PRODUCTION AND TEST OF THE PROTOTYPE β= 0.85 FIVE CELL CAVITY FOR THE TRASCO PROJECT

E.Chiaveri, R.Losito S.Calatroni CERN, 1211 Geneva 23 Switzerland, A.Dacca`, G.Gemme, R.Parodi[&], INFN-Genova Via Dodecaneso 33 16146 Genova-ITALY, D.Barni, A.Bosotti, C.Pagani, G.Varisco, INFN-LASA Via Fratelli Cervi 22 1Segrate Milano.

Abstract

The Trasco project is an R&D program aimed to the test of the feasibility of the main Components of an Accelerator Driven System aimed to the transmutation of Nuclear Waste.

The results obtained On the High Beta Structure Foreseen for the High-Energy section Of the Proton linac are presented. The five cell Structure was produced using the standard CERN Process for The LEP cavities slightly optimized for the Different cavity design imposed by the different application (Low energy ~1 GEV 30mA Proton Beam)

The Five-cell cavity reached at 4.5K the design Goal of 5.5 MV/m accelerating field at the Qo values of 2.5 $x10^9$at the onset of the Heavy Electron loading. The ultimate field (limited by the Available RF Power and the Helium refrigerator plant at 4.5 K) was 10 MV/m with a Qo value of 10^9.The low Field (1MV/m) Qo value of the cavity was $5.6x10^8$

The very same Values of the Quality factor and field where obtained in the single cell test cavity used for the sputtering process optimization.

1 INTRODUCTION

The TRASCO project is R&D effort jointly supported by ENEA (the Italian Agency for the development of new energy sources) and INFN (the Italian organisation for the research in the field of the Subnuclear and Nuclear Interactions). The project is granted from the Italian Government trough a grant for the technological transfer to the Italian industries.

The aim of the project is the design, test and production of critical components of an Accelerator Driven Sub-critical Nuclear Reactor for the transmutation of long lived radionuclides produced in standard light water nuclear power plants.

INFN is responsible for the design of the High Current (30 mA), High energy (500Mev to 1GeV) Proton accelerator driving the Intense Neutron source used to keep Running the fission Process in the sub-critical Nuclear reactor.

As a first step in the development process we decided to use already existing components for the RF system and to use for the cavity construction the state of the art techniques proven in mass production.

For The aforementioned reasons the first cavity prototypes were designed at the frequency of 350 MHz.

At this frequency, due to the R&D effort driven by the LEP construction, all the relevant RF equipment as Power amplifiers, RF distribution systems and Cavity couplers (rated at the nominal power of the proton linac) already exist, while the Building technique for the linac Modules is assessed for β=1 Cavities.

The phase speed for the linac cavities ranges from β=.5 to β=.85. We started to develop first the higher beta cavities using the niobium on copper technique of the LEP Cavities.

Therefore we signed an agreement with the CERN for the construction and test of a five-cell prototype cavity to take full advantage from the experience gained by the SL-CT group at CERN.

The SL-CT group is responsible for the development, testing and installation of the LEP Superconducting RF modules.

Under the agreement CERN built and tested a full scale prototype of the β=.85 accelerating cavity on the geometry defined by INFN; for this reason the sputtering process for the cavity needs to be modified to cope with the cavity geometry of the proton linac.

INFN provided the design of the accelerating cavities and the needed support for the ESCA_Auger analyses eventually needed in the process of adapting the sputtering process to the new cavity geometry.[1]

We decided to build cavity equipped with LEP Type cut-off tubes having a main coupler port and a full set of ports for the High Mode couplers.

2 CAVITY PRODUCTION

The cavity was built forming half cells by spinning starting from a OFHC copper sheet 3.5 mm thick following the standard LEP cell production.

[&] E-mail: Parodi@ge.infn.it

The full cavity is built using 8 equal half-cells for the body of the module plus two different half cells to get the needed field flatness for an optimum acceleration.

The half-cells of both types were formed then deep elettro-chemically polished to remove the first layer of the copper.

This heavy polishing removes the surface layer of the copper sheet having a heavily distorted crystal lattice.

