RF CHARACTERISTIC STUDIES ON THE WHOLE ACCELERATING STRUCTURE FOR THE BEPCII LINEAR ACCELERATOR

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Abstract

An accelerating structure is one device to boost the particle energy. 2856 MHz 3 m long travelling wave disk-loaded accelerating structure is applied in BEPCII linac, its RF characteristics are mainly determined by the 84 regular cells located between the input and output couplers. Input and output couplers need to be included when the whole structure RF characteristics are simulated before fabrication; otherwise it would be difficult to obtain the travelling wave fields excited in the whole structure. If the real 3D couplers are modelled during the design process, a large amount of computer resources and time need to be used. However, if the redesigned azimuth symmetric coupler is used to replace the real 3D one during the simulation process, much less computer resources and time are required. With this method proposed here, the simulation results agree well with the theoretically calculated and experimentally measured ones.

INTRODUCTION

The travelling wave (TW) disk-loaded accelerating structure is one of the key components in normal conducting (NC) linear accelerators, such as the BEPC and BEPCII linacs [1, 2], and has been studied for many years. Usually after the dimensions of each cell and the two couplers are finalized, the structure is fabricated and tuned, and then the whole structure RF characteristics are measured by using a vector network analyzer. Before the fabrication, the whole structure RF characteristics are less simulated. This is because of the structural scale (couples of meters long and centimeters in diameter at S-band) and also the personal computer capability limitations.

Because the RF characteristics of the TW structures with several tens of cells are mainly decided by the regular cells, one method to use redesigned power couplers with azimuth symmetry to replace the original 3D waveguide ones in finite element analysis (FEA) can be used. Then the whole structure RF characteristics, such as the electric field amplitude distribution along the structure's axis and the VSWR curve, can be analyzed by using the multi-physics software package ANSYS [3] with much less computer resources required.

In BEPC and BEPCII linear accelerators, 56 units of 3 m long constant gradient disk-loaded accelerating structure are employed. Table 1 shows the main specifications. Fig. 1 shows the schematic of the input/output coupler. To balance the electromagnetic field asymmetry existed in this kind of single feed input/output coupler, appropriate eccentricity offset is applied. If this real coupler shape shown in Fig. 1 is used to simulate the whole structure RF characteristics, at least 1/2 model (180^o azimuth angle) needs to be created, which is impossible to do with only one PC.

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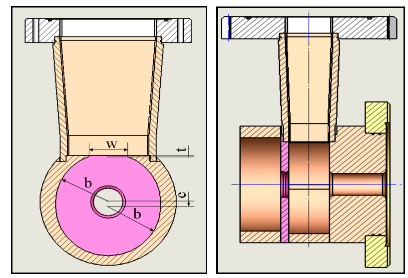

Figure 1: Schematic of the input/output coupler for the accelerating structure of the BEPCII linac. *b*—radius; *e*—eccentricity offset; *w*—coupling aperture width; *t*—coupling aperture thickness.

Table 1: Main Specifications of the TW Structure for BEPCII Linac

Parameters	Units	Values
Operating frequency	MHz	2856
Operating temperature	^{o}C	45.0±0.1
Number of cells		84 regular cells 2 coupler cells
Section length	mm	3009 (86 cells)
Phase advance per cell		$2\pi/3$
Cell length	mm	34.99
Disk thickness	mm	5.84
Iris diameter (2a)	mm	26.231–19.243
Cell diameter (2b)	mm	83.460–81.781
Shunt impedance (r_0)	MΩ/m	54.6–63.9
Q factor		13990–13836
Group velocity	v_g/c	0.0208–0.0070
Filling time	ns	830
Attenuation coefficient	Np	0.57

ANSYS SIMULATION METHODOLOGY

The high frequency modal and harmonic solver modules in ANSYS can be used to perform the numerical finite element analysis on the whole structure RF characteristics. By using one program for all of the simulations any problems of meshing inconsistency between different types of software were eliminated.

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A complete RF analysis on the whole TW disk-loaded structure requires 3 steps, as outlined below. Currently, the ANSYS high frequency modal and harmonic solver modules have the limitation that only 3D elements can be used. To minimize the CPU time and memory use, an axis-symmetric 3D model with a 1^{o} azimuth angle (1/360 model) can be created to carry out the analysis. Otherwise, the azimuth angle of the model needs to be adjusted correspondingly.

1) With an HF119 high frequency tetrahedral element, modal analysis was performed in the vacuum part of each accelerating cell, the cell diameter 2*b* was varied to tune the 2π/3 mode resonating at the nominal operating frequency (2856MHz for the BEPCII linac) by fixing the iris diameter 2*a*.

