shown in Fig. 2.

The 300 mm diameter helium gas return pipe (HeGRP), required to recover the 18 mbar cold gas evaporated from the 1.8 °K He bath, is also used as main support beam for the accelerator module. The HeGRP operating pressure is specified to be 2 ABar, the test pressure 3 ABar.Cross sections of the cryomodule at the location of a cavity and at the location of the quadrupole are shown in Fig.3 and Fig.4 respectively.

The HeGRP beam is supported from above by three support posts that provide the necessary thermal insulation; posts are fastened to large flanges on the upper part of the vacuum vessel, by means of adjustable suspension brackets (ASB). The scope of the adjusting mechanism is to allow for the accelerator module axis to be brought into its proper

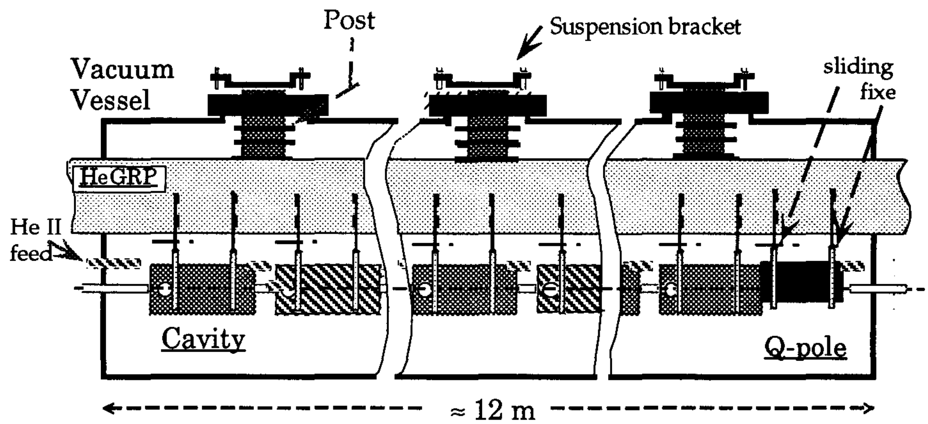

Fig. 2. - Schematic view of the cryostat

position, independent of the absolute position of the vacuum vessel flanges on which it rests.

In the longitudinal direction the center post ASB is fixed to the vacuum vessel while the two end brackets are allowed to move to accomodate differential shrinkage during temperature cycling.

The posts [5] consist of a fiberglass pipe terminated by two shrink-fit stainless steel flanges (Fig.5). At appropriate intermediate positions, optimised to minimise the heat leak, two additional shrink-fit flanges are provided to allow intermediate heat shield connections to 4.2 °K and 70 °K. The post diameter has been chosen to push up the assembly main mechanical resonance frequency, corresponding to a pendulum-like motion, to ≈25 Hz, far enough above the dangerous 10 Hz (rep. rate) frequency.

The accelerator module (8 cavities + quadrupole+ auxilliary equipment) is attached to the gas return pipe by means of stainless steel collars (two half-collars, upper and lower, bolted to each other), equipped with adjusting screws for alignment; the screws are spring loaded to prevent them from losing contact during cooldown and warmup. The support system is designed to allow the accelerator module to move with respect to the vacuum vessel during thermal cycling: because the center point of the assembly is fixed to the vessel, the outer ends will be displaced longitudinally by up to 15 mm. The flexible cavity main couplers have to accomodate a displacement of the same magnitidude.

The loads on the HeGRP and the pipe computed deflection under load are shown in Fig.6.

Two aluminium radiation shields are provided at intermediate nominal temperatures of 4.2 °K and 70 °K. Each shield is made in two halves and each half consists of 3 sections for assembly and thermal reasons (See fig.3.6). The half-shields upper sections are supported by the post intermediate flanges: they are bolted on to the center post but can slide on the end post, to avoid buildup of excessive forces on the posts during thermal cycling, when temperature differences of ≈100 K can develop between different points of the shield sections. Shields are cooled by means of flexible copper braids connected, at regular intervals, to the centerline of the shield upper section; the braids are directly connected to the cooling pipes, and their cross section is such as to keep the ΔT between shield connection and pipe to ≤ 10 K and ≤ 2 K for the 70 K and the 4.5 K levels respectively.

