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ANALYSIS OF THE ELECTROMAGNETIC FIELD IN THE COUPLER OF NORMAL TEMPERATURE TRAVELLING-WAVE ACCELERATING TUBE

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Abstract

With the developed requirement of the beam quality in modern accelerators, rapid development of all kinds of accelerating structures with different frequencies and materials have been achieved. However, the normal temperature travelling-wave (TW) accelerating structures which are widely used in Free Electron Laser (FEL) are still indispensable. For reducing the beam emittance, it is very important to optimize the symmetry of the high-order electromagnetic field in the coupler of such accelerating structures. In this paper, the symmetry of the electromagnetic field in TW accelerator couplers using different coupling mechanisms was analysed. A lot of design optimization as well as the result analysis work has been done for the three kinds of commonly used waveguide-coupled TW accelerating structures: single-feed electrical-coupling, dual-feed electrical-coupling using magic tee in feeding waveguide and dual-feed magnetic-coupling using J-type feeding waveguide. Finally, basing on lots of simulation results and the performances during the fabrication, measurement and RF conditioning of these three kinds of structures, the J-type racetrack coupler type is regarded as the best choice.

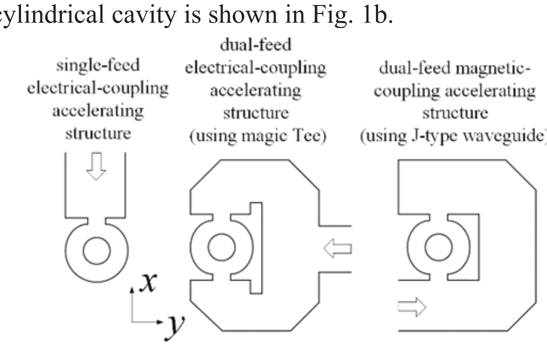
INTRODUCTION

The SLAC-type normal temperature travelling-wave accelerating structure is widely used in the large high-energy electron linear accelerators all over the world. The rotational-symmetrical cylindrical cavity or the racetrack cavity is usually used as the input coupler for this kind of accelerating structure. The rotational symmetry of the cylindrical cavity is affected by the introduction of the coupling hole of the cavity, which results in an asymmetry of the electromagnetic field within the envelope of the beam and then degrades the beam quality by increasing the beam emittance. By using the dual-feed accelerating structure instead of the single-feed, the symmetry of the electromagnetic field of the cylindrical cavity is improved, however, along the vertical direction of the two symmetrical coupling holes in the dual-feed cylindrical cavity, the symmetry is still affected. For further improving the symmetry of the electromagnetic field within the envelope of the beam, the racetrack cavity is adopted by elongating the cylindrical cavity along the vertical direction of the two coupling holes.

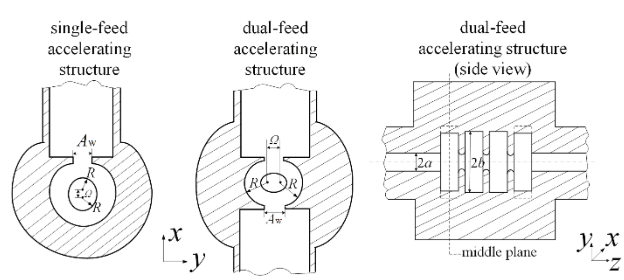
The research work concerning the improvement of the symmetry of electromagnetic field in the racetrack cavity comparing to the cylindrical cavity has been done in some articles [1]. However, all of them are focused only on one of the coupling mechanism, or only on the symmetry of electrical field. On the basis of considering several kinds of coupling mechanisms, the comprehensive analysis and compare work for the symmetry of electromagnetic field between the cylindrical and racetrack cavity has been done and some inferences has been given here.

STRUCTURE OF THE COUPLING CAVITIES

For better analysing the improvement of the symmetry of electromagnetic field in the racetrack cavity, three commonly used coupling mechanisms (numbered as coupling mechanism 1 to 3 in sequence) are chosen: the single-feed electrical-coupling (central frequency 2998 MHz), the dual-feed electrical-coupling using magic tee in feeding waveguide (central frequency 2856 MHz) and the dual-feed magnetic-coupling using J-type feeding waveguide (central frequency 2856 MHz). The structures of them are shown in Fig. 1a and the difference between the racetrack cavity and the cylindrical cavity is shown in Fig. 1b.



(a) Cylindrical cavity



(b) Racetrack cavity

Figure 1: Structure diagram of the input cavities.

