SC BETA GRADED CAVITY DESIGN FOR A PROPOSED 350 MHZ LINAC FOR WASTE TRANSMUTATION AND ENERGY PRODUCTION

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Abstract

A 100-1600 MeV, 25 mA, superconducting proton linac is under study by INFN for waste transmutation and energy production[1]. The linac will be split in three sections with elliptical five cell superconducting cavities (350 MHz) designed for synchronous beta 0.5, 0.65 and 0.85. The first cavity type, β=0.5, will be bulk niobium, with a stiffening structure for mechanical stability. The two other cavity types will be made of copper with sputtered niobium. In this paper we describe the criteria used to optimize the design of the cavities. A cell coupling of 1.7% has been chosen, while peak electric and magnetic fields on the cavity surface below 16 MV/m and 40 mT are required by the machine scheme. A parametrization of the cavity geometrical parameters allowed the full control of the RF and mechanical properties of the cavities. To validate the choice of the final geometry high order modes and multipacting calculations have been performed. Prototypes of these cavities will be built and tested in a collaboration with CERN and the industry (Zanon) during the next two years.

1 INTRODUCTION

INFN has started a three year program (TRASCO) aimed to the conceptual design and to the R&D on components of a high power proton linac for energetic applications. The high energy end (> 100 MeV) of such a machine is foreseen as a three section superconducting linac at the CERN 352.2 frequency. In the following we describe the design work on the superconducting structures and the planned activities on cavity prototypes.

2 THE STRUCTURES

The SC linac design uses five cell structures in the three different sections, at the synchronous values of β=0.5, 0.65 and 0.85[1-2]. The choice of the number of cells per structure is motivated from a compromise between the structure efficiency and its operating energy range, because the energy acceptance narrows as the number of cell increases. Five cell structures give the highest active length per cavity, compatible with a three section linac design. The reference energy for such a scheme ranges from 100 MeV to 1.7 GeV.

2.1 Definitions used in the parametrization

For sake of clarity, to define the transit time factor of a cavity, we write the energy gain of the cavity as:

$$\Delta W = q\Delta V_{acc} = qE_{acc} L_{act} T(\beta, \beta_c)\cos\phi_s$$

where:

$L_{act} \equiv N\lambda\beta_c/2$ is the definition of the active cavity length, E_{acc} is the accelerating gradient for the particle at $\beta = \beta_c$, that is, defined as: $E_{acc} \equiv \Delta V_{acc}{}^{\max}/L_{act}$ and ϕ_s is the synchronous phase.

In this definition the transit time factor is normalised to 1 at the nominal particle velocity $\beta = \beta_c$. Note also that the geometrical cell length is not equal to the defined active length of the cell. As a matter of fact, we chose to indicate the β values for the cavities not from the cell to cell distance, but from the behavior of the transit time curve of the whole (end-cell compensated) cavity in the desired energy range[3], as shown in Figure 1 for the β=0.65 cavity. In particular, the geometrical β values for the three structures are: 0.475, 0.623 and 0.826.

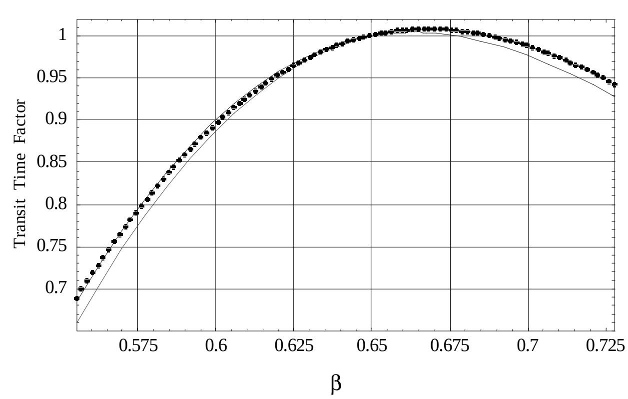

Figure 1: The dotted curve is the transit time curve of the cavity chosen for section II of the linac, as computed from the SUPERFISH fields, the two thin lines are the TTFs for an ideal cavity (sin-like fields) with β=0.652 and 0.648. All the TTF curves are normalized to 1 at the energy gain of a particle with β=0.65.

2.2 Cavity parametrization

The cavities have been designed with an elliptical iris and an elliptical equator, on the basis of e.m. and mechanical considerations. A sketch of the geometry is presented in Figure 2. The end cells have been modified with respect to the inner cell geometry in order to achieve field compensation. The magnetic volume reduction needed for compensation is obtained by slightly increasing the angle α, with fixed R_{iris} and d (See Figure 2).

