LOW-BETA STRUCTURE FOR HIGH ENERGY PART OF PROJECT X*

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Abstract

Long 11-cell, β=0.81 L-band structure is considered as an initial stage of the high-energy part of the Project-X in order to accommodate to a standard Type-4 cryomodule. The cavity shape is optimized for maximal energy gain providing the same time field flatness along the structure not worse than for ILC β=1 cavity, and the same ratio of surface magnetic field to electric field. The results of spectrum analysis for monopole and dipole HOMs is presented as well.

INTRODUCTION

The main part of the 2 MW proton source, Project – X [1], that is under development at FNAL, is the 8-GeV H^- linac. In the linac basic design [2] the high –energy part of the accelerator consists of three sections: so-called S-ILC for the acceleration from 400 MeV to 1.2 GeV, the ILC1 part for acceleration from 1.2 GeV to 2.4 GeV, and ILC2 part for acceleration up to 8 GeV. The parameters and the cryomodule schemes are shown in Fig. 1. In S-ILC part 7 cryomodules are used that contain eight 8-cell, β=0.83 squeezed SC cavities at 1.3 GHz, and two focusing lenses (see Fig. 1).

Sections	S-ILC	ILC1	ILC2
β	0.83	1	1
# of cavities	56	63	224
# of cryomodules	7	9	28
E_{peak}, MV/m	52	52	52
Focusing	FR^2DR^2	FR^3DR^4	FR^8DR^8

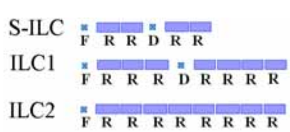

Figure 1: Basic design parameters [2] of the high-energy part of the linac (above), focusing scheme for the sections (below). F - focusing lens, R - cavity, D – defocusing lens.

Different types of squeezed elliptical SC cavitiess were considered for these purpose, see review [3] at present Conference. However, 7- or 8-cell cavities require development of a special cryostat that is time-consuming and expensive. In this paper the idea is presented to use a standard Type-4 ILC cryomodule for S-ILC part with squeezed β=0.81 cavities. The cavity has 11 cells and the same length as for 9-cell, β=1 ILC cavity that allows use a cryomodule length more effectively. The required rf power is about the same, and the same couplers may be used as for β = 1 cavities. In addition, exactly the same auxiliary components (vacuum vessel, tuner, tooling, etc) may be used. Note, that this scheme allows the same type of cryomodule in all three sections of the high-energy part of the linac. Below the variants for cryomodules and focusing system are discussed as well as details of the 11-cell cavity design.

GENERAL

Thee are the following proposed changes compared to the basic design [2]: (i) in S-ILC section the magnet configuration change from FR^2DR^2 to ILC-like R^4FDR^4FD with a doublet instead of a quad (see Fig. 2); (ii) long cavities (11-cell) instead of short (8-cell); (iii) Maximal surface electric field change from 52 to 50 MV/m, (iv) S-ILC section is based on the same Type-4 cryomodule. To keep the same focusing properties in S-ILC section, an additional doublet in the separate cryostat is used (needs to be designed); (v) in ILC1 and ILC-2 sections Type-3 cryomodule with two quads inside is replaced by Type-4 cryomodule with one quad in the middle, it is ILC compatible solution; (vi) to save the same focusing in ILC1 section, an additional quad in separate cryostat is added similar to one in S-ILC section.

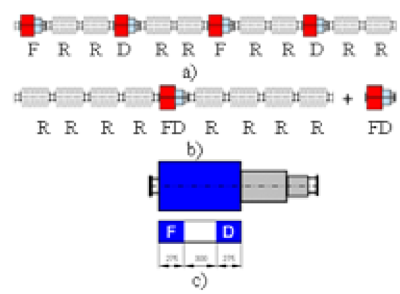

Figure 2: The cryomodule scheme: (a) - basic design that contains four lenses and eight 8-cell cavities; (b) proposed Type-4 ILC cryomodule containing eight 11-cell cavities and doublet, and additional doublet in a separate cryostat; c) schematic of the doublet.

The gradient in the S-ILC section is relaxed to 19 MeV/m (that corresponds to the peak surface field of 46 MV/m) instead of 23.7 MeV/m in the basic variant in order to make transition to β=1 at the end of a cryomodule. The beam dynamics was optimized for this scheme using Trace3D code [4]. Note, that six cryomodules with 11-cell cavities may be used with the surface electric field of 53.6 MV/m. The calculated beam envelopes in S-ILC section and matching of the S-ILC section to ILC1 section are shown in Figure 3.

Parameters of the sections are shown in the Table I.

