Design and experiments for the waveguide to coaxial cable adapter of a cavity beam position monitor

LI Xiang(李享)[1,2,3] ZHENG Shu-Xin(郑曙昕)[1,2,3;1)]

[1] Department of Engineering Physics, Tsinghua University, Beijing 100084, China
[2] Key Laboratory of Particle & Radiation Imaging (Tsinghua University), Ministry of Education, Beijing 100084, China
[3] Key Laboratory of High Energy Radiation Imaging Fundamental Science for National Defense, Beijing 100084, China

Abstract: The waveguide to coaxial cable adapter is very important to the cavity beam position monitor (CBPM) because it determines how much of the energy in the cavity could be coupled outside. In this paper, the waveguide to coaxial cable adapter of a CBPM is designed and experiments are conducted. The curve shapes of experiments and simulations are very similar and the difference in reflection is less than 0.1. This progress provides a reliable method for designing the adapter.

Key words: CBPM, waveguide to coaxial cable adapter, physics design, coupling coefficient

PACS: 29.27.Fh, 29.27.Eg **DOI:** 10.1088/1674-1137/35/1/016

1 Introduction

The cavity beam position monitor (CBPM) is used for measuring an electron beam's transverse position. In order to make the beam transport along the axis of facilities, CBPMs are assembled on linacs, injectors, and undulators of free electron lasers (FELs). The CBPM measures the beam's transverse position using the dipole mode excited by the passing beam, and the dipole mode field is designed to transmit outwards through two stages of coupling in most of the recent designs [1–3]. As shown in Fig. 1, the field in the cavity is coupled into the waveguide where the dipole mode TM110 changes to TE10 mode, and this is the first-stage coupling. The Q_{ext} of the first-stage is determined by the size and location of the coupling hole between the cavity and the waveguide. Then the TE10 mode transmits through the waveguide to the coaxial cable adapter where it changes to TEM mode, and this is the second-stage coupling. The adapter's reflection determines how much of the TE10 mode energy could come through, so it also partly determines the total Q_{ext} of the two stages of coupling. People often expect that the total Q_{ext} of the two stages is the same as the first-stage, so the adapter's reflection should be as small as possible at the working frequency. That is because if the adapter's reflection is large, in order to obtain the same Q_{ext} the coupling hole between the cavity and the waveguide has to be enlarged, and the Q_0 of the cavity will decrease, which is unwanted. If the adapter's reflection is unknown, the total Q_{ext} of the two stages is also unknown, which is also unwanted. Therefore the adapter's reflection should be as small as possible, for example smaller than 0.1. In this paper, the adapter of a CBPM whose working frequency is 5.712 GHz [3] is designed and experiments are conducted. This provides a reliable method for designing the adapter of the CBPM.

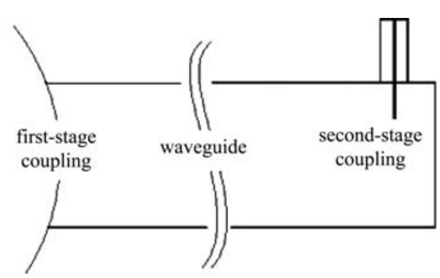

Fig. 1. Schematic diagram of the coupling.

Received 23 February 2010

1) E-mail: zhengsx@tsinghua.edu.cn

2 Physics design of the waveguide to the coaxial cable adapter

2.1 Simulation modeling and physics design methods

The reflection of the adapter is determined by two parameters: one is the distance between the probe of the SMA cable and the sealed end of the waveguide, which is defined as "*ap*"; the other one is the length of the probe, which is defined as "*al*". The usual way to make the adapter is that "*ap*" is determined first and a hole to fixate the SMA feedthrough is drilled there, and then "*al*" is changed to search the smallest reflection. The simulation modeling and physics design methods we used are approximations to the practical process.

