NEW STRUCTURAL DESIGN OF SCDTL STRUCTURES FOR THE TOP LINAC

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Abstract

A new structural design of the 3 GHz SCDTL cavities of the TOP Linac has been developed to solve thermal dissipation and mechanical stability problems affecting the previous version. Indeed although the duty factor is not higher than conventional copper coupled-cavity structures, the very small (1.2 cm diameter) drift tubes and stems inside a tank have to be carefully cooled in order to avoid mechanical distortions that could affect resonant frequency and field distribution. A higher coupling coefficient has been also obtained. The paper describes the last fabrication scheme design of the structure and the results of prototype tests.

1 INTRODUCTION

For the TOP Linac [1], a proton linear accelerator for protontherapy, the SCDTL structure at 3 GHz is under development to be used in the accelerating energy range 7 - 70 MeV. The construction of these RF cavities, composed by small DTLs coupled by side coupling cavities, requires a lot of tests and models. The structure is small: bore hole is 4 mm diameter, inner tank diameter is 6 cm, and all the structure has to be constructed precisely with a tolerance less than 0.05 mm. The principal aim in this phase of the project is to build within the first half of 1999 a structure 1.4 m long, composed of 11 accelerating tanks, that we call SCDTL-0, ready to accelerate protons from 7 MeV to 13.5 MeV, and test it with particles using as injector, probably the Van De Graaff existing at LNL-INFN. In the following the evolution of the structure is described and completed with some results of last calculations and measurements.

2 EVOLUTION OF THE GEOMETRY

Since the beginning SCDTL structure was conceived to contain 5, 6 or 7 full $\beta\lambda$ cells per tank. This position, that can be considered the main difference with respect to the CCDTL Los Alamos structure [2] , has been kept up to now even though more detailed calculations, measurements and modifications are planned for the tanks exceeding λ in length.

2.1 Former designs

As to the cell structure, from the beginning we decided to support a drift tube with a single 5 mm diameter cylindrical stem [1,3]. In the first model, Model#1, the drift tube had a spherical shape (fig.1) so that it could be machined as a single piece with the stem: the four stems were then bolted to a base plate inserted in the tank.

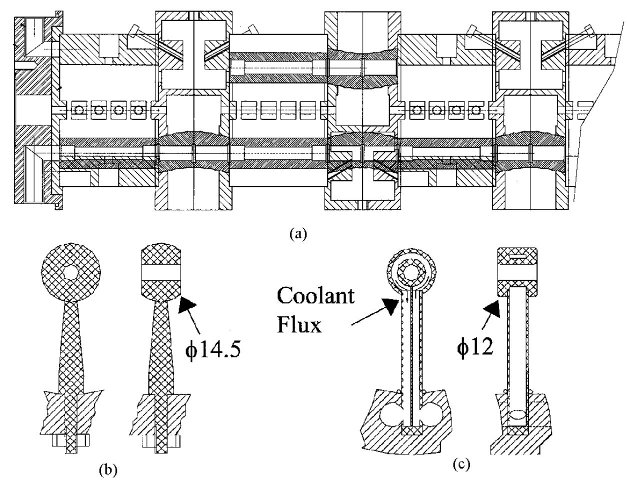

Fig. 1: (a) SCDTL, old design, model #2; Stem arrangement in (b) Model#1 and (c) Model #2

This design was abandoned for the more conventional cylindrical drift tube, that showed a better shunt impedance, 10% higher, and the Model#2 was built [3]. At the same time calculations were done about the RF heating of the structure during operation indicating a dissipation of 7 W in the stems and 5 W in the drift tubes when working at full power (400 Hz, 5 µs). The related temperature increase must be kept within 1 °C to avoid structure detuning. This convinced us to guarantee a more appropriate cooling. Some tests were done on a sample, heated by a resistor in the drift tube bore hole, to check if circulating coolant only in the base plate or only in the stem could solve the problem, but without success. Therefore the drift tube was building of two pieces, to create a cylindrical channel into the drift tube, coaxial to the tube itself, that was connected to the coolant channels in the tank body by a channel in the stem, split in two by a separating stainless steel slice (fig. 1c). In fig. 2 we compared the temperature increase vs heating power between the case when the coolant is circulated only in the stem and the case when it is circulated both in the stem and in the drift-tube. It can be seen that in the second case the temperature increase is contained within 1°C up to 8 W.