This lattice distortion is produced both by the Cross Rolling process leading to the final thickness of the copper sheet, and by the spinning procedure leading to the half-cell production.

The LEP Cavities production has shown that poor copper crystal lattice will always lead to sputtered Niobium films with poor RF quality (mainly producing high RF Losses and low accelerating fields)

After the first polishing the resonant frequency of the half-cells was measured ad the half-cells sorted to form cells with the right resonant frequency when assembled in the full accelerating structure.

This procedure will minimise the amount of tuning needed to get the optimum field flatness and the maximum accelerating field from the structure with the minimum of RF power dissipation.

Usually in the latest production of the LEP cavities, this procedure resulted in field flatness coping with the production specifications of one per cent.

In our case we got after the welding, an overall field flatness of 5%, not too bad considering the different geometry.

We therefore decided to skip the tuning step of the production procedure and to go on with the final chemical polishing removing 20 microns of copper just before the sputtering operation.

3 NIOBIUM FILM COATING AND THE DEMO CAVITY

The coating of the accelerating structure was done using a slightly modified LEP_Cavity procedure.

Minor modifications are needed to adapt the sputtering process and to deposition magnetron to cope with the shape of the shortened B=.85 cavity.

This step of our program was greatly helped by the experience gained by the SL_CT group in the reduced beta program developed at CERN in the previous years.

The sputtering magnetron was shortened to reduce the dimension of the sputtering source and increase the landing angle of the Niobium atoms on the copper surface.

To even more improve the deposition angle, and improve the quality of the film in the cavity transition region the cavity shape was optimised to avoid cavity regions seen at grazing angle by the Niobium atomic beam.

Sure, as usual, You can have nothing without loosing something. The price for this optimisation was again a small decrease of the cavity volume giving a lower amount of stored energy for the same frequency.

This fact gives higher wall dissipation for the same accelerating field. In our geometry if compared with a non-optimised geometry a 10% lower Qo value is obtained for the same value of Surface Resistance of the Niobium.

The sputtering of a cavity with a new geometry being a quite risky business even having the unparalleled experience of the CERN, some process adjustment is often needed.

For this reason we mutually agreed (INFN and CERN) to have a single cell (TRASCO Geometry) produced and tested before the completion of the five-cell module.

This Intermediate stage will allows for a fast revision of the deposition process in case of nasty surprises in the cavity performances.

The fabrication process of a single cell cavity is by far less expensive than the fabrication of a five-cell structure. In case of troubles we can afford (as a last resource) to cut the cavity and analyse the surface at well-defined spot with the ESCA_AUGER facility We have installed in Genoa for this purpose.

A half-cell of the cavity is shown in figure 1

Figure 1; half of the Single cell cavity ready for the ESCA AUGER Measurements at the Genoa Lab

4 EXPERIMENTAL RESULTS

4.1 SINGLE CAVITY TESTS

The Single cell cavity was ready for the first measurement at the beginning of December 1998.

As often experienced in Niobium on copper cavities, the overall performance of the cavity was good.

The electron loading of the cavity starting at 2-2.5 MV/m in the first run disappeared in a stable way (not anymore even a feeling of NREL at this level) after 600 seconds of RF processing.

The Qo versus accelerating field characteristic (figure 1) after the processing shows a smooth decrease of the Qo with the increasing field. Non resonant Electron Loading (NREL) started to be significant at accelerating fields over 5 MV/m and increased exponentially following RF modified the Fowler -Nordheim (FN) law with a field enhancement factor of 100.

The standard helium processing lasting 12 hours does not produced any substantial improvement in the cavity performances

The cavity reached a maximum field of 7 MV/m at full power.

No hints of self-sustaining Multipactoring (MP) barriers were experienced. The experimental data confirming the extensive computer simulations performed in Genoa with the TWTRAJ Code[2]. Only the mild limitation of the field in the very first run is consistent with the first (N=1) MP barrier at the equator sustained by the large NREL current feeding the resonant trajectories.

Once the NREL processed away the MP barrier disappears due to the electron multiplication factor less than one along the trajectories of that particular barrier.

