STUDY OF A NOVEL SUPERCONDUCTING STRUCTURE FOR THE VERY LOW BETA PART OF HIGH CURRENT LINACS

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Abstract

A novel superconducting structure is proposed to accelerate protons in energy range of 5-20 MeV. The comparison with 3-gap cross-stem structure both from the point of view RF efficiency and technological aspect of manufacture and maintenance of operating sc structures has been done. Results of M.A.F.I.A. simulations are given.

1 INTRODUCTION

At present, high current proton linacs have been proposed as the drivers for many research and technology applications such as: transmutation of nuclear wastes, spallation neutron sources, production of radioactive ion beams, neutrino plants and technological neutron irradiation tools.

The typical linac architecture includes a room temperature RFQ, and low, intermediate and high β sections. For the lower energy section (5 - 85 MeV), the superconducting (sc) cavity option, consisting of a few families of independently phased resonators (β = 0.1-0.43) can be one of the possible solutions.

This paper presents novel design of 352 MHz 4-gap superconducting resonator which we call ladder resonator, following the high current 5 MeV normal conducting RFQ, capable to provide efficient acceleration in β = 0.1-0.2 of velocity range The specific application, for which it is proposed in this paper, is a proton driver for the production of exotic nuclear species, in the framework of the EURISOL design study, funded the European Commission [1], for a next generation ISOL facility in Europe.

2 CONSTRAINTS ON THE LOW-β CAVITY DESIGN

A preliminary sc linac design of EURISOL driver foresees a distance of 340 mm between the first couple of superconducting quadrupole magnets in a FODO lattice. It means that the total accelerating length of the resonator will be rather short. We accept the L_{int} = 200 mm as the inner length of the structure in electrodynamics calculations with the M.A.F.I.A. code [2].

Two 4-gap structures with β_{opt} = 0.12 and β_{opt} = 0.17 are proposed for the very low velocity section of the high intensity sc proton linac. Only the first (β_{opt} = 0.12) will be considered in the paper.

Transit Time Factor (TTF) preliminary considerations are described by fig. 1. An analytical comparison of resonators with three, four and five gaps for the two families of resonators with β_{opt} = 0.12 and β_{opt} = 0.17 is shown. A flat accelerating field distribution is assumed in the curve calculations.

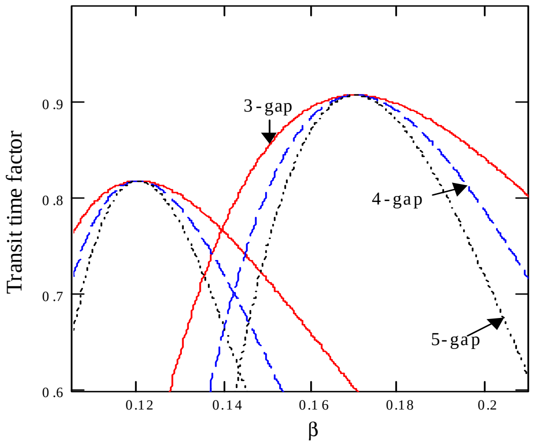

Figure.1: TTF of 3, 4, 5-gap low-β resonators (β_{opt} = 0.12 and β_{opt} = 0.17). The effective gap width is 35 mm.

It can be noted that the 5-gap option, besides being ruled out by the small longitudinal space available, as outlined above, has also an unfavorable TTF curve. The TTF curves of the 4-gap options are already acceptable

3 DESIGN REQUIREMENTS

In the choice of the resonator geometry we have considered both rf parameters and some technological aspects of the structures.

Our experience of a sc RFQ investigation [3] and also results of the first 2-gap sc spoke cavity (β = 0.2) tests [4,5], convinced us not to exceed in the design a maximum surface electric field of $E_{s,p}$ = 30 MV/m.

As for the maximum surface magnetic field $B_{s,p}$, we decided not to exceed 0.065 T, which is commonly accepted as a still reasonable value.

The best possible flatness in the accelerating field along the gaps should be achieved.

Easy access to the interior volume is an important advantage of any sc structures. It can be provided by flanged joints in region where $B_s < 5$ mT, as was tested at INFN-LNL sc RFQ [3]. This would allow easy inspection and treatment of surfaces exposed to the rf fields, including possible mechanical repair, chemical etching, high pressure water rinsing (HPWR).

The frequency separation between the operational and the higher order modes should be enough large in order to keep a proper field distribution, when construction errors are taken into account.

4 CROSS AND LADDER GEOMETRY

We have investigated two kinds of resonators: 3-gap cross-stem (see fig.2), and also a novel 4-gap resonator, which we call ladder (see fig.3), featuring three parallel stems.

The current density over the cavity surface is quite evenly distributed in crossed-stem resonators, but there is no place in the cavity with $B_{s,p} < 5$ mT where it would be possible to put a large size flange. The latest option is possible in the ladder resonator. In order to achieve flatness of the accelerating field along the gaps for multi-gap cross -stem resonators extra space in the first and last gaps should be added, while it is not necessary in the 4-gap ladder structure.