The 3D electromagnetic field simulation software MAFIA is used in physics design, and the simulation modeling is shown in Fig. 2. The waveguide is "BJ-84", and it is made from oxygen-free copper. Its right end is sealed and thereby it short-circuits, and its left end is set as a nonreflecting port (Port-1). At the upper side of the waveguide there is an SMA coaxial cable. The distance between its probe and the right end of the waveguide is "*ap*", and the length of the probe is "*al*". The upper boundary of the cable is also set as a nonreflecting port (Port-2). In simulation, the microwave power is fed from Port-2 and the reflection factor S_{22} is calculated. As mentioned above, the goal of physics design is to reduce S_{22} at the working frequency as far as possible, so the two parameters "*ap*" and "*al*" are adjusted to achieve that.

The process of physics design is as follows [4]. Firstly, the initial values of "*ap*" and "*al*" are set. Then one of these two parameters (for example, "*al*") is fixed, and the other one ("*ap*") is swept. The curves of S_{22} in the frequency range from 5.5 GHz to 6 GHz are calculated, and the "*ap*" corresponding to the smallest S_{22} at 5.712 GHz is selected. This "*ap*" is set as the initial value of the second parameter sweep, in which "*al*" is swept. The curves of S_{22} from 5.5 GHz to 6 GHz are calculated again, and the best "*al*" is selected. Then this "*al*" is set as the initial value in the third parameter sweep. This process is repeated and the smallest S_{22} at 5.712 GHz and the corresponding "*al*" and "*ap*" are obtained.

Theoretically, if "*al*" and "*ap*" change continuously, S_{22} at a single frequency (for example, 5.712 GHz) could decrease to zero. However, since the machining accuracy is not better than 0.1 mm, the sweep step of "*al*" and "*ap*" is set to 0.1 mm. Correspondingly, the goal of design is to reduce S_{22} at the working frequency as far as possible, and S_{22} should be lower than 0.1 in the neighboring frequency range (such as 100 MHz). Therefore more than 99% of the microwave power is able to transmit through the adapter without reflection, so $Q_{\rm ext}$ of the two stages of coupling will not deteriorate.

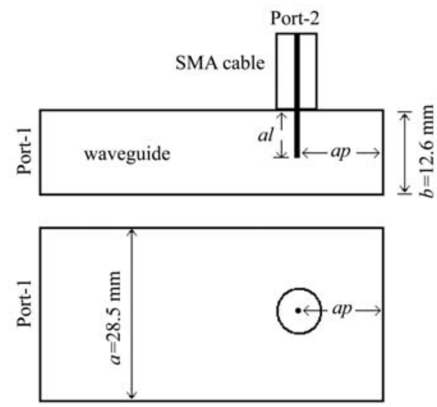

Fig. 2. Schematic diagram of the simulation modeling.

2.2 Results of the physics design

Using the method discussed above, al=9 mm and ap=10.8 mm are finally determined. S_{22} at 5.712 GHz is 0.009, which is the minimum at this frequency. The curve of S_{22} is shown in Fig. 4(a). The frequency range of $S_{22}<0.1$ around 5.712 GHz is about 350 MHz, which achieves the goal of the design.

3 Experimental results of the waveguide to the coaxial cable adapter

3.1 Experimental set and method

The experimental set is shown in Fig. 3(a), and it consists of 3 parts. From left to right there are a moving load with very small reflection, a waveguide, and a micrometer screw device. An SMA coaxial cable pedestal, which is shown in Fig. 3(b), is assembled on the waveguide. The pedestal is connected with the cable of a vector network analyzer (VNA), and because they have the same impedance, there is nearly no reflection at the port of the pedestal. Therefore the port of the pedestal is equivalent to Port-2 in Fig. 2. The length of the probe is the key parameter "*al*" in simulation. In order to observe how S_{22} changes with respect to "*al*", several pedestals with different "*al*" are made and exchanged in experiments. The micrometer screw device pushes an oxygen-free copper block to move accurately in the waveguide, and the distance between the block and the probe is "*ap*". The moving load is connected to the left port of the waveguide, and because its reflection is very small, the microwave power in the waveguide can transmit outwards from the left port of the waveguide nearly without reflection. Therefore the left port of the waveguide is equivalent to Port-1 in Fig. 2. In experiments, one of the SMA pedestals is assembled on the waveguide, and "*ap*" is controlled by the micrometer screw device. The moving load method [5] is used to measure S_{22} at 5.712 GHz under different "*al*" and "*ap*", and the experimental results are compared with those of the simulation.