The only drawback was the rather low Qo value at low field X.Yx10^9, resulting in a Qo value of 2x10^9 at 5.5 MV/m of accelerating field.

The TRASCO design goal is 3.5x10^9 @ 5.5 MV/m and @ 4.5 Kelvin, this value corresponds to the LEP cavity goal scaled to the TRASCO geometry.

The Results of the first measurement of the single cell cavity were only a little below the projected performances of our cavity.

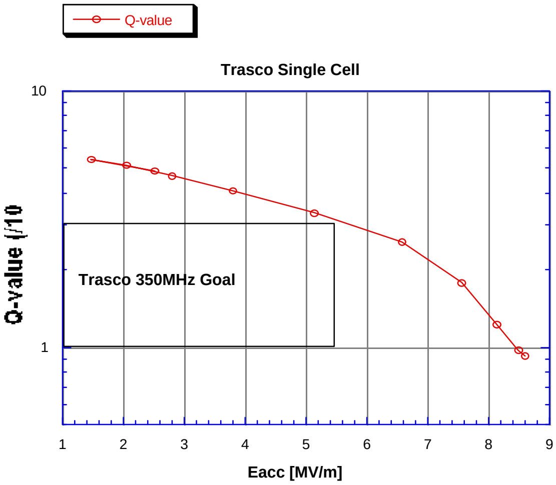

Figure 2; Single cell Trasco cavity Qo versus field plot @4.5 K; Qo is plotted in 10^9 units, accelerating field in MV/m.

We therefore decided to strip the niobium film, remove another 40 micron of copper and coat again the cavity without any change in the sputtering parameters.

The cavity was tested in the late February 1999; the results of this measurement (exceeding the TRASCO specification) are reported on figure 2.

The overall behaviour of the cavity is very similar to the one of the first one; the only difference where:

1) The Qo at low field reached the nominal value foreseen for the cavity on the basis of the LEP cavities results.
2) the electron loading was even more mild, no NREL barriers were hit at low field, the standard NREL with field enhancement ~100 started at 5.5 MV/m

Again (as in the LEP cavities) the 12+ hour Helium processing of the cavity at high field gave us only a scant .5 MV/m gain in the maximum field without changing the Q versus field characteristic around the TRASCO working point.

Running the cavity at low temperature greatly improved the Qo with a gain of about a factor eight, but does no changed so much the maximum achievable field. (Figure3)

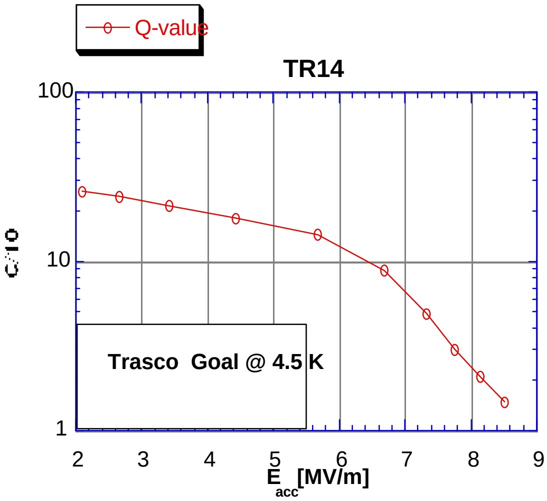

Figure 3; Single cell Trasco cavity Qo versus field plot @1.8 K; Qo is plotted in 10^9 units, accelerating field in MV/m

The eight time reduction in surface RF losses of the niobium shows in the full extent the effect of the losses due to the NREL current captured and accelerated by he cavity field.

A plot of the cavity losses versus field shows the exponential growth of the losses with a knee around 5 MV/m.

A best fit plot, using the standard expression for the FN losses, [3] gives a field enhancement factor of 110-120, in agreement with the value found fitting the X-ray intensity (measured outside de cryostat) versus field data

The exponential growing law of the FN current result in a limitation of the accelerating field due to the fast increase of the losses.

In both cases 4.5 K or 1.8 K the accelerating field @Qo=10^9 is a value around 10 MV/m; decreasing the temperature does not give at this frequency the advantage found at higher frequency.

