Two-mode polarized traveling wave deflecting structure*

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In this paper, we propose a two-mode polarizable deflecting structure, as a new concept for bunch measurement and beam control. With two modes of HEM11 and HEM12 operating in the same structure on horizontal and vertical directions, respectively, the operation status can be switched between the two polarization modes. They can be operated simultaneously with two independent input power sources. With two-mode deflecting structure, the bunch distortion caused by the geometric wake-fields in the accelerating structure can be measured by one structure.

Keywords: Deflecting cavity, Two-mode, Polarizable

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I. INTRODUCTION

For normal bunch diagnostics, bunch length measurement by deflecting structure is a high resolution and reliable method [1]. The geometric wake-fields in the accelerating structure induce beam breakup instability and bunch distortion in both transverse planes. The deflection plane of deflecting structure is horizontal when bunch distortion occurs in the vertical plane or vice verse. In order to manage wake-field effect on both transverse planes, two single mode operation deflecting structures are needed [2]. We proposed a two-mode operation deflecting structure with two modes operating in the structure independently. They are powered by different klystrons and a switch system is used to select the deflection plane. The two mode operation structure occupies smaller installation space than two single mode structures. The preliminary design of the cells is discussed in this paper.

II. INITIAL SCHEME OF POLARIZED DEFLECTING STRUCTURE

The polarizable deflecting structure is capable of measuring the bunch in different deflection planes when the input power changes. Figure 1 shows the operation schematics.

The two-mode operation traveling wave deflection structure is of polarizable nature. The horizontal and vertical deflecting voltages can be written as

$$V_x = E_x \sin\varphi_x \sin\omega_x t,$$
$$V_y = E_y \sin\varphi_y \sin\omega_y t, \qquad (1)$$

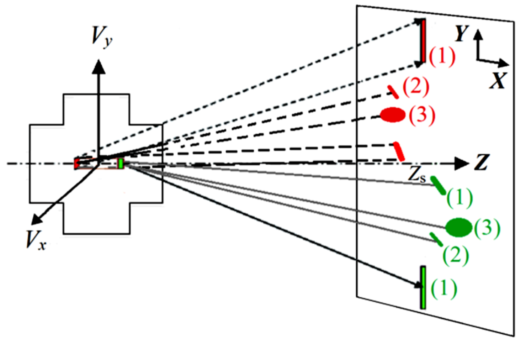

Fig. 1. (Color online) Schematics of the two-mode polarizable deflecting structure.

where, the subscripts x and y denote horizontal and vertical directions, respectively; E_x and E_y are deflecting field; $\sin\varphi_x$ and $\sin\varphi_y$ correspond to the feed-in power for scaling the input power; and ω_x and ω_y are angular frequency of input power changing over time. All the parameters are used to adjust the deflecting voltage. Figure 2 shows the deflecting force V_x and V_y, and their resultant force in the deflection plane.

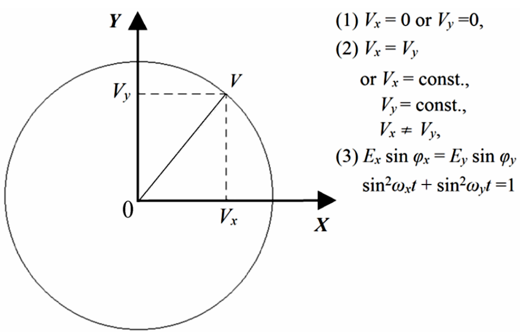

Fig. 2. (Color online) Vector analysis of deflecting force in deflection plane.

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As the input power changes in real-time, the deflection plane and the deflecting force also change in real-time. Thus, the following functions can be realized: 1) the horizontal or vertical deflection plane becomes a single mode deflecting structure [3]; 2) the deflection plane can rotate an angle when the deflecting voltage V_x and V_y are fed simultaneously and kept synchronous change, i.e., when the deflecting voltage changes, the polarization plane does not change; 3) when the deflecting voltages change asynchronously in the horizontal and vertical directions, both the deflection plane and deflecting force change, and the deflecting voltage meets Relation (3) in Fig. 2. Relation (1) and (2) of the polarizable deflecting structure are changeable polarization plane, being the $Y-Z$ or $X-Z$ plane or the plane with a fixed angle of $Y-Z$ plane, For Relation (3), the deflecting plane and force are changeable along with the feed-in power, and the track of slice is a spiral line, instead of a straight line, and the profile on screen is an circle.

In general, structure works at a determined frequency [4], for the design of two-mode polarizable deflecting structure, choosing an operating mode is the primary [5]. As we know, the operating mode in deflecting structure is HEM11 mode [6], which is a hybrid of TM11 and TE11 mode in disk-loaded waveguide [7], or TM11-like mode. HEM11 mode is a dipole mode with a polarization degenerate mode. For suppressing polarization of the deflection plane, asymmetry is the important feature of deflecting structure [8].