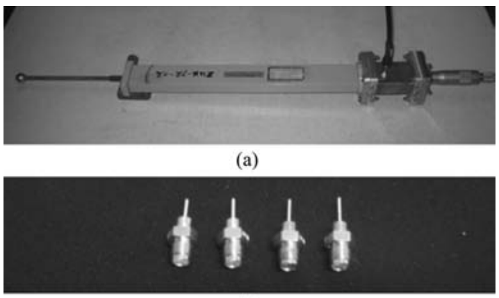

Fig. 3. Pictures of the experimental set (a) and SMA pedestals (b).

3.2 Experimental results with respect to "*ap*"

According to the simulation results, at first the SMA pedestal whose "*al*" is 9 mm is assembled on the waveguide and "*ap*" is set to 10.8 mm. The curve of S_{22} from 5.5 GHz to 6 GHz is measured and compared with the simulation, which is shown in Fig. 4(a). The experimental result of S_{22} reaches its minimum of 0.076 at the frequency of 5.67 GHz, and S_{22} at 5.712 GHz is 0.09. The experimental standard deviation (SD) is approximately 0.01. The simulation result of S_{22} reaches its minimum of 0.008 at 5.71 GHz, and S_{22} at 5.712 GHz is 0.009. In the frequency range around the minimum of S_{22}, both of the two curves rise, and the slopes are close to each other in the higher frequency range. However, in the lower frequency range the shapes of the curves are different. Because the experimental set is imperfect and is somewhat different from the simulation modeling, the difference of S_{22}, which is about 0.1, seems reasonable.

As mentioned above, when making the practical adapter of the CBPM, the distance between the SMA feedthrough and the sealed end of the waveguide ("*ap*") will be determined first, and then the hole to fixate the feedthrough will be drilled there. Since it is difficult to repair the hole on the waveguide, people expect to predict the position of the feedthrough accurately according to the results of the physics design. Therefore, besides the curve of S_{22} from 5.5 GHz to 6 GHz, how the S_{22} at 5.712 GHz changes with respect to "*ap*" is even more important. Fig. 4(b) shows the experimental and simulation results of S_{22} at 5.712 GHz when *al*=9 mm and *ap*=9.2–12.2 mm, and each point is measured by moving load method. It can be seen that the experimental result of S_{22} at 5.712 GHz reaches its minimum 0.08 when "*ap*" is 10.4 mm. The experimental SD is less than 0.01. The simulation result reaches its minimum 0.009 when "*ap*" is 10.8 mm, and the difference between the experiment and simulation is less than 0.1. Therefore people could find the best "*ap*" quite accurately by simulation.

Although the approximation between experiments and simulations has been demonstrated, people still need to consider the difference brought by error in practice. Fig. 4(c) shows the simulation result of the minima of S_{22} at 5.712 GHz for each "*ap*", and from this curve people could predict the change of S_{22} while "*ap*" has some error, or in other words how the error will affect S_{22}. For example, if the error is 0.4 mm, which makes "*ap*" change from 10.8 mm to 10.4 mm,

