EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN — SL DIVISION

CERN SL-99-024 CT

Technical Developments on Reduced -β Superconducting Cavities at CERN

R. Losito

Abstract

Several authors proposed the construction of superconducting proton linacs using the LEP2 cavities once LEP will be decommissioned. However only a fraction (about half) of these cavities can be used as they are for the high-energy part ($\beta \sim 1$) of such a linac, the low energy part requiring the development of accelerating structures optimized for lower values of the particle velocity.

At CERN an R&D programme on reduced-β single-cell cavities started in 1996 in order to study and explore the limits of the technology successfully used for the production of LEP2 cavities (copper cavities niobium-plated using the magnetron sputtering technique). Four different geometries were extensively investigated, each representing part of a multicell structure optimized for particles having $\beta=0.48$, $\beta=0.625$, $\beta=0.66$ and $\beta=0.8$ respectively. The results were encouraging for the last two types and therefore a new phase of R&D aimed at the production of multicell cavities for $\beta=0.66$ and $\beta=0.8$ was started. The goal is to demonstrate simultaneously the feasibility of such cavities and the possibility of producing them by low-cost modification of LEP cavities.

In the paper, after a brief review of the results obtained on the single-cell cavities, we shall present in more detail the procedure for the transformation of the LEP cavities, which should allow a realistic estimate of the costs of such operation.

Presented at PAC-99, 1999 Particle Accelerator Conference
New York
29 March-2 April 1999

Geneva, Switzerland
March, 1999

TECHNICAL DEVELOPMENTS ON REDUCED-β SUPERCONDUCTING CAVITIES AT CERN

O. Aberle, D. Boussard, S. Calatroni, E. Chiaveri, E. Haebel, R.Hanni, R. Losito, S. Marque, J. Tückmantel, CERN, 1211 Geneva 23, Switzerland

Abstract

Several authors proposed the construction of superconducting proton linacs using the LEP2 cavities once LEP will be decommissioned. However only a fraction (about half) of these cavities can be used as they are for the high-energy part (β~1) of such a linac, the low energy part requiring the development of accelerating structures optimized for lower values of the particle velocity.

At CERN an R&D programme on reduced-β single-cell cavities started in 1996 in order to study and explore the limits of the technology successfully used for the production of LEP2 cavities (copper cavities niobium-plated using the magnetron sputtering technique). Four different geometries were extensively investigated, each representing part of a multicell structure optimized for particles having β=0.48, β=0.625, β=0.66 and β=0.8 respectively. The results were encouraging for the last two types and therefore a new phase of R&D aimed at the production of multicell cavities for β=0.66 and β=0.8 was started. The goal is to demonstrate simultaneously the feasibility of such cavities and the possibility of producing them by low-cost modification of LEP cavities.

In the paper, after a brief review of the results obtained on the single-cell cavities, we shall present in more detail the procedure for the transformation of the LEP cavities, which should allow a realistic estimate of the costs of such operation.

1 INTRODUCTION

In 1996 an R&D programme has been launched at CERN to study the feasibility of reduced-beta niobium/copper superconducting cavities. The motivation of this work resides in the various proposals for high-intensity proton linacs to be used for different purposes (e.g. for the drive beam of an energy amplifier, transmutation of radioactive waste, for neutron and muon sources, for FEL applications etc.) [1-3]. The 352 MHz superconducting RF system successfully working in LEP has been considered for a reconversion, after LEP decommissioning in year 2000, into the medium β (0.5 ÷ 0.8) and high β (~1) part of some of these linacs. One reason for that is of course economical, but there are also other important points in favor of this option:

- the reliability of the system has already been demonstrated during operation in LEP, where only about 10% of the downtime was due to faults of the RF system.
- the large aperture of the irises (over 200 mm), which is made possible by the choice of the frequency of operation (352 MHz), should prevent the activation of the cavities by the beam halo.

Each LEP "module" is made up of 4 cavities and delivers in average 40 MV to the beam (hopefully 47 MV in 2000). Considering the variation of the transit time factor from cavity to cavity due to the acceleration along a linac, a superconducting machine going from ~240 MeV up to ~2 GeV would need between 50 and 80 of such modules, with several stages optimized for growing betas. LEP cavities, which are designed for β=1, have a reasonable efficiency (R/Q) only starting from ~1GeV, β~0.9 (which corresponds anyway to a half of the linac).

Our research has shown that for values of β ranging from 0.66 up to 0.8 the reconversion of LEP cavities into reduced β niobium/copper cavities is feasible, and can be very interesting from the economical point of view. For lower values of β (0.48, 0.625) on the contrary the RF performances of the cavities produced with the niobium/copper technology are not so satisfactory, so the interest of modifying LEP cavities into β~0.5 cavities is low.

We will present in detail the results of the RF measurements and the procedure we used to transform one 4-cell existing LEP cavity into a 5-cell β=0.8 cavity fully equipped, and the real costs of such an operation.