An eccentric circle structure is adopted in coupling mechanism 1 (Fig. 1b) to compensate the asymmetry of electromagnetic field resulted from the introduction of the single coupling hole. The centre of the eccentric

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circle moves along the –*x* direction and finally has the distance of *Ω* to the centre of the beam. The racetrack cavities are adopted in coupling mechanism 2 and 3 (Fig. 1b) to compensate the asymmetry of electromagnetic field resulted from the introduction of the two symmetrical coupling holes. By cutting the cylindrical cavity into two half-cavities (radius *R*), and then pulling the two half-cavities apart along the direction of the diameter of cavity until the distance between the centres of the two half-cavities equals to *Ω*, the racetrack cavity is achieved (Fig. 1b). The two half-cavities connect through a straight parallel side wall (length *Ω*).

ANALYSIS OF THE SYMMETRY OF THE ELECTROMAGNETIC FILED

The optimization work started from the cylindrical cavity, and then the best racetrack cavity can be found by gradually increasing the offset value *Ω* and comparing the two values of amplitudes of the electrical (magnetic) fields along different directions but at the same radius. The best *Ω* should be the one that whether you increase or decrease it, the symmetry of the electrical (magnetic) field will be worse.

The relative error of the amplitudes of the electrical/magnetic fields at the same radius along ±*x* directions (+*x* and +*y* directions) in the middle plane are compared for coupling mechanism 1 (coupling mechanism 2 and 3) in Fig. 2a (Fig. 2b and 2c). For better comparison, the relative value of offset *Ω* (divide absolute *Ω* value by the wavelength of the central frequency in free space) is used in the abscissa in Fig. 2.

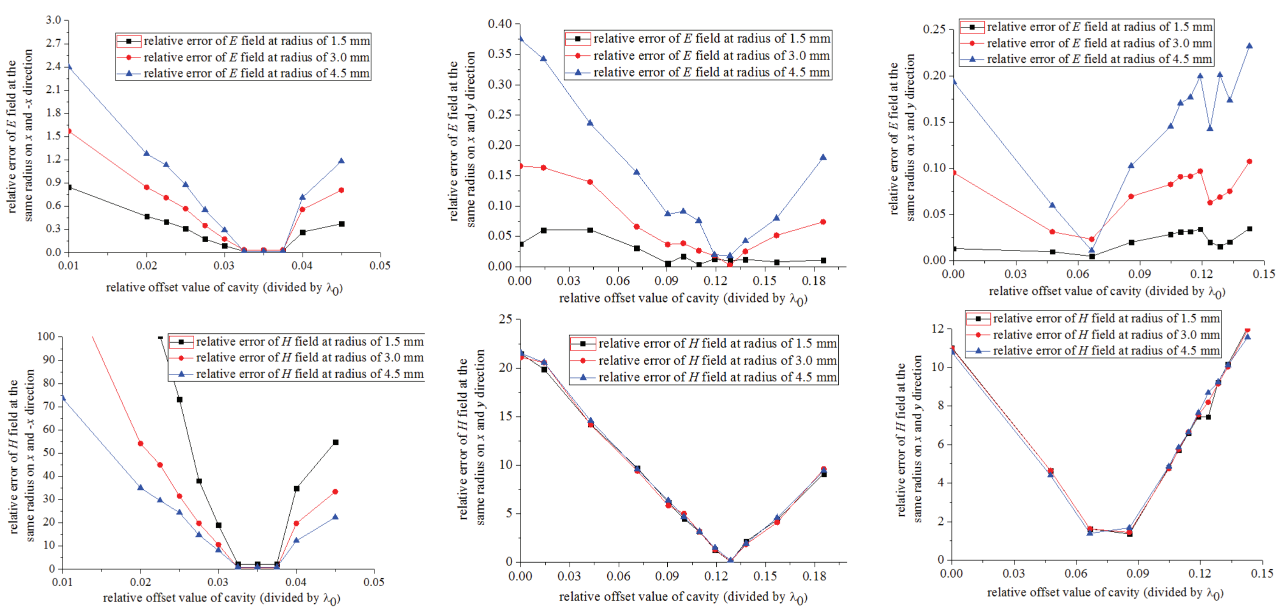
For the best *Ω*, the comparison of the electrical (magnetic) field distribution between the cylindrical cavity and the racetrack cavity of the three coupling mechanisms are shown in Fig. 3a, 3b and 3c respectively.

The following inferences can be drawn from the above analysis:

1. For coupling mechanism 1, the symmetry of the magnetic field is still not very satisfying even in racetrack cavity (the bottom picture of Fig. 2a). So the coupling mechanism 1 may not a good choice.

2. For all the three coupling mechanisms, the symmetry of the magnetic field are worse than the electrical field (under the same condition, the relative error of the magnetic field is much bigger), which can be easily seen by comparing the top and bottom pictures in Fig. 2a, 2b and 2c. So the racetrack cavity mainly improves the symmetry of the magnetic field.

3. For all the three coupling mechanisms, the best symmetry of both the electrical field and magnetic field are obtained at the same value of *Ω*, which is called the best *Ω*.



(a) Input coupler of coupling mechanism 1.
(b) Input coupler of coupling mechanism 2.
(c) Input coupler of coupling mechanism 3.