The cavity main couplers penetrate both shields and end each at a separate flange on the vacuum vessel side. Special radiation shield 'cones', that also serve as thermal anchoring points for the coupler body, are provided at the shield penetration locations.

Five additional cooling pipes are run through the cryomodules (temperatures are nominal): 2.2 K two-phase pressurised He forward, to cool the cavities; 4.5 °K pressurised He forward, also used to cool the quadrupole lens windings; 4.5 °K pressurised He return, also used to cool the 4.5 °K shield; 70 °K He forward, also used to cool the quadrupole beam pipe; 70 °K He return, also used to cool the 70 °K shield. A further pipe, running through the vessel is used as shield for the drive wires of the tuner stepping motors.

All pipe connections in between modules are welded; bellows are provided as needed, to mechanically decouple the modules and allow for thermal contraction.

All surfaces at 70 °K and 4 °K, facing surfaces at ambient temperature or at 70 °K respectively, are covered with multilayer insulation (MLI). Ten and thirty layers of MLI are provided on the 4K and 70 K shields respectively . The He vessel, the HeGRP and the quadrupole 4 °K feed pipes also have a 5 layer wrap, to reduce heat transmission in case of vacuum failure.

Vacuum vessels are connected to each other by means of a cylindrical sliding sleeve, equipped with O-rings for vacuum tightness; radiation shield

