Helium Vessel for the TTF Cavity

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DESY

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Introduction /Abstract

The He tank contains the super fluid helium needed for cooling the RF cavity[1] of the TESLA Test Facility. It also supports the cavity, and takes part in tuning it.

The design put forward in this note differs from an earlier one in that it incorporates recent proposals for the TESLA cryogenic system[2] leading to smaller He inventory, reduced cold mass and gentler yet faster cool down and warm up. Further it reduces Lorentz force detuning, and - by being more compact - opens the way for a less costly smaller future cryostat.

The tank is made from titanium rather than the more commonly used stainless steel to reduce problems with joining to niobium, and relative shrinkage with respect to the cavity.

Cryogenic features

The earlier design of the He vessel (Fig. 2) was with ca. 380 mm substantially larger in outside diameter than the cavity. With the liquid He partially filling the He supply tube, the 2 phase flow in steady state passes through the upper part of the He tank with a rather generous amount of He surrounding the cavity and an unnecessarily large gas-liquid interface.

The present design (Fig. 1) has a He vessel diameter slightly larger than that of the cavity, a separate 2 phase tube of 72 mm inner diameter connected to the He vessel by a vertical tube of diameter 60 mm, and a LHe volume of only 22 l as compared to 65 l of the earlier design (both vessels considered filled with liquid to the axis of the 2 phase tube).

Further, while in both designs cool down through the 2 phase tube would present no problems with one cavity after the other filling with liquid, there may during warm up be insufficient heat exchange between hot gas above and cold cavities below with buoyancy preventing the gas to flow downward. This effect would be more pronounced in the present design.

To remedy this, a tube of diameter 40 mm feeding He to the *bottom* of the tanks via capillaries of diameter 3 mm has been introduced (Fig. 3). The flow is distributed quite evenly over the string of He vessels because the capillary has much greater flow resistance than the 40 mm tube, and heating is therefore much gentler and more effective than in the old design. Cool down can of course also occur via the capillaries.

Tune shift

The He vessel with tuner bounds the environment that is capable of effecting shifts of cavity tune from (in decreasing importance) Lorentz forces, He pressure fluctuations and temperature changes. Only the first 2 effects will be treated, as temperature influence under steady state operation is negligible (below 10K very little, if any, thermal contraction occurs).

Consider the cavity held to constant length by some ideally rigid external constraint. At $E_{acc} = 25$ MV/m the Lorentz forces would produce a calculated tune shift of - 347 Hz due to deformation of *cell form*. The cavity, in addition, would exert a force of $F = - 31$ N on the constraint (the cavity wants to become shorter). Removing the constraint will cause the cavity length L to decrease elastically, and suffer a tune shift of:

(1) $$\Delta f_{unconstr.} = -347 + \partial f/\partial L \cdot \partial L/\partial F \cdot F$$

That one may superimpose the 2 contributions has been verified by first computing the cavity form change produced by both effects acting together, and then the corresponding tune shift, which equalled that from (1).

With $F = -31$ N, and measured values [3] of
$\partial f/\partial L = 404$ kHz/mm, and
$\partial L/\partial F = 3.25 \cdot 10^{-4}$ mm/N there results:

$$\Delta f_{unconstr.} = -4416 \text{ Hz.}$$

This intolerably large tune shift demonstrates the need for rigidity in the *real* constraint consisting of tuner, He tank and conical vessel - heads (for the earlier design, also the dome shaped vessel-heads). The calculated Lorentz force induced tune shift for each of the above named components as well as the resulting total tune shift is recorded for the 2 tank versions in Table 1.

Tank type	tuner	head dome	tank tube	head dome	conical head	deform. cell form	total shift
large dia.	-68	-140	-23	-161	-59	-347	-798
small dia.	-68	___	-43	___	-59	-347	-517

Table 1. Contributions to tune shift [Hz] at 25 MV/m (see text)

The rather large contributions from the head domes do not exist for the smaller vessel, and favour it by a decrease of tune shift by 281 Hz.

