

A Calculation Method for RF Couplers Design Based on Numerical Simulation by Microwave Studio^{*}

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Abstract A numerical simulation method for coupler design is proposed. It is based on the matching procedure for the $2\pi/3$ structure given by Dr. R. L. Kyhl. Microwave Studio EigenMode Solver is used for such numerical simulation. The simulation for a coupler has been finished with this method and the simulation data are compared with experimental measurements. The results show that this numerical simulation method is feasible for coupler design.

Key words RF coupler, microwave studio, numerical simulation calculation, eigenvalue

1 Introduction

For a Linac accelerating structure, the RF coupler is an important component. A proper RF coupler must be matched with the regular feeding waveguide in order to feed the input microwave power into the accelerating cavities effectively by tuning the coupling aperture, the so called “Match”. It should also have synchronous frequency for the proper phase advance in the whole structure by tuning the diameter of coupling aperture, the so called “Tune”.

Originally the coupler design is performed experimentally. However, in such a way it will cost one much time even for those who are experienced in the RF coupler design. With the wake and development of numerical electromagnetic Codes, the RF coupler design based on numerical simulation becomes popular. Some numerical calculation methods based on 3D-code such as MAFIA had been discussed in detail^[1, 2]. However, by these means it is inconvenient to model a complicated 3D structure. They require experiences in generating mesh model for accu-

rate calculation results and it is very time consuming for the necessary time domain calculation in MAFIA.

CST Microwave Studio (MWS), which is also based on the Finite Integration Method (FIT), has a very friendly user interface to create all kinds of complicated 3D structures. With the help of the special mesh generation properties PBA (Perfect Boundary Approximation) and TST (Thin Sheet Technology), it will need less mesh cells for a good mesh model so that we can get a same calculation error by costing less time than that in MAFIA.

In this paper a novel numerical calculation method with the MWS Eigenmode Solver is proposed, which is based on the experimental method for the RF coupler design (the so called Kyhl Method)^[3].

2 Basic theories

RF coupler parameters optimization, in fact, is a process searching for the proper values of b , h and t to realize the “Tune” and “Match” of the coupler. Here b is the diameter of the coupler cavity, h is the

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coupling aperture and t is the thickness of the coupling iris and is always determined firstly in a usual design by experiment. Then b and h are optimized to achieve the critical coupling of the RF coupler.

With the equivalent circuit method it is convenient to analyze the tuning and matching procedure of an RF coupler and to know what will appear when the RF coupler reaches critical coupling in a certain operation mode. In the following an RF coupler design for the $2\pi/3$ mode is discussed.

An RF coupler for the $2\pi/3$ mode with the critical coupling can be proved by the following steps.

1) Detune the coupler cavity with the usual metallic plunger. Determined those “detuned short” positions $P_{2\pi/3}$, $P_{\pi/2}$ and P_{mean} in the input waveguide corresponding to each of three frequencies $f_{2\pi/3}$, $f_{\pi/2}$ and f_{mean} . Here $f_{2\pi/3}$ and $f_{\pi/2}$ are the frequencies of the $2\pi/3$ and $\pi/2$ modes, respectively and $f_{\text{mean}} = \frac{1}{2} \cdot (f_{2\pi/3} + f_{\pi/2})$. The “detuned short” position should locate at the regular section of input waveguide. The corresponding input impedance point Z_1 on a Smith Chart Plot is shown in Fig. 1.

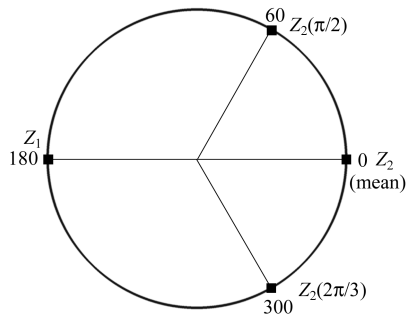


Fig. 1. Impedance points on a Smith Chart Plot.

