DEVELOPMENT OF A CRYOSTAT FOR THE 4-CELL 352 MHz SC ACCELERATING CAVITIES FOR LEP

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1. INTRODUCTION

The upgrading of LEP by s.c. cavities will require installation and operation of a few hundred 350 MHz, 4-cell cavities in the accelerator tunnel [1]. It is at present anticipated to install eight cavities per rf-cell which have a length of ~ 24 m. A tunnel slope of up to 1.5% and a tunnel diameter of 4.4 m have to be accommodated. For the design of adequate cryostats the following guiding lines were considered: Up to eight cavities with their He tank could be housed in a common insulation vacuum (fig. 1). Cryostats should be modular and allow installation of individual cavities or groups of two cavities (with a total length not exceeding 6 m thus enabling normal transport inside the access pits and machine tunnel). A high accessibility to all critical parts like couplers, tuners and beam tube connections should be guaranteed. This requirement dictates a lateral access through the vacuum tank and thermal radiation shield which should also permit the removal and replacement of any one 4-cell cavity without disturbing the neighbouring units. Cavity connections to the beam vacuum system as well as repairs should be possible under reasonably clean and dustfree conditions, particularly when keeping cavities under a slight overpressure of dry, dustfree protective gas.

In the course of 1983 preliminary discussions on a possible cryostat design started. Already at the early stages of the discussions, it became apparent that the final design of the cryostat could benefit from the introduction of some novel construction concepts to meet the requirement of accessibility to all the cavity components whilst keeping construction cost down to a reasonable level.

A test programme was launched and a 1/5 scale model vacuum tank was constructed and tested. The main feature of this model was a frame and sealing skin design which offers complete accessibility to the inside of the vessel. The results obtained prompted the design and construction of a full size model which was completed in 1985 and proved the feasibility of the new concepts. A thin copper radiation shield mechanically clamped to the piping carrying the refrigerant and thus easily removable to meet the requirement of accessibility also proved adequate to intercept and evacuate the heat radiated by the vacuum tank. The measured static thermal load of this 2400 litres volume liquid helium cryostat was 10 W.

The design of the cryostat for the 4-cell 350 MHz LEP cavities was started in 1985 and first cold tests were performed at the beginning of 1986.