In Table 1 we report the main electromagnetic characteristics of the three structures: the ratio between the peak electric field on the cavity surface with respect to the accelerating field, the ratio of the maximum magnetic field with respect to the accelerating field and the cell to cell coupling. The geometrical parameters of the structures and the operating values for the accelerating gradients in the linac design have been chosen in order to limit the maximum surface electric field below 16 MV/m and the maximum surface magnetic field below 40 mT. A cell to cell coupling of 1.7% has been required to the structure. Table 2 reports the geometrical dimensions of the internal cells of the three cavities.

The cavity shapes have been extensively investigated with the SUPERFISH[4] and OSCAR2d codes[5].

Table 1: Main e.m. characteristics of the three structures.

β_c	E_p/E_{acc}	B_p/E_{acc} (mT/MVm^{-1})	Cell to cell coupling (%)
0.5	3.4	8.1	1.8
0.65	2.7	6.5	1.7
0.85	2.3	4.6	1.7

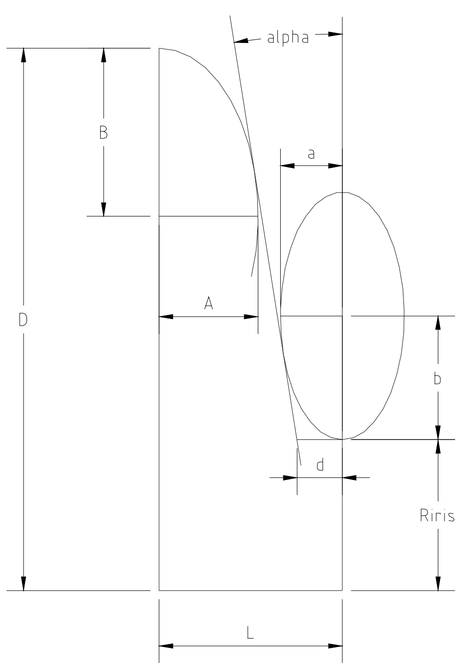

Figure 2: Definition of the geometrical parameters of the elliptical cavities.

Table 2: Geometrical parameters (in mm) for the internal cell geometry, at the working cryogenic temperature.

β_c	0.5	0.65	0.85
A	47.1	71.6	131.3
B	80.1	121.8	196.9
a	33.4	44.8	35.4
b	60.1	89.6	56.7
d	26.8	32.8	26.8
L	101.1	132.6	175.7
D	392.2	392.7	385.2
R_{iris}	99.4	109.3	114.3

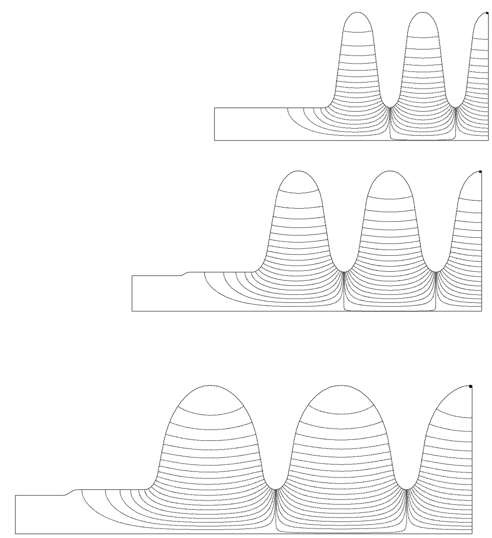

Figure 3: The shapes and the fields in the three structures (top β=0.5, middle β=0.65 and bottom β=0.85), as from SUPERFISH calculations, shown in the right proportions.

2.6 Mechanical issues of the structures

The behavior of the bulk niobium and copper cavities under vacuum has been investigated with structural analysis tools, in the elastic and in the elastoplastic regime. The structural analysis lead to the choice of an elliptical equator, so to achieve a more homogeneous stress distribution along the geometry with respect to the usual elliptical iris and round equator design.

Only the lowest β cavity was found to be unstable under vacuum and needs a stiffening structure for mechanical stability. A stiffening structure has been designed and tested with simulations under the structural loads of the normal cavity operating conditions. The construction and test (at room temperatures) of a full scale copper prototype of the β=0.5 five cell cavity (including stiffening elements) is one of the major objectives of the TRASCO program, to set the fabrication technology and to validate the structural calculations.

Figure 4 shows a summary of the stress calculations for the 3 cells under vacuum (and no stiffening). Only in the β=0.5 cell high stresses lead to plasticity instability.

