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Dynamic Behaviour of Electron Beam under Rf Field and Static Magnetic Field in Cyclotron Auto-Resonance Accelerator

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Abstract--The cyclotron auto-resonance accelerator (CARA) is a novel concept of accelerating continuous gyrating charged-particle beams to moderately or highly relativistic energies, which can be used as the high power microwave source and applied in environment improvement area, particularly in the flue gas pollution remediation. In CARA, the continuous-wave (CW) electron beam follows a gyrating trajectory while undergoing the interaction with the rotating TE-mode rf field and tapered static magnetic field. In the process of gyrating acceleration, the phase synchronization with the rf field is automatically maintained, so to speak, with auto-resonance. Simulation models are constructed to study the effect of rf field and static magnetic field on electron beam in CARA, where the beam energy, trajectory and velocity component are analysed. The simulation results match reasonably well with theoretical predication, which sets up a solid foundation for future designs of CARA.

I. Basic Theory & Simulation Model

In CARA, when the static magnetic field satisfies a certain resonance condition, the gyrating electrons are maintained in phase synchronism with a rotating TE_{11} waveguide field under guiding magnetic field Bz, then electron beam can be continuously accelerated. e, m_o, β_z, n and γ are the electron charge, rest mass, normalized axial velocity, refractive index and relativistic factor respectively. The synchronous axial guiding magnetic field is

$$B_z = m_0\omega\gamma(1-n\beta_z)/e$$

For simplicity and high refractive index, a cylindrical waveguide is modelled. The related parameters and curves shown in Table. 1 and Figure. 1.

Parameter	Value
Length of waveguide	2 m
Radius of waveguide	0.5 m
Refractive index n	0.9935
Initial γ of electron	1.4892
Rf field frequency	2.575 GHz