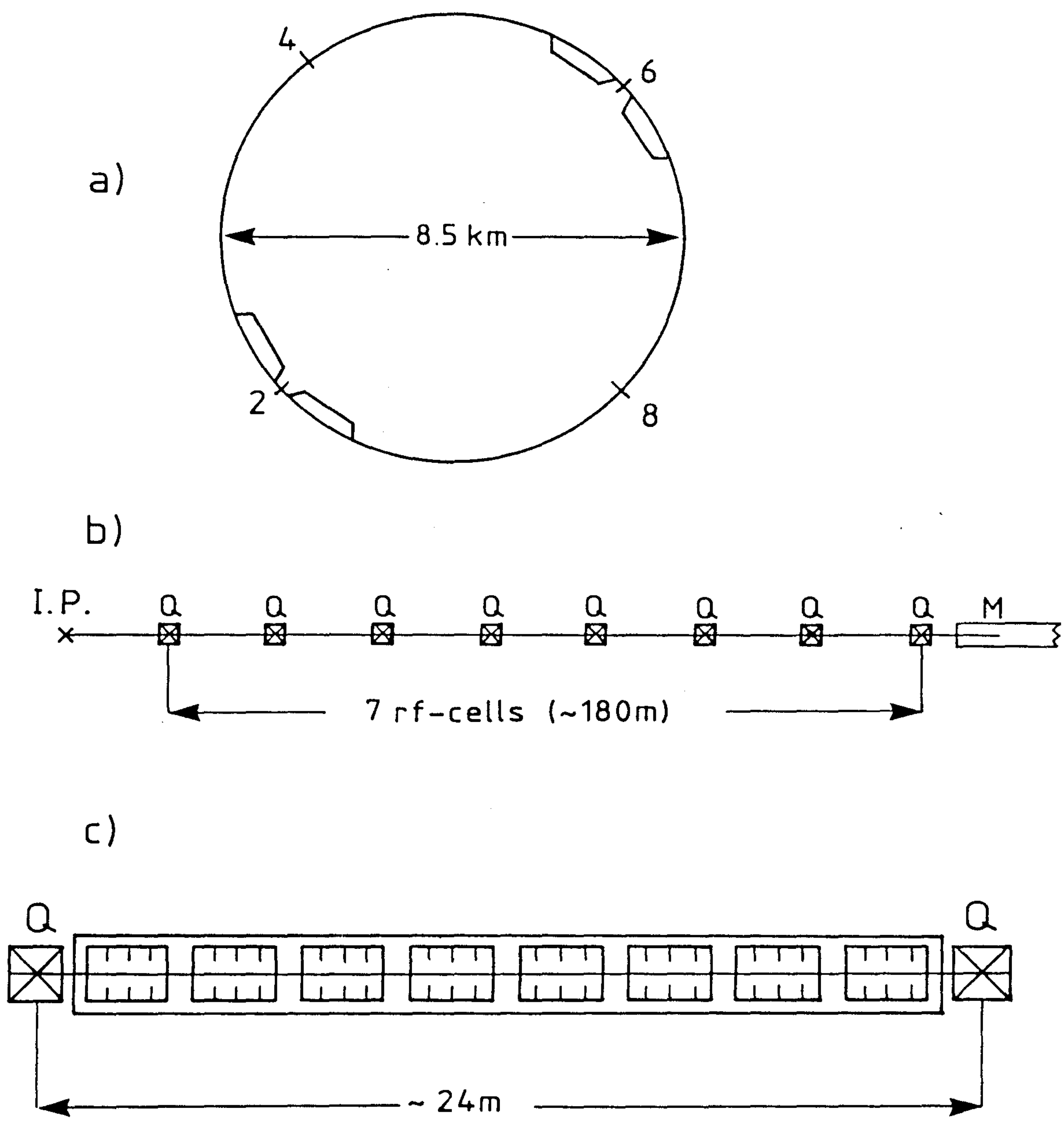

Fig. 1 (a) General layout of rf stations for LEP in interaction regions 2 and 6.

(b) Layout of rf cells at one side of an interaction point.

(c) Layout of eight s.c. 4-cell cavities in one rf cell. These cavities may be housed e.g. in a common vacuum tank or in 2 independent vacuum tanks.

2. DESCRIPTION OF THE CRYOSTAT

The cryostat houses a 4-cell, 352 MHz cavity (diameter : 755 mm; length : 2410 mm) with which it forms a module of total length of 2553 mm. Modules can be assembled end-to-end.

For safety reasons, the quantity of liquid helium present in the LEP tunnel should be kept small; this consideration has dictated the construction of a jacket type helium tank which contains some 200 litres of liquid helium at 4.2 K.

The helium tank (fig. 2) is made from 2 mm thick stainless steel sheet welded throughout. Its main body is made up of two half-shells which match the shape of the Nb cavity. The seal between the niobium cavity and the helium tank is achieved at the stainless steel Conflat flanges which equip all the cavity ports (beam tubes and couplers). Each flange is brazed to the Nb cavity and its outer diameter is machined so as to provide a circular lip to which the lip of the corresponding helium tank port is welded. In this way, the copper seals of all Conflat flanges merely separate the machine ultra high vacuum (inner cavity volume) from the thermal insulation high vacuum. Each end flange of the cavity/He tank assembly is equipped with three arms to which the three tuning rods are attached (figs 3 and 4). They determine the overall cavity length and thus its frequency [2]. Any change in cavity length involves an elastic deformation of the cavity four cells. The helium tank surrounding the cavity has been equipped with a flexible section at each end of the tank so that the variation in overall length can be achieved without adding an important load on the tuning rods.

Although the tuning system described in [2] is functionnally part of the s.c. cavity alone, it structurally belongs to the helium tank assembly and as such it is an integral part of the cryostat.

The evaporated He-gas is collected by a common volume welded to the four cells of the He tank and piped to a liquid/gas phase separation vessel (fig. 4) housed inside the central dome of the vacuum vessel.

All connections to the refrigerator as well as He level gauges will be located at the central dome. Their layout has not yet been finalised because it will depend on the He distribution system to be adopted for LEP [3]. At present layouts allowing operation with liquid helium dewars and/or with a refrigerator have been tested and operated.