2 RESULTS OF SINGLE-CELL CAVITIES

Since August 1996 four different types of single-cell copper cavities niobium-plated using the magnetron sputtering technique were produced at CERN: β=0.48, β=0.625, β=0.66 and β=0.8. The best performances obtained for each type are shown in fig. 1 and 2. A typical performance of a LEP cavity is shown as well in fig. 1.

The Q(Eacc) curve for the β=0.8 cavity fits the expectations (calculated by scaling with the geometry factor the analogous LEP cavity curve). For the others the results are lower than the scaling, showing a degradation of the niobium film quality. This is probably due to the low impact angle of the niobium atoms on the surface of the cavity during the sputtering process for these geometries (for more details see [4]). In spite of that, we believe that it is reasonable to use at least the β=0.66 cavity if one limits the average accelerating field to 3 MV/m.

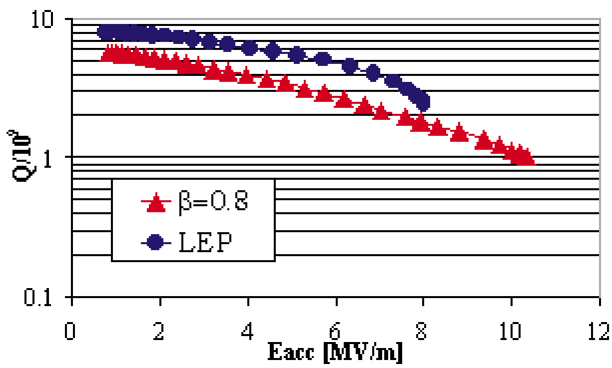

Figure 1:Results for a 4-cell LEP cavity and a single-cell β=0.8 cavity (all limited by amplifier power)

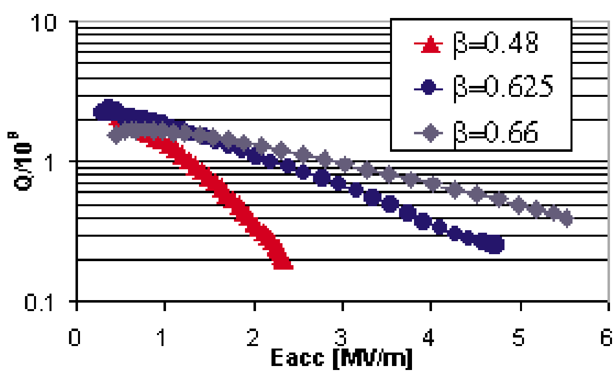

Figure 2:Results for β=0.48, β=0.625, β=0.66 single-cell cavities (all limited by amplifier power)

3 THE 5-CELL β=0.8 CAVITY.

The length of a cell is related to the β for which it is optimized. Since 5*0.8*λ/2=4*1*λ/2, a 5-cell β=0.8 will have exactly the same length than a 4-cell β=1.

This consideration is the basis for a low cost transformation of a LEP cavity. In fact as the lengths are the same, we can re-use almost all the ancillary equipment:

- *the thermal tuners*, which provide coarse tuning and have a range of at least ±25 KHz;
- *the magnetostrictive tuners*, which provide fine and fast tuning and have a range of ±1KHz;
- *the two "cut-offs"*, which are the part of the cavity connecting the two end cells to the beam pipe (see fig. 4). These are the most expensive mechanical parts of the whole copper cavity, because all the flanges for the different couplers have to be welded on them;
- some parts of liquid helium circuit;
- *the vacuum tank*, which provides the thermal insulation between the helium tank and the atmosphere at 300K;
- *the main coupler and the Higher Order Modes (HOM) couplers*, after some minor modifications to adjust the coupling factors.

In practice we need to build only the 5 copper cells and the helium tank.

The necessary steps for the transformation are the following:

- dismounting the cavity from its vacuum tank ;
- chemical etching of the niobium layer on the whole cavity, to clean the cut-offs;
- cutting the helium tank and the copper cavity at the cut-off level;
- production of the new copper cells;
- welding of the cells to the old cut-offs;
- coating a new niobium layer;
- welding the new Helium tank;
- remounting the cavity in the old vacuum tank.

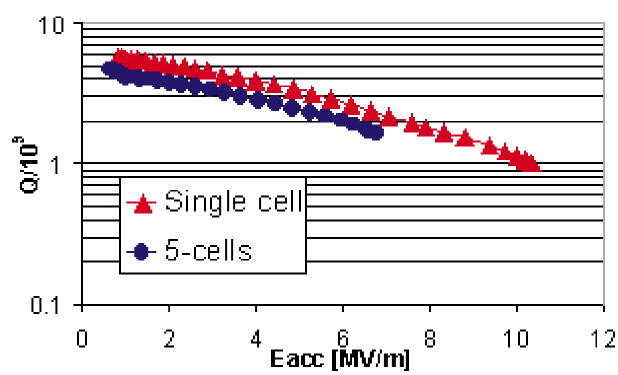

Figure 3: Comparison of the results for the single-cell and the 5-cell β=0.8 (all limited by amplifier power).