Due to asymmetry of the structure, frequencies of the two polarization degenerate modes are separated. In order to realize the function of deflecting in horizontal and vertical directions, one mode with deflection force operated in horizontal direction, and the other mode in vertical direction. Considering the frequency of power source and the deflection ability [9], a primary design with two input system at 5.712 and 11.424 GHz is a balance scheme [10]. HEM11 mode is the most suitable mode for a deflecting structure, and its high order mode, HEM12, shall be of the same deflecting character and meet the demand of doubling the frequency of HEM11 mode. Summing up the considerations, operation modes of the polarizable deflecting structure are HEM11 and HEM12 at horizontal and vertical directions, at the operation frequencies of 5.712 and 11.424 GHz, respectively.

III. ANALYSIS OF REGULAR CELLS

The HEM11 mode in an axis-symmetry structure degenerates in twofold, which leads to the rotation of polarization plane. To solve this problem, SLAC proposed two types of deflecting structures: two symmetry caves on the cavity wall [11] and two symmetry holes on the iris [12]. Advantages of the caves type structure were discussed in Ref. [13]. For a polarizable deflecting structure, the frequency tuning is difficult and inconvenient, but the caves type make the tuning process not so complicated. Caves type cells are the best selection for regular cells. For a two-mode traveling wave structure, however, the phase advance of each mode is a problem to solve before the frequency of each mode can be tuned to required frequency.

A. Phase advance analysis

For a traveling wave structure working at the speed of light, its periodic length is determined by the operation mode and phase advance. For a two-mode polarizable deflecting structure, the HEM11 and HEM12 modes differ in frequency. To ensure the structure working in the two modes at the speed of light, the phase advance of the two modes has to keep the relationship as

$$Phase_{\text{HEM11}} = Phase_{\text{HEM12}}/2, \tag{2}$$

where $\text{Phase}_{\text{HEM11}}$ and $\text{Phase}_{\text{HEM12}}$ are phase advance of HEM11 and HEM12 mode, respectively. The variables are phase advance of the two modes. Possible phase advance combinations are given in Table 1.

TABLE 1. Phase advance (π) of HEM11 and HEM12

HEM11	1/2	1/3	1/4	1/5	2/5	1/6	...
HEM12	1	2/3	2/4	2/5	4/5	2/6	...

B. Sensitive analysis

Considering the frequency tuning and fabrication of the structure in the future [14], the frequency sensitivities are simulated, including cell radius, iris radius and iris length. The results are shown in Fig. 3. The frequency of HEM11 and HEM12 mode varies with beam hole diameter ($2a$), cell diameter ($2b$) and iris length (t). The HEM11 mode works at the backward state, and HEM12 mode at forward state. Therefore, the frequency varies with $2a$ in the opposite direction of HEM11 and HEM12. Frequency sensitivities of cell parameters are listed in Table 2.

TABLE 2. Frequency sensitivity

Size mode*	b	a	t
HEM11 (MHz/mm)	−170	−64.7	11.8
HEM12 (MHz/mm)	−415	213.2	60

* a, holes radius; b, cell radius; t, iris length.

C. Coupler consideration

A pair of input and output couplers is sufficient for single mode operation traveling wave structure, while for two-mode operation traveling wave deflecting structure, two pairs of couplers are applied. To ensure the power systems working independently through input couplers [15], and avoid leaking of high frequency power into a port of low frequency power radiation, an additional low Q cavity transparent for lower frequency is used [16] (Fig. 4).