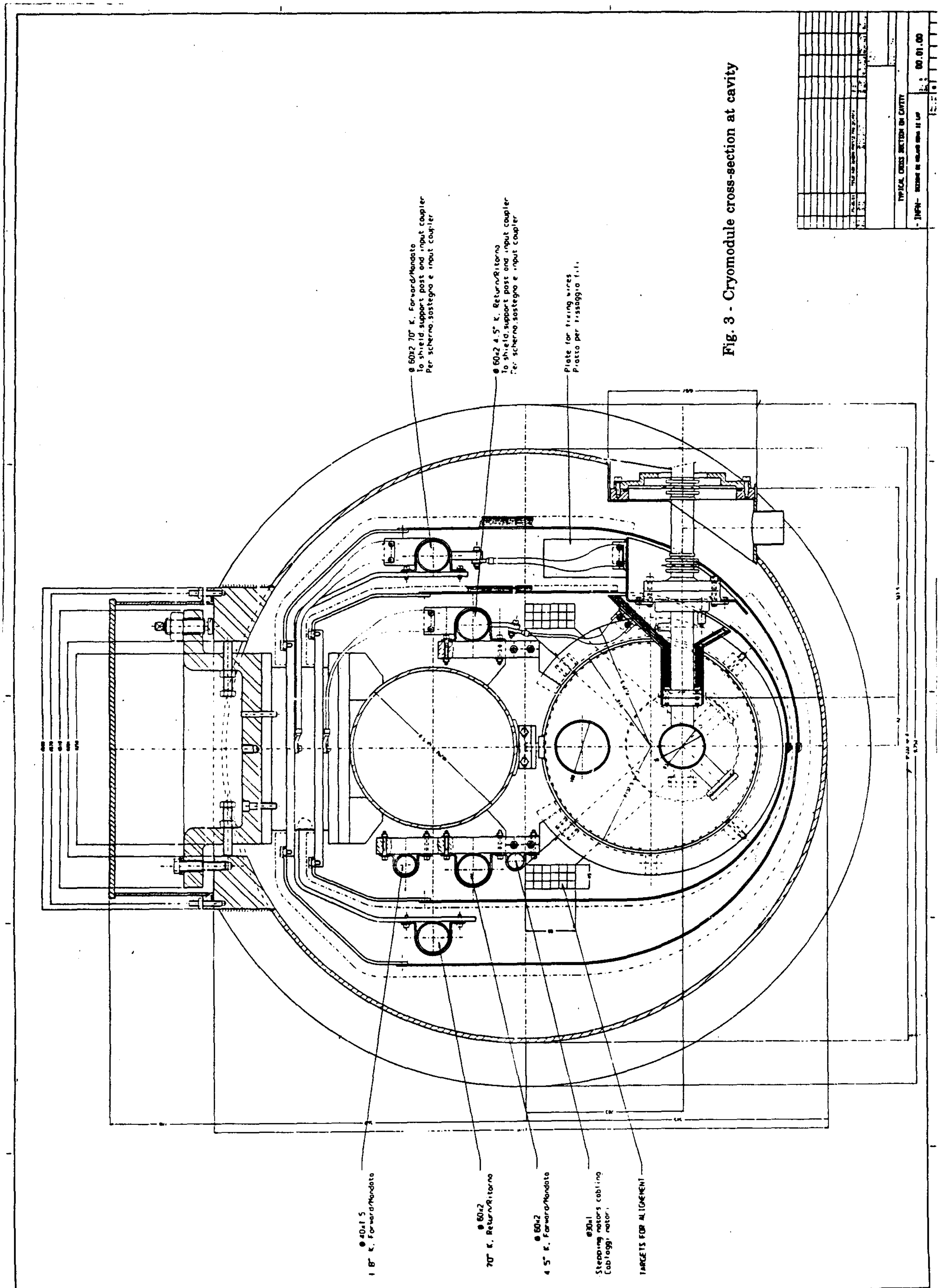

Fig. 3 - Cryomodule cross-section at cavity

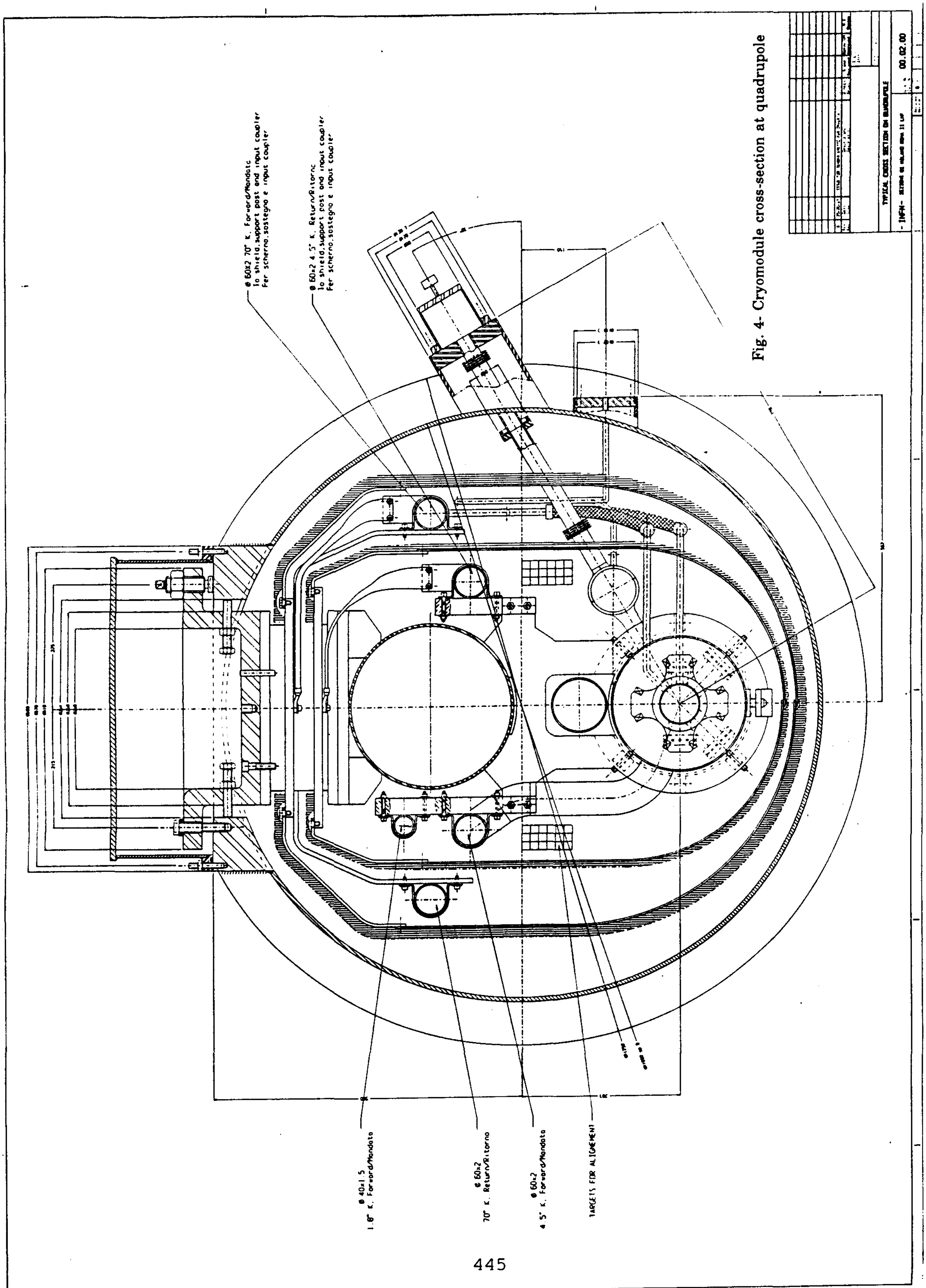

Fig. 4- Cryomodule cross-section at quadrupole

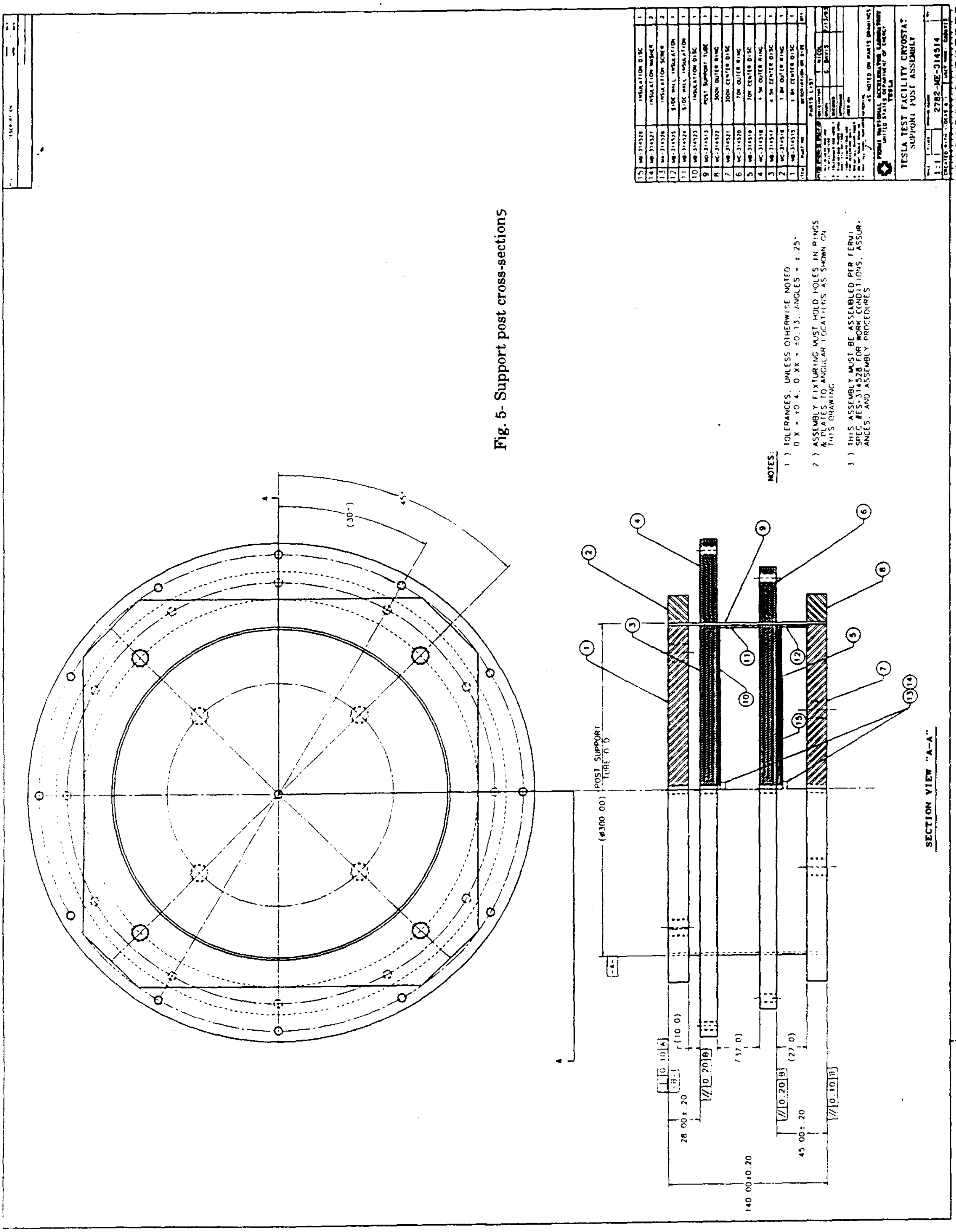

Fig. 5- Support post cross-sections

connection pieces are also provided. A relief valve on the sleeve and appropriate venting holes on the shields prevent excessive pressure build-up in the vacuum vessel in the event accidental spills of LHe from the accelerator module.

Wires and cables of each module are brought out at the module itself, through flanges equipped with vacuum-tight connectors.

The thermal behaviour of the HeGRP during cooldown shall be studied experimentally to check that no significant stratification occurs, resulting in a nonuniform temperature distribution across its diameter.

Furthermore, approximately 128 thermosensors and 2 accelererometers shall be installed on the prototype cryomodule to be able to follow temperature distributions during cycling in detail and to measure vibration frequencies and amplitudes.