Table 1: Related parameter in CARA

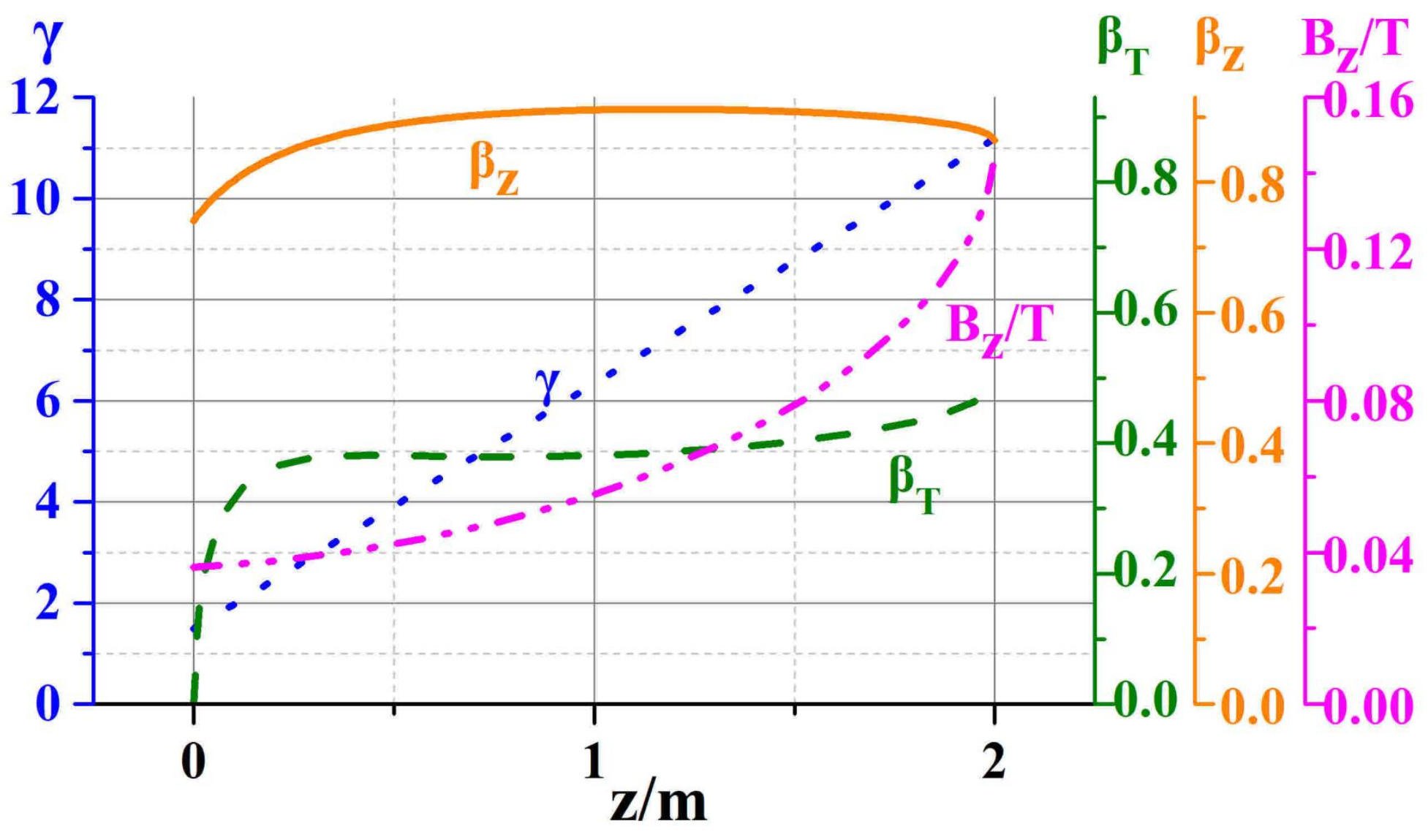


Figure 1: Dependence of initial guiding magnetic field B_z, electron energy γ, transverse velocity β_T and axial velocity β_z on axial distance z in CARA (from z=0 to 2).

II. SIMULATION ANALYSIS

● *Dynamic behaviour under different rf field*

The rf field strength can be adjusted by changing the rf field scaling factor S_{rf}. The resulting curves of electron beam is shown in Figure. 2 and Figure. 3.