Figure 2 : 352 MHz 3-gap cross-stem resonator

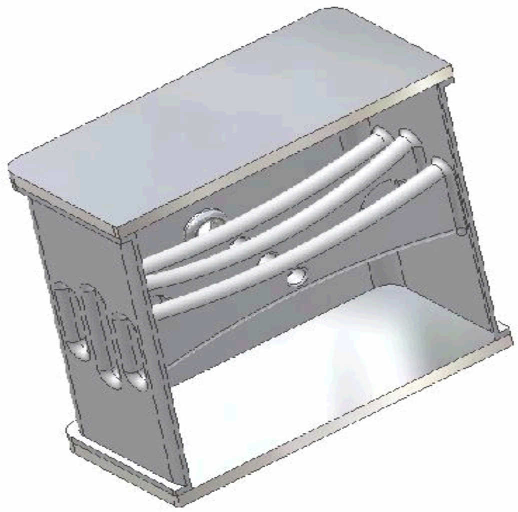

Figure 3: 352 MHz 4-gap ladder resonator

Geometric dimensions of both the 3-gap cross-stem and the 4-gap ladder resonators are shown in Table 1.

Table1: Cavities geometric dimensions

Cavities	3-gap cross-stem	4-gap ladder
Inner length	200 mm	200 mm
Inner height	256 mm	450 mm
Internal width	256 mm	450 mm
Beam bore diameter	25 mm	25 mm
Gap length	25 mm	25 mm
Stem thickness	26 mm	26 mm
Stem width at aperture	60 mm	65 mm
Central stem base width	-	166 mm
1st & 3d stem base width	-	125 mm
Coupling hole diameter	-	70 mm

5 M.A.F.I.A. RESULTS

The shape of both resonators has been optimized with the M.A.F.I.A. code. As for the 3-gap cavity, their stems are bent for efficient use of the resonator interior.

As for the 4-gap ladder structure, the stem shape has been optimized to reduce stored energy and surface magnetic field, and to get flatness of E_a. Degeneration of the accelerating π-mode with higher order modes is avoided by two coupling holes on the central stem at symmetric positions with respect to the beam axis. Large lateral flanges located at 225 mm from the beam axis, where $B_{s,p} = 1.5$ mT, allows easy access to the inner volume.

The main results of the simulations are summarized in Table 2. The distribution of E_z along beam axis is shown in fig.4 and fig 5. As can be seen from fig. 6 and fig. 7, the maximum magnetic field density ($B_{s.p} = 0.065$ T), in the ladder cavity is reached at coupling hole, providing 4 MHz mode separation.. As has been checked via simulations, with the proposed design a positioning error of 0.1 mm of one of the stems in the longitudinal direction causes a deviation of about 1% in the flatness of the accelerating field, which is acceptable good.

Table 2: RF parameters of the resonators

Cavities	3-gap cross-stem	4-gap ladder
$B_{s,p}$ (set as limit) [T]	0.065	0.065
$E_{s,p}$ [MV/m]	32	21
Energy gain at β_{opt} [MV]	0.954	1.15
Acc. field E_a [MV/m]	4.77	5.8
U/E_a^2 [J/(MV/m)^2]	0.0465	0.059
RF coupling %	35	1.2
Q - at 4K (assumed)	6.4×10^8	5×10^8
G [Ω]	58	44.75
$B_{s,p}/E_a$ [T/(MV/m)]	0.0136	0.0112
RF power diss.(4 K) [W]	7.7	10
B_{max} (flanged joint) [T]	-	0.0015
E_a flatness on 4 gaps [%]	79	100

As can be seen from Table 2, the ladder resonator has higher accelerating field, which has been achieved for

$E_{s,p}$= 21 [MV/m]. It means that increasing of the E_a is still possible, by reducing the $B_{s,p}$ and increasing $E_{s,p}$.

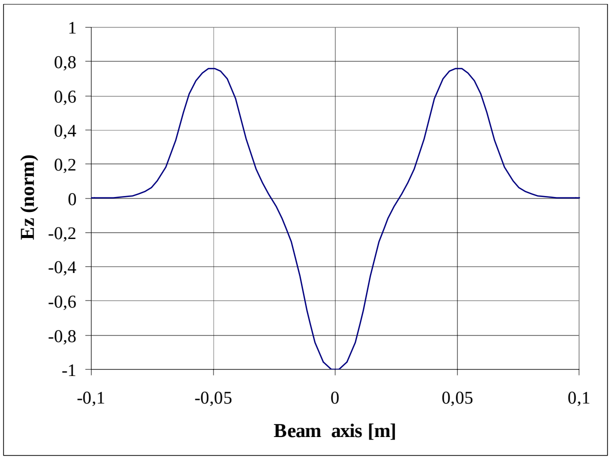

Figure 4: E_z along beam axis of 3-gap cross-stem cavity.

