PRECISE DESIGNING OF RF COUPLER FOR ACCELERATOR STRUCTURE

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Abstract

Coupler design for travelling wave accelerator structure was performed using 3D EM code, HFSS. How to improve the accuracy was firstly investigated. The actual design was confirmed by comparing with the experimental measurement. The calculation accuracy in reflection coefficient was found to be better than 0.05.

INTRODUCTION

According to Global Linear Collider Project Report, the accelerator structures for the X-band main linacs are based on the constant-gradient, travelling-wave, disk-loaded type design [1]. The structure is operated at *5π/6* mode with its active length of 60 cm where the group velocity varies from 4% to 1% of light velocity. KEK takes a major part at manufacturing prototypes of X-band structures for GLC project based on the capability of the high-precision machining of cells. The principle of the structure fabrication at KEK is to eliminate the tuning process after assembly and bonding procedures.

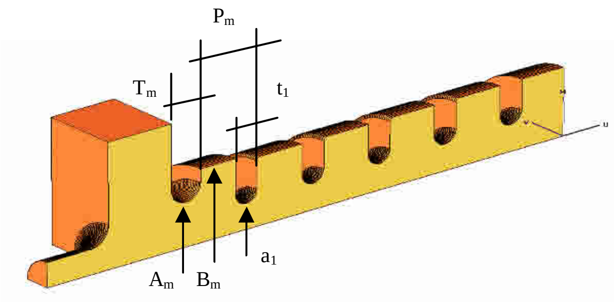

Fig.1 Input coupler of H60VG3 accelerating structure.

Up to date the coupler is one of the critical parts of the high gradient accelerating structure. Since it matches the sufficiently large reflection from the diaphragmatic circular waveguide, high intensity electric and magnetic fields appear at the surface of the coupler. This may cause the RF breakdowns resulting in future surface erosion. On the way to minimize these fields several coupler designs were proposed [2]. Considering the low surface fields, the short length of low accelerating field and probably the good coupling to the trapped dipole modes, we preferred so called "waveguide" coupler design. Here, as shown in Fig.1, the matching element is the fat diaphragm in a wide wall of rectangular waveguide.

The present candidate for the final structure design, H60VG3, 0.6 m long with a phase advance of 5π/6 per cell. To keep the constant gradient the group velocity (v_g/c) is changed from 3% to 1% along the structure. Both input and output couplers of this type structure, H60VG3K1 [3], were designed, fabricated and low-power measured at KEK. The description of the whole process is the theme of this paper.

PROPER USAGE OF THE ANSOFT HFSS

All of the physical structure parameters *a*, *b* and *t* are smoothly varying functions of the cell number. Therefore short section of the structure close to the coupler can be treated as periodic structure with constant parameters and the well-known "Kroll's" method could be applied [4]. For the field evaluation the ANSOFT HFSS code ver.8.5 was used [5].

All calculations were performed with structure dimensions at manufacturing temperature at 20^0C. Because operation temperature of the structure is 45^0C we shifted the calculation frequency (according to the thermal factor of Cu) from 11.424 GHz to 11.429 GHz.

Since the structure parameters were determinated beforehand with a high-precision frequency domain code [3], the cell-to-cell phase advance value was firstly investigated in order to establish the accuracy treatment of the regular section necessary for precise coupler simulation. Because the frequency separation between the center and the higher end of the passband near the output region is as narrow as several MHz, we believe that the tolerable frequency error in calculation is less than 1 MHz, which corresponds to 1^0 per cell.

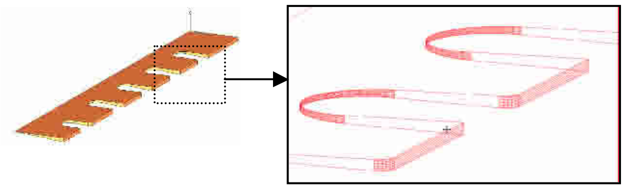

Fig.2 Pseudo 2-D model of accelerating structure.

The HFSS uses a finite-element method for solving electro-magnetic fields. It requires defining mesh points and the result of calculation depends on the quality of the used mesh.

In order to obtain the optimum mesh, first a narrow angle segment (pseudo 2-D model) of a structure was calculated (Fig.2). Fig.3 illustrates the dependence of the cell-to-cell phase advance along the structure on the maximum mesh cell size and that on the number of divisions of a circle applied to the rounded diaphragm surface. In order to obtain the closest phase advance value to the design, we concluded that the maximum mesh cell size should be less than 1 mm and the optimum number of segments for defining rounded diaphragm is 24.