The tune shift produced by a change in He pressure Δp also arises from 2 additive effects: With cavity length held constant, there has been measured [3] :

$$(\partial f/\partial p)_{\text{cell deformation}} = 10.3 \text{ Hz/mbar.}$$

The effective area of the large bellow near the tuner exceeds that of the cavity which also acts like bellow. Therefore, increasing the He pressure tends to lengthen the cavity. The corresponding tune shift (ignoring pressure induced tune shift) has been calculated for the cavity constrained by the small He tank and tuner at:

$$(\partial f/\partial p)_{\text{length change}} = 10 \text{ Hz/mbar.}$$

Adding the 2 contributions results in a total tune shift of

$$(\partial F/\partial p)_{\text{total}} = 20.3 \text{ Hz/mbar.}$$

Since 1 mbar is the expected approximate steady state fluctuation of He pressure, pressure induced tune shift is relatively unimportant.

The choice of titanium

Titanium competes with the more commonly used stainless steel as material for the He tank, the 2 phase tube and the various bellows. In this application titanium has the following advantages over stainless steel:

- It is well matched to Nb in thermal expansion. The $(\Delta L/L)_{RT\rightarrow 4K}$ is:

$$1.43 \cdot 10^{-3} \text{ for niobium,}$$
$$1.51 \cdot 10^{-3} \text{ for titanium, and}$$
$$3 \cdot 10^{-3} \text{ for stainless steel.}$$

Shrinkage relative to niobium is seen to be 20 times smaller for titanium than for stainless steel. Cool down produces therefore only negligible stress at the Nb - Ti joint between cavity and tank and merely a maximum stress of 3 N/mm^2 in a cavity which was stress free at RT. With a stainless steel tank this value would be 60 N/mm^2. As a consequence there is no need for operating the tuner during cool down to limit cavity stress, if titanium is used for the tank.

- Lower mass of cavity He vessel and therefore higher frequencies for modes of resonant vibration of the cavity-He tank assembly.

- Direct welding to niobium is possible. Stainless steel may be joined to Nb only via intermediate metals such as copper. Such joints have not been developed for the particular geometry required here and are considered risky by some experts. The increased cost for this type of joint about balances the higher material-cost of the niobium vessel.

Selected features of the helium vessel

In the following discussion all pressures will be referred to vacuum.
Because under certain non stationary states of operation the pressure in
the He vessel may reach 2 bar, the test pressure has been set at 3 bar. The
unalloyed Ti foreseen for the tank will stand the corresponding maximum
stress of only 7.2 N/mm^2 safely, especially since it will not turn brittle at
LHe temperature[4]. Ti is not a material formally qualified for use for low
temperature pressure vessels. However, personnel safety is formally
assured to the satisfaction of the Safety Agency by having the He vessel
contained in the vacuum vessel of the cryomodule.

The He tank tube with outside diameter of 240 mm and a wall thickness of 5
mm leaves a radial gap of 9 mm for He flow between it and the cavity, and
is thick and stable enough to sustain the machining of weld preparations at
the ends. It can accept the forces introduced locally at the tank support
stations and the tuner mounting points without appreciable local
deformation (Fig. 1 and 3). Further, its detuning contribution (Table 1) is
about equal to that of tuner and conical head.

Assembly of cavity and He tank proceeds in the following sequence: The
bellow unit is electron beam welded to the conical head at the tuner end.
The cavity is then introduced into the tank and the bellow collar welded to
the vacuum vessel. At the input - coupler end the connecting collar is then
put in place and welded to conical head (by electron beam) and vacuum
tank tube. At the joint between connecting collar and tank, variation in
cavity length, due to warm-tuning it, can be taken up such that at the tuner
end the dimension 6.1 mm is achieved(Fig. 1).