2) Retract the detuning plunger so as to detune the following cavity. At the frequency P_{mean} given in step 1) the coupler cavity is deformed mechanically by tuning its diameter to get the proper input impedance point Z_2 in position f_{mean} which should be one quarter of a guide wavelength away from the impedance point Z_1 on a Smith Chart as shown in Fig. 1. We can find that the coupler cavity reaches “Tune” at this moment with the help of the Equivalent Circuit Analysis.

3) Leave the detuning plunger in position. One can take the input impedance data in position $P_{2\pi/3}$, at the $2\pi/3$ mode frequency, which corresponds to the

point $Z_2(2\pi/3)$ on a Smith Chart Plot. At the $\pi/2$ mode frequency, one can take the input impedance data in position $P_{\pi/2}$, which corresponds to the point $Z_2(\pi/2)$ on a Smith Chart Plot. If there is $1/3$ guide wavelength difference between the two impedance points on a Smith Chart Plot, as shown in Fig. 1, it means that the coupler reaches the critical coupling, i.e. $\beta=1$.

3 Introduction on the reference model

An RF coupler used in SLAC is referred as the model for the numerical simulation. It serves for the $2\pi/3$ mode structure whose sketch can be given in Fig. 2 and 3. b_0 , h_0 and t_0 are the experimental values of parameters b , h and t respectively.

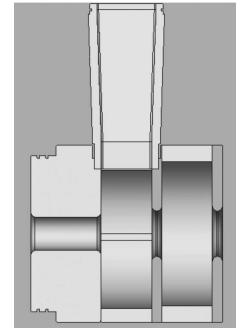


Fig. 2. Sketch of the coupler cavity.

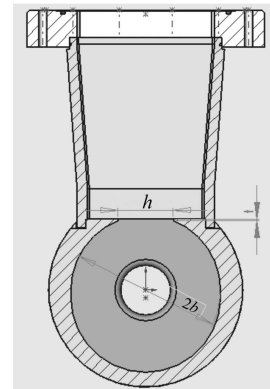


Fig. 3. Sketch of the coupler cavity.

4 The simulation procedure by CST microwave studio

4.1 Mesh model generation

1) Only the coupler cavity under design and an accelerating cell are required in an experimental procedure by Kyhl Method. So the minimum mesh model

consists of a coupler cavity, an accelerating cell and a detuning metal plunger.

2) In the mesh model we take the same structure parameters as those in the experimental model except for the parameters b and h . For the improvement of calculation efficiency it is better to offer the properly estimated values for b and h in experiences.

3) A certain formula is edited to keep the parameter t constant regardless of the changes of b or h during the creation of the mesh model.

4) The regular section of the input waveguide should be long enough to contain all “detuned short” positions.

5) It is better to give up the automatic mesh generation function and implement the mesh generation with the help of VBA (Visual Basic script) in MWS. Only in this way is it possible to obtain the consistent mesh cells and to get the approximate calculation error regardless of the changes of mesh model parameters.

The mesh model used in this simulation is shown in Fig. 4. The coupler cavity, an accelerating cell and the detuning plunger can be seen.

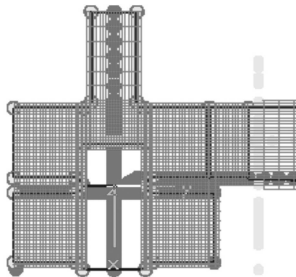


Fig. 4. 2-cell mesh model.

6) It can be found that the mesh densities near the loading disk and the coupling aperture are higher than those of other areas under careful observation on the mesh model. This kind of mesh setting is very helpful for the improvement of calculation error and calculation efficiency.

7) The red points marked in the mesh model are used for the determination of boundary of mesh cells. They are named “Fixpoints” in MWS and their coordinates can be set by VBA.

8) The blank part inside the mesh model represents the detuning plunger. MWS allows that mesh cells aren't necessary in the PEC region to reduce the

number of required mesh cell. (Note: This function is available only in the time domain calculation).

4.2 The simulation procedure

With the equivalent circuit analysis we have an idea that when an RF coupler working in $2\pi/3$ mode reaches the “Tune” and “Match”, at the same mode frequency f_{mean} and at the same reference position, the input impedance of the detuned coupler cavity has a π phase difference from that of the first detuned accelerating cell.