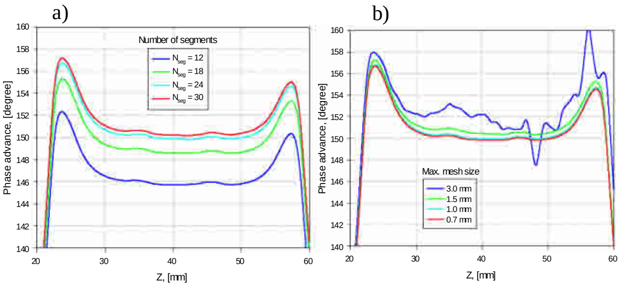

Fig.3 Pseudo 2-D model; cell-to-cell phase advance along the structure vs. a) maximum mesh element size and b) the number of segments of rounded diaphragm.

Next step was to repeat the similar study with 90 degree segment (3D-model) of a structure. The results of these calculations are shown in Fig.4. We found that maximum mesh size for this case should be less than 1.5 mm and the optimum number of rotation step to specify 90 degree segment is 45 (2 degree step) to maintain the error in the phase advance per cell less than 1^0 per cell.

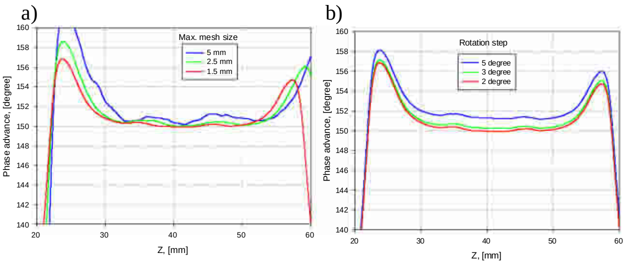

Fig.4 3-D model, cell-to-cell phase advance along the structure vs. a) maximum mesh element size and b) the step of rotation.

Taking the above mentioned cares on meshing to represent the geometry of the structure, we are now ready to simulate the coupler itself.

CALCULATION RESULTS

Actual coupler calculations

The coupler matching elements are shown in Fig.1. The dimensions which affect the matching are aperture A_m and thickness T_m of diaphragm, the outer diameter B_m and a matching period P_m. Since two of them (aperture A_m and thickness P_m) freely vary the amplitude and phase of reflection coefficient we can fix the remaining parameters. We chose that B_m was equal to the outer diameter of first regular cell for the input coupler case and to that of the last regular cell for the output coupler case. The thickness T_m of the diaphragm was chosen to be large enough to reduce the electric fields on the diaphragm surface. Therefore, we only need to execute the two parameter optimization to match the coupler. The optimization was done using Hooke-Jeeves method [6]. The results for both input and output coupler are shown in Fig.5.

The required tolerances for the coupler fabrication were studied. For this end the relevant matching parameters were varied slightly around the optimum values to see the change of VSWR as shown in the Fig. 5(b) for output coupler case. The VSWR changes nearly symmetrically as the matching parameters vary. Thus, the required tolerances are also symmetrical around optimum values. The most severe tolerance is for B_m (outer radius of the cell) parameter. To keep the VSWR from output coupler less than 1.1 we need to have the tolerance of B_m dimension to be 2 μm. Other matching parameters are not so sensitive and the manufacturing tolerance is 10 μm. For input coupler we found the same tolerance requirements.

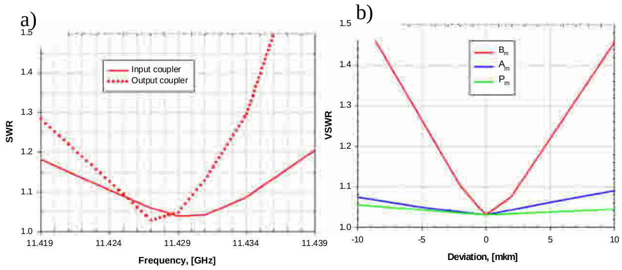

Fig.5 Coupler optimization results, a) VSWR vs. freqs. and b) the tolerance calculations for output coupler at freq. 11.429 GHz; *Bm*, *Am*, *Pm* are matching coupler parameters.

Calculation on experimental setup

Before making the actual H60VG3K1 structure, we performed the low power measurements on the similar coupler setup to prove the above calculation method. Two cold models, one for input and the other for output couplers, were studied. Each setup consists of the coupler itself and several regular cells terminated by a special matching cell at the end followed by a circular waveguide with a movable conical RF load. The matching cell compensates the reflection of TM_{01} mode between the circular waveguide and the regular part of the structure. Thus, we can study the reflection from the cold model of the coupler with a matching load at the end of circular waveguide. The results of calculations are shown in Fig.6. Red solid lines show the reflection only from the coupler itself whereas red dotted lines that only from matching cell. The blue lines show the reflection from the actual cold measurement setup which combines reflections both from coupler and matching cell. We understand that these setups are good enough for our comparison purpose, but it should be noted that this output coupler setup was not optimized yet simply due to time limitation.

