Mechanical Characteristics of the RF Cavity for the TESLA TEST FACILITY

H. Kaiser

Deutsches Elektronen-Synchrotron DESY
Notkestraße 85, 22603 Hamburg, Germany

Introduction/Abstract

The superconducting 1.3 GeV RF cavity foreseen for the TESLA TEST facility to be erected at DESY is made from niobium and has 9 cells [1].

This paper describes the scheme used for stiffening the cells to, among other goals, substantially reduce Lorentz-force induced detuning. The resulting calculated -and in some cases measured- mechanical and RF properties are then presented and discussed.

Optimization of Cavity Geometry

Primarily cavity stiffening is needed for reducing tune shift due to Lorentz-forces.

The geometry of the stiffened cavity is optimized by first computing the electromagnetic field for the π-mode in the unperturbed cavity [2]at Eacc=25 MV/m (Fig.1. For convenience the quantities $\epsilon_0 E^2$ and $\mu_0 H^2$ at the inner surface are plotted). The pressure on the cell wall is then

$$P = \frac{1}{4}(\mu_0 H^2 - \epsilon_0 E^2) \qquad (1)$$

The resulting change of cell form is computed for a particular geometry of stiffening with the FEM code "IDEAS" and results in a cell volume change ΔV. This causes a frequency shift Δf [3]that is to be minimized:

$$\frac{\Delta f}{f_0} = \frac{1}{4W} \int_{\Delta V} (\epsilon_0 E^2 - \mu_0 H^2) dV \tag{2}$$

where

$$W = \frac{1}{4} \int_{v} (\epsilon_0 E^2 + \mu_0 H^2) dV \tag{3}$$

and f_0 =resonant frequency of the unperturbed cavity.

Description and Features of the Stiffening Scheme

The stiffening geometry shown in Fig.2 has been choosen for the TTF cavities. The diameter of the stiffening tube has been optimized for minimum frequency shift due to Lorentz-forces. The characteristics of this stiffening scheme are:

- The stiffening tube is loaded in an almost ideal way. It connects the walls of adjacent cells and thus causes compensation of equal and opposite forces. It is under axial tension with only small circumferencial stress. Only a relatively small amount of Niobium is needed.

- The frequency shift at constant cell length due to Lorentz forces computed by (2) as described is -394 Hz for a 2.5 mm thick cavity wall. Without stiffening it would be -875 Hz. The deformations of cell wall for these 2 cases are shown in Fig.3 and Fig.4. It is seen that deformation of the stiffened cell is negligible for the region where the electric field is large (near the iris), but nearly unchanged with respect to the unstiffened cell where the magnetic field dominates near the equator. As a result the corresponding contributions to frequency shift are -16 Hz and -378 Hz. No elegant scheme exists to reduce the latter contribution. Only increasing the wall thickness near the equator could decrease stress and deformation here.

- The constraint needed to hold cell length constant esperiences at Eacc =25 MV/m a force of 31 N (the cavity wants to become shorter). A *real* constraint, consisting for example of a He vessel around the cavity and some tuning mechanism, is not ideally rigid and will allow some decrease $-\Delta L$ of cavity length causing the aforementioned frequency shift of -394 Hz due to change of cell form to be *enhanced* by $-\Delta L[mm] \cdot 530[kHz/mm]$ (c.f. Table 1). This effect imposes lower limits on the rigidity of He-vessel, tuner and He-vessel head at the non-tuner end. For instance, the conical plate (Fig.2) connecting the cavity to the He-vessel at the input-coupler end contributes -59 Hz to detuning at 25 MV/m.

- For plastically increasing the length of a particular cell for tuning purposes the necessary force is introduced just outside the stiffening tube against the neighbouring cells leaving them undistorted and therefore undetuned.

  In an unstiffened cavity, plastically lengthening a cell is known to detune its neighbours.

- Flexural rigidity and resonant frequencies are increased [4]with respect to unstiffened cavity (c.f. Table 1).

- The stiffening tubes are compatible with external etching requirements where through 2 diametrically opposed slots the acid can drain completely with cavity axis horizontal. The welds to the half cells are continuous and by electron beam, as are all other welds on the resonator.

