SUPERCONDUCTING SUPERSTRUCTURE FOR THE TESLA COLLIDER

M. Ferrario, INFN, Frascati, Italy

J. Sekutowicz, DESY, Hamburg, Germany

Ch. Tang, Tsinghua University, Beijing, China

Abstract

We present the layout of a cavity chain (superstructure) allowing a simplification in the RF system and thus significant cost reduction of the TESLA linear collider. The proposed scheme increases the fill factor and makes an effective gradient of an accelerator higher. We discuss the preliminary measurements on existing copper models of the TESLA Test Facility (TTF) accelerating structures and computations performed for the most promising version of the layout.

1 INTRODUCTION

The superstructure, shown in Fig. 1, made of four 7-cell standing wave cavities (sub-units) can be an alternative layout to the present cavity arrangement in the TESLA linear collider [1, 2]. The main difference between both layouts is the cavity to cavity coupling, k_{ss}, occurring in the superstructure due to enlarged diameter of interconnections. It enables the transfer of RF power from cavity to cavity to feed 28 cells instead of 9 cells, as in the current TTF design, with one fundamental mode (FM) coupler. This reduces the number of couplers in the collider, simplifies the RF power distribution system and cryostats, and lowers the investment cost. In the superstructure, similar to the TTF design, HOM couplers are attached to inter-connections and each sub-unit is equipped with a tuner. In this way, two major limitations in number of cells fed by one FM coupler: the field flatness and the HOM damping can be handled still at a sub-unit level. The synchronism between an ultrarelativistic beam and the accelerating mode requires that the shortest possible interconnection be $\lambda/2$ long. When the number of cells in one sub-unit, N, is an odd number the π-0 mode (π cell-to-cell phase advance and 0 cavity-to-cavity phase advance) can be used for the acceleration.

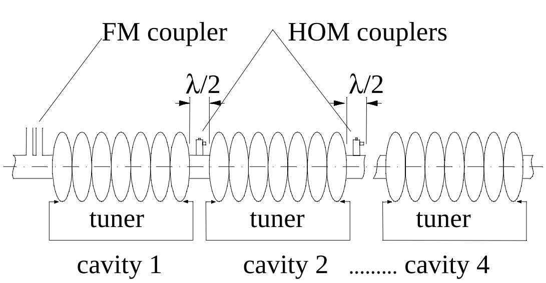

Fig. 1. Superstructure, four 7-cell cavities coupled by short interconnections.

In the TTF design, the effective accelerating gradient, E_{eff}, within the cryomodule will be 17.8 MV/m only, while the cavities will be operated at 25 MV/m. There are two reasons for this: a small fill factor and an unflatness of the accelerating field. The fill factor, a ratio of the active cavity length to the total cavity length, has a low value of 0.75 due to the oversized interconnections which are at present $3\lambda/2$ long. The former arguments: good cavity separation for the accelerating mode and a simplicity in the phase adjustment, can be hardly accepted from the point of view of a future energy upgrade above 500 GeV or luminosity upgrade since they lead to 7 km of passive length in both linacs and can be replaced with other technical solutions.

The unflatness of the accelerating field, a difference between maximum and minimum amplitude, within the TTF structure is usually ~ 10%. It causes ~5 % reduction of E_{eff} because the achievable gradient is often limited by the cell with maximum field. The amplitude error scales with N^2. The TTF cavities with 9 cells are at the limit and each mechanical, chemical or thermal treatment perturbs the field profile.

The proposed superstructure increases E_{eff} since the interconnections are shorter and the field profile becomes more stable for a less number of cells in an individual sub-unit. Parameters of the proposed superstructure are listed in Table 1. The last row of the table shows E_{eff} for the operation at 25 MV/m. The E_{eff} value is computed

Table 1. Parameters of the superstructure

Parameter		
radius of mid /end iris	[mm]	35/57
fill factor		0.875
k_{cc} , cell-to-cell coupling		0.019
k_{ss} , cavity-to-cavity coupling		$3.6\cdot10^{-4}$
field instability factor, N^2/k_{cc}	[10^3]	2.6
(R/Q) / sub-unit	[Ω/m]	906
E_{peak} / E_{acc}		2.0
H_{peak} / E_{acc}	[Oe/(MV/m)]	41.8
E_{eff}	[MV/m]	21.2

according to the bigger fill factor given in the third row and corrected with the expected field unflatness. This is scaled from the value observed for the TTF cavities, proportional to the field instability factor given in the sixth row. The resulting E_{eff} for the superstructure is higher than E_{eff} of the TTF cavity by 19 %.