2) By using the obtained dimensions of the first/last cells in Step 1, the redesigned axis-symmetric vacuum models of the input/output coupler as shown in Fig. 2 can be defined. To minimize the reflection coefficient at the input/output coupler port to the level of 10^{-2} to 10^{-3}, all of the dimensions shown in Fig. 2 except those related with the middle two cells can be adjusted. Once a flat electric field amplitude distribution along the redesigned coupler's axis is obtained and the phase difference between the middle two cells is ~120^{o} (2π/3), the coupler's dimension can be finalized.

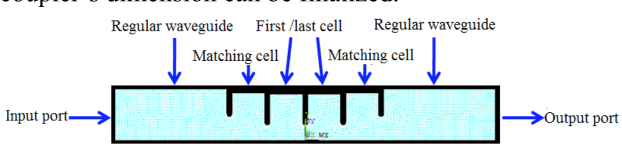

Figure 2: Schematic of the redesigned input/output couplers with azimuth symmetry.

3) Now the vacuum part of the whole structure can be modeled with the obtained cell and coupler dimensions from Steps 1 and 2. Harmonic analysis was carried out by defining the two redesigned couplers in Step 2 as input and output ports, respectively. Impedance boundary condition of copper was applied to the other outer boundary surfaces. Using the built-in macro 'SPARM' and 'HFPOWER', the scattering (*S*) parameters and the total time averaged losses can be calculated. If a harmonic response over a frequency range is performed, the *S* parameters at each frequency step for each port will be calculated, the structure's bandwidth (VSWR≤1.2) can then be known by checking the S11/VSWR data.

It is worth to point out that the mesh size consistency in all of the above analysis steps is the key for acquiring the correct simulation results. Only in Steps 1 and 2, the corresponding model dimensions need to be adjusted.

THE BEPCII LINAC STRUCTURE

By using the structural dimensions listed in [1] and the method proposed in last section, the whole structure RF characteristics on the accelerating structure of the BEPCII linac were studied.

Figure 3 shows the ANSYS model and meshing of the 43rd accelerating cell. Fig. 4 shows the corresponding electromagnetic field distributions of the 2π/3 mode operating at 2856MHz.

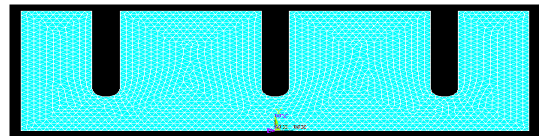

Figure 3: ANSYS model and meshing of the 43rd accelerating cell.

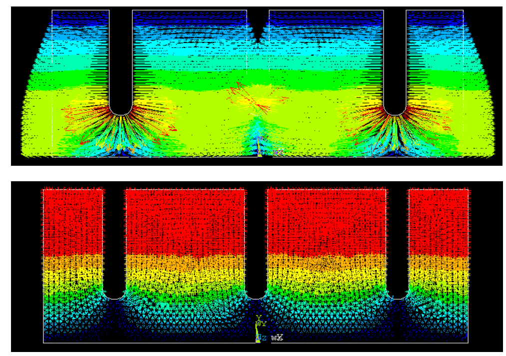

Figure 4: Electromagnetic field distributions of the 2856MHz 2π/3 mode in the 43th accelerating cell

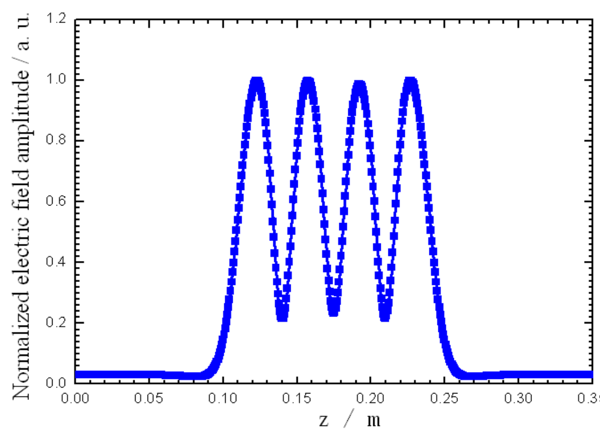

Figure 5: On-axis electric field amplitude distribution in the redesigned input coupler with azimuth symmetry.

Figure 5 shows the on-axis electric field amplitude distribution in the redesigned input coupler with azimuth symmetry of the accelerating structure for the BEPCII linac. This coupler includes two matching cells and two regular accelerating cells; the calculated phase shift between the middle two accelerating cells is ~119.4^{o}. Correspondingly, the dimensions of the output coupler can be obtained with the same method.

The 1/360 model of the accelerating structure for the BEPCII linac is shown in Fig. 6. By appropriately defining the input and output ports in ANSYS, the amplitude distribution of the electric field along the whole structure's axis of the BEPCII linac accelerating structure can be obtained, which is shown in Fig. 7.