Some information about “Tune” can be got through the following two steps.

1) Detune the coupler cavity in a proper length of the metal plunger. Define the boundary condition of the end port of input waveguide as “Electric”. Solve the Eigenmode problem to find a proper length (L) of the regular section of input waveguide. The length denoted by L_{mean} satisfies the condition $f = f_{\text{mean}}$. The snapshots of electric fields are shown in Fig. 5.

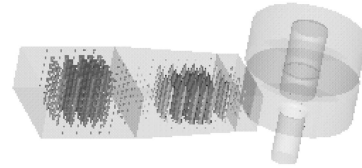


Fig. 5. The snapshots of electric fields when the coupler cavity is detuned.

2) Detune the accelerating cell by changing the length of the metal plunger and set $L = L_{\text{mean}}$ in MWS. Define the boundary condition of the end port of input waveguide as “Magnetic”, which implies that the input impedance has a π phase difference from that in step 1). The Eigenmode problem is solved to obtain the mode frequency f . If $f < f_{\text{mean}}$, b should be decreased; if $f > f_{\text{mean}}$, b should be increased.

Repeat step 2) till $f = f_{\text{mean}}$ is satisfied. The snapshots of electric fields are shown in Fig. 6.

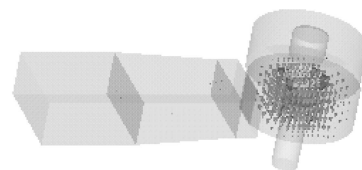


Fig. 6. The snapshots of electric fields when the accelerating cell is detuned.

Steps 1) and 2) show how to realize and judge the “Tune” of a coupler cavity.

Some information can be found about the coupling coefficient β with the help of a Smith Chart Plot after the discussion of the section of basic theories. Fig. 1 shows that for a coupler cavity with a critical coupling at the mode frequency $f_{\frac{2\pi}{3}}$ and at the position $P_{\frac{2\pi}{3}}$ the impedance point Z_2 ($2\pi/3$) has a $4\pi/3$ phase difference from the impedance point Z_1 . So it is clear that the nearest “detuned short” position will be $\lambda_g/6$ away from the position $P_{\frac{2\pi}{3}}$ in the direction away from the coupler cavity when the accelerating cell is detuned.

So the following two steps are given to check the coupling of coupler cavity.

3) Restore the length of the detuning plunger to that in step 1) to detune the coupler cavity again. Define the boundary condition of the end port of input waveguide as “Electric”. With the MWS Eigenmode Solver a proper value of L can be found to satisfy $f = f_{\frac{2\pi}{3}}$. The L is denoted as $L_{\frac{2\pi}{3}}$.

4) Recover the length of the detuning plunger as that in step 2) to detune the accelerating cell again. Define the boundary condition of the end port of input waveguide as “Magnetic”. Find an L to make f same as $f_{\frac{2\pi}{3}}$ and the L here is denoted as $L'_{\frac{2\pi}{3}}$.

If $L'_{\frac{2\pi}{3}} - L_{\frac{2\pi}{3}} = \frac{1}{6}\lambda_g$ is satisfied, it means that the coupler cavity is matched.

5) If $L'_{\frac{2\pi}{3}} - L_{\frac{2\pi}{3}} < \frac{1}{6}\lambda_g$ is satisfied, it means that the coupler cavity is under coupling. The coupling aperture h should be increased to strengthen the coupling between the input waveguide and the cavity. Otherwise the coupler cavity is over coupling and the h should be decreased to weaken the coupling.

Once the parameter h is changed, the steps 1) to 4) have to be repeated till the relation $L'_{\frac{2\pi}{3}} - L_{\frac{2\pi}{3}} = \frac{1}{6}\lambda_g$ is satisfied.

Note: From step 3) to 5) the guide wavelength λ_g corresponding to $f_{\frac{2\pi}{3}}$ is always used. To improve the calculation error it is necessary to calculate λ_g under the same mesh generation rule of input waveguide as

those used in other steps.