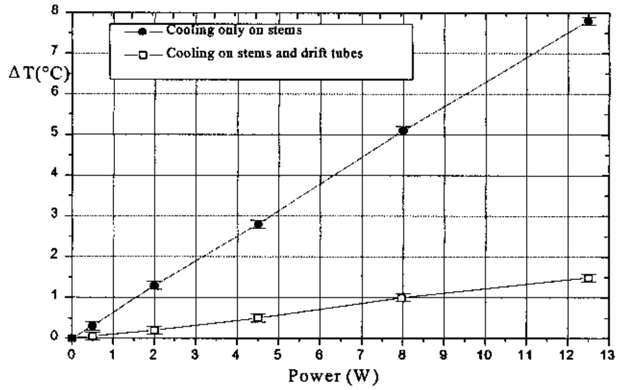

Figure 2: Comparison of the temperature increase in the case of only stem cooling and drift tube and stem cooling

However, while the cooling properties were found to be satisfactory, the mechanical strength was very poor, due to the number of brazes needed to build the system. This fact, joined to the choice of brazing each stem-drift tube assembly directly onto the cavity body, thinking to align the system by an axial ceramic rod during brazing, led to many problems in the structure tuning. It is obvious that is impossible to get the correct frequency of the various tanks just at the first machining and in the Model #2 it was found hard to tune the tank after the stem-drift-tube assembly was brazed to the tank body. Moreover, several samples got deformed after manipulation being them made of fully annealed copper, and this caused the complete loss of precision in the alignment.

The alignment, indeed, is an hard task in this 3 GHz design. The main problem arises from the permanent magnet quadrupoles (PMQ, 3.3 cm long, 20 mm o.d, 6 mm i.d, 200 T/m, made by ASTER Ent., USA) alignment, that, in this first module must be done within ±0.05 mm, but also the various gaps must be precisely assembled so that the tanks axis must be aligned within ±0.1 mm.

Mechanically, the structure consisted [3] (fig. 1) of cylindrical tanks closed by two cylindrical flanges that carried half drift tube on the tank face and half coupling cavity on the other. The cylindrical outer geometry was selected in order to gain the maximum machining precision from the symmetry. The coupling cavity was completely separated from the tanks by a 1 mm wall in which an elliptical slot was drilled for the coupling. The first neighbouring coupling coefficient has been measured for the Model #1 as 2.7% and Model#2 as 3.1%.

As to the brazing, we had to use six alloys (from Nioro (960°C) down to Incusil (730°C), and there were three brazing steps for the drift tubes and three large brazed surfaces per tank that can affect the axial alignment.

The PMQ housing was shared by two flanges. This could cause problems after the brazing, because a very small misalignment in the brazing step could prevent a good positioning of the PMQ on the axis.

2.2 Actual design

All these considerations pushed us to completely review the mechanical structure, and the new conceived structure is shown in fig. 3. The external mechanical cylindrical symmetry has been abandoned in favour of a squared external geometry, in which a single piece contains one tank, the complete PMQ housing, a slice of a full coupling cavity with its two coupling slots, one for each side, and half drift tube, practically the end flange, of the next tank. The remaining slice of coupling cavity, with the two noses, is made of two symmetrical pieces, is pre-brazed, and is bolted for tuning and finally brazed to the body.

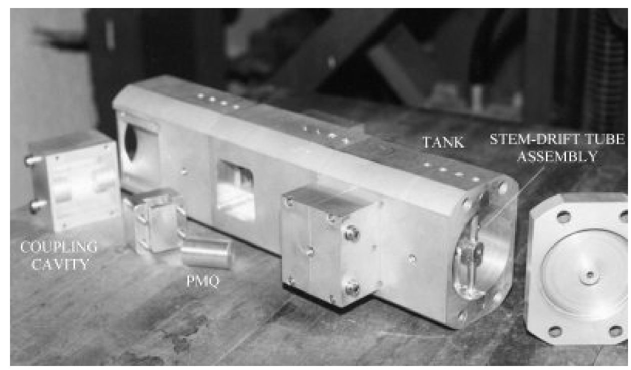

Figure 3: Aluminum model of first three tanks of SCDTL-0

All the system is thought for a completely computer controlled machining. Stems and drift tubes have now been completely changed. They form a unique solid assembly that can be inserted into slots in the tank walls. In fig. 4 the construction drawings are shown.

The cooling channels are drilled in three different copper pieces that are brazed (Palcusil 15) together. Then the piece is leak tested and machined to produce the final assembly. This allows a easier tuning: the tank has a smaller inner diameter that can be enlarged slipping off the stem-drift tube assembly, and then reinserting it. All the manufacture is made within 0.05 mm. The cooling scheme is such that the four drift tubes are cooled in parallel and the various assemblies are in series. Four different channels are drilled in the tank body to cool the rest of the copper.