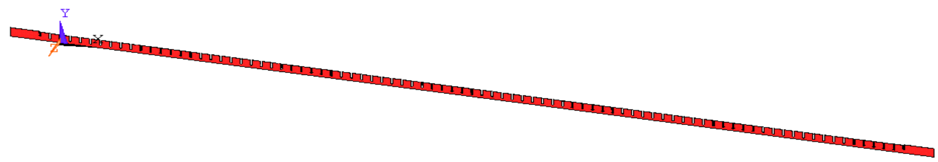

Figure 6: The 1/360 model of the accelerating structure for the BEPCII linac (total 84 regular cells and 2 coupler cells).

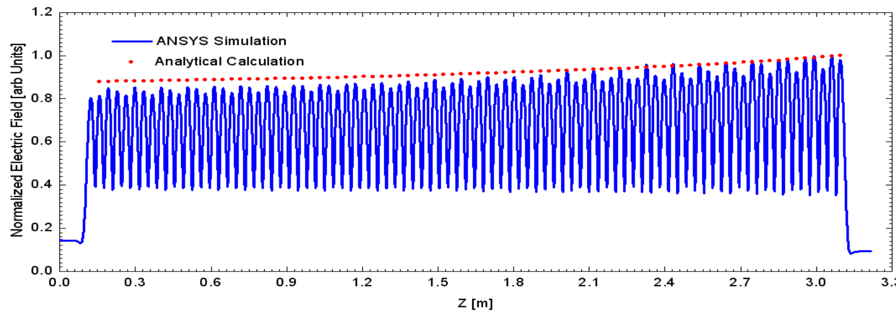

Figure 7: The electric field amplitude distribution along the structure's axis of the BEPCII linac accelerating structure.

In Fig. 7, one can see that there are 86 peaks for the ANSYS simulation result. The 1st and 86th peaks correspond to the matching cells of the input and output couplers, respectively. The middle 84 peaks correspond to the 84 regular accelerating cells. The ANSYS simulation result is consistent with the analytical one, which can be calculated with the analytical formulae listed in [4] after obtaining each cell's RF parameters such as the frequency, the quality factor Q, the shunt impedance R and the group velocity v_g. Usually, the former three ones can be calculated with SUPERFISH [5], and the last one with MAFIA [6].

With –34 dB reflection coefficient at the input port, the ANSYS simulated power attenuation coefficient to the output port is 0.56 Np (~4.85 dB), which is very close to the experimentally measured (0.57 Np) and the analytically calculated (0.54 Np) ones. By using the averaged value of the ANSYS calculated quality factor Q, which is ~13750, the corresponding filling time can be estimated to be 856 ns, which is only 26 ns longer than the experimentally measured value of 830 ns.

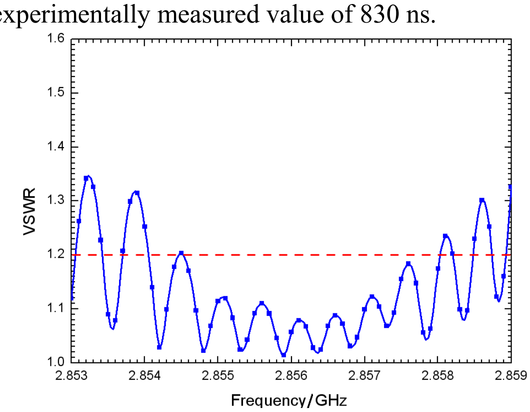

Figure 8: The ANSYS simulated VSWR curve.

Figures 8 and 9 show the ANSYS simulated and the experimentally measured VSWR curves, respectively. It can be clearly seen that the simulated frequency bandwidth is 2858.05–2854.5=3.55 MHz, while the measured one is 2858.3–2853.6=4.7 MHz. In Fig. 8, the VSWR at 2854.5 MHz is exactly 1.2, if it is not considered to be the lower limit of the bandwidth, then the ANSYS simulated bandwidth would be 2858.05–2854.05=4 MHz. Consequently, the difference of the bandwidth results between ANSYS and experiment would go from 1.15 MHz to 0.7 MHz.

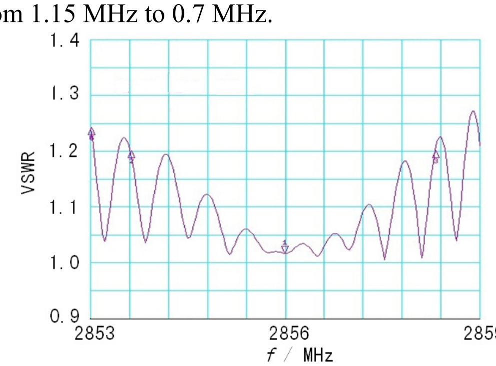

Figure 9: The experimentally measured VSWR curve.

CONCLUSION

By replacing the real 3D waveguide coupler with an axis-symmetric on-axis coupled one in ANSYS, the whole structure RF characteristics on the TW disk-loaded accelerating structure can be done with much less computer time and memory. The consistency between the simulation and experimental results of the BEPCII linac accelerating structure shows the validity of the method proposed in this paper.

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