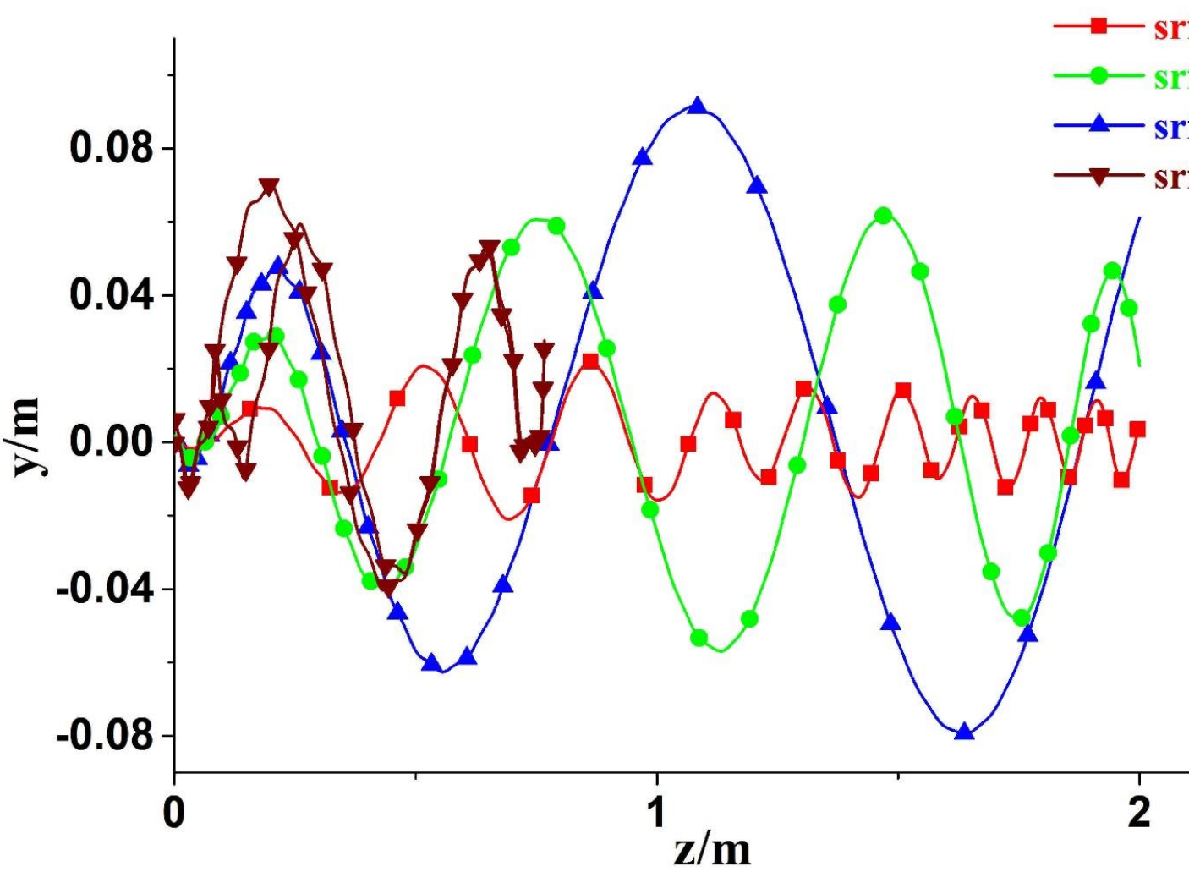


Figure 2: The projection of the motion of electron on the y-z plane under different rf field strength S_{rf}