- The "connecting ring" at the ends of the undulated structure stiffens the end cells in a way characteristic for the inner cells, allows cooling for part of the end tube, serves as a reference for the cavity axis, may be attached to the tuner or handling devices during processing and forms part of the He-containment. The shape of this ring is carefully optimized to keep maximum stess below 29 N/mm^2 [3].

- All 9 cells share equally in cold tuning. The field distribution over the 9 cells is very nearly left unchanged by changing cavity length.Small changes are only possible in case of variation of wall thickness from cell to cell. If in a hypothetical resonator of initially flat field distribution the cells 1 to 5 were at the permitted minimum wall thickness of 2.65 mm, and the cells 6 to 9 at the permitted maximum of 2.95 mm, the field-unflatness produced by a tune shift of 500 kHz (caused by changing the cavity length) would be 13%.

- The cavity, at its end tubes is provided with HOM-[5]and input [6]couplers, as shown and has a pick up antenna. The flanges at the end tubes are formed onto the prefabricated tubes and are intended to be sealed with metal gaskets ("Helicoflex").

Verification of Calculated Characteristics of Cavity

The properties related to elastic deformation of the stiffened cavity have been checked on Nb 9-cell test cavities with wall thickness variation similar to that of Fig.5 as far as it is possible at RT with low power RF. The results are indicated in Table 1 and agree relatively well with the calculated values if one considers that the real cell wall is non-uniform and that its average value is larger than the 2.5 mm wall assumed for the calculations.

As the Young's modulus of Nb changes little with temperature, the values of Table 1 will also approximately hold at LHe-temperature.

Characteristics	stiffened		unstiffened		Unit
	calc.	meas.	calc.	meas.	
Effect of Lorentz-forces at Eacc=25 MV/m length held constant					
Frequency shift due to H-field only	-378		64		Hz
Frequency shift due to E-field only	-16		-939		Hz
Total frequency shift	-394		-875		Hz
Tuning					
force to change cavity length by 0,18 mm	517	554	290	282	N
Frequency shift as function of cavity length	530	404	440		kHz/mm
Effect of change of external pressure at const. length					
Frequency shift	+15	$10,3 \pm 1$	-12		Hz/mbar
Max. stress a 3 bar	12		26		N/mm^2
Sag, Vibration					
Deflection, one end supported other end fixed	0,2	0,17			mm
Frequency of lowest transverse vibration mode	50,8		32,8		Hz
Frequency of lowest longitudinal vibration	199		166		Hz

Table 1. Selected Properties of TTF-Cavity. Calulated values are for a cell wall 2.5 mm thick; measured values are for a test cavity with thickness of cell wall as in Fig.

References

[1]E. Haebel, et al., " Cavity Shape Optimization for a Superconducting Linear Collider " , Proc. of the 15th Inter. Conf. on High Energy Accel., 957 (1992)

[2]Calculations performed by M. Marx, Jacek Sekutowicz, DESY; A. Mosnier, Saclay and Messimo Ferario INFN Frascati

[3]Calculation by H.B. Peters, DESY

[4]H.A. Schwettmann, Stanford University, Private Communication

[5]J. Sekutowicz, this Workshop

[6]B. Dwersteg, et al., "TESLA Main Coupler Development at DESY",this Workshop

Acknowledgements

Ge. Meyer and H.B. Peters are especially thanked for their engaged participation in statics analysis, cavity design and tests on experimental cavities.

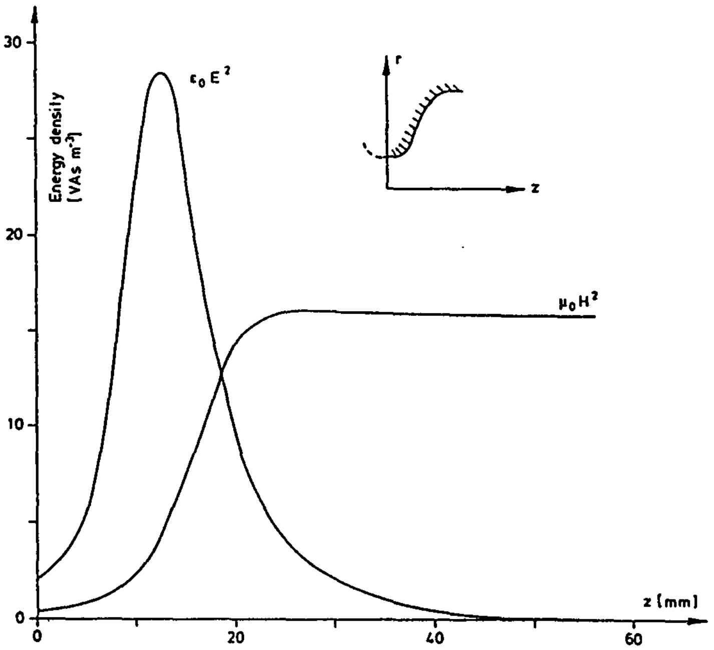

Fig.1 Energy density at inner surface of a half cell.