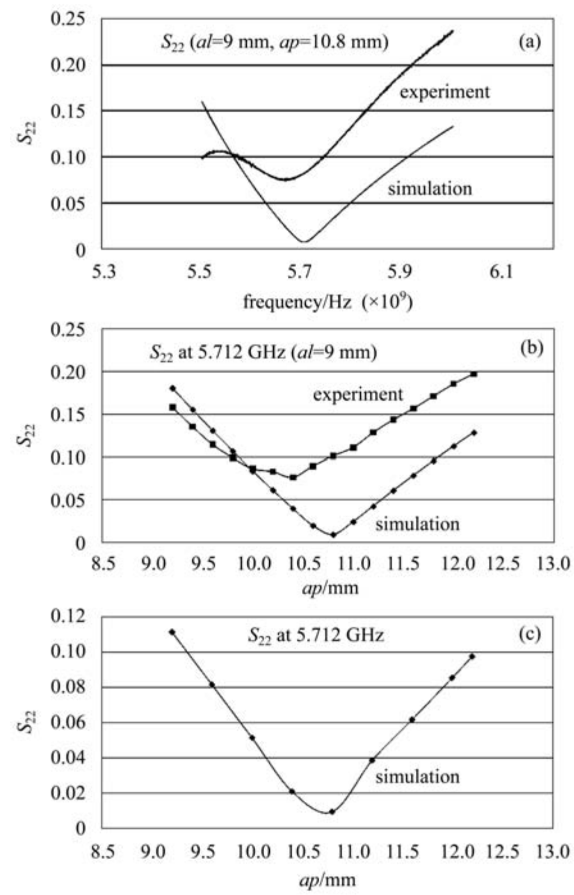

Fig. 4. Experimental and simulation results with respect to "*ap*".

people know from the curve that the minimum of S_{22} will change from 0.009 to 0.02, which increases by 0.01. And because the shapes of the experimental and simulation curves are very similar, people could predict that the measured minimum of S_{22} will increase by about 0.01 in practice.

3.3 Experimental results with respect to "*al*"

After determining "*ap*", people often adjust "*al*" to search the minimum of S_{22} at 5.712 GHz, so how the S_{22} at 5.712 GHz changes with respect to "*al*" is also very important. According to the experimental results shown in Fig. 4(b), "*ap*" is fixed to 10.4 mm, and the SMA pedestals whose "*al*" is different from 9 mm are assembled to the waveguide in turn, and the results of experiments and simulations are shown in Fig. 5. The SD of the experimental results is still approximately 0.01. It can be seen that the experimental results are a bit larger than simulation, but the difference between them is less than 0.1, which means they agree well with each other. According to the fitting curves, *ap*=10.4 mm and *al*=9 mm is the best choice in practice.

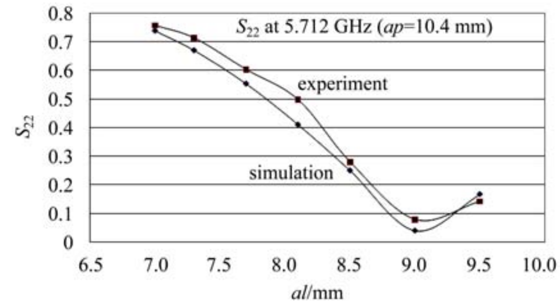

Fig. 5. Experimental and simulation results with respect to "*al*".

4 Conclusions

In this paper, the physics design and experiments of a waveguide to coaxial cable adapter are discussed. The curves of S_{22} in the frequency range from 5.5 GHz to 6 GHz, and the results with respect to "*ap*" (or "*al*"), are shown. The curve shapes of experiments and simulations are very close and the difference in reflection is less than 0.1. Therefore a reliable method of physics design for the adapter is provided.

References

1 Yoichi Inoue, Hitoshi Hayano, Yosuke Honda et al. Physical Review Special Topics -Accelerators and Beams, 2008, **11**: 062801

2 Sean Walston, Stewart Boogert, Carl Chung et al. Nuclear Instruments and Methods in Physics Research A, 2007, **578**: 1–22

3 CHU Jian-Hua, TONG De-Chun, ZHAO Zhen-Tang. Chinese Physics C (HEP & NP), 2008, **32**(5): 385

4 Yosuke Honda. Waveguide to Coaxial Cable Adapter for IP-BPM. http://acfahep.kek.jp/subg/ir/nanoBPM/library/honda.report/ipbpm_adapter_0.050929.pdf

5 YAO Chong-Guo. Electrical Linear Accelerator. Beijing: Science Press, 1986. 572–587 (in Chinese)