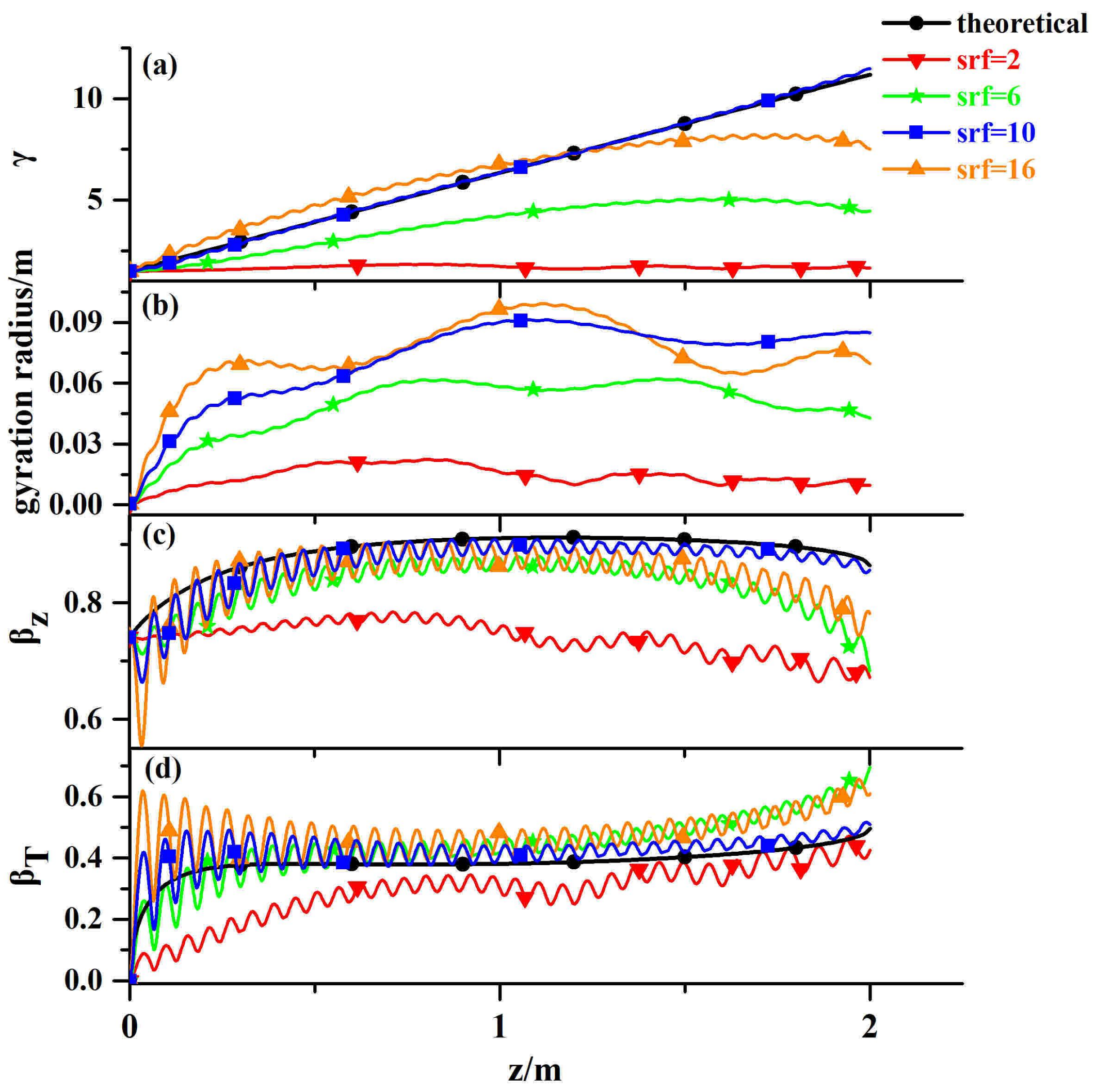


Figure 3: Dependence of (a) electron energy γ, (b) gyration radius ρ, (c) axial velocity β_z and (d) transverse velocity β_T on axial distance z at different S_{rf} value in CARA for a tapered axial magnetic field shown in Fig. 1.

● *Dynamic behaviour under static magnetic field*

The rf field scaling factor S_{rf} =10 remains a constant in this model. The perturbation magnetic field is set as

$$B_z^{'} = B_z(z_0)+\alpha\bullet(B_z(z)-B_z(z_0))$$

where the B_z is initial magnetic field shown in Fig. 1. By adjusting the parameter α, the perturbation magnetic field with different slope can be obtained. The larger the α value, the larger the magnetic field at each point along z axis.

The resulting curves of electron beam is shown in Figure. 4 and Figure. 5.