Figure 2: Relative errors of the electrical (magnetic) fields at the same radius using three different coupling mechanisms.

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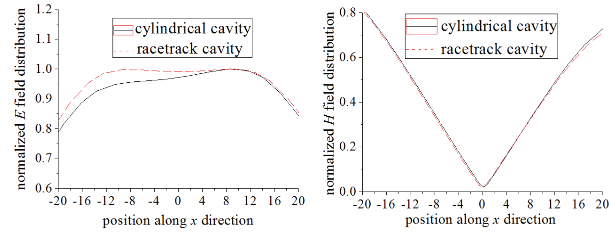
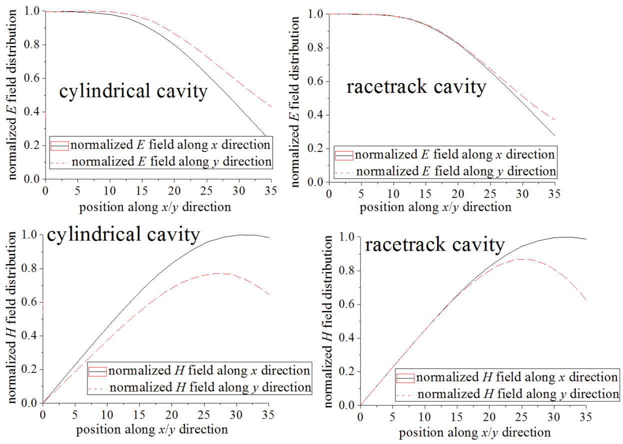
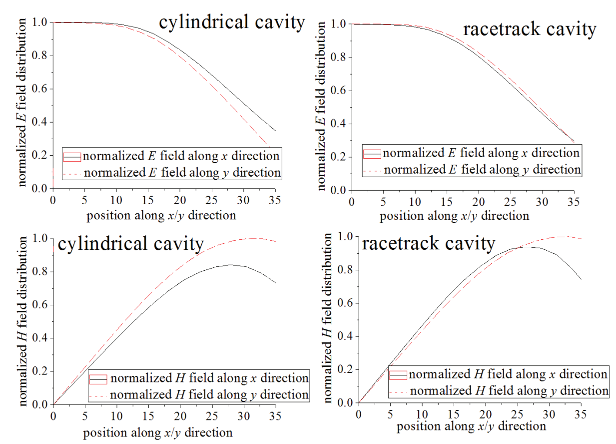


(a) Input coupler of coupling mechanism 1



(b) Input coupler of coupling mechanism 2



(c) Input coupler of coupling mechanism 3

Figure 3: The comparison of the electrical (magnetic) field distribution between the cylindrical cavity and the racetrack cavity using three different coupling mechanisms.

THE MEASUREMENT RESULTS OF THE PROTOTYPE OF COUPLING MECHANISM 3

The prototype of the accelerating tube using coupling mechanism 3 is shown in Fig. 4. The voltage standing wave ratio of the input and output coupler are less than 1.05 at central frequency, and the phase error is less than ±2.0° together with an insertion loss of 3.37 dB (filling time 0.731 μs). The commissioning work is done after the microwave cold test. With the pulse repetition frequency of 10 Hz, the prototype has got a measured accelerating gradient of 21.2 MV/m (pulse width 4 μs without SLED) and 30.6 MV/m (pulse width 1 μs with SLED), which satisfies the design requirement with SLED.

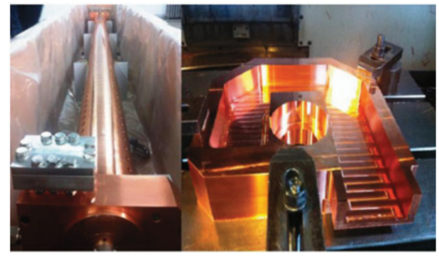


Figure 4: Prototype of the J-type accelerating tube.

CONCLUSION

The symmetry of electrical (magnetic) field within the envelope of beam of cylindrical and racetrack cavities are analysed considering three different coupling mechanisms. According to the simulation data, the coupling mechanism 1 is not a good choice because of a relative bad symmetry of magnetic field even in the racetrack cavity. As for coupling mechanism 3, the symmetry of electrical field is very good in both the cylindrical and racetrack cavities while the symmetry of magnetic field can be improved using the racetrack cavity, so it is considered a good choice of the input coupler. Furthermore, the symmetry of the magnetic field is worse than the electrical field for all the three coupling mechanisms. The symmetry of both the electrical and magnetic fields can be obtained at the same offset value *Ω*. Finally, the results of the microwave cold test and the commissioning for the prototype using coupling mechanism 3 are reported, which satisfies the design requirement. The future work will focus on the quantitative analysis of the influence on the beam emittance in both the cylindrical and racetrack cavities.

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