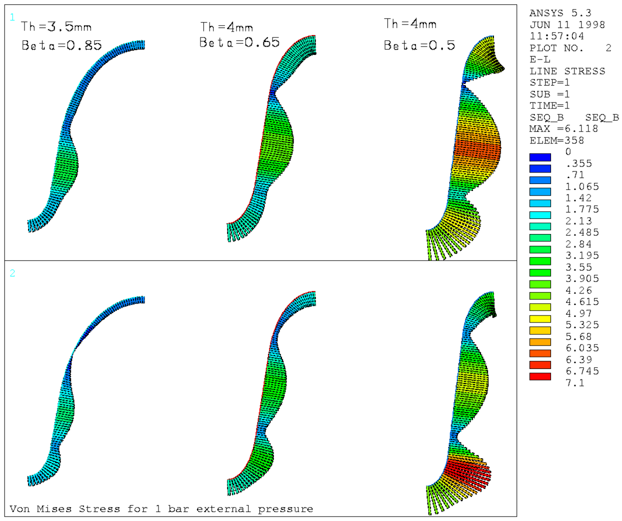

Figure 4. Stresses on the internal (top) and external (bottom) side of the cell walls. Left: β=0.85, Middle: β=0.65, Right: β=0.5 cavity. Units are kgf/mm^2.

3 HIGH ORDER MODES AND MULTIPACTORING

The possible excitation of high order modes in the five cell structure can be of some concern due to the very high current foreseen for the linac operation. Minimal perturbations of the cavity fields could result in a beam halo growth, leading to beam losses beyond the threshold of severe activation of the machine. For this reason we performed a thorough check of the high mode distribution in the structure using our OSCAR2d code[5]. The work is still in progress, but the analysis of the first bands of the β=0.85 five cell structure, that is, in any case, the most critical, shows very low R over Q values for all the high order modes, due to the crossing of the TM011 and TM020 bands. This crossing gives (as shown in Figure 4) a very peculiar field distribution on some high order modes, resulting in a decrease of the shunt impedance.

The choice of a beam tube diameter equal to the inner irises diameter helped in easing the high order mode behavior of the accelerating structure. In this case the RF field freely propagates trough the cavity for any frequency above the beam tube cut off. For this same reason no RF field can be trapped in the beam tubes, avoiding the "tube modes" that were measured in the LEP cavities.

We also checked the effect of the main coupler on the on-axis distribution of the electric field. This analysis was performed using the HFSS code on a β=0.85 structure, with a LEP type main coupler connected to the port.

We then used the TWTRAJ postprocessor for the simulation of possible electron loading effects (multipatoring) in the cavity. The first results of the simulations confirmed that no harmful problem are foreseen due to the low operating values of the surface field and to the elliptical shape at the equator.

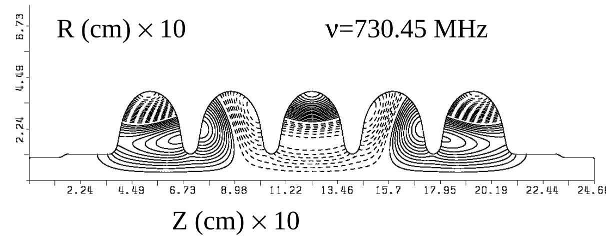

Figure 5. A high order mode resulting from the crossing of the TM011 and TM020 bands of the β=0.85 cavity, from OSCAR2d computations.

This latter choice gives a stronger longitudinal component of the electric field along the surface, which pushes the electrons strongly towards the cavity equator, where the resonant condition for one point multipactoring is broken.

4 CAVITY PROTOTYPES

A collaboration with CERN has been established in order to build and test prototypes of the TRASCO structures at the CERN facilities. A copper sputtered with niobium β=0.85 cavity is under construction by CERN, based on the design reported here. After sputtering the cavity will be tested at CERN.

On the basis of this experience a second β=0.85 cavity will be built with the Italian company Zanon and tested at CERN. In this second phase also a cryostat, derived from the CERN and INFN (TESLA) experience will be designed and build for a possible horizontal test.

In parallel, the TRASCO program foresees the production (with Zanon) and test (at CERN) of a single cell β=0.5 cavity, together with the fabrication and test (at room temperature at LASA) of a completely stiffened β=0.5 five cell copper cavity.

5 CONCLUSIONS

We reported here the design of the INFN TRASCO superconducting cavities for a high current proton linac aimed at energetic applications. The design has been completed and a collaboration for cavity prototypes has been set with CERN and the Italian company Zanon.

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