Weights :

- HeGRP (OD: 300 mm, ID: 288 mm, 12 m long) :	5300	N
- n. 8 Cavities :	15700	N
- n. 1 Quadrupole ass'y :	1400	N

Dynamic loads :

Vertical : 1 g ; Sideways : 1 g ; Longitudinal : 1.8 g.

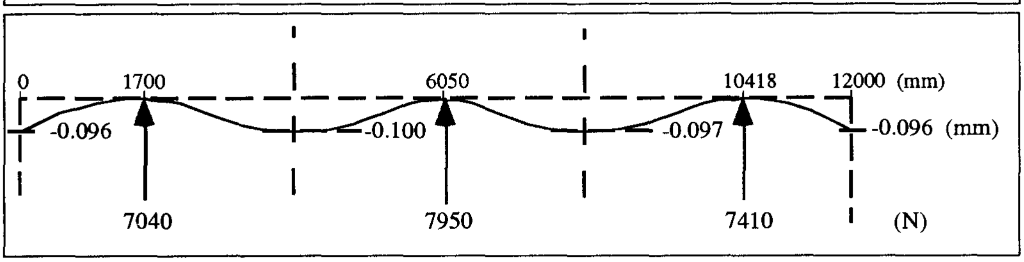

Fig. 6- Loads and HeGRP computed deflection under load

The anticipated static heat load budget for the Cryomodule is ≤4 W @ 1.8 °K, ≈14 W @ 4.5 °K, ≈120 W @ 70 °K; except for the last figure it is in good agreement with that in the original design report.

4 Special assembly tooling

4.1. Suspension system assembly tooling

Because the assembly shall be subject to thermal cycling over a very large temperature range, and because tight alignment tolerances have to be kept on the hanging mass, buildup of stresses is as much as possible avoided throughout construction and assembly. A sketch of the various assembly phases is shown in Fig.7.

All ribs connecting the three post-supporting flanges and the 18 upper half-collars to the HeGRP are welded to the as-received pipe. The HeGRP is then subjected to an appropriate treatment to prevent permanent deformations in the pipe material, caused by internal stresses having exceeded the material elastic limit or by changes in the structure of the material itself, from taking place after alignement, during subsequent assembly stages and/or during cooldown. The pipe shall also preferably be straightened to better than ± 3 mm, by a procedure to be determined and depending on the kind of treatment applied. After treatment, the HeGRP is tranferred onto a bench on which an ideal beam axis surveyed to ≤ 0.1 mm is defined and put to rest on (adjustable) supports longitudinally positioned in correspondence with the three support-post locations; the reactions on each of the supports are made equal to those computed for the straight pipe.