The thermal radiation shield consists of a self-supporting piping frame (fig. 5) which carries cold gas evaporated from the liquid He bath and of two support rings, brazed onto the pipings and to which the radiative shield (0.5 mm thick Cu sheets) is clamped mechanically. This method of thermal contacting has proven very satisfactory and an easy accessibility to the cavity ports and helium tank is maintained. The cold shield is covered by a superinsulation mattress of 40 layers (in 4 separate sections) which can be easily removed.

The cavity with its He tank, the tuning system, the radiation shield piping and support as well as the phase separation vessel form a unit which is suspended at each end to the vacuum vessel frame by two rods of low thermal conductivity (fig. 4). In the longitudinal direction this assembly is fixed by another thin tube to the vacuum tank so as to make the main coupler port a "fixed point" with respect to the vacuum tank.

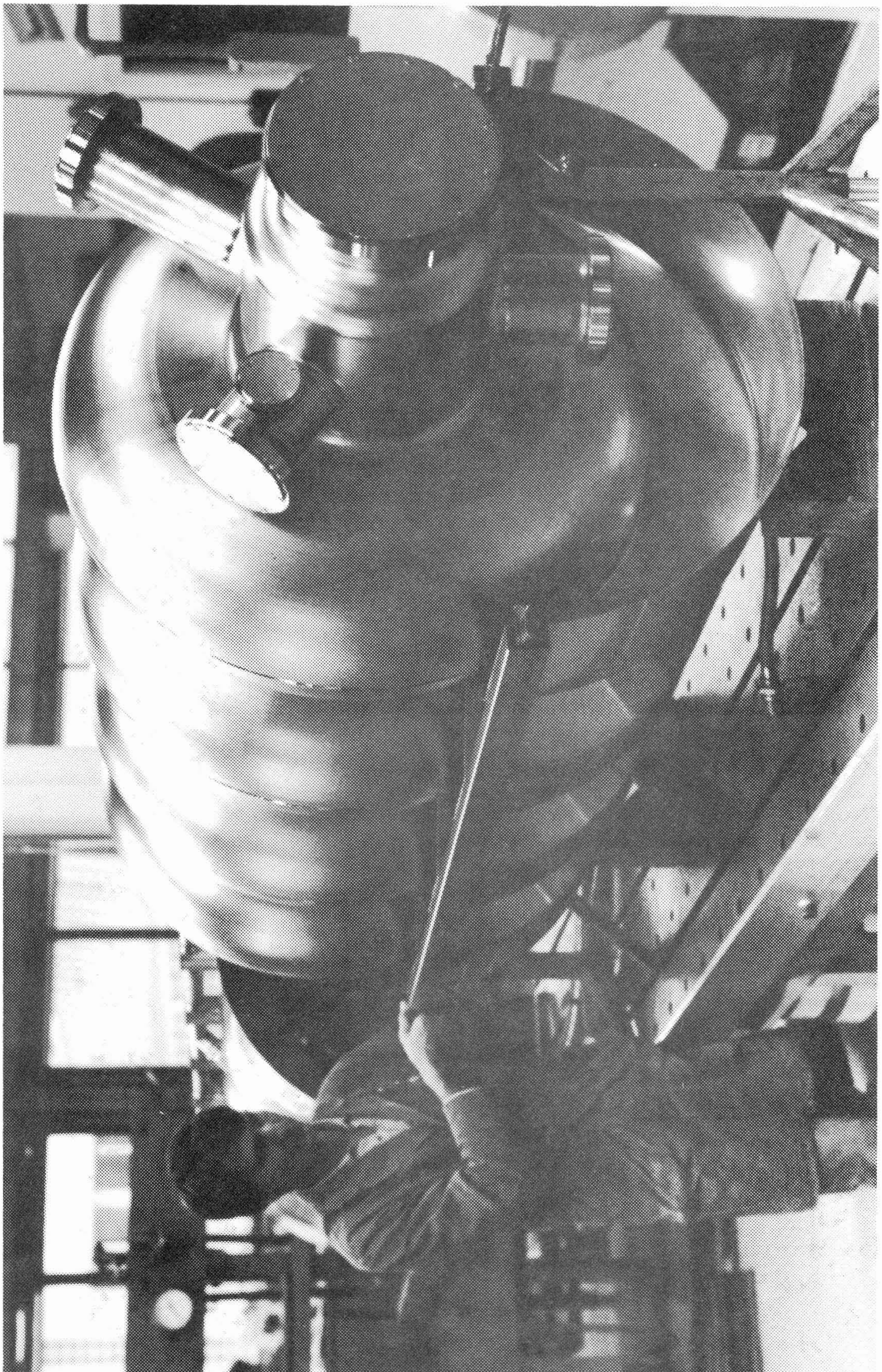

Fig. 2 A 4-cell 350 MHz Nb cavity for LEP with beam tubes and coupling ports. Below: one half of the He tank to be welded around the cavity.

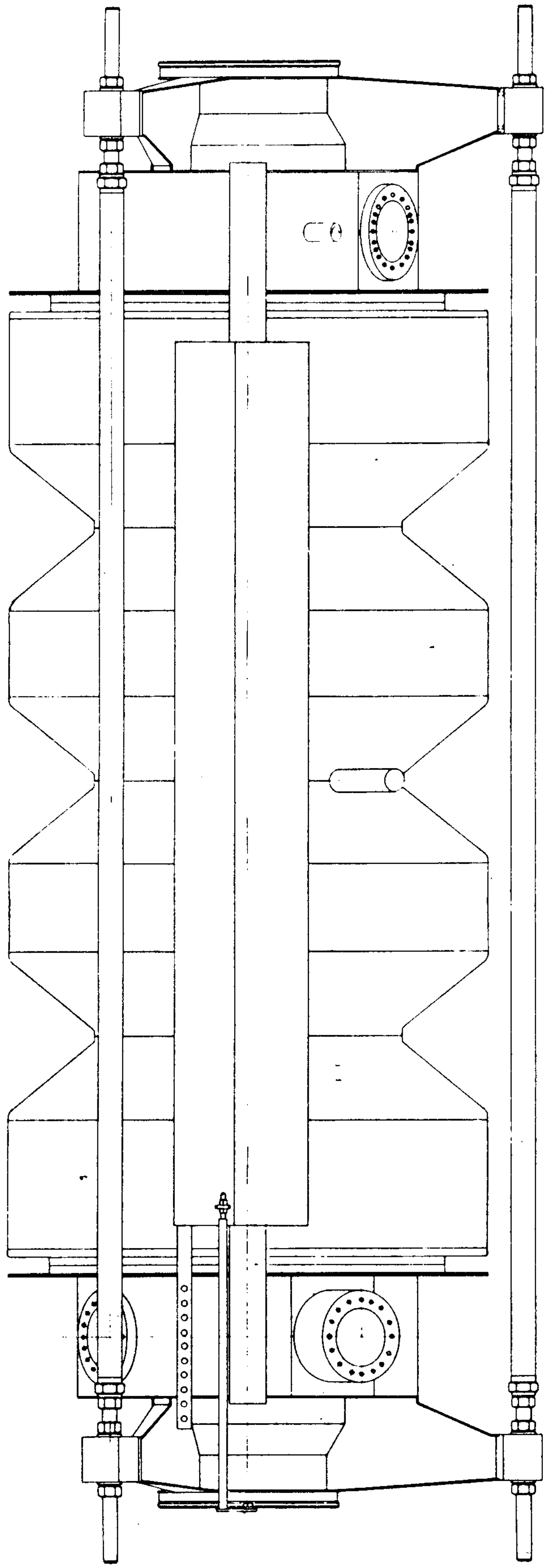

Fig. 3 Layout of He-tank welded around the cavity with tuning rods and GHe collector seen from above.