4.3 Comparison between simulation data and experimental results

1) Take $t = t_0$. When $L'_{\frac{2\pi}{3}} - L_{\frac{2\pi}{3}} = \frac{1}{6}\lambda_g$ is satisfied, we denote the h, b by $h_{\text{cal}}, b_{\text{cal}}$ respectively.

The following conclusions can be found by the comparison between the simulation data and the experimental results:

$$\frac{h_{\text{cal}} - h_0}{h_0} \cdot 100\% = +1.1\%,$$

$$\frac{b_{\text{cal}} - b_0}{b_0} \cdot 100\% = -0.2\%.$$

2) Another new 4-Cell mesh model is generated in MWS. This model consists of one input coupler cavity, two accelerating cells and one output coupler cavity as shown in Fig. 7.

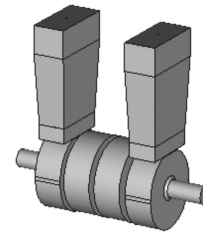


Fig. 7. 4-cell mesh model for F-Domain calculation.

Set $b = b_{\text{cal}}$ and $h = h_{\text{cal}}$. The reflection coefficient $|S_{11}| = -57\text{dB}$ is given at the $2\pi/3$ mode frequency with the help of MWS frequency domain solver.

The reflection coefficient $|S_{11}|_0 = -57\text{dB}$ is got from the measure of the coupler cavity with the parameters of $b = b_0$ and $h = h_0$ at the same frequency.

3) With the help of the MWS Field Monitor the electric field amplitude and the phase variation along the axis are given in Fig. 8 and 9.

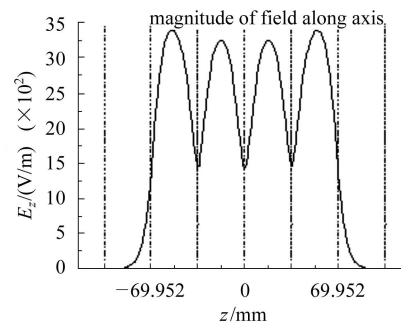


Fig. 8. Magnitude of electric field along axis.

In Fig. 8 it can be noticed that the field is periodic in the regular accelerating cells and it is symmetric about the center of the whole structure.

In Fig. 9 the phase advance in the two regular accelerating cells is about 122° which is close to the expected value of 120° ; the phase variation in the coupler cavities is nearly zero across half the cavity and totals to 60.5° for the whole cell.

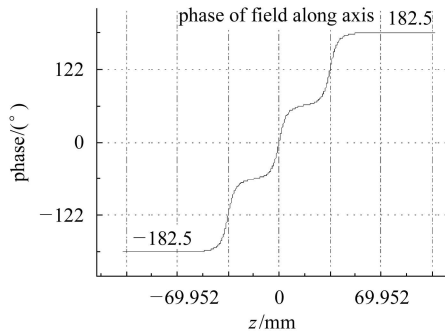


Fig. 9. Phase variation of electric field along axis.

5 Conclusions

A novel numerical simulation method for RF coupler design is proposed in detail in this paper based on the good understanding of Kyhl Method. It can be performed by the MWS Eigenmode solver only. With the comparison between the simulation data and the experimental results, it shows that a satisfying accuracy can be obtained and this method can serve as an effective theoretical guide for RF coupler design.

The method proposed here needs less CPU-time and hardware demand of PC compared with the methods given in Refs. [1] and [2]. This method makes mesh model generation more convenient and it is good enough for engineering application in the RF Coupler design.

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一种基于微波工作室的盘荷波导耦合器设计方法*

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摘要 提出了一种新的盘荷波导耦合器数值设计方法;通过分析Kyhl提出的耦合器调节原理,将输入阻抗之间的相差关系转换为耦合器输入波导的边界条件关系,由此利用Microwave Studio的EigenMode Solver求解本征值问题来实现对耦合器调谐、调匹配过程的模拟;并给出一个实例来说明数值计算方法的可行性和可靠性.

关键词 盘荷波导耦合器 微波工作室 数值模拟计算 本征值

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