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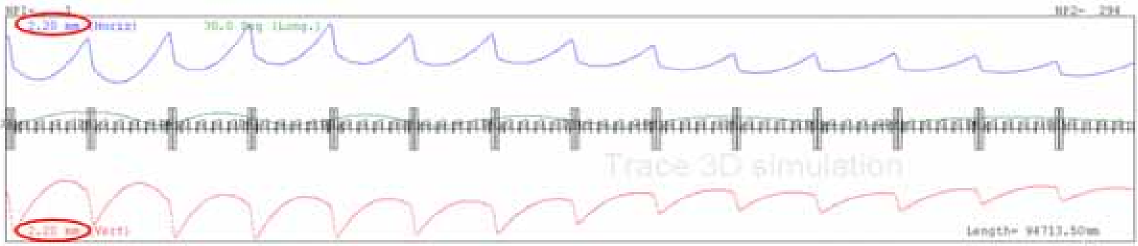
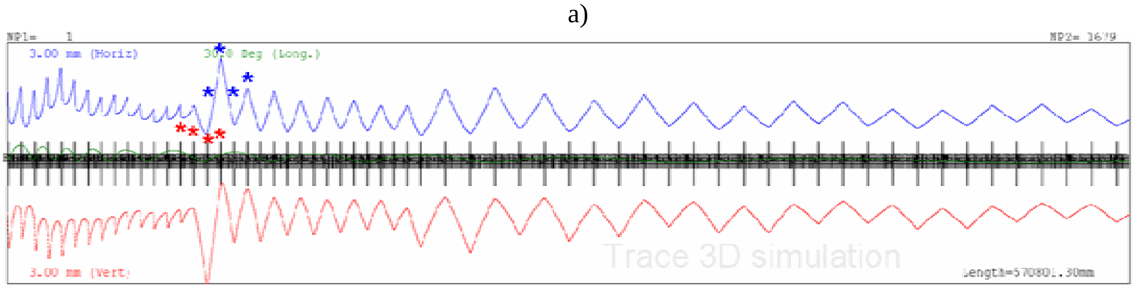


a)



b)

Figure 3: The beam envelope in S-ILC section (a) and S-ILC matching to the ILC1 (b). Blue – horizontal, red – vertical, green – longitudinal r.m.s. size in deg. Stars show the elements used for matching.

Table 1: Parameters of the Sections

Sections	S-ILC	ILC1	ILC2
β	0.81	1	1
# of cavities	56	64	232
# of cryomodules	7	8	29
# of cells	11	9	9
Gradient, MeV/m	19	25	25
Focusing	FDR^4	FR^4DR^4	FR^8DR^8

Another, much more attractive approach is to use modified Type-4 ILC cryomodule that has ports for lens leads in the positions of 2d, 5th and 8th cavities. The scheme of the focusing in this case is shown in Figure 4. Note, that this approach doesn't demand a separate cryostat for a doublet.

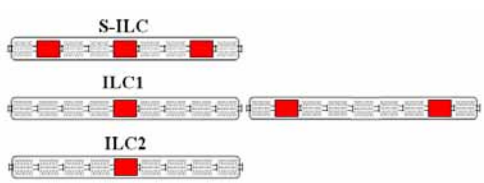


Figure 4: Modified Type-4 ILC cryomodule schematics. The cryomodule in S-ILC section contains three quads in the positions of 2d, 5th, and 8th cavities, and six 11-cell cavities. ILC1 has the two different quad location: in 5th position, and in 2d and 8th positions.

The cavity optimization was made taking into account that for the higher number of the cells in the cavity the coupling is to be higher as well in order to preserve the field flatness along the cavity. For fixed flatness the coupling k_c is roughly proportional to the $\sim N^{3/2}$ [5], N is the number of cells in the cavity. For ILC cavity N=9 k_c=1.87%; thus, for N=11 k_c=2.47%. It was suggested also that (i) maximal surface magnetic field is fixed to be the same as for ILC cavity; (ii) the maximal surface electric field does not exceed one for ILC cavity; (iii) the geometrical dimensions are determined to maximize the acceleration gradient. Parameters of the regular cell optimized by SLANS code [6] are shown in Figure 5, the end caps were optimized to provide the filed flatness. Lorentz detuning factor was calculated for mid cell using ANSYS, see Figure 6. The optimal stiffening ring radius is 45 mm. Note the longer cavity has pay-off: the surface fields are to be the same as for ILC cavity, thus, the acceleration gradient for a longer structure is smaller; longer cavities can be used in more narrow energy range and the risk of occurrence of trapped modes is greater in longer structure. However, 11-cell cavity is still more effective than the shorter cavities being used in Type-4 ILC cryomodule, see Figure 7, where energy gain per cavity is shown as a function of β for the β=0.81 cavities containing different number of cells. For comparison, the same dependence is shown for ILC β=1 cavity, and triple-spoke cavity (TSR) that will be used at the end of the low-energy part of the linac [2].