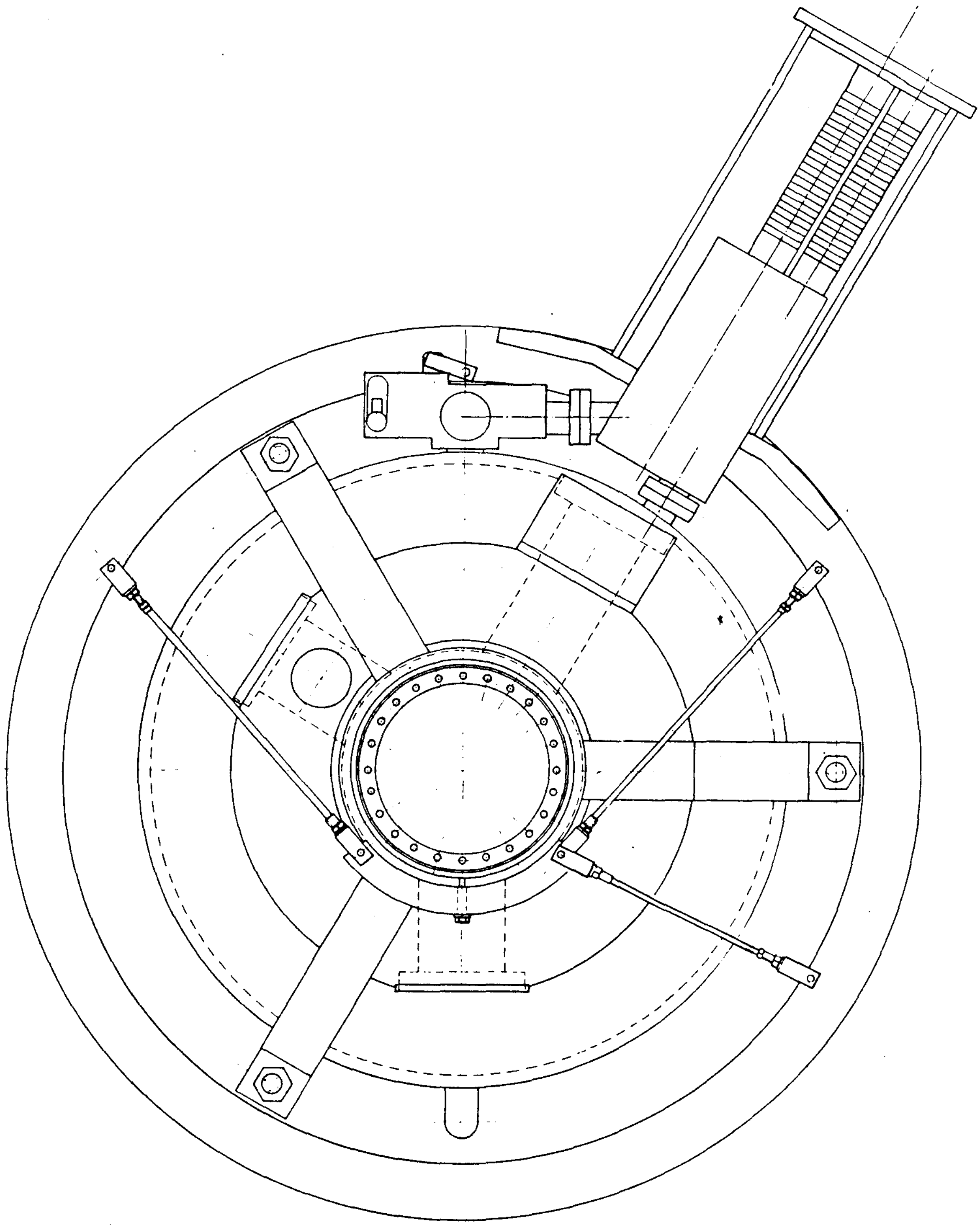

Fig. 4 End view of cavity with He tank, cryogenic dome, phase separation vessel, supporting rods and arms for tuning rods.

With the axial and radial position registering members provided, it is expected that the alignment tolerances with respect to a beam line are about ± 0.3 mm in both planes.

The vacuum vessel is a cylinder 2553 mm long, 1100 mm in diameter, laying horizontally and strapped on a cradle equipped with adjustable legs; the beam axis is 80 cm off the ground. Its main supporting frame is made up of two end rings and a top plate which is welded to the two rings.

