SUPERSTRUCTURES FOR HIGH CURRENT FEL APPLICATION

J. Sekutowicz, K. Beard, P. Kneisel, G. Wu, TJNAF, Newport News, 23606 VA, USA
C. Thomas, Synchrotron SOLEIL, 91192 Gif-sur-Yvette Cedex, France
S. Zheng, Tsinghua University, 100084 Beijing, China

Abstract

The next generations of FELs at TJNAF will produce coherent light at power levels of 10 kW and 100 kW, respectively [1]. To achieve these power levels, 200 MeV electron beams of 10 mA and 100 mA have to be accelerated in the linear accelerators of the devices. The accelerators will be based on superconducting technology. Stable operation of these machines is only possible if the cavity Higher Order Modes (HOM) excited by the beams can sufficiently be damped. One of the possible accelerating structures which can fulfill this requirement, is a superstructure (SST) made of two weakly coupled subunits and equipped with appropriate HOM couplers. Based on the positive experience at DESY with 1.3 GHz superstructures, we are investigating for possible use similar structures in the linacs for the FEL upgrades. We have built a copper model of the proposed superstructure, based on two copper models of the 5-cell CEBAF cavities. This contribution presents measured results on this model. We are now in the process of fabrication a Nb prototype and hope to perform its cold test by the end of this year.

INTRODUCTION

Two superstructures have been recently successfully used at DESY to accelerate a pulsed 4 mA electron beam to an energy of 47 MeV [2]. The acceleration process was very stable and the measured bunch-to-bunch energy variation was below achievable test accuracy of $2\cdot10^{-4}$ [3]. In addition, the experiment at DESY showed that the HOM suppression in two tested 2x7-cell superstructures was very good and no HOM-driven instability was observed.

The proposed superstructure is based on the original CEBAF 5-cell cavities [4]. Two cavities (subunits) couple to each other via a half wave length long interconnecting beam pipe, which provides 0.04 % coupling (Fig. 1). The superstructure features one HOM coupler at each end and two HOM couplers at the interconnecting beam pipe. The couplers are based on the coaxial line technique and are almost identical to TESLA HOM couplers [5]. Their outer diameter is 40 mm. There is still enough space to add more HOM couplers if required.

This SST allows for much better HOM suppression than a standard 10-cell cavity since HOM couplers can be attached to the interconnection in the "middle" of the structure. In addition, a standard waveguide Fundamental Power Coupler (FPC) at one end, as for the CEBAF cavities, is used to feed the RF-power into all 10 cells. A shape modification of the inner end cells is necessary to compensate for the larger inner diameter of the interconnecting pipe and to maintain the right frequency and the field flatness in the accelerating mode. Each 5-cell subunit will be housed in an individual LHe vessel and each will be equipped with a cold tuner. The computed RF-parameters of this SST are listed in Table 1.

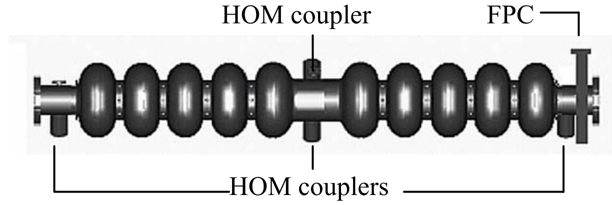

Figure 1: 2x5-cell superstructure equipped with four HOM couplers and only one FPC to feed 10 cells with RF-power.

Table 1. RF-parameters of the 2x5-cell superstructure

Parameter		
Frequency of the accelerating mode	[MHz]	1497
Cell-to-cell coupling, k_{cc}	[%]	3.29
Subunit-to-subunit coupling for, k_{ss}	[%]	$4\cdot10^{-2}$
Subunit field instability factor, N^2/k_{cc}	[10^3]	760
(R/Q)	[Ω]	926
Geometric factor, G		275
Distance to the next resonance	[kHz]	335
E_{peak}/E_{acc}		2.64
B_{peak}/E_{acc}	[mT/(MV/m)]	4.74
Active length	[m]	1.0

The field profile of this SST's accelerating mode is very insensitive to frequency errors of an individual cell. It is much less sensitive than in the case of a standard cavity with the same number of cells. This is due to possible frequency correction over each individual 5-cell subunit by means of the cold tuner. Moreover, the field profile within a subunit is very stable, because the cell-to-cell coupling, k_{cc}, is very strong The SST can increase the active length in a cryomodule while the number of input couplers will be reduced. In the standard 8 m long

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CEBAF cryomodule, with forty active cells, one could house six SSTs with sixty active cells. By comparison the current upgrade design allows for fifty-six cells (eight 7-cell cavities). The distance between superstructures would be 233 mm, requiring modification of the beam line layout and adaptation of a TESLA-like tuner [6] as well as use of Nb bellows with few convolutions to relax mechanical tolerances and simplify string assembly. The first prototypes of a Nb bellows has been manufactured at JLAB and the engineering work is in progress [7].