The number of brazing steps is reduced. We have to use five alloys, and there is one large surface brazing per tank. The PMQ is housed within a rectangular aluminum box that is inserted in a rectangular grave and there bolted. The precision is guaranteed by machining, and not by assembling. Tuning screws are placed 90° from stems, two per drift tube. The structure will be inserted in a cylindrical stainless steel vacuum chamber and fixed to it.

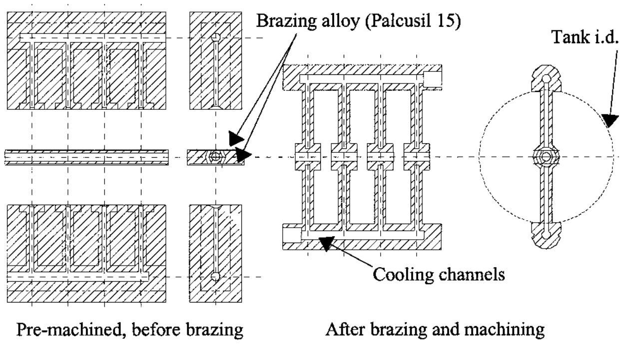

Figure 4: Drawing of the stem-drift tube assembly

5 3-D CALCULATIONS

To include the influence of the structure asymmetries due to the stems and the coupling slots we started a 3D modeling of the SCDTL structure using MAFIA and the module SOPRANO of the package OPERA-3D [4].

The study of a single DTL tank (the first in the module, β=0.1235) without coupling slots showed that the use of double stems on each drift tube, improves the electric field stability in the operating mode, although with a (tolerable) reduction of a 15% in the shunt impedance respect to the single stem scheme [5].

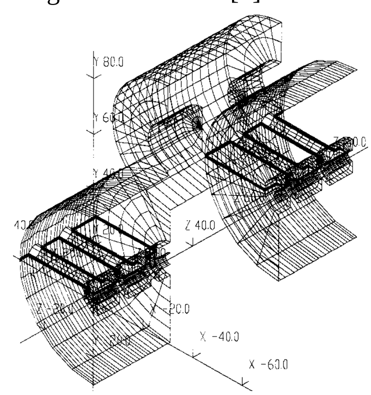
Figure 5: Input geometry for SOPRANO. The stems are in x direction and the z axis coincides with the beam axis.

To estimate the values of first coupling coefficient k in a system where the cavity length increase steadily along the structure, the initial and the final triplet of the first module, composed respectively by the accelerating tanks number 1 and 2 (β=0.1235, 0.1275) coupled by a 45.92 mm long reentrant cavity and the tanks number 10 and 11 (β=0.16064, 0.16486) coupled by a 58.97 mm long reentrant cavity were simulated. The coupled system composed by a tank and half coupling cavity was computed, getting two oscillating modes; then we got the $\pi/2$ mode frequency imposing the Dirichlet condition on the coupling cavity symmetry plane. Using these three frequency values in the equations of the coupled circuits theory we obtained the value of k relative to the first tank as 4.68 % and the oscillation frequencies of the single cavities. We repeated the same procedure for the second tank of the triplet, getting 4.62%. Analogously, for the last triplet the values are 4.135% and 4.1%. The reduction of 14% along the module is consistent with the increasing of the square root of the tank volumes of about 15%. The average longitudinal electric field is constant in the module according to the beam dynamics calculations assumptions. This corresponds to a weak increase of the peak longitudinal electric field in the longer tanks.

The higher modes in each triplet were also computed. The nearest one is higher 730 MHz in the first tank and 422 MHz in the last. In the coupling cavities, the frequency difference between the TM011 mode and the TM010 mode is 630 MHz in the first and 236 MHz in the last. From this analysis it results that the variable tank length does not seem to cause problems in the first module, but the trend is that both the coupling coefficient and the distance of the higher modes from the operating one reduce with the increase of the cavities length with consequences on the structure sensitivity to tuning errors and power - flow droop. Further 3D-calculations on the tanks of the successive modules will investigate the field stability when the tank length becomes equal or greater than the wavelength.

5 RF MEASUREMENTS

Up to now we have completed the Aluminum model of fig.3 and a copper model of three cavities is almost ready. Its stem-drift tube assembly has been made and successfully leak tested. Measurements on an Al model corresponding to the first three tanks of SCDTL-0 showed a k value ranging between 4.28% and 4.13%, decreasing tank by tank toward the higher energy side, being the coupling iris size is constant within the machining tolerances. The other coupling coefficients are measured as: neighbouring tanks $-4\cdot 10^{-3}$, and neighbouring coupling cavities $6\ 10^{-4}$, very small, according to the fact that the stems form a sort of separation inside a tank that prevents two coupling cavities to see each other.

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