The He tank is fastened with 3 screws each at the 2 support stations to Ti
plates with outside diameter eccentric to the tank axis. With these plates
the tank - cavity unit may be held and aligned from the support rings that
are fixed to the diameter 300 mm He-return tube. There is provision for
alignment in the axial direction as well as transversely and azimuthally at
the 2 support stations (Fig. 1a).

The aforementioned capillary with inside diameter of 3 mm and made from stainless steel is connected with a "Conflat" type flange from stainless steel to a mating flange from Ti, welded to the bottom of the tank. This "mixed metals" connection has been tested at 1.8 K and found to be leak tight. The capillary tube is formed into an expansion loop to sustain ± 15 mm maximum relative longitudinal motion between the diameter 40 mm warm up / cool down tube and the tank(Fig. 3).

The 2 phase He tube is rigidly connected via the short 6 0 mm tube at one end to the He tank. At the other end it is transversely guided, but longitudinally free to accommodate longitudinal expansion relative to the He tank. To connect it to its neighbours each 2 phase tube is fitted with a bellow for accepting tolerances as well as thermal shrinkage and flanges for a machine made fusion TIG weld that may - if necessary - be ground open and redone (Fig. 1).

At the tuner end of the He tank there is provision made for attaching two cantilever - shaped fixing brackets to the He tank(Fig. 3) such that - during testing the cavity (pressure and leak tests) - there may be no relative longitudinal motion between cavity and tank with possible damage to the cavity. To this end, the fixing brackets engage into slots of the split connecting ring joining cavity and tuner. The brackets may remain in place during connecting up of cavities at the beam tube and while the tuner is being mounted. After the last named operation they need of course to be removed. The tuner acts on the cavity via short fingers (not shown) that are connected to the split connecting ring with axial and transversal possibility of adjustment. The laterally quite rigid large bellow (Table 2) defines the transverse position of the cavity relative to the tank.

outside diameter of tank	240	m m
wall thickness	5	m m
material	titanium I (unalloyed)	
mass	21.2	kg
large bellow near tuner: transverse spring rate longitud.spring rate	80000 190	N/mm N/mm
operating pressure	16 ··· 2000	mbar
test pressure	3	bar
max. stress at 3 bar	7.2	N/mm^2

Table 2 . Miscellaneous data of helium vessel

Outlook

The new design of He vessel is smaller in outside diameter than the earlier design by 140 mm. This much, the next generation vacuum tank of the TTF cryomodule could be reduced in diameter and thus its cost be lowered. Moreover, the promising new cryogenic ideas can be tested, and experience be gained regarding fabrication and performance of the titanium parts, and the niobium-titanium welded joints.

References

[1] D. Proch, 6th Workshop on RF Superconductivity, Newport News (1993).
[2] G. Horlitz, D. Trines, T. Peterson, 15th Int. Cryogenic Eng. Conf., Genova (1994).
[3] H. Kaiser, 6th Worksh. on RF Superconductivity, Newport News (1993).
[4] DIN 17869, Entwurf (Mai 1990).

Fig.1 New design of the He-Vessel with reduced diameter

He-return pipe

tank support station

transversal guide for 2 phase He-tube

tank support station

weld flange

"large bellow"

1384,8

HOM coupler

main coupler

connecting collar

weld preparation

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HELIUM-TANK-CAVITY

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1 P4 DOKUMENTATION

capillary with expansion loop

999

1028,5

supporting ring

HOM coupler

tuner

6,1

125,2

X

B

B

A

A

SECTION B-B

he-return-tube

298.5

bracket for azimuthal alignment

support plate

2 phase he-supply tube

12.1

24.0

screw for transversal adjustment

warmup/cooldown tube 40 dia.

VIEW X

he-return-tube

60 outer dia. connecting tube

support-ring

capillary,3 inner dia.