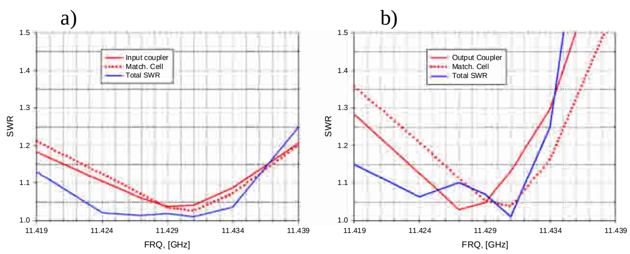

Fig.6 Coupler cold model calculations. VSWR vs. Freqs. a) for input and b) output coupler cold models.

COMPARISON WITH THE MEASUREMENTS

Two low-power models mentioned in the previous chapter were measured using the scheme as shown in Fig.7. The RF signals generated in sequence by HP 8510C network analyzer are fed to the corresponding rectangular waveguide input of the coupler, and S_{11}, S_{12} or S_{22}, S_{21} set of S-parameters are measured independently. For nominal operation the coupler should be fed symmetrically. Therefore we need to add signals from both RF ports of network analyzer in order to obtain the reflection from the coupler ($R_{coupler}$) in nominal operation. Taking into account the symmetry of measuring setup, we can derive:

$$R_{coupler} = S_{11} + S_{21} = S_{22} + S_{12} \qquad (5)$$

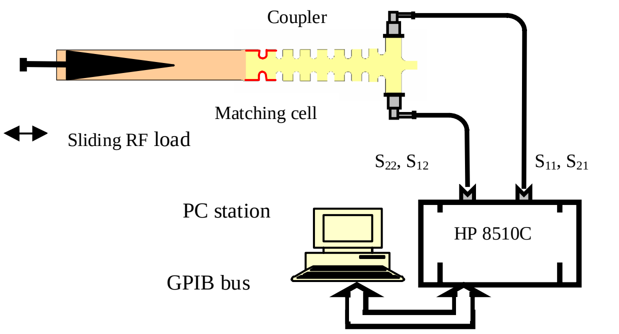

Fig.7 The experimental setup for low-power coupler model measurements.

The matching RF load is connected to the circular output of the coupler. Because it is difficult to make the ideal, non-reflected RF load, the measured reflection includes the reflection from the load. A set of complex reflection coefficients at different load positions was obtained, as shown in the Fig. 8. The reflection points form a circle on a complex plane when shifting the load in a circular waveguide. The center of this circle represents the actual reflection from the coupler with a perfect matched load.

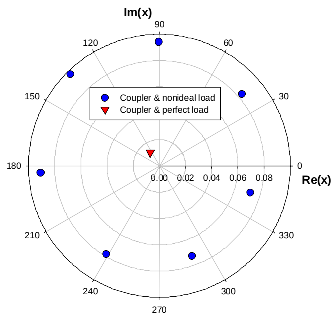

Fig. 8 Reflections from the experimental setup with different RF load positions.

The comparisons of measured data with the calculated ones are shown in Fig.9. Here the frequency correction was performed taking into account the thermal expansion of copper material and the dielectric constant of the gases, air with water vapor, filling the setup. An experimental formula was applied for the dielectric constant [7].

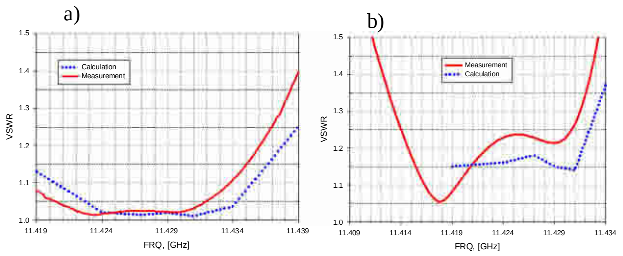

Fig. 9 The low power measurement results for a) input coupler model and b) output coupler model.

In the case of input coupler the measured VSWR at working frequency is below 1.05 and the behavior of the calculated curve coincides well with the measured one. That of the output coupler is rather worse, about 1.2, due to non-optimal dimensions of the matching cell in the setup. The measured VSWR also agrees well to the calculated one. From these comparisons, we concluded that the calculation agrees with the experiment within the error of the reflection coefficient of 0.05.

CONCLUSIONS

Coupler design for traveling wave accelerator structure was performed using 3D electromagnetic code, HFSS. The accuracy of the calculations was investigated depending on various input geometry parameters and internal code settings. The low-power models of the couplers were fabricated using high precision machining technology. The actual design was confirmed by comparing with the experimental measurement. The calculation accuracy in reflection coefficient was found to be better than 0.05.

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