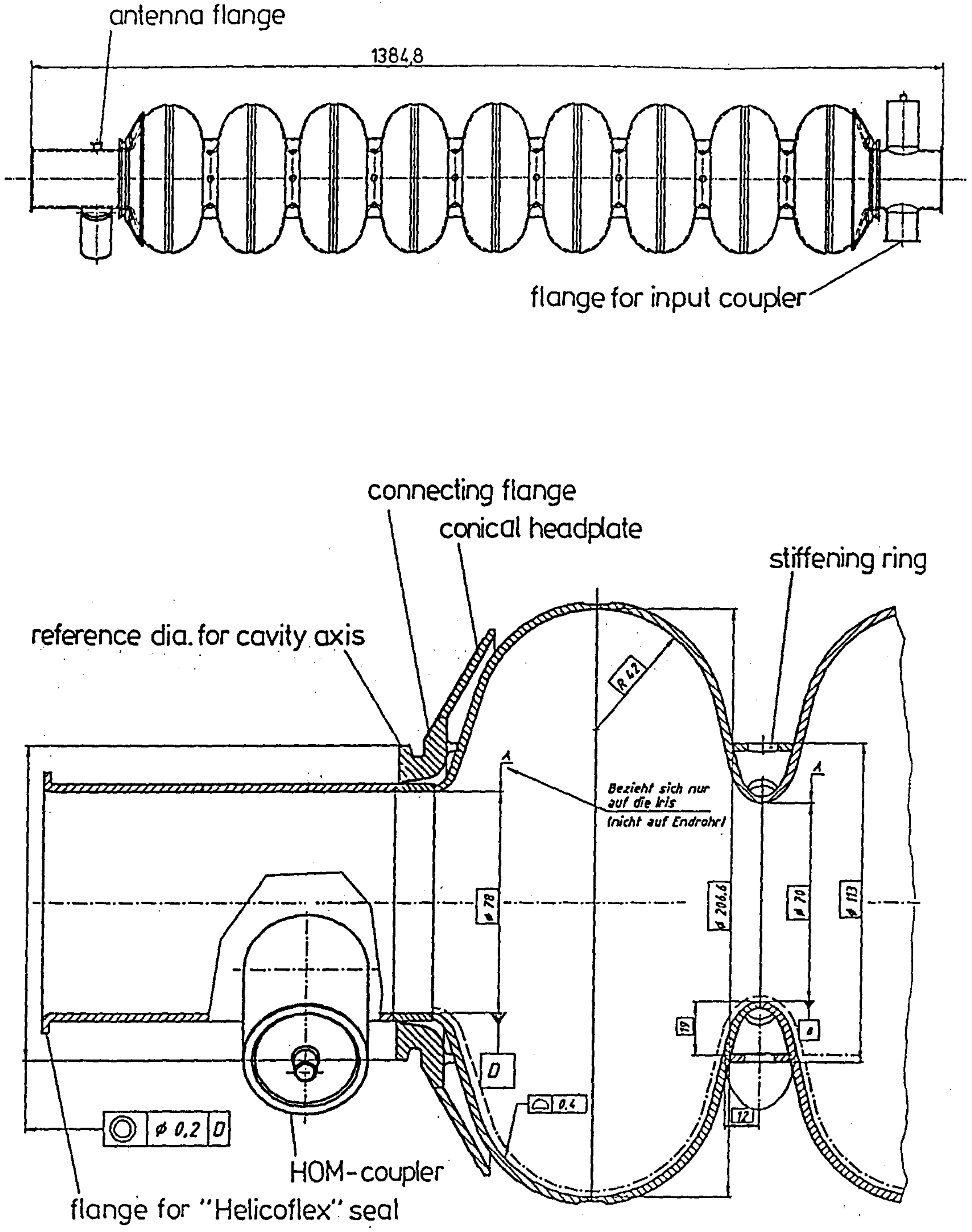

Fig. 2 TTF Cavity

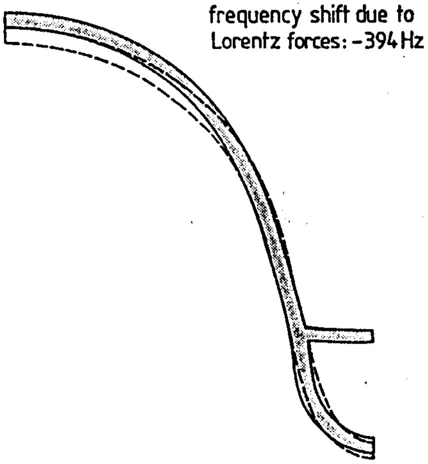

Fig.3 Deformation of a 2.5mm thick stiffened cell wall due to Lorentz forces at Eacc = 25 MVm⁻¹ (gray = deformed)

