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 $5\pi/6$ 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.

The present candidate for the final structure design, 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°C. Because operation temperature of the structure is 45°C 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 determined 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° per cell.

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.
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° per cell.

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.

**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.
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 ($R_{\text{coupler}}$) in nominal operation. Taking into account the symmetry of measuring setup, we can derive:

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

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

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.

REFERENCES