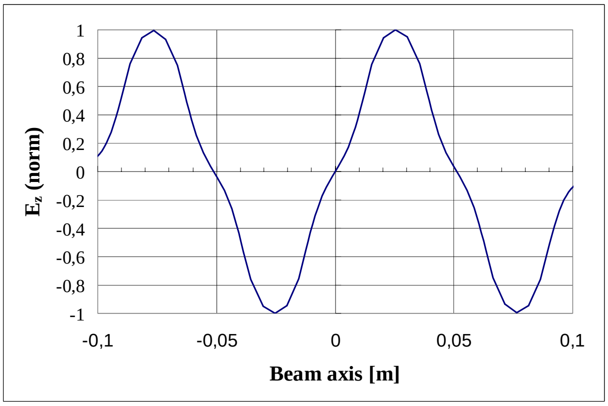

Figure 5: E_z along beam axis of 4-gap ladder cavity.

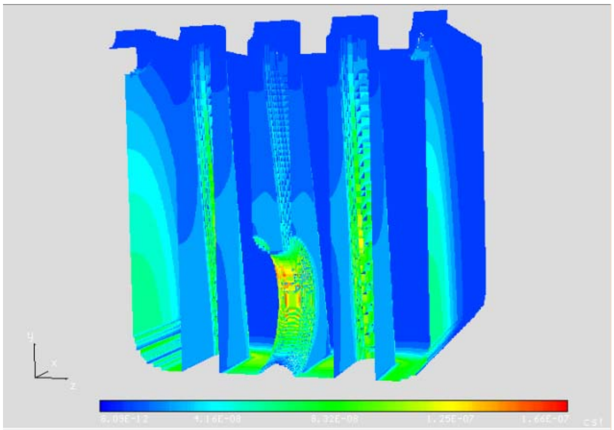

Figure 6: 3-d M.A.F.I.A. plot of the magnetic field distribution on a quarter of the resonator

As can be seen from fig. 6, magnetic fields are mainly concentrated in central part of the resonator among ladder type stems and they are quickly vanishing going towards the stem-less side. It allows to use flanged joints in the ladder resonator. Fig. 7 shows in detail the magnetic field distribution near the surface of the central stem.

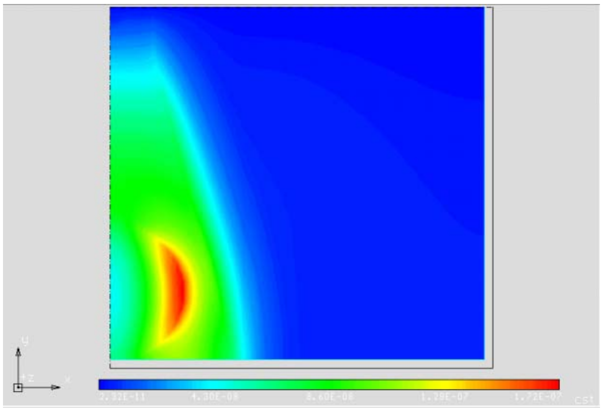

Figure 7: 2-d M.A.F.I.A. plot of the magnetic field distribution near the central stem surface.

6 CONCLUSION

The proposed 352 MHz 4-gap ladder resonator can be a competitive structure for the very low energy section of a high current proton linac (β = 0.1 - 0.2). It has good rf parameters, easy access to the interior of the resonator, due to flanged joints, 100% E_z flatness over the gaps.

The design study of the ladder cavity will be continued with: optimization of the stem shapes, to improve rf parameters, electromagnetic and mechanical analysis of the end-plates, to be used as slow tuners of the resonant frequency; studies of a possible stiffening system, associated with a computational optimization of the mechanical structure with respect to the vibration eigen-modes; technical drawing of a resonator prototype and of the liquid helium dewar housing it, for sc tests to be done in an existing test cryostat at INFN-LNL. A preliminary application of the ladder resonator has been calculated for the EURISOL driver linac [6].

7 REFERENCES

[1] A. Pisent, "EURISOL, 2nd Town Meeting". http://www.ganil.fr/eurisol

[2] M. Bartsch et al., Computer Physics Communications 72 (1992) 22-39.

[3] G.Bisoffi et al.," Superconducting Radiofrequency Quadrupoles", Proc. Of the 10th Workshop on RF-Superconductivity, Tsukuba (J), September 6-11,2001.

[4] J.R. Delayen, “Medium-beta" Superconducting Accelerating Structures”, Proceedings of the 10th Workshop on RF Superconductivity, Tsukuba, September 2001.

[5] T.Tajima et al., “Evaluation and Testing of a low-β Spoke Resonator”, Proceedings of the 10th Workshop on RF Superconductivity, Tsukuba, September 2001

[6] A. Pisent et al, "Study of a Superconducting 100 MeV Linear Accelerator for Exotic Beam Production", this conference.