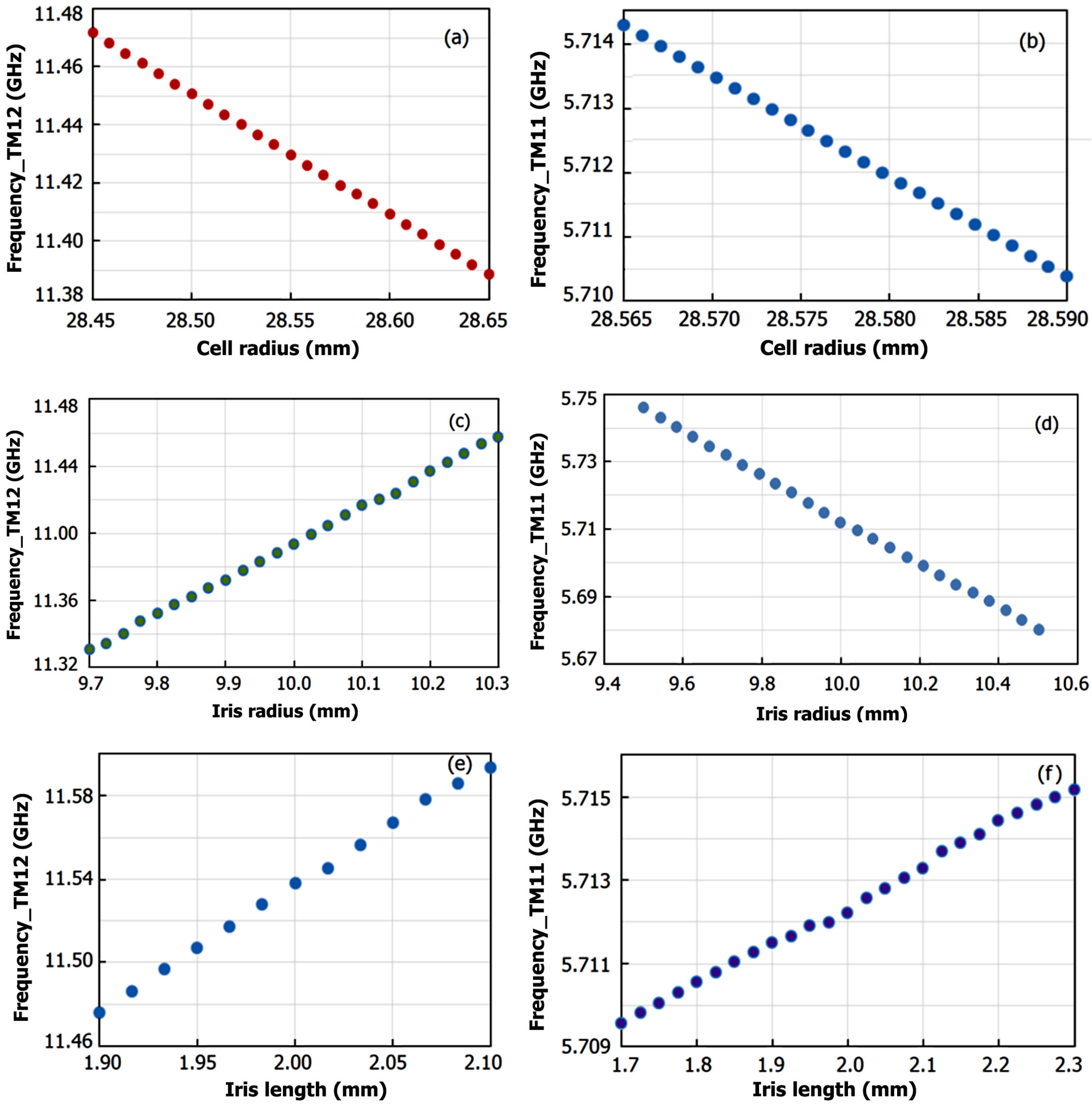

Fig. 3. (Color online) Frequency sensitivity simulations.

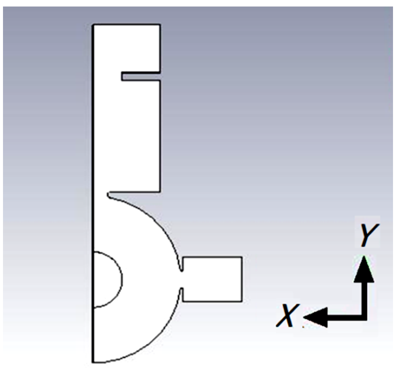

Fig. 4. (Color online) Preliminary consideration of coupler.

IV. SIMULATION OF TWO-MODE DEFLECTION STRUCTURE

The selection of phase advances is mainly determined by the dispersion characteristics. As described in Ref. [17], the dispersion characteristic of HEM11 mode changes in beam holes from backward to forward. The simulation results of dispersion is shown in Fig. 5. The phase changes with frequency sharply from phase $0°$ to $180°$, which is the reason that 0 and π modes do not occur in traveling wave structure [18]. On the other hand, phase advance is related to periodic length of the cells. This means that the phase advance shall not be too small, so that the periodic length shall not be too short. Also, phase advance of the HEM12 mode should be considered. Taking all the conditions to consideration, $2\pi/5$ and $4\pi/5$ mode are the most suitable and opti-

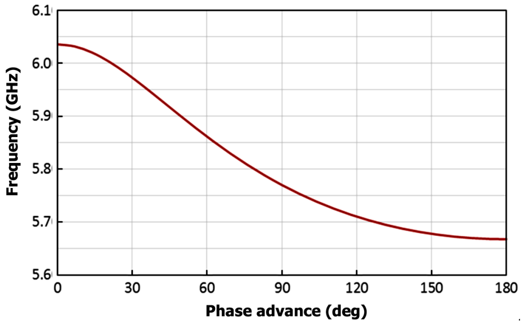

Fig. 5. (Color online) Dispersion characteristic of HEM11 mode.