MEASUREMENTS ON THE COPPER MODEL

The copper model of the proposed SST has been retrofitted from two existing copper models of 5-cell cavities by modifying the two inner end cells at the interconnection side (Fig. 2). We built this model to verify our prediction of some RF-properties of the accelerating mode. The second purpose was to look at the suppression of HOMs.

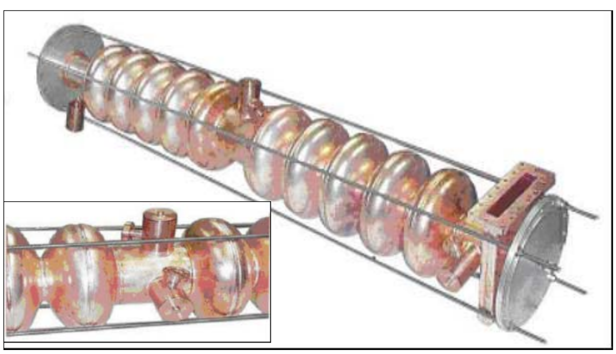

Figure 2: The copper model of the superstructure. The zoomed picture shows the interconnection with two HOM couplers

Accelerating Mode

The measured field profiles of the accelerating mode and its nearest neighbour are shown in Fig. 3 and Fig. 4. Both agreed very well with the theoretical computed profiles. The superstructure FPC is placed at ~90 mm, from the last iris of the end cell. The measured Q_{ext} of the FPC for the accelerating mode is $2.5 \cdot 10^7$. The value of Q_{ext} can be adjusted by means of a waveguide 3-stub tuner and/or by choosing a different position of the end short in the FPC waveguide on the opposite side of the axis.

Damping of HOMs

Parasitic cavity modes, mainly dipoles, can spoil the quality of the beam. The computed frequencies and the (R/Q) values of the high impedance dipoles are listed in Table 2 together with measured values of frequency and Qext. The two last columns show measured data for both polarizations. We measured frequency and Qext of all dipoles up to 3.15 GHz for three different angular positions of the HOM couplers. The best result, shown in Fig. 5, was used for simulation of the FEL 10 kW upgrade with MATBBU [8]. For this, the standard 7-cell upgrade cavities have been replaced with the superstructures, but the whole optics of the beam line remained unchanged. The result was very encouraging (Fig. 6). The threshold beam current (red in Fig. 6) went up to 103 mA (10 mA needed for this upgrade). The current was limited by the dipole mode No. 7 (see Table 2). Additional HOM couplers would further improve the threshold.

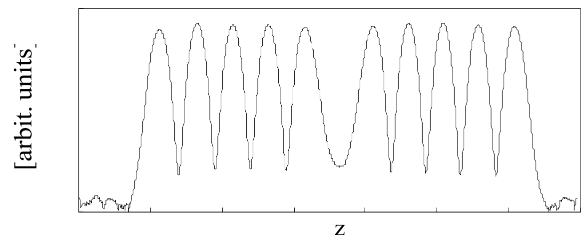

Figure 3. Accelerating π-0 mode. Measured field profile on axis.

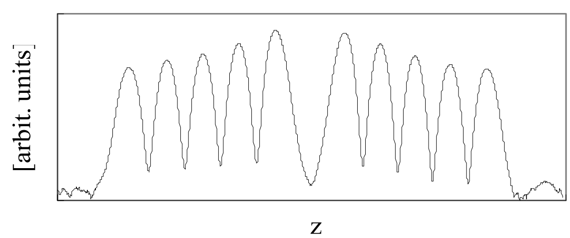

Figure 4: Nearest neighbouring mode π-π. Measured field profile on axis.