Seven staves (10 mm thick) braced together and bolted to the two end rings and to the top plate complete the cylindrical structure which has to withstand the forces due to the external atmospheric pressure (fig. 5). This structure as well as its supporting cradle, domes and end covers are made from aluminium alloy. A 1 mm thick stainless steel sheet sealing envelope is wrapped around the cylindrical structure and fastened by means of twelve pairs of stainless steel sheet straps welded to the sealing envelope. The straps are bolted to each other via swivel blocks. Sealing between the main frame and the stainless steel envelope is achieved by a 7 mm diameter, 11 metres long rubber O-ring type seal (hardness between 45° and 65° shore). This seal is housed in a groove machined along both edges of the top plate and in the outside diameter of the two end rings. The two welds fastening the top plate to the end rings require to be leak tight and the 4 top plate/end rings groove junctions are machined across the weld metal.

The vacuum vessel top plate carries three domes aligned to the beam axis (fig. 5). The centre dome is used for the cryogenic connections and for the liquid helium level gauge; one end-dome houses the cavity Main RF Coupler [4] whilst the second end-dome carries the connectors for the two Higher Order Mode RF Couplers, and all electrical connections. A thermally insulated line transferring cold gas to the main coupler inner conductor is located at the centre dome whilst a warm gas return line is housed at the second end-dome. The domes as well as the main coupler and the He-transfer lines can be removed without opening of the sealing skin of the vacuum tank. For reasons of future developments foreseen in the LEP tunnel (LHC) the space immediately above the s.c. cavities must be kept free from obstructions. This constraint dictates that the vacuum vessel top plate and domes be set at an angle of 30° off the vertical axis.

Where two cryostats are assembled end to end, the two vacuum tanks are bolted together and sealed with a rubber O-ring whilst the two cavities are linked by a flexible stainless steel bellow and sealed with Conflat copper seals. At the end of a line of cavities, where it is required to go from liquid helium temperature to ambient temperature, a flat circular cover equipped with an extension seals the end of the vacuum vessel. A thin stainless steel beam tube installed between the cavity and the machine vacuum chamber is connected to the vacuum vessel extension via a flexible bellow. Heat radiated by the end cover is reduced by a 40 layer mattress of superinsulation installed against the inner face of the cover and by a 0.5 mm thick copper shield strapped to the cold helium gas piping.

For the operation of s.c. Nb cavities a shielding of surrounding magnetic fields to a level of ~ 100 mG is needed. For the LEP cryostats this shielding is achieved by two pairs of simple Helmholtz coils placed against the sealing envelope of the vacuum tank.