2 PRELIMINARY MEASUREMENTS

2.1 Field Profile

Four existing Cu models of 9-cell TTF cavities have been used for preliminary RF measurements on the superstructure. The length of beam tubes, the diameter of which is only 78 mm, was adjusted to get k_{ss} value equal to this from Table 1. Each of the four cavities has been tuned individually for the flat field profile and the chosen frequency of the π-0 mode. After assembly, the field profile of π-0 mode for whole superstructure was measured (Fig. 2). The unflatness of this field, obtained after small correction of end cells, was less than 4 %.

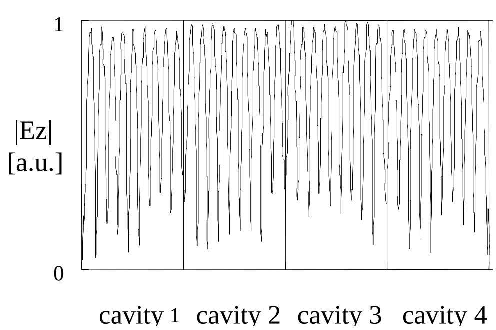

Fig. 2. Measured field profile in the pre-prototype of the superstructure.

2.2 Transient State

The transient state of each cell from the chain has been computed with help of HOMDYN code [3] to confirm reliability of the mathematical model. The computed curves, voltage vs. time, have been compared to the measured curves [4]. The agreement between the computed and the measured results was good. As an example, both curves for cell No. 36 are shown in Fig. 3. The small difference comes mainly from the variation of the cell-to-cell coupling in the cavities. This is due to machining errors in the iris region and causes that when π-0 mode frequency of all sub-units is the same, frequencies of other modes differ from each other. The uncorrected differences in frequency make the sub-units stay uncoupled for these modes and behave like separate cavities. Since in the present cavity design there is no means to adjust the cell-to-cell coupling this phenomena was taken into account in the energy gain computation discussed in the next section.

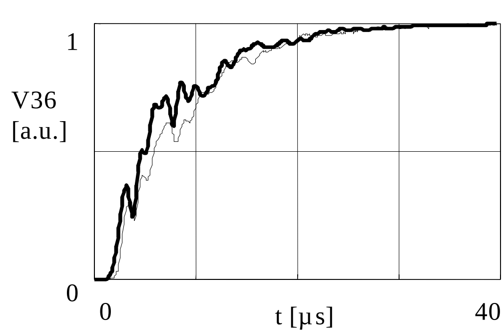

Fig. 3. Transient in cell No. 36: computed (bold line), measured (standard line).

3 ENERGY GAIN AND BUNCH-TO-BUNCH ENERGY SPREAD

There are 28 modes in the FM passband. The cavity-to-cavity coupling causes each of 7 modes of a single cavity is split into a group of 4 modes. When the superstructure is well tuned, (R/Q)s of these resonances are small, with an exception of the accelerating π-0 mode. Their Q values and thus beam impedances (R/Q)·Q, depend on how they couple to the input line via FM coupler. For the energy gain computation, which have been performed with help of the HOMDYN code, Q values were set in the following way. For the 16 modes with low stored energy in the end cells, whose field pattern is sensitive to the uncorrected differences in frequency, we choose Q of 10^9 to simulate no coupling to the input line (no damping). For the other modes the Q values were scaled from the Q of the accelerating mode according to their field pattern in the superstructure. These Q values are shown in Fig. 4. The energy gain was computed for the reference design operation of the TESLA collider [5] and for three higher luminosity operation options proposed in [6]. The results are summarized in Table 2. The energy gain in stage-III is shown in Fig 5. In all four cases, bunch-to-bunch energy spread is negligible (see the last row in the table). Additionally, for the reference design, the influence of a charge fluctuation on the energy gain has been computed. The case where the fluctuation is ±5% is shown in Fig. 6. Here, the energy spread is bigger, almost 10^{-3} and is of to the same order as for the TTF cavity.

