DESIGN OF SUPERCONDUCTING CAVITIES FOR 650 MHZ SECTION OF CW LINAC FOR PROJECT-X FACILITY*

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Abstract

Project-X is the proposed high intensity proton facility to be built at Fermilab, US. The Linac is divided into two sections on the basis of operating frequencies i.e 325 MHz and 650 MHz The high energy section of CW linac (160MeV - 3GeV) will be operated at 650MHz frequency & it is composed of two families of superconducting (SC) elliptical cavities which are designed for the geometrical beta 0.61 and 0.90. This paper presents the concept of 650 MHz cavities for Project X including the choice of the basic parameters, i.e. number of cells, geometrical beta, apertures, coupling coefficients, etc. The formulation of cavity optimization and RF results for optimized shapes are also discussed in this paper.

INTRODUCTION

The proposed Project-X facility is based on 3 GeV, 1mA CW SC linac [1]. Schematic of the baseline configuration of the linac is shown in Fig. 1. It includes an ion source which provides 5 mA pulsed beam of H^- ions. Beam is accelerated through the RFQ which is operated at room temperature at 325 MHz frequency. The RFQ is followed by Medium Energy Beam Transport (MEBT) section, which, in turn is followed by SC linac. Linac is segmented into two sections: low energy part and high energy part. The low energy section (2.5-160 MeV) uses three families of SC single spoke resonators i.e. SSR0, SSR1 & SSR2 which are operated at 325 MHz. The high energy section of the SC linac (160 MeV-3.0 GeV) uses two families of 5 cell SC elliptical shape cavities i.e. geometrical beta (β)=0.61 and β=0.9 which are operated at 650 MHz.

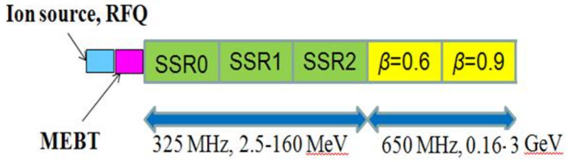

Figure 1: Acceleration scheme

PROSPECTS OF 650 MHZ CAVITIES

The initial proposal for the Project–X (ICD-1) used the 1.3 GHz cavity for the acceleration of beam in high energy section but later it was decided to replace it by 650 MHz cavity (ICD-2). There are lot of benefits due to reduction in operating frequency and these are listed below:

- It simplifies the beam dynamics; Project-X front end operates at 325 MHz, and 2-fold frequency jump at transition to the high energy stage for 650 MHz is easier than 4-fold for 1.3 GHz.
- Lower frequency allows larger aperture that is essential for proton linacs (because of activation, the losses should be smaller than 1 W/m).
- Losses caused by intra-beam stripping will be smaller for lower frequency as well.
- Effect of cavities focusing will be smaller at lower frequencies.
- HOM impedances (transverse and longitudinal) are smaller at lower frequency, and it may in principle allow to get rid of HOM dampers, which may be a source of many problems for proton accelerators (multipacting, RF leak, etc).

DESIGN OF 650 MHZ CAVITY

Goal of the cavity shape optimization was to decrease the field enhancement factors (magnetic and electric) to improve the interaction between the beam and the cavities. In order to do this, the cavity aperture should be as small as possible but there are following constraints which decide the size of aperture:-

Field flatness:- For a given relative error in the frequencies ($\delta f/f_\pi$) of the cavity cells, field flatness ($\delta E/E$) (relative electric fields in adjacent cells) is determined mainly by the distance between the operating frequency and the frequency of the neighbouring mode $\pi(n\text{-}1)/n$, as follows from the linear perturbation theory [2], or by the coupling (k) between the cavity cells and the number of cells (n):

$$\delta E/E \sim f_\pi \,/\, |f_\pi - f_{\pi(n-1)/n}| = f_\pi/\delta f \sim 1/(kn^2)$$

Thus, for required field flatness $k \sim 1/n^2$, and the cavity with smaller number of cells allows smaller coupling k & hence small field enhancement factor. For 9-cell ILC cavity one has $\delta f/f_\pi$ of 6.10^{-4} ($\boldsymbol{k}$=1.87%) so for the same value of $\delta f/f_\pi$, required coupling coefficient (k) in 5 cell cavity should be at least $\boldsymbol{k} > 0.6\%$. RF cavity is efficient for wider range for small number of cells.

Beam losses: - The large aperture provides large transverse acceptance and thus reduces beam losses.

Mechanical stability: - The larger aperture leads to higher stability w.r.t. cell deformations. It also reduces micro- phonics and Lorentz force detuning (LFD) however LFD is not our main concern as its effects are negligible for CW mode.

Reliable surface processing: - The large aperture is useful from the surface cleaning point of view as it

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provides better ability for chemical etching at the equator region.

The RF design of 5 cell, 650 MHz β=0.61 and β=0.9 cavities are optimized using above guiding principles. The RF parameters are summarized in Table1.

Table 1: RF Parameters of the 650 MHz Cavities.