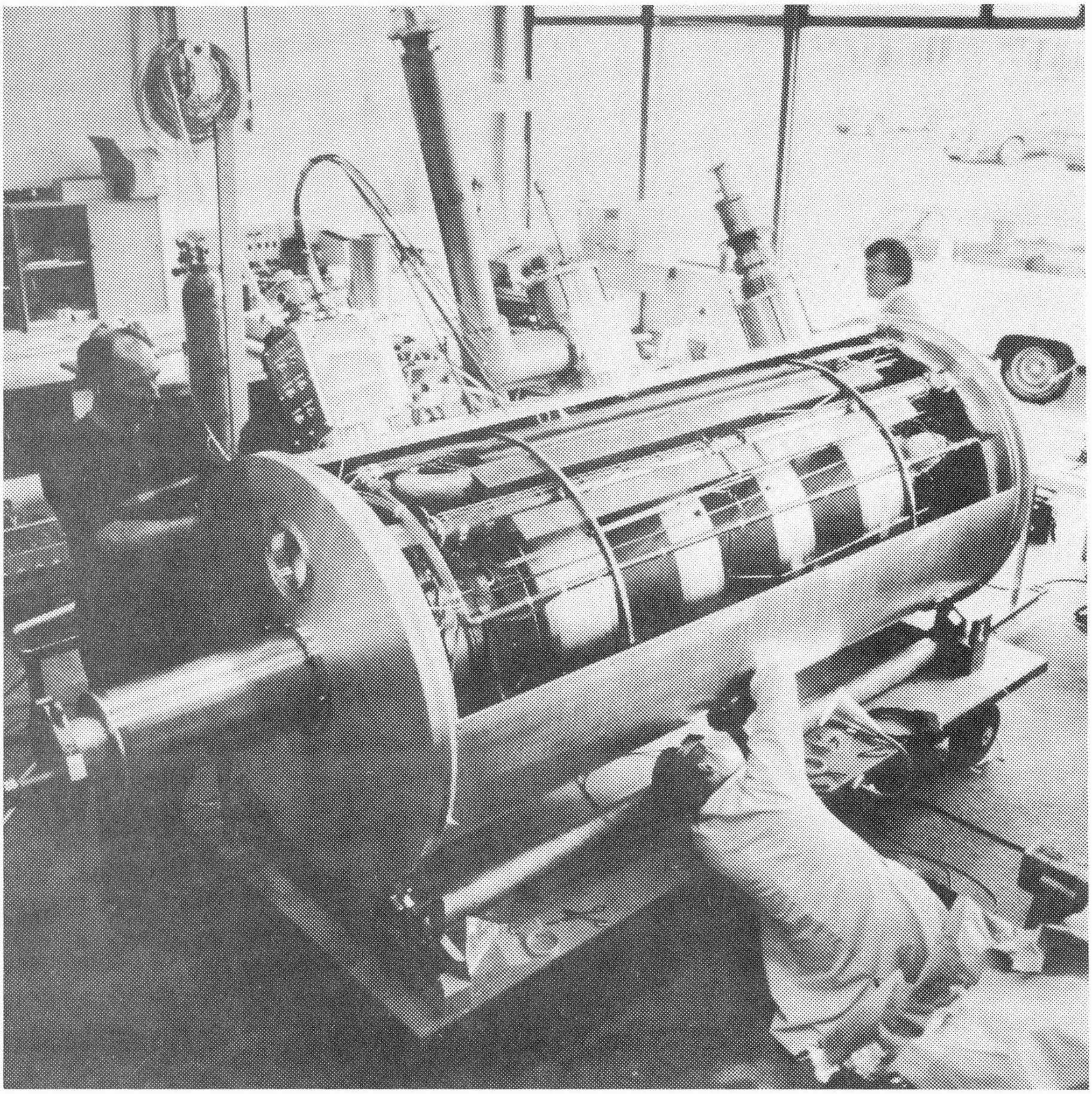

Fig. 5 Photograph of cavity inside the vacuum tank with two staves and cold shield removed. The three domes of the upper vacuum tank plate can be seen.

3. RESULTS

Up to now 2 cryostats (fig. 6) have been fabricated and tested at CERN, two more have been ordered from industry.

The first cryostat and cavity have been cooled with dewars whilst equipped with beam tubes but without main coupler. With a temperature of the cold shield of 70 K (and a cold He-gas flow < 0.1 g/s) static losses were measured to ≦ 14 W. The cryostat was later on operated with a 4.2 K refrigerator. A typical cooldown cycle lasts about 7 h from 300 K to complete filling with LHe. The cavity has been equipped with 2 main couplers (1 on the beam axis) to perform high power tests, by 2 higher order mode couplers [4] and by frequency tuners and numerous tests of various components have been done. A total operation time of 8 months and 7 cooling cycles have been performed up to now.

A second cryostat has been installed with a LEP 4-cell Nb cavity in the CERN SPS for a beam test. The cavity was equipped with a main coupler, two hom couplers and a (reinforced) tuning system [2]. Pumping during operation is performed by the SPS vacuum system. The cryostat was cooled by dewars located at the surface and linked to the cavity 60 m below by a 100 m long flexible transfer line. This system has worked without major problems. Typical cooldown and filling times are 7-10 h. A total operation time of about 1 month and 6 cooldown cycles have been performed up to now. It has been found that the static losses of this cryostat depend on the He level. The extremely tight time schedule of this beam test has not yet allowed to measure these losses in a reliable way.

4. CONCLUSION

At CERN cryostats of novel design for operation with 4-cell cavities in LEP have been developed, constructed and tested. After many months of operation and many mounting and cooldown cycles performed on two units it is felt that this design is a sound basis for future operation in LEP. The two vessels, the He-tank as well as the insulation vacuum tank which uses a large sealing envelope have displayed a satisfactory behaviour.

Static losses are not yet completely analyzed and further effort is needed to optimize cryostat performance. The layout of phase separators and He feeding lines still has to be finalised and thermoacoustic vibrations have to be carefully avoided. Some further studies will be dedicated to the final layout of cold He-gas circuits at the main coupler, tuners and cold shield. Assembling together two complete cavity-cryostat modules under the clean conditions required to preserve the quality of the cavity inner surface will be given a realistic test in the near future.

