DEVELOPMENT OF THE SCRF β=0.81 CAVITY FOR PROTON DRIVER

I. Gonin, T.Khabiboulline, N.Solyak

FNAL, Batavia, IL 60510, U.S.A.

Abstract

Proton Driver Linac needs different types of superconducting accelerating cavities to accelerate protons from 15 MeV to 8 GeV. In high energy part of the linac E > 400 MeV it was proposed to use two types of elliptical 1.3 GHz cavities: squeezed β=0.81cavity and TESLA cavity. In paper we discuss two possible designs of the elliptical β=0.81 cavity for the beam acceleration in range of 400-1200 MeV: SNS cavity, scaled to 1.3 GHz, and Low Losses (LL) cavity. The shape of LL cavity was optimized to improve Hpeak/Eacc ratio. In paper we present the analysis of cavity electromagnetic properties, calculations of the high order modes and detuning due to Lorentz forces for both designs. Better cell-to cell coupling in LL cavity allows use of the 8-cell design. The disadvantage of LL design is ~10% higher surface electric field with compare to SNS scaled design. The final choice of design will be done after additional studies in frame of MSU/FNAL collaboration by the end of 2005.

INTRODUCTION

Proton Driver linac requires about sixty β=0.81 cavities. Cavity length (number of cells) needs to be optimized to reduce the cost of the linac. Optimum length is always trade-off between advantages from using longer cavity (less number of cavities, couplers, etc.) and arising difficulties (field flatness, and reduction of transit time factor for proton energy different from synchronous). The optimum number of cells in cavity is found 7-8 depending of cavity shape.

For the PD SC cavities we suppose that the maximum surface field not exceeds fields in TESLA cavity with 26 MV/m accelerating gradient. We assume that this level can be reliably achieved with existing state-of-art technology of superconducting cavities. The corresponding maximum value of surface fields in TESLA cavity are: Epeak = 52 MV/m and Hpeak = 111 mT. Fig.1 shows the energy gain per cavity in comparison of 6-cell and 8-cell cavities, both at with 52 MV/m surface peak electric fields and -30 degrees beam out of crest phase. As seen from picture 8-cell cavity option is more effective to compare with 6-cell cavity, that will allow reduce ~10 cavities (including power couplers, phase shifters etc) or ~2 cryomodules.

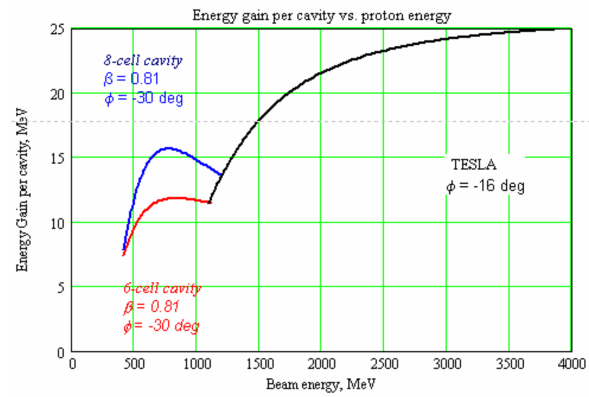

Fig.1. Energy gain per cavity vs. proton energy. Acceleration out of crest phase is included.

RF DESIGN OF β=0.81 CAVITY

For the geometry of the squeezed cavity we consider two choices. The first one is SNS like design, scaled from 805 MHz to 1300MHz. By adding two more mid-cells this cavity can be extended to 8-cell cavity.

The second choice is new optimized design for 8-cell cavity. The goal of optimization was to reduce Hpeak/Eacc ratio, which allows minimize the power losses in cavity, or, for the same surface magnetic field, and increase achievable acceleration gradient. The diameter of the end-tube was chosen the same as for TESLA cavity. In this case we can use the same TESLA design of the end-groups, including HOM couplers, main coupler, antenna and conical flanges. The only difference is the cell geometry.

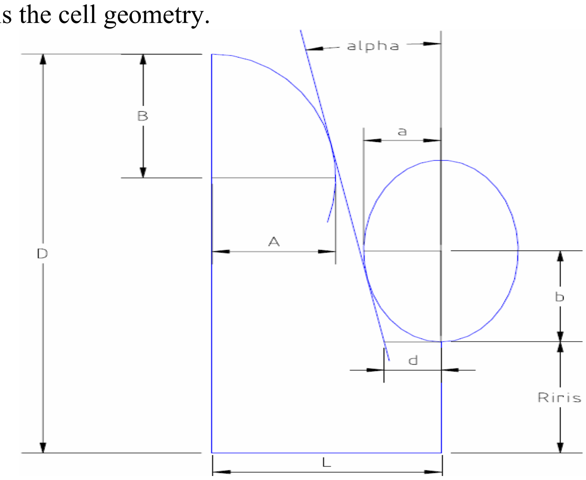

Figure 2. Cell shape parameterization.