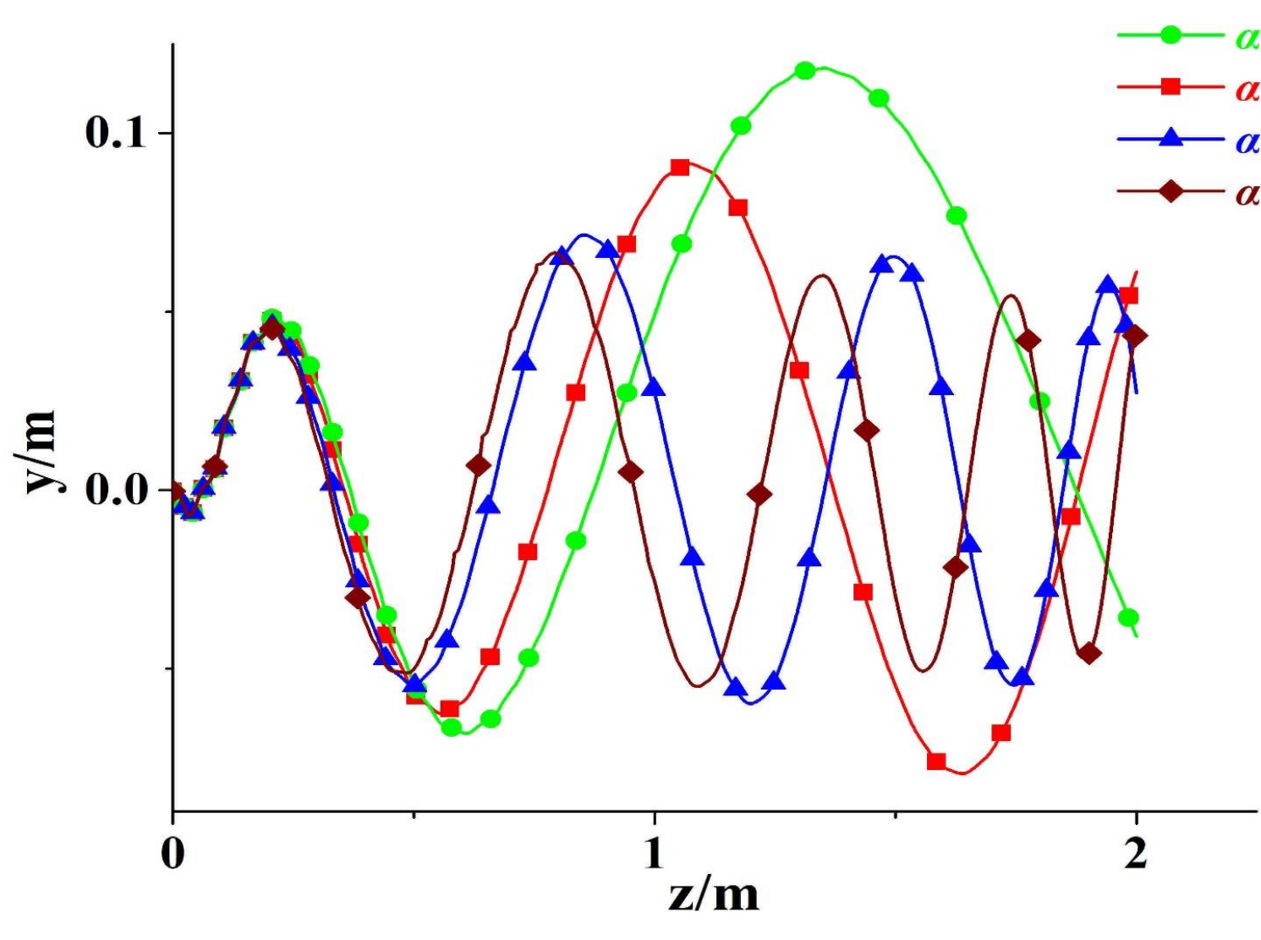


Figure 4: The projection of the motion of electron on the y-z plane under different magnetic field parameter α.