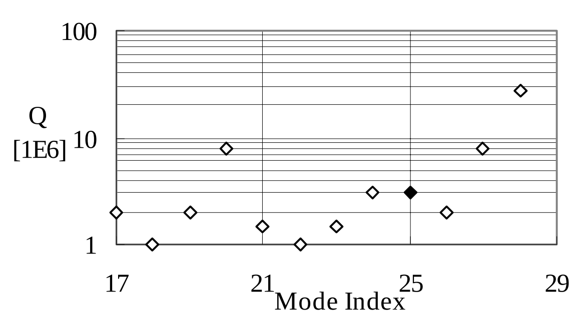

Fig. 4. Q values for modes loaded by input line via the FM coupler: (◆) accelerating mode, (◊) other modes.

Table 2. Energy gain and bunch-to-bunch energy spread for the superstructure.

	Ref. Design	Stage-I	Stage-II	Stage-III
# of Bunches /Train	1130	1410	2820	4028
Bunch Spacing [ns]	708	674	337	236
I_{beam} [mA]	8.2	9.5	9.5	9.5
Energy Gain [MeV]	82.5	72.5	72.5	72.5
Energy Spread [%]	0.0043	0.0062	0.0069	0.0055

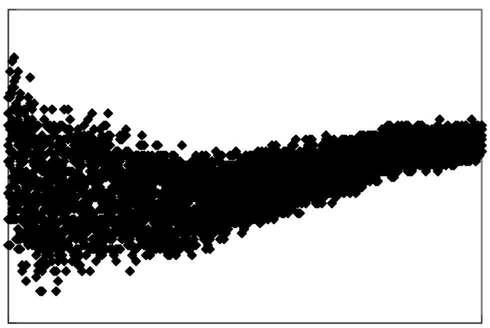

Fig. 5. Computed energy gain for stage-III.

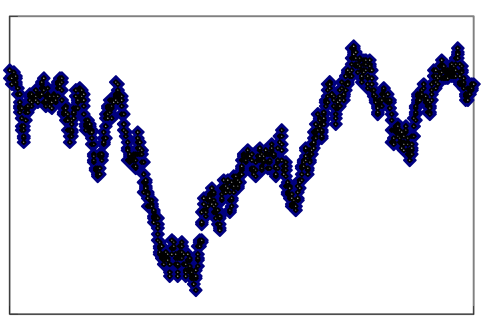

Fig. 6. Computed energy gain coming from the ±5 % charge fluctuation.

4 THE HOM DAMPING SCHEME

For the bigger diameter of the interconnecting tubes almost all HOMs are above cutoff. According to the computation, their field strength is high enough for damping with HOM couplers attached at middle of the interconnections. In that way, each HOM coupler can be exploited to damp modes from two neighboring cavities. Such a scheme will require fewer HOM couplers than the current one, but this must be proven experimentally. The couplers have to couple both electrically and magnetically as well, due to a standing wave pattern of HOMs in interconnections. One should mention that the HOM couplers used at present already have this coupling characteristic providing the required Q values of 10^4-10^5.

5 FINAL REMARKS

The number of couplers, tuners and LHe vessels for both layouts is given in Table 3.

Table 3. Changes in the RF system

	TTF design	Super-structure
Number of FM couplers	19230	6181
Number of HOM couplers	38460	24724
Number of tuners and LHe vessels	19230	24724

The proposed superstructure is not yet proven experimentally. In the near future, copper models of the superstructure and HOM coupler will be ready. The RF measurements on those models should help us to verify the computation we have done up to now for the super-structure made of four 7-cell cavities. However, with the copper models we won't be able to prove finally the numerical simulation of the bunch-to-bunch energy spread. For that a Nb prototype must be built and tested with the beam.

ACKNOWLEDGMENTS

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