The playing parameters for the mid-cell optimization are wall inclination angle (α) and ellipse ratios at the iris and equator (see Fig.2). Iris radius was fixed ri=30 mm, the equator radius was defined by working frequency. As a reference point for the comparison the SNS-like geometry was used. The decreasing of the inclination angle redistributes magnetic field along the bigger surface, which cause reduction of the peak magnetic field and increasing of shunt impedance and geometrical factor. It also increases cell-to-cell coupling and even rigidity of the cavity. Only one parameters become worse – the surface electric field, but DESY experience shows that the cavity performances are not limited by electric field if appropriate surface preparation is applied (high pressure water rinsing, clean assembly, etc). The main parameters of the cavity for two different inclination angles vs. ellipse ratio at equator are shown in Fig.3. All parameters are normalized to the parameters of SNS-like cavity.

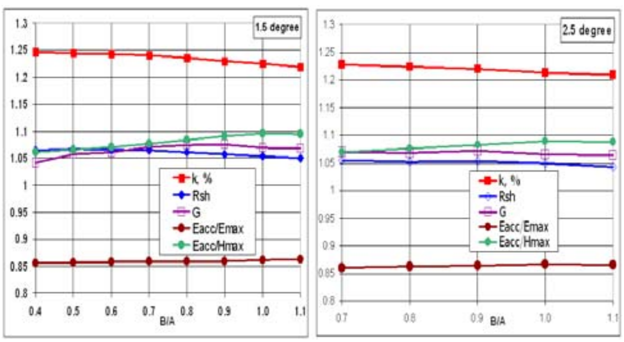

Figure 3. Normalized cavity parameters vs. ellipse ratio at cell equator for inclination angle 1.5 and 2.5 degree.

The chosen geometry of the cavity and main parameters are shown in Fig.4. As one can see the magnetic field in this geometry is ~10% lower than for SNS-like design for the same accelerating gradient. The TESLA cavity parameters are shown in the table for comparison.

	Scaled SNS	LL Squeezed	TESLA
β	0.81	0.81	1
Wall angle [deg]	7	2.5	13.3
Ep/Ea	2.19	2.47	2.0
Bp/Ea (mT/MV/m)	4.79	4.33	4.26
k (%)	1.52	1.8	1.87
R/Q per cell (Ω)	80.8	84.2	115
G (Ω)	227	245	270
Eacc (MV/m)	25	25	25
Ep (MV/m)	54.8	61.7	50
Hp (mT)	119.8	108.8	106.5
N cell	6/8	8	9
(N_cell)2/(b*k)	2924/5200	4390	4330
(R/Q*G) / N_cell	18342	20629	30472

Figure 4. Main cavity parameters at E_acc = 25MV

The sensitivity of the field flatness to frequency errors in multi-cell cavity is defined by parameter:

$$a_f = (Ncell)^2 / (\beta \cdot k)$$

Where k is cell-to-cell coupling. The next table shows comparison of that parameter for the scaled SNS and LL cavities with those for other cavities. One can see that 7-cell SNS cavity and 8-cell LL cavity have the same parameters as TESLA 9-cell cavity, where the field flatness is better than 95%.

Scaled SNS 6 / 7cell	LL β=0.81 8-cell	LL SEBAF	SNS β=0.61	RIA β=0.47	TES LA
30 / 40.8	**43.9**	32.9	38.8	**50.4**	**43.3**

MONOPOLE MODES IN LOW LOSSES SQUEEZED CAVITY

The dispersive diagram for the monopole modes and the plot of the R/Q for 8-cell LL cavity are shown in Fig.5. Dotted line corresponds the proton beam with β=0.81.The maximum R/Q correspond working frequency 1300 MHz.

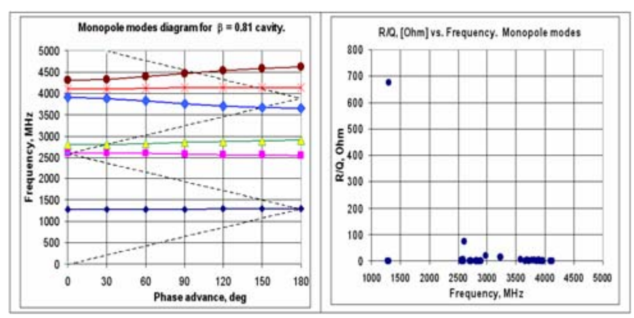

Figure 5. Dispersive diagram of the mid-cell (left) and R/Q vs. frequency (right) for monopole modes.

