THE RESONANT METHOD OF STABILIZATION FOR PLANE OF DEFLECTION IN THE DISK LOADED DEFLECTING STRUCTURES

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Abstract

The hybrid HE11 mode in the cylindrical disk loaded deflectors is twice degenerated. To ensure operational performance and stabilize the position for the plane of deflection, the dispersion curve for modes with Perpendicular Field Polarization (PFP) must be shifted in frequency with respect to the curve for modes with operating Deflecting Field Polarization (DFP). Several solutions, based on the deterioration of the axial symmetry of the structure, are known for this purpose. The resonant method of stabilization is proposed. Resonant elements - slots, coupled only with PFP modes, are placed in the disks. Two branches of dispersion curve for composed slot - structure modes are generated and placed symmetrically with respect to the non perturbed dispersion curve for DFP modes. In the plane stabilization it provides qualitative advantage with respect a simple frequency shift, because cancels, in the first order, the influence of PFP modes on the plane of deflection. The criteria for the slots definition are presented. The examples of application for the traveling and the standing wave S-band deflectors are described.

INTRODUCTION

The Disk Loaded Waveguide (DLW) with the hybrid $HE_{11}$ mode is widely used for charged particle deflection both in Traveling Wave (TW) and Standing Wave (SW) mