DEVELOPMENT OF SUPERSTRUCTURES FOR HIGH CURRENT APPLICATION*

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Abstract

Devices for acceleration of electron currents beyond 100 mA are becoming increasingly interesting for high power Free Electron Lasers (FEL) or for Energy Recovering Linacs (ERL). To achieve photon beams of several hundred kW, low emittance electron beams of up to 1 A have to be delivered to undulators from a driving linear accelerator. High quality beams and stable operation of accelerating sections are only possible if Higher Order Modes (HOM) generated by the beams can be sufficiently damped. The positive experience with the HERA 4-cell cavities [1], in which the dominant monopole modes are damped to Q_{ext} ~ 700 and all dipole modes to Q_{ext}< 6000 makes it highly likely that a superstructure (SST) consisting of two weakly coupled subunits and employing coaxial HOM dampers of the DESY type can be successfully adapted to a properly designed cavity for acceleration of a ~1 A beam. This contribution describes the first approach to design a 750 MHz SST for a 1 A electron beam. The calculated R/Q values of the HOM's of this SST are quite favorable. The total impedance of the first 16 monopole modes is ~ 140 Ω, approximately a factor of 3 smaller than the impedance of the fundamental mode. It seems very likely that the HOM's can be suppressed to the appropriate levels for stable beam operation. In order to explore achievable damping, a 1500 MHz copper 1:2 model of the SST was built and the Q_{ext} – values of the dominant HOM's were measured with various HOM coupler configurations. It can be concluded with some confidence that the necessary damping for a 1 A machine can be achieved with the proposed superstructure configuration. However, it is essential to repeat these measurements on a 1:1 model.

INTRODUCTION

In 2002, 2x5-cell SST's were proposed as a replacement for 7-cell cavities in order to increase the instability threshold of the linac driving upgrade of the IR FEL at JLAB [2]. Beam dynamics simulations with MATHBBU showed that with these new cavities the threshold increased almost by a factor of 26 from 4 mA to 103 mA [3]. This significant improvement was due to much better HOM damping. For damping measurements, both SST and 7-cell structures were equipped with four identical HOM couplers. Appropriate positioning of HOM couplers in the SST (two were attached at the interconnecting tube) results in much better suppression of parasitic modes that limit performance of 7-cell cavities, in spite of having three more cells.

The next upgrade of the FEL at JLAB or the next generation of coherent light sources, radiating power of the order of several 100 kW's, will require higher currents, in the range 0.5-1 A. Two major changes to present JLAB accelerating structures will be undertaken to ensure strong reduction of parasitic impedances and thus stable machine operation.

First, we propose to lower the cavity resonant frequency to 750 MHz. The IR- demo and upgrade versions of the JLAB FEL's were driven by 1.5 GHz linac. This will result in much lower (R/Q)'s of transverse parasitic modes. Secondly, following encouraging results measured on 2x5-cell SST, we propose to use an SST, but based on subunits with only two cells and equipped with more HOM couplers.

750 MHZ SST; COMPUTATION

The proposed SST, made of two 2-cell subunits and having four HOM couplers attached is shown in Fig. 1. There is enough space to attach nine HOM couplers if needed, three on each end-tube and three on the interconnection, azimuthally spaced at 120°. An input coupler port is placed at the left end-tube. Some geometry data are listed in Table 1. The RF-parameters of the fundamental mode (π-0) are listed in Table 2 and the amplitude of the accelerating field on axis is shown in Fig. 2. Computed frequencies and (R/Q)'s of parasitic dipole modes and monopole modes are listed in Tables 3 and 4 respectively.

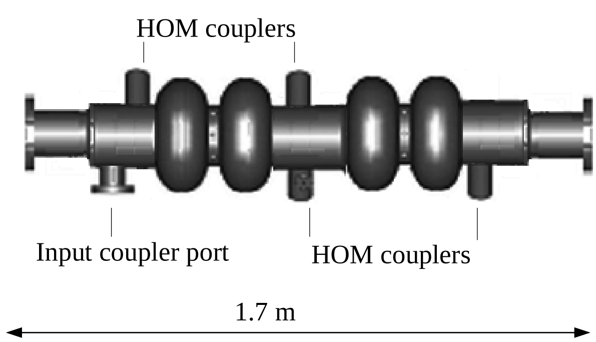

Figure 1: Layout of proposed SST 2x2-cell, 750 MHz with four HOM couplers and with the port for input coupler.

Table 1: Geometry of the 750 MHz SST.

Equator Ø	[mm]	363
Center iris Ø	[mm]	130
Beam tube Ø	[mm]	180
Beam tube Ø after taper	[mm]	120
Cell length	[mm]	200
Length of interconnecting tube	[mm]	200
HOM coupler body Ø	[mm]	~ 70

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Table 2: RF properties of 2x2-cell SST.

Frequency	[MHz]	749.55
Geometry Factor	[Ω]	280
(R/Q)	[Ω]	354.5
Epeak / Eacc	-	2.2
Bpeak/ Eacc	[mT/(MV/m)]	4.74
Coupling between subunits	[%]	0.024

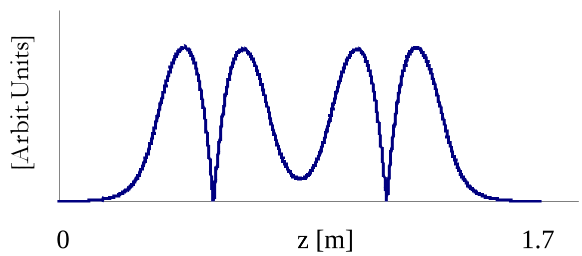

Figure 2: Computed E_{acc} amplitude on axis of the accelerating π-0 mode.

The computation confirmed that the (R/Q)'s of dipole modes are very low. Except for mode No. 5, all others have (R/Q) < 1 Ω/cm^2. The transverse electric field on axis of mode No. 5 (Fig. 3) indicates that a significant part of the energy is stored in the interconnecting tube to which two (three) HOM couplers can be attached. This should provide good damping of that mode. Impedances of monopole modes are spread over whole computed frequency range, partially above the cut-off frequency of the end beam tubes. The computation showed that all monopole modes also have strong fields in the end beam tubes and/or in the interconnection. Thus there should be enough coupling to

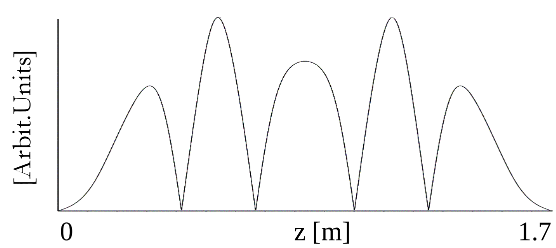

Figure 3: Computed transversal electric filed amplitude on axis of the highest impedance dipole modes.

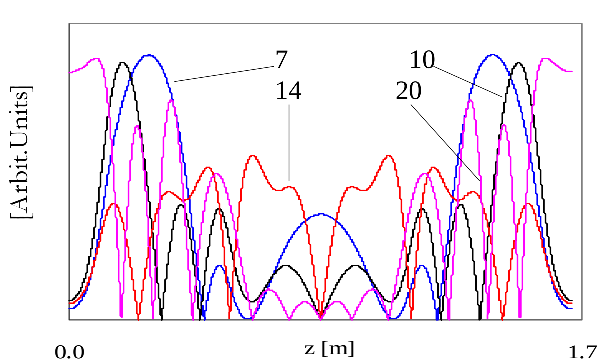

Figure 4: Computed electric field amplitude on axis of the four monopoles modes with the highest (R/Q).

HOM couplers to keep Q_{ext} of these modes very low. The electric field amplitudes of the highest impedance monopole modes No. 7, 10,14 and No. 20 are shown in Fig. 4.

Table 3: Dipole modes of 750 MHz.

Mode	f [MHz]	R/Q [Ω/cm^2]
1	854.72	0.10
2	863.41	0.15
3	889.84	0.23
4	904.81	0.43
5	989.99	2.82
6	1000.50	0.00
7	1072.89	0.10
8	1074.66	0.55
9	1124.02	0.02
10	1124.02	0.17
11	1137.38	0.42
12	1302.59	0.02
13	1330.87	0.00
14	1340.75	0.16
15	1413.94	0.26
16	1435.34	0.28
17	1534.49	0.75
18	1565.74	0.52
19	1565.87	0.01
20	1640.35	0.03
21	1645.74	0.02
22	1706.16	0.79
23	1720.45	0.00
24	1749.72	0.05
25	1764.65	0.01
26	1775.82	0.08
27	1814.24	0.07
28	1906.71	0.01
29	1921.95	0.13
30	1939.47	0.05

Table 4: Monopole modes of 750 MHz.

Mode	f [MHz]	R/Q [Ω]
5	1308.13	3.81
6	1315.96	0.07
7	1316.84	20.02
8	1360.73	8.71
9	1400.08	0.17
10	1402.31	13.76
11	1446.81	4.79
12	1506.11	0.27
13	1522.50	0.68
14	1543.08	36.53
15	1575.14	8.05
16	1646.74	9.34
17	1647.14	6.73
18	1724.10	4.95
19	1898.32	0.71
20	1900.47	19.68

SCALED 1500 MHZ MODEL

Some of the computed results presented above can be verified with measurements of the 1:2 model of the proposed SST. We have built a 1500 MHz copper model using existing tooling for the original CEBAF cavities. The model (Fig. 5) has been equipped with four coaxial type HOM couplers, based on the TESLA design, which were built for models of the 7-cell CEBAF upgrade cavities. Prior to HOM damping measurements, the model was tuned to balance the amplitudes of the accelerating mode in all four cells (95 %, Fig. 6).

We have performed the preliminary HOM damping measurements after attaching four HOM couplers. The results are summarized in Table 5, Measured Q_{ext}, are rather low and can even be lower when additional HOM couplers are attached. We plan to measure damping with seven HOM couplers (three additional couplers are being manufactured).