We performed all these steps on an old LEP spare cavity. The cut-offs were laser-cut from the stainless steel He tank, to insure a good surface quality for the subsequent welding. The 4 cells were separated by plasma cutting. We built a helium tank much simpler (and cheaper) than the LEP one which should result in a slightly bigger consumption of liquid He. All the other operations are quite standard.

We measured the bare reconstructed cavity (without He tank) and the result is reported in fig. 3. It is interesting to note that the degradation of the performance from the single-cell to the 5-cell cavity is less than 25%. We are limited only by the power of the amplifier.

Some photos of the transformation process are shown in fig. 4-5. We are presently mounting the cavity into the vacuum tank and we will measure it before summer '99.

The cost of the whole operation amounts to approximately 20% of the price of one new LEP cavity.

Figure 4: Laser cutting the He tank at the good dimension. The cutoff is visible inside the tank.

4 FUTURE DEVELOPMENTS.

Since 6*0.66*~λ/2=4*1*λ/2 one can envisage a low cost modification of a LEP cavity into a β=0.66 6-cell cavity. We showed that for a single-cell this geometry gives acceptable performances up to 3 MV/m, but the scaling of this performance to 6-cell should be demonstrated by an experiment that will be done only if a real interest in that will arise. Some measurements would also be necessary on the main couplers and HOM couplers to determine the modifications needed to get the good coupling factors.

5 A TENTATIVE SCHEME FOR A LINAC.

A possible solution for a superconducting proton linac using the cavities described above (to be confirmed by beam dynamics simulations) could consist of three sections, β=0.66, β=0.8, β=1. The injection energy could be around 240 MeV (β~0.6). To reach 2 GeV one would need around 56 6-cell cavities β=0.66, 78 5-cell cavities β=0.8 and 140 LEP cavities. The price to be paid for the cavities (including main and HOM couplers and the cold tests) of such a linac would be less than 10% of the price paid for the LEP energy upgrade.

6 CONCLUSIONS

We have shown the results of the measurements of single and multi-cell reduced-beta cavities produced at CERN with the niobium sputtered on copper technology used for LEP2 cavities.

We believe that the minimum value of β for which one can obtain reasonable performances for this kind of cavities is around β=0.66. Because of simple geometrical considerations, β=0.8 and β=0.66 multi-cell cavities can fit a vacuum tank of a LEP β=1 cavity, leading to a low cost recycling of the LEP2 RF accelerating system.

We built a 5-cell β=0.8 cavity by modifying a LEP cavity at ~20% of the cost of a new LEP cavity. This estimate includes: cavity and ancillary equipment modification, manpower cost and low temperature tests.

About the same price would be spent to modify a LEP cavity into a 6-cell β=0.66 cavity.

A linac using β=0.66, β=0.8 and β=1 cavities could accelerate particles from 240 MeV up to 2 GeV.

7 ACKNOWLEDGEMENTS

We are indebted to all of our technicians, without their work this development would not have been possible. We are grateful as well to our colleagues of EST/SM group for chemical treatment and in particular H. Neupert for niobium coating.

REFERENCES

[1] D. Boussard et alii, "Preliminary parameters of a Proton Linac using the LEP 2 RF System when decommissioned", CERN/SL-RF Technical Note 96-04.
[2] C. Rubbia, J.A. Rubio, "A tentative programme towards a full scale energy amplifier", CERN/LHC 96-11.
[3] R. Garoby, M. Vretenar, "Proposal for a 2 GeV Linac Injector for the CERN PS", PS/RF/Note 96-27.
[4] C. Pagani et alii, "A high Current Linac with 352 MHz SC Cavities", Proceedings of the 1996 Linac Conference.
[5] R. Losito, "Design of a β=0.66 monocell cavity", CERN SL-Note-98-008 (RF).

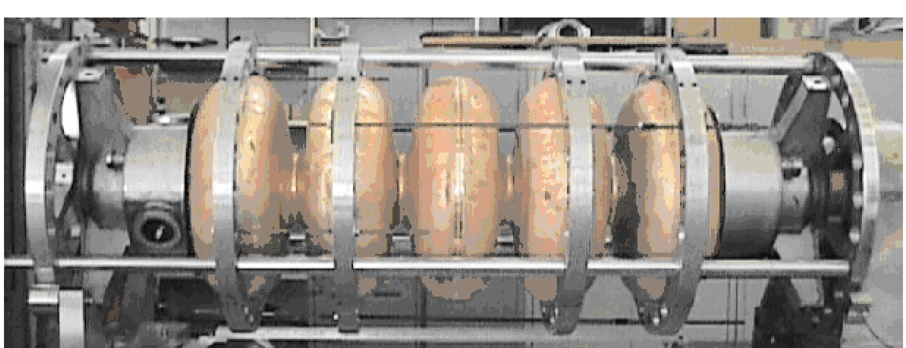

Figure 5: The 5-cell cavity ready to be electron beam welded on the cut-offs using an internal gun.