The HeGRP resting on the supports is adjusted so that the centers of its end sections define the pipe reference axis, to better than ± .2 mm. Post carrying flanges and upper half-collars are then welded to their respective ribs to within ± 1 mm of their ideal position. Next, the fiberglass posts and their respective ASBs are be mounted on the post-carrying flanges, also to within ± 1 mm. Appropriate pins ensure that the ASBs can be dismounted and remounted to within ≤ ± 0.1 mm. The upper sections of the radiation shields, all supply pipes, cabling anchor plates, etc., shall also be assembled on the HeGRP at this stage. The bracket adjusting screws are finally made to take up the weight of the structure, monitoring displacements and load distributions by means of comparators and dynamometric tools; three spherical optical targets are fastened (but not permanently since readjustment may become necessary during final assembly of the module) to the brackets and positioned with respect to the ideal reference axis to within ≤ 0.1 mm; a reference surface, horizontal to within ≤ 0.2 mm/m, is also established on each bracket. Targets and reference surfaces allow the geometry of the pipe to be surveyed precisely throughout the following assembly stages.

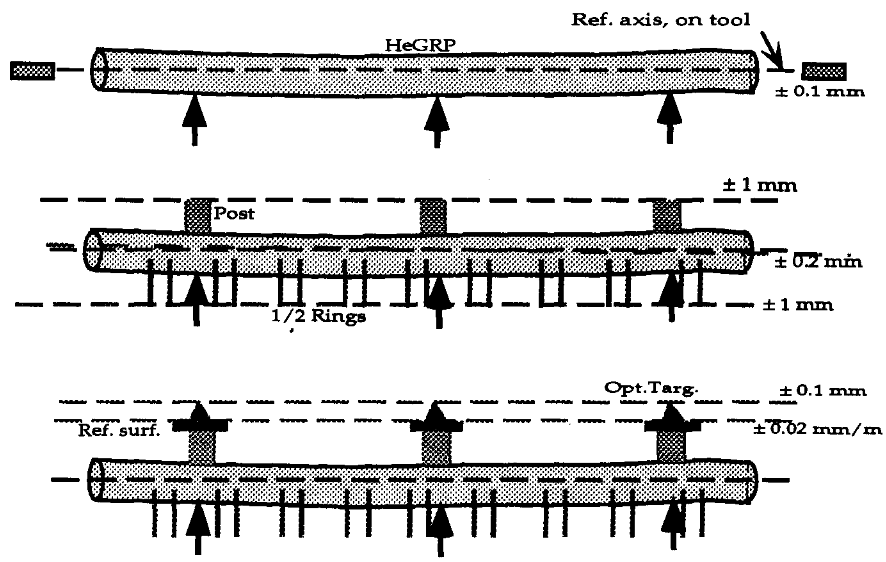

Fig.7. - Sketch of the AM suspension system first assembly phases

4.2. Accelerator module lifting rig

The tooling is used to connect the accelerator module, assembled and aligned to better than ± 0.2 mm and delivered to assembly Station 1 in the assembly hall on a carriage rigidly guided by a rail in the floor, to the HeGRP assembly. The latter is brought to Station 1 directly above the accelerator module carriage and lowered onto a bench, sketched in Fig.8.a. bench is rigidly fastened to the hall floor. The bench carries three shelves, horizontal and level (under load) to ± 0.1 mm and positioned to match the assembly suspension brackets. A local surveyed ideal AM axis and the optical targets and reference surfaces on the suspension brackets allow the HeGRP to be positioned so that the AM supporting upper half-collars are in place with respect to the AM itself to << ± 1 mm. Finally, the lower half-collars are fastened to the upper ones and the adjustment screws brought in contact with the AM outer vessels so as to block it into position. The whole assembly can be then transported to the final alignement Station 2.