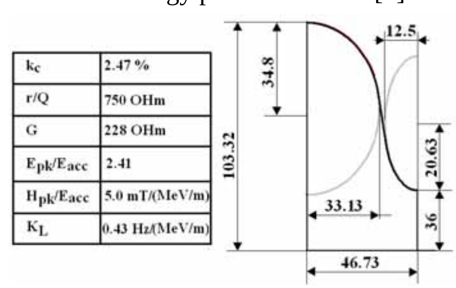


Figure 5: Parameters and dimensions (in mm) of the optimized regular cell. Lorentz factor K_L is given for optimal stiffening ring.

In the Table 2 the monopole HOM spectrum is shown. The modes 13-15 of the 3d branch have the highest r/Q. The resonance frequencies are about 2848 MHz, that is far of the nearest beam current harmonic of 325 MHz, 2925 MHz. However, chopping 33% at 53 MHz [1] will produce a first side spectrum line at 2872 MHz that is still far of the resonance taking into account spread of frequencies of ~6 MHz [7]. Chopping 6% at 89 kHz [1] produces much smaller spectrum line. Dipole mode spectrum is shown in Table 3.

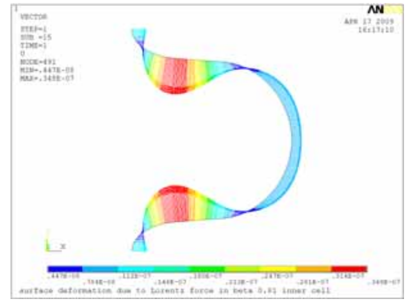
Table 2: Monopole Mode Spectrum

mode number	frequency, MHz	r/Q, Ohm
1	2696.84	5.92E-01
2	2698.78	3.84E-01
3	2701.87	7.35E-01
4	2705.90	6.94E-02
5	2710.64	1.50E-01
6	2715.68	8.22E-03
7	2720.78	3.60E-01
8	2725.59	1.01E-02
9	2729.78	4.41E-01
10	2732.94	3.18E-02
11	2737.53	2.48E+00
12	2737.57	5.04E-01
13	2847.79	6.13E+00
14	2847.89	2.39E+01
15	2848.08	1.00E+01
16	2848.34	2.93E-01
17	2848.69	2.39E+00
18	2849.1	8.56E-02
19	2849.54	1.26E+00
20	2849.93	2.43E-02
21	2850.44	3.71E+00
22	2850.46	8.77E-02

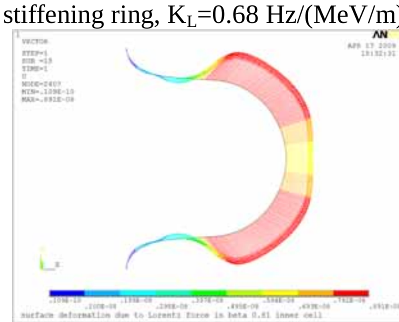
Table 3: Dipole Mode Spectrum

mode number	frequency, MHz	$r_\perp$/ Q, Ohm/cm²
1	1754.7	0.000355294
2	1755.99	0.0773029
3	1757.75	0.000861171
4	1759.61	0.473891
5	1761.34	0.000492231
6	1762.83	5.88134
7	1764.05	13.6904
8	1764.98	4.3609
9	1765.63	0.00924244
10	1766.02	0.144142
11	1822.49	1.14278
12	1822.49	0.677775
13	1874.05	1.66406e-005
14	1886.47	0.0103965
15	1906.51	0.0023291
16	1933.42	0.00443845
17	1966.18	0.00247328
18	2003.39	0.0144589
19	2043.08	0.000550195
20	2082.42	0.00158643
21	2117.35	0.00224054
22	2142.34	6.40971e-005

The modes 6-8 of the 1st branch have the highest $r_\perp/Q$. The resonance frequencies are about 1763-1765 MHz that is far of the nearest beam current harmonic of 325 MHz, 1625 MHz. However, chopping 33% at 53 MHz will produce a third side spectrum line at 1784 MHz that is still far of the resonance.



a) No stiffening ring, K_L=0.68 Hz/(MeV/m)^2



b) With the ring, K_L=0.43 Hz/(MeV/m)^2

Figure 6: Mid cell deformations caused by the Lorentz force. Wall thickness is 3 mm.

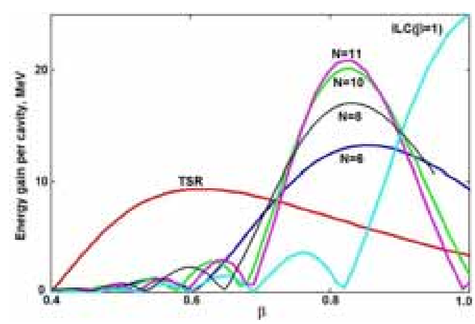


Figure 7: The energy gain per cavity versus β for the β=0.81 cavities with different number of cells. The surface peak electric field is 50 MV/m.

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