The capture field value for the electron is proportional to the frequency of the cavity.[4]

Therefore, in geometrically similar cavities, the NREL knee in the RF losses increases roughly proportional to the operating frequency. Moving at higher fields the onset of the exponentially growing Qo drop.

This physical law greatly reduces the possibility of increasing the maximum achievable field at 350 MHz. simply by lowering the operating temperature of the cavity to gain a higher Qo value.

The only possibility left is to reduce both the temperature and the field emission from the cavity surface.

After the successful test the single cell was stripped and coated again to check for possible improvements. The obtained results were the carbon Copy of the previous one.

The meaning of this last measurement was: No more memory effect of the production strains on the Copper substrate was found

4.2 FIVE CELL CAVITY RESULTS.

The Single cell results gave the impetus to continue the experimentation in a hurry.

After removing from the copper cavity an amount of copper equal to the sum of the copper removed in the Two step of polishing in the single cell the cavity was coated an tested in may 1999.

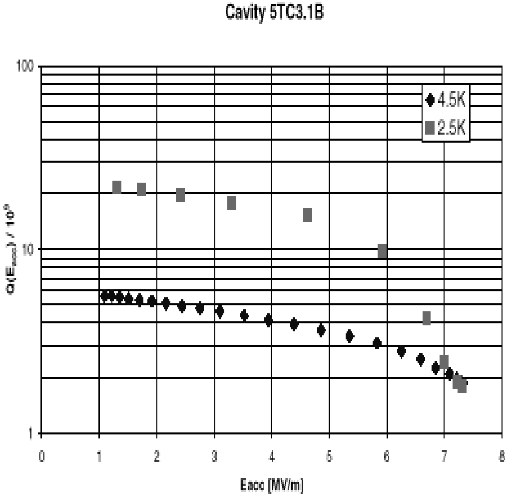

Figure 4; Final results of the measurements on the TRASCO 5 cell module @ 4.5 and @2.5 Kelvin

The results of the measurements at 4.5K and 2.5 K are shown on figure 4

Since from the first test the cavity exceeded the TRASCO goal exactly reproducing the single cell results.

As In the single cell cavity lowering the temperature improves the Qo up to 5-6 MV/m but does not increases so much the maximum accelerating field.

The only difference found was a slightly higher NREL due to the larger number of accelerating cells and cumulative effect in the acceleration of the Field emitted current. The electrons emitted in any cavity are captured and accelerated in and efficiently drain energy from the following cells.

5 CONCLUSIONS

The prototype, operating at 350 MHz, of a five cell superconducting cavity for the High-energy section of the TRASCO proton linac was built and tested.

The obtained results meet the foreseen goal, reaching the design value of a Qo of $3x10^9$ @ 5.5 MV/m accelerating field and 4.5Kelvin operating temperature.

The limitation on the operating point of the cavity was due to the increase of the RF losses with the increasing field.

This limitation is exactly the same limitation experienced in the LEP cavities.

The next step of the TRASCO program at 352MHz is the test of the cavity in a LEP-Type Cryostat. This test will demonstrate the achievable accelerating field for a cavity fully equipped with a 300 KW RF Power Coupler and a complete set of High order modes dampers.

6 REFERENCES

[1] C. Pagani, D. Barni, G. Bellomo, P. Pierini, INFN Milano LASA[†];R. Parodi[†], INFN Genova *Proceedings of the Linac98 conference.*

[2] P.Fernandes, R.Parodi *Proceedings of "Particles accelerator conference"* Ieee catalog 89CH2387-9 R.Lindstrom and Louise Taylor. Editors Washington DC 16-19 March 1987.pag-1857

[3] H.Padamsee, j.Konobloch,T.Hays,*"Rf Superconductivity for Accelerators"* Jon Wiley &sons,inc, page 233.

[4] P.Fernandes, R.Parodi, G.Bienvenu, "*An Investigation On The Field Emitted Electrond In Travelling Wave Accelerating Structures*" Nuclear Instruments And Method A , A320 (1992)1-8.