4.3.Final alignement and assembly bench

The HeGRP and accelerator module assembly is placed on the bench, similar to that of § 4.2 and sketched in Fig.8.b, where final assembly and alignement shall be performed. It is brought to rest on the bench support shelves horizontal and flat to ≤ 0.1 mm. Cavities and quadrupole are fine-aligned using the support collars adjustment screws so as to bring them all on the ideal locally surveyed AM reference axis, within the specified tolerance. Optical-targets and horizontal reference surfaces on the suspension brackets are then readjusted to refer to the AM reference axis to within ±0.1 mm and then finally blocked. The targets allow the AM configuration to be reproduced within tolerance, using the bracket adjusting screws, when the cold mass is hung in its final position from the cryostat vacuum vessel upper flanges, independent (within the adjustment range) of the absolute position of the latter.

4.4 Cold mass insertion into the vacuum vessel tooling

The assembly is completed by adding the lower sections of the radiation shields, superinsulation, piping and cabling, with the loaded beam assembly resting on the bench and by rechecking the alignement. The final operation, sketched in Fig.9, is then to insert the completely assembled cold mass into the vacuum vessel.

The cold mass is lifted on an outhanging beam that engages the HeGRP and the ASBs are dismounted. Fig. 9 is self explanatory as concerns the following operations. Once the cold mass has