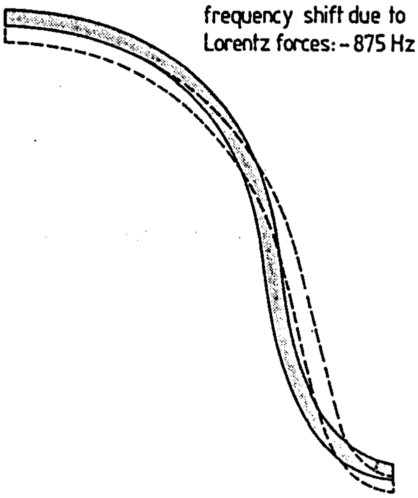

Fig.4 Deformation of a 2.5mm thick unstiffened cell wall due to Lorentz forces at Eacc = 25 MVm⁻¹ (gray = deformed)

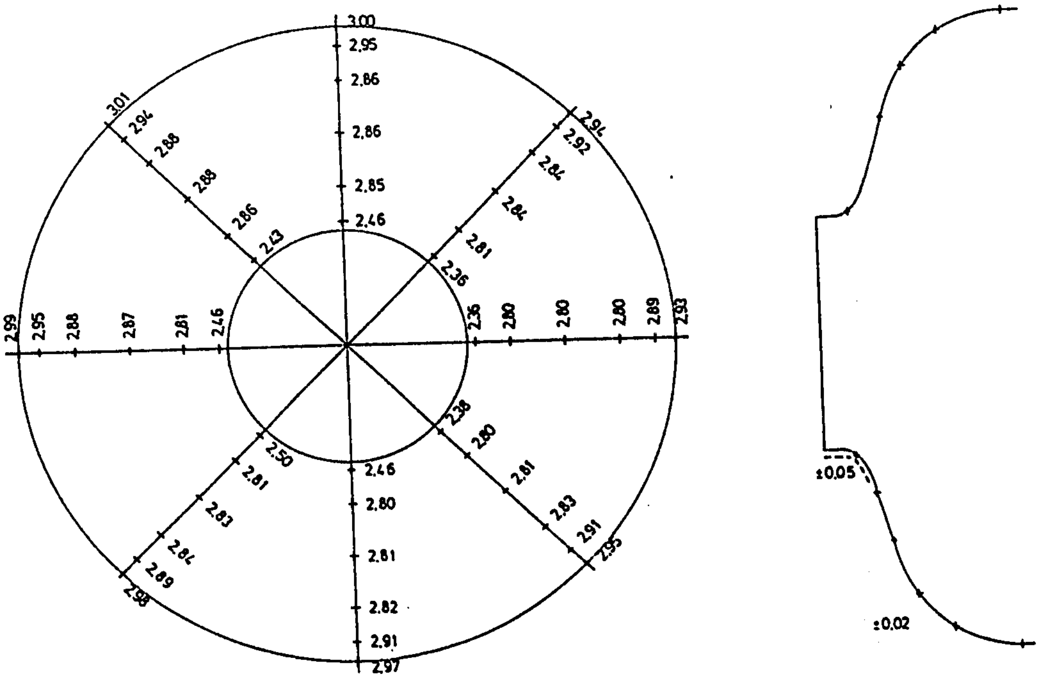

Fig. 5 Typical measured thickness variation of cavity cell