Fig.1a Cross Section of new He-Tank

HELIUM-TANK-CAVITY

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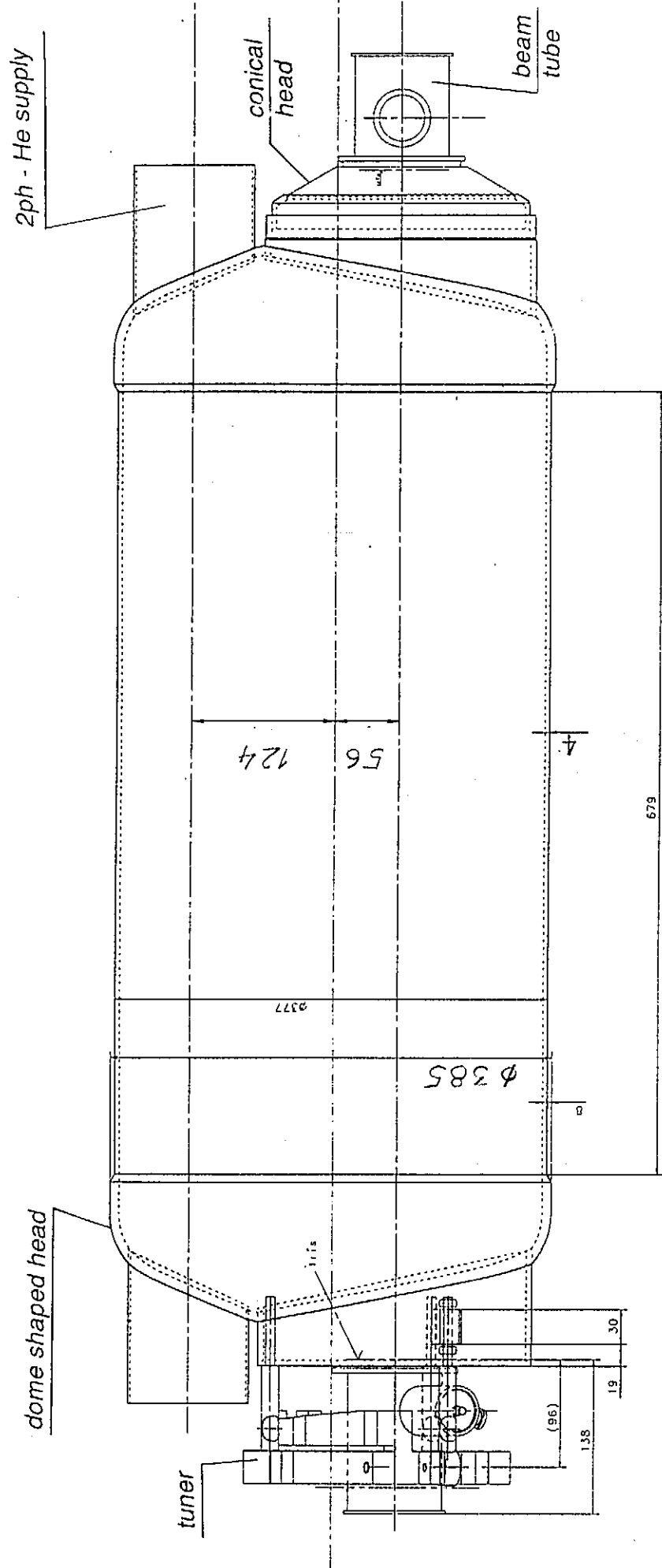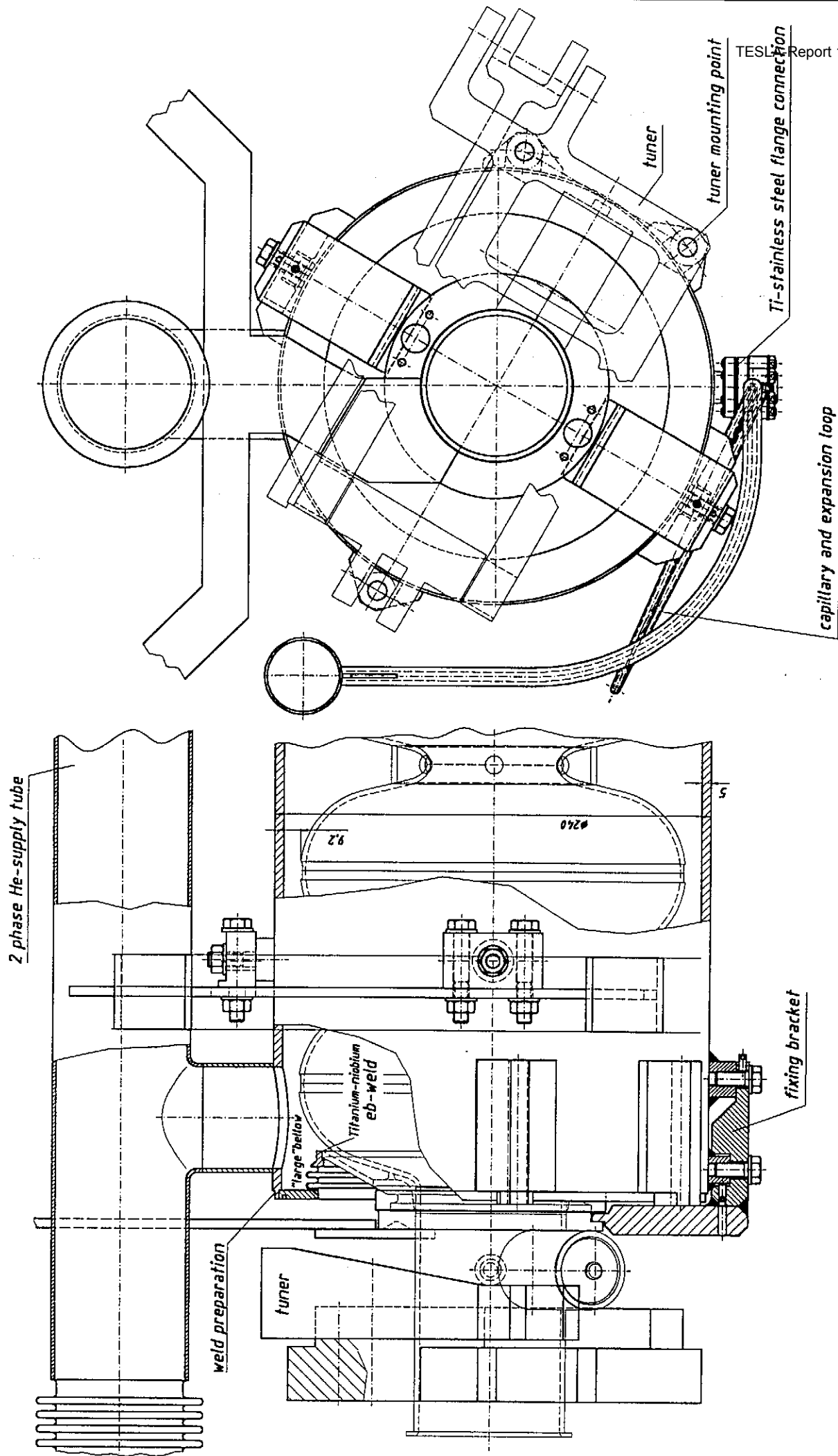2 94 DOKUMENTATION

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Fig.2 Earlier design of He-vessel with larger diameter

Fig.3 Attachements to He-vessel

2 phase He-supply tube

tuner mounting point

tuner

Ti-stainless steel flange connection

capillary and expansion loop

Titanium-niobium eb-weld

large bellow

weld preparation

tuner

fixing bracket

Ø240

9.2

Zubehör für
Heliumtank-Cavity

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