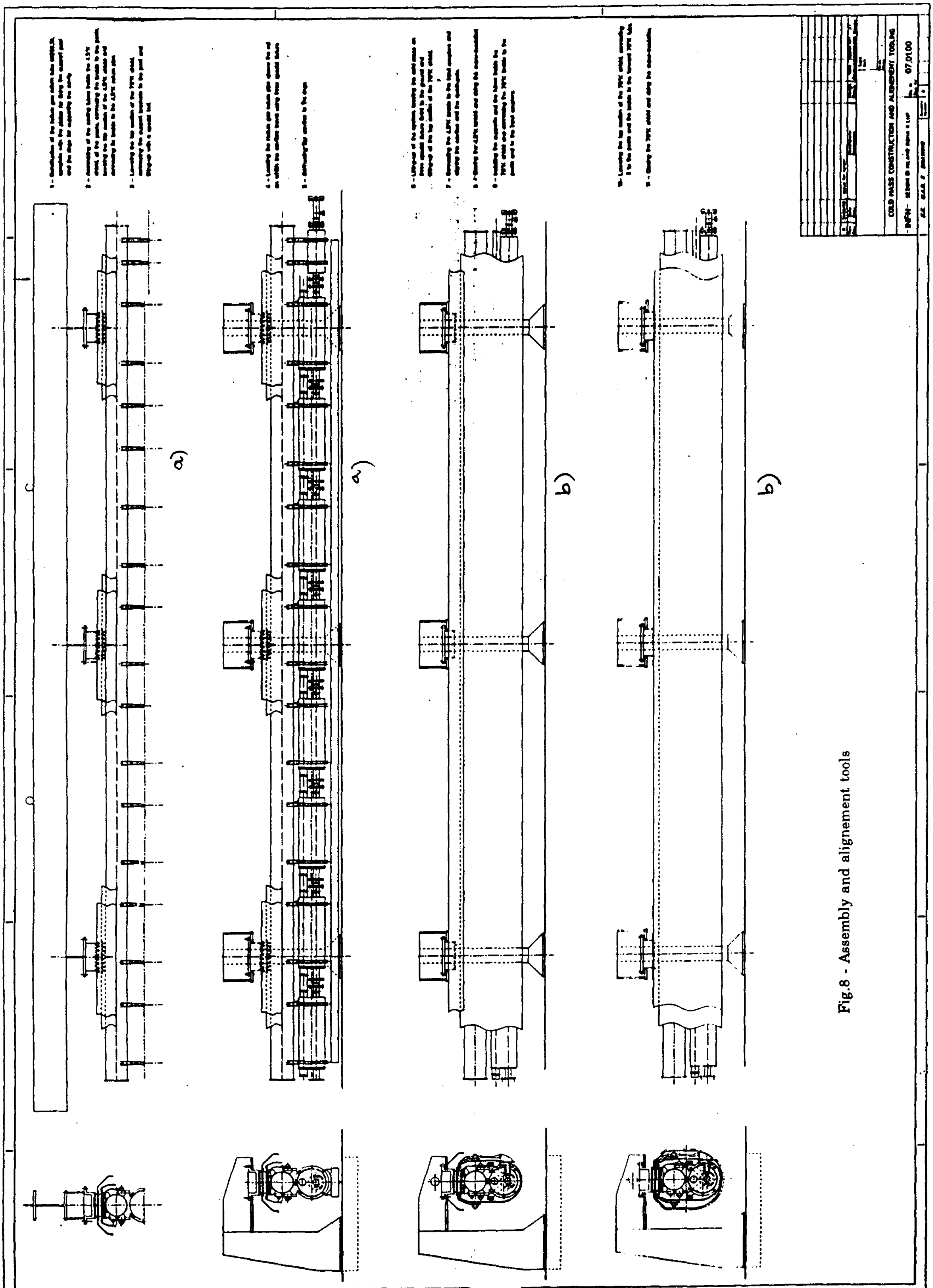

Fig.8 - Assembly and alignement tools

The cold mass is lifted on an outhanging beam that engages the HeGRP and the ASBs are dismounted. Fig. 9 is self explanatory as concerns the following operations. Once the cold mass has been inserted in the vacuum vessel, the ASBs are bolted back unto the posts through the vacuum vessel upper flanges, and pinned into position.

When the adjustment screws are set to reproduce the bracket optical targets alignment, the AM module alignement is reproduced to the required tolerance.

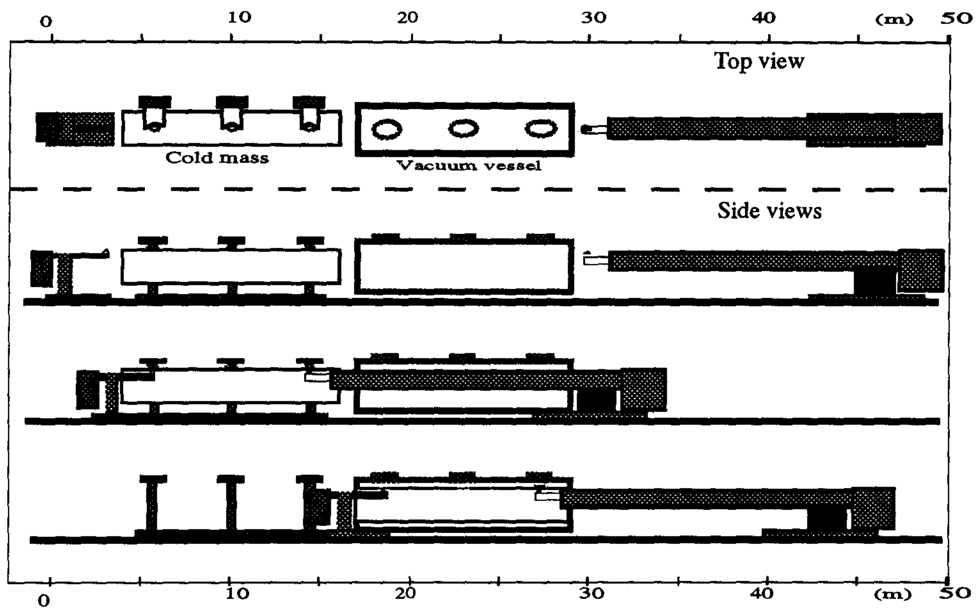

Fig. 9. - Schematic view of the AM insertion into the cryostat sequence.

5. Aknowledgements

The cryostat design work has taken advantage from close collaboration with DESY and FNAL and from several helpful discussions with the Saclay group. We are especially indebted to H.Kaiser, G.Meyer, D.Trines, S.Wolff of DESY and to T.Peterson of FNAL/DESY.

References

[1] Tesla Collaboration Rep. 93-01.

[2] H.Kaiser, TESLA Cavity prototype", these Proc.

[3] M.Champion et al, "Input coupler and windows for TESLA" and B.Dwersteg et al. " Tesla input coupler", these Proceeedings.

[4] S.Wolff, private communication

[5] T.Nicol, FNAL Int.Rep. TM-1794 (Aug.92) and private communications.