Beta	0.61	0.9
R/Q, Ohm	378	638
G-factor, Ohm	191	255
Max. gain per cavity, MeV(on crest)	11.7	19.3
Accelerating Gradient, E_{acc}, MV/m	16.6	18.7
Peak surface electric field,E_{pk},MV/m	37.5	37.3
E_{pk}/E_{acc}	2.26	2
Peak surface magnetic field, B_{pk}, mT	70	70
B_{pk}/E_{acc}, mT/ MV/m	4.21	3.75

POWER COUPLER

Every 650 MHz cavity of the SC linac is powered via coaxial fundamental power coupler. The operational requirements of power coupler for 650 MHz cavity are summarized below:

- It should be able to transmit about 5-30 kW RF power to cavities in CW regime.
- It should allow assembling of RF cavities with a coupler in clean room and further installation in cryomodule.
- Couplers should not increase the cryogenic losses significantly. The cryogenic losses per cavity at 2K are ≤ 25 W & coupler contribution in these losses should not be more than 1W.
- From installation and hardware point of view, it is good to have similar design of power coupler in all sections.
- Simple, reliable & cheaper coupler is preferred.

The power coupler for 650 MHz cavities has been designed using above guiding principles. Layout of the coupler is shown in Fig. 2.

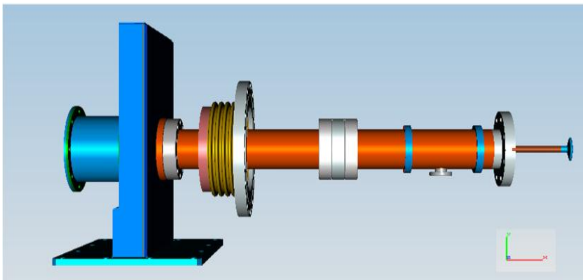

Figure 2: Power coupler for 650 MHz cavities.

The outer and inner diameters of coupler are 73 mm and 12.7 mm respectively. Outer conductor is thin-wall stainless steel pipe coated with copper. Inner conductor is copper pipe. Coupler is dismountable. It is divided in two parts by vacuum coaxial ceramic window. Vacuum part, which includes a ceramic window, has to be mounted into ILC-type cryomodule assembled with cavity. It determines maximum length of vacuum part. Vacuum part includes three thermo-anchors at 5K, 70K and 300K. Inner conductor of coupler is air cooled. Coupler is connected to the cryomodule through bellows to compensate for thermal shrinking. Simulations have been performed to study multipacting behaviour of power coupler. Fig. 3 shows the multipacting distribution of growth rate with power.

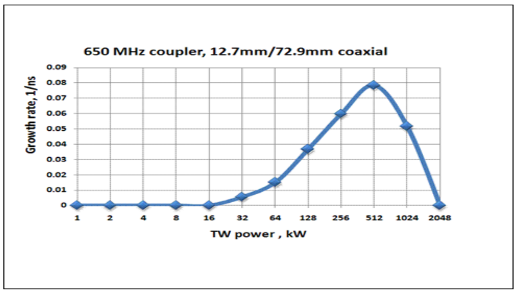

Figure 3: Multipacting growth rate

MECHANICAL DESIGN & ANALYSIS

A series of mechanical analysis has been performed for both families of 650 MHz cavities to verify the maximum allowable working pressure and plastic deformation limit of cavities [3]. It is found that for wall thickness of 4mm, β=0.61 and β=0.9 single cavity do not undergo any plastic deformation for working pressure of 1 bar, however, for safety pressure of 2 bar, β=0.9 cavity does not show any plastic deformation but β=0.61 cavity experiences some plastic deformation. Parallel studies are in progress to design the helium vessel with mechanical design of cavity to reduce the frequency shift due to helium pressure fluctuation which is a major source of microphonics. Fig.4 shows layout of β=0.9, 5 cell 650 MHz cavity with space for HOM damper.

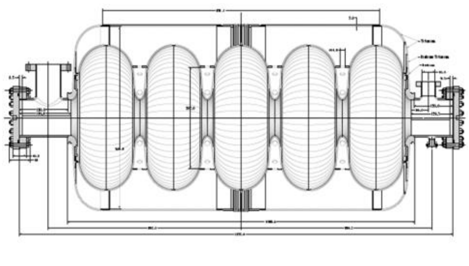

Figure 4: Layout of 650 MHz β=0.9 cavity .

CONCLUSION

5 cell, 650 MHz cavities are designed for β=0.61 and β=0.9 for high energy section of Project-X SC linac. The operational requirements for power coupler are formulated and a coaxial power coupler is proposed.

REFERENCES

[1] S.D. Holmes "Project X: A Multi-MW Proton Source at Fermilab", IPAC 2010.
[2] H. Padamsee, "RF Superconductivity for accele rators", John Wiley & sons, Inc., p.136.
[3] S.Barbanotti et al, "Status of 650 MHz cavity", LINAC 10.