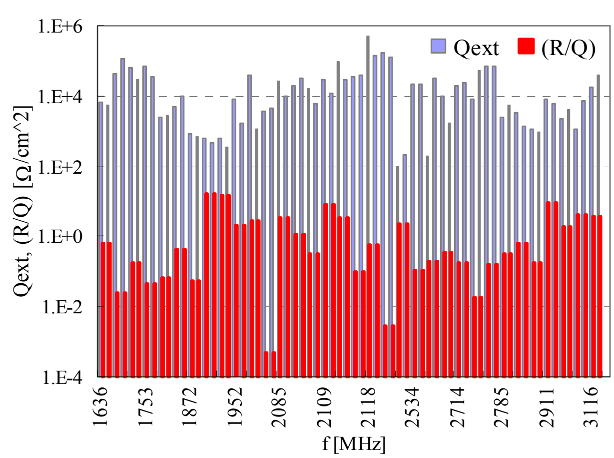

Figure 5: An example of the measured Q_{ext} of dipole modes. The (R/Q) values are shown to illustrate which mode is dangerous for the beam quality.

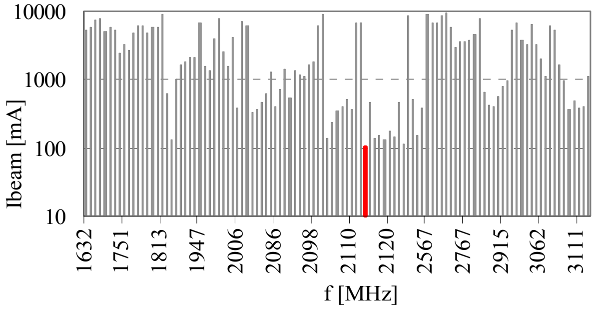

Figure 6: Limitation in the beam current as computed by MATBBU for measured values of frequencies and Q_{ext} of all dipoles up to 3.15 GHz.

Table 2. Computed and measured dipole modes

No. -	$f_{computed}$ [MHz]	(R/Q) [Ω/cm^2]	$f_{measured}$ [MHz]	Q_{ext}
1	1873.96	16.4	1879.79	$6\cdot10^2$
1a	1873.96	16.4	1882.07	$5\cdot10^2$
2	1933.51	14.2	1940.28	$6\cdot10^2$
2a	1933.51	14.2	1941.00	$4\cdot10^2$
3	1950.43	2.1	1952.48	$8\cdot10^3$
3a	1950.43	2.1	1953.07	$2\cdot10^3$
4	2005.28	2.8	2003.56	$4\cdot10^4$
4a	2005.28	2.8	2006.33	$1\cdot10^3$
5	2080.71	3.3	2085.00	$3\cdot10^4$
5a	2080.71	3.3	2086.06	$1\cdot10^4$
6	2110.80	7.8	2108.83	$3\cdot10^4$
6a	2110.80	7.8	2109.09	$1.\cdot10^4$
7	2122.21	3.5	2114.33	$9\cdot10^4$
7a	2122.21	3.5	2114.73	$3\cdot10^4$
8	2201.99	2.2	2189.22	$1\cdot10^2$
8a	2201.99	2.2	2199.74	$2\cdot10^2$
9	2933.19	9.5	2911.38	$8\cdot10^3$
9a	2933.19	9.5	2912.17	$6\cdot10^3$
10	2941.47	2.0	2940.21	$2\cdot10^3$
10a	2941.47	2.0	2940.87	$4\cdot10^3$
11	3063.85	4.1	3065.21	$1\cdot10^3$
11a	3063.85	4.1	3068.26	$7\cdot10^3$
12	3124.27	3.9	3115.54	$2\cdot10^4$
12a	3124.27	3.9	3116.51	$4\cdot10^4$

An important feature of a superstructure is the possibility to change the frequency of a parasitic mode during operation. The subunits' frequencies of a parasitic mode are usually different due to imperfections in the shape of cells. This causes the stored energy in the subunits to be unbalanced (unlike the accelerating mode). Moving the cold tuner of one subunit by an appropriate amount of steps in one direction and the tuner of the other subunit by the same amount but in the opposite direction, one can change the frequencies of all modes which have unbalanced energy, simultaneously keeping the frequency of the accelerating mode constant.

FINAL REMARKS

The Nb prototype of the proposed superstructure is being manufactured. Two spare 5-cell CEBAF cavities have been qualified in cold tests and reshaping of end cells will be performed by the end of July. We plan to test the prototype by the end of this year to verify experimentally the RF-properties of this superstructure. One of the major objectives in this test will be to explore the tuning and possible heating of the HOM couplers attached to the interconnection under cw operation. The test results will be a guide to improve further the HOM suppression, in particular for accelerators with beam currents in the 1 A range. The superstructure and its HOM damping characteristics can relatively easily be re-scaled to a lower frequencies (750 MHz or 500 MHz) and additional damping devices could be added if required.

ACKNOWLEDGMENTS

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