Acknowledgements

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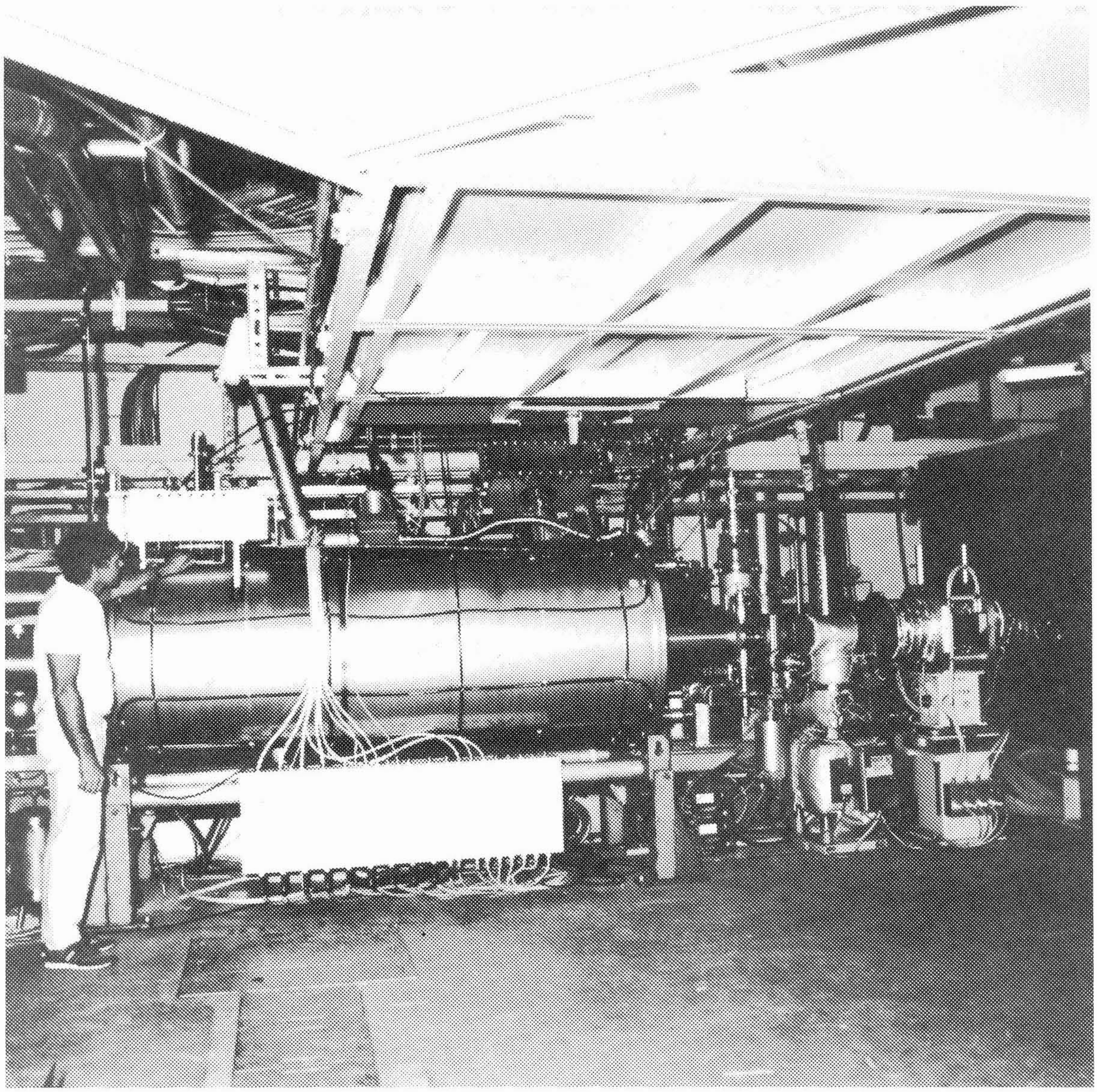

Fig. 6 Cryostat installed at CERN SPS. To the right the waveguide-coaxial transition can be seen. Near the middle of the top plate one sees the flexible He-transfer line connection.

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