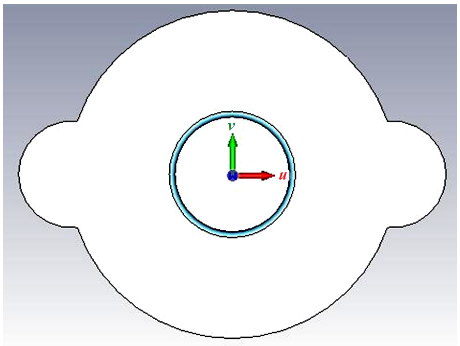

Fig. 6. (Color online) Caves type simulation model.

mization scheme. Figure 5 shows that the HEM11 mode is a backward wave, and the sensitivity simulation of iris radius from Fig. 3 demonstrates that HEM12 mode is forward wave, indicating that the input ports of two modes are at the downstream and upstream of the structure, respectively.

After selection of the modes and phase advance, and simulation of the sensitivity of frequency, cell simulations can be carried out. Figure 6 shows the simulation model, with two symmetric caves on the horizontal cavity wall. Table 3 listed the parameters of the model.

TABLE 3. Parameters of simulation model

Periodic length (mm)	10.5
Iris length (mm)	2
$Phase_{\text{HEM11}}$ (°)	72
f_{HEM11} (horizontal) (GHz)	5.712
$Phase_{\text{HEM12}}$ (°)	144
f_{HEM12} (vertical) (GHz)	11.424

As described above, the caves affect the frequency on horizontal sensitively, and the sensitivity analysis has proved that the frequency of two modes change with iris diameter at the opposite direction. Therefore, it is feasible to satisfy the frequency of two modes at 5.712 GHz and 11.424 GHz simultaneously by changing the iris diameter, cave center and cave diameter. The final cell simulations are shown in Fig. 7. The HEM11 and HEM12 modes work at 5.712 and 11.424 GHz, respectively. Figure 8 shows the electric field distribution in the five cells.

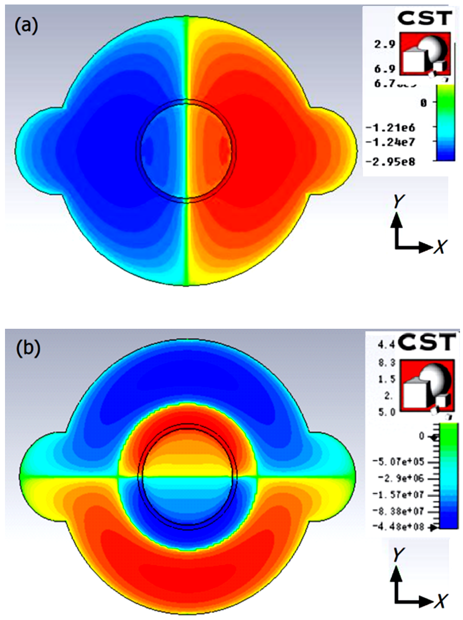

Fig. 7. (Color online) Cell simulation results. (a) horizontal, HEM11 mode, (b) vertical, HEM12 mode.

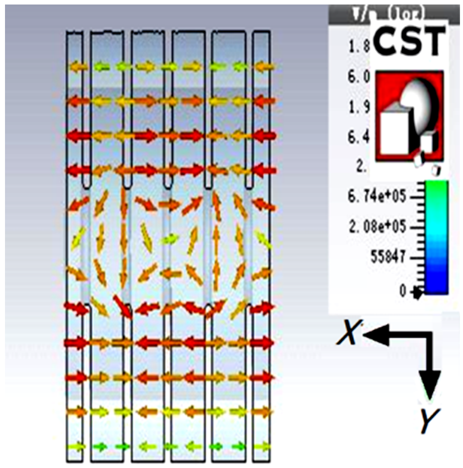

Fig. 8. (Color online) Electric field distribution of HEM11 mode in five cells.

The concept design and cell simulations are thus completed. The two mode operation structure work on the condition of low repetition frequency, low feed power, and normal temperature, the thermal effect generated by power loss is under control.

V. CONCLUSION

The application and development of deflecting structure have proved that deflecting structure plays an important role in accelerating field [19]. Two-mode polarizable traveling wave deflecting structure, as a new diagnostic and control tool, with its multifunction, has been preliminary designed. The design scheme, including cell type, operating modes and phase advance, are all taken into accounts. The simulation results show great improvement in realizing measurement or deflection on any direction of beam. In the first phase, a novel concept and cells design are proposed, while a new type of coupler will be designed and the fabrication will be carried out.

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