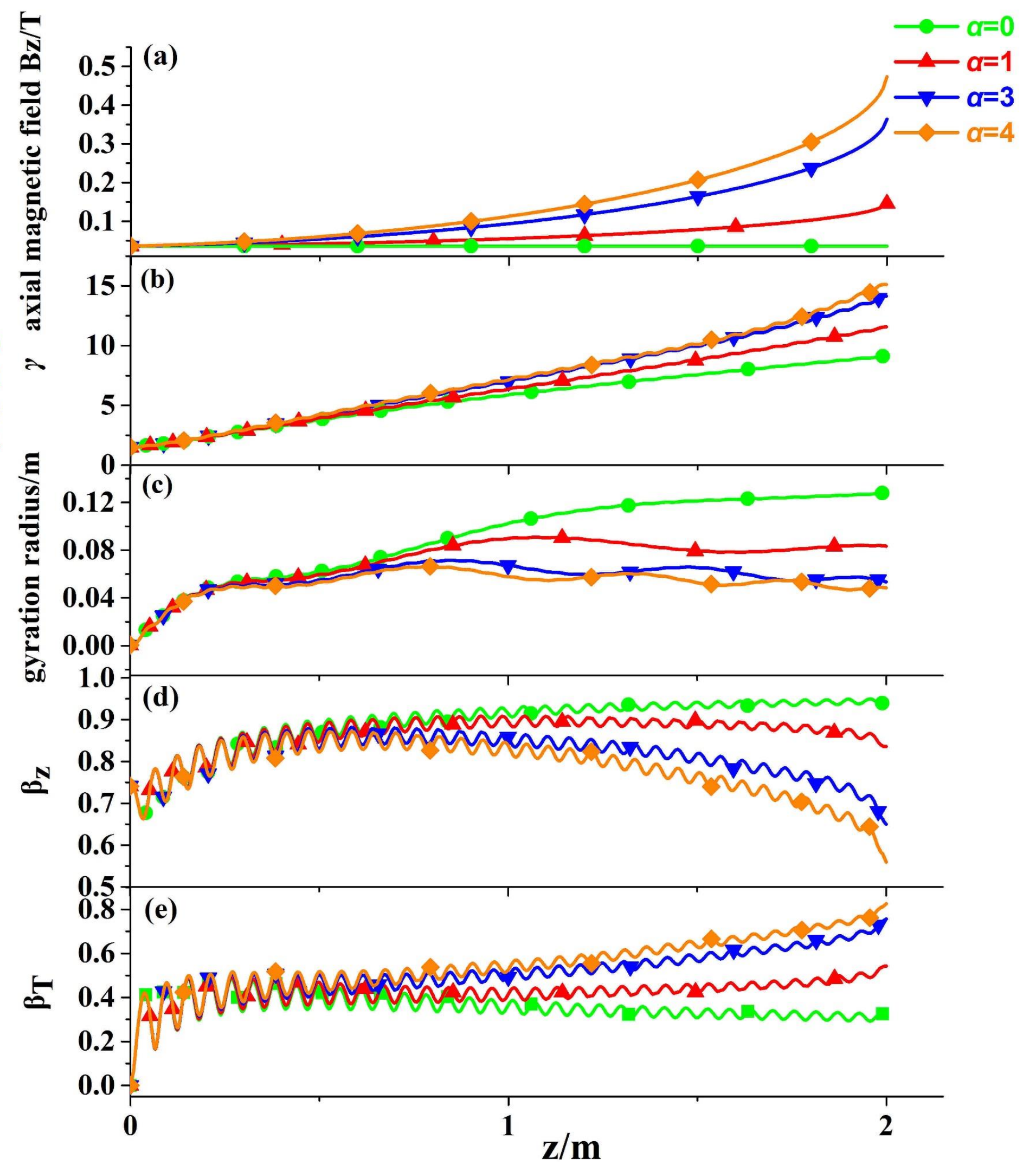


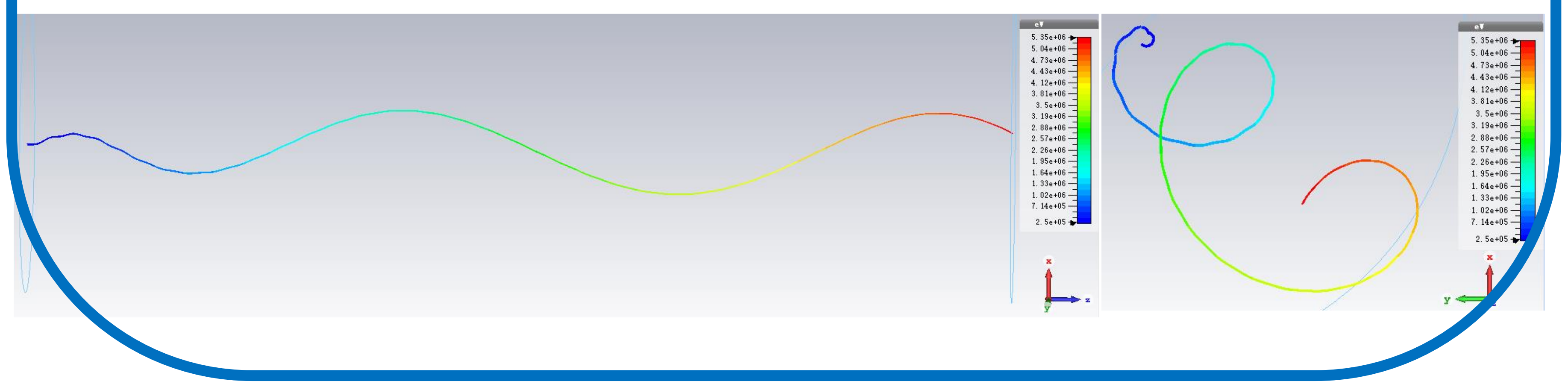
Figure 5: The (a) axial magnetic field Bz distribution along z axis under different α value, dependence of (b) electron energy γ, (c) gyration radius ρ, (d) axial velocity β_z and (e) transverse velocity β_T on axial distance z under a tapered axial magnetic field shown in (a).

III. CONCLUSIONS

(i) When the electron is maintained in phase synchronism with a rotating TE_{11-35} waveguide field using up-tapered axial magnetic field, with axial distance z, γ grows almost linearly, ρ increases and then remains almost unchanged, β_T has a rapidly growth at the beginning and then remains almost a constant, and β_z increases slightly then remains almost unchanged.

(ii) As S_{rf} increases, the revolution number decreases, and the growth rate of γ, ρ and β_T increase obviously while the β_z decreases. The electron will reverse when the S_{rf} is too big. The γ, ρ and β_z at the exist of the waveguide (z=2m) have the maximum value while the β_T has the minimum value as rf field scaling factor S_{rf} increases.

(iii) As α increases, the revolution number, γ and β_T increase obviously while ρ and β_z decreases. The electron will reverse when the slope exceeds a threshold value.



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