DIPOLE HIGH ORDER MODES

Dispersion diagram for the dipole modes, calculated for mid-cell geometry is shown in Fig.6 (plot on the left). One can see that only 1st and 3rd pass bands are narrow, that means that we can expect highest R/Q for these modes. Right plot in Fig.6 shows R/Q value vs. frequency calculated for full 8-cell cavity. Field distributions for HOMs with the highest parameter R/Q is plotted on Fig.7. All of them have good coupling with the beam pipe and can be effectively dumped by HOM couplers. As it was mentioned above end groups design for β=0.81 cavity is the same as TESLA cavity.

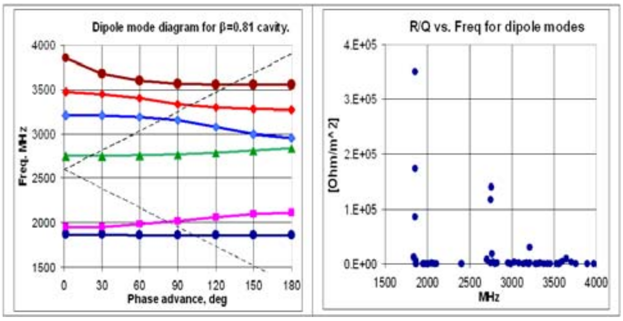

Figure 6. Dispersive diagram of the mid-cell (left) and R/Q vs. frequency (right) for dipole modes.

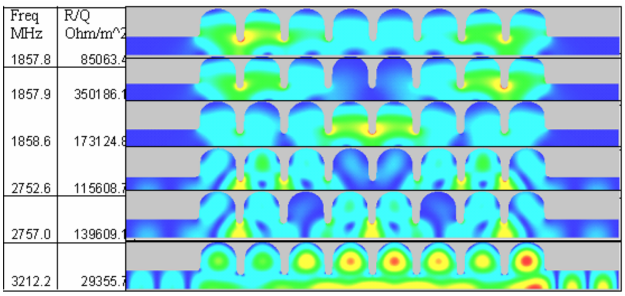

Fig.7. E-field pattern for dipole HOMs with the highest R/Q.

LORENTZ FORCES DETUNING

Lorentz forces were simulated by ANSYS for the regular mid-cell with the fixed longitudinally at the irises. As known from simulations of the Lorentz detuning for the TESLA cavity these boundary conditions provide good agreement with the experimental data. Electromagnetic pressure distribution along the surface of the mid-cell is shown in Fig.8 on the left. Pressure is negative for electric field and positive for magnetic field. The picture of the surface displacement due to Lorentz forces, simulated for Eacc=25 MV/m is plotted on right. Both electric and magnetic fields detune cavity in the same direction.

Cavity detuning can be reduced by stiffening rings as it was done in TESLA cavity. The position of ring was optimized to get the minimum detuning. The result of optimization is shown in Fig.9 (left) where detuning coefficient KL is plotted vs. position of stiffening ring. The minimum detuning will be for 42.5mm. Thickness of ring 3 mm is the same as thickness of niobium used for cavity production. The increasing of the wall thickness reduces Lorentz detuning almost linearly (Fig.9 on right). The stiffening ring in simulation was in optimum position.

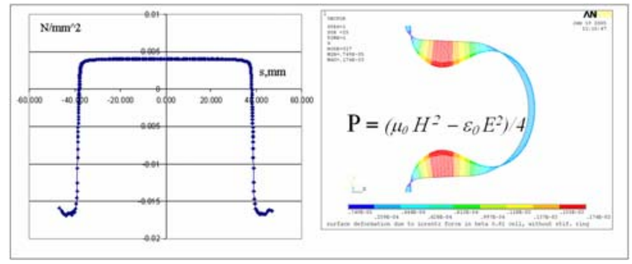

Figure 8. Pressure distribution along the cavity (left) and vector of displacement in the cavity (right).

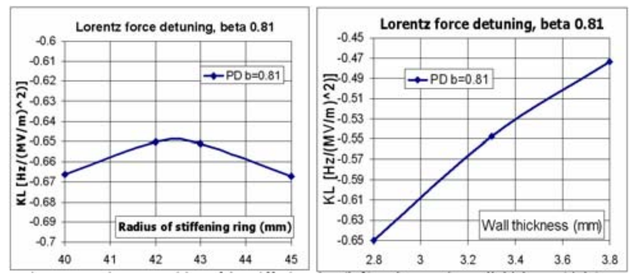

Fig. 9 Detuning vs. position of the stiffening ring (left) and vs. cavity wall thickness (right).

CONCLUSION

Preliminary studies of two different designs for squeezed elliptical cavity with b=0.81 SNS-scaled cavity and Low Losses cavity shows that both designs will work for the Proton Driver, but LL design has more advantages: lower surface magnetic field and higher cell-to-cell coupling. This is important for 8-cell cavity. End-tube assembly for LL cavity assumed the same as for the TESLA cavity. Lorentz forces for LL is smaller that for TESLA cavity. HOM analysis didn't show trapped modes with high R/Q. Need more studies and optimizations to accept design.

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