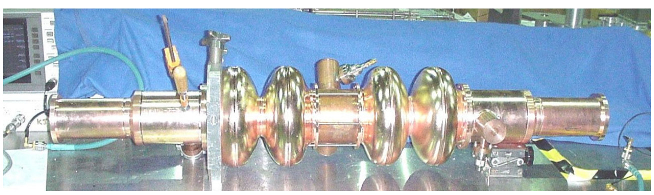

Figure 5: 1500 MHz copper model of the 2x2-cell SST.

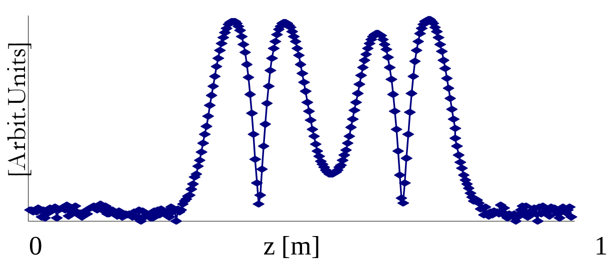

Figure 6: Measured field profile of the accelerating mode (after tuning).

Table 5: Measured values of Q_{ext} for monopoles and dipoles.

	Monopoles		
	f [MHz]	R/Q [Ω]	Q_{ext}
8	2632.19	0.7	473
9	2643.01	5.5	776
10	2679.79	2.7	295
11	2789.56	1.4	2292
12	2832.14	5.2	647
13	2897.00	1.6	981
14	2939.12	21.1	320
15	2994.62	2.8	5163
16	3028.67	29.0	not detectable
	Dipoles		
	f [MHz]	R/Q [Ω/cm^2]	Q_{ext}
5 a	1920.26	9.5	306
5 b	1926.50	9.5	343

FINAL REMARKS

Since the architecture and beam optics of a high current driving linac are unknown at present, we cannot specify limits in Q_{ext}, although it is obvious that lower values are preferable.

It seems reasonable to expect that, in a linac operated in energy recovery mode, most of the beam spectral power would be carried at the second harmonic of the cavity fundamental. We tried to estimate the HOM power deposited if a 750 MHz SST is operated with a 1 A beam and damping of parasitic modes is as it was measured on the scale model. Power deposited by 1 A accelerated and 1 A decelerated beams is shown in Fig. 7 a, b as a function of the relative frequencies of beam spectral lines and monopole modes. The original match (Fig. 8) is changed to simulate fabrication errors by shifting computed frequencies of monopoles randomly in the range ±60 MHz. For this frequency range the deposited power can be as much as 50 kW (Fig. 7a). If frequency spread is in the range of ±20 MHz the deposited power is below 700 W (Fig. 7b), which is still rather high but it can be transferred out of cryostat by proper coaxial cables used in output lines of all HOM couplers. At the original position only 200 W will be deposited. The conclusion is that a proper design of a high-current cavity will avoid overlapping of beam spectral lines and parasitic modes and careful fabrication of cavities will be required to avoid unacceptably large deposited power.

The next step towards a 1 A structure will be building a copper model at 750 MHz for further optimization of

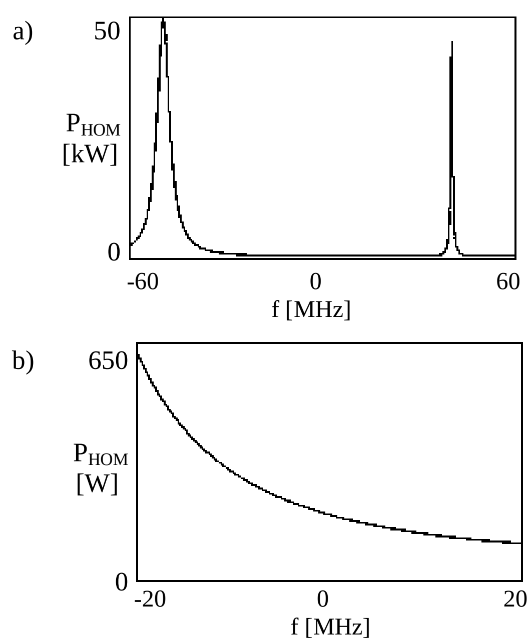

Figure 7: Power deposited in computed monopole modes of the 750 MHz SST vs. relative frequencies of modes' frequency and the beam spectral lines; a) $\Delta f = \pm 60$ MHz, b) $\Delta f = \pm 20$ MHz.

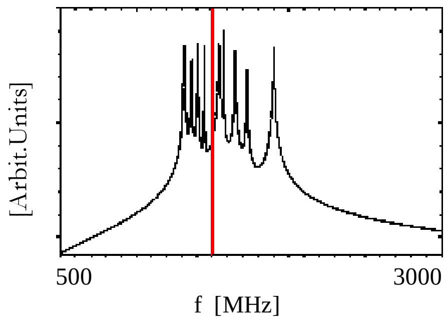

Figure 8: Relative frequencies of computed 750 MHz SST monopoles and the one spectral line at 1500 MHz.

the HOM damping and to study a new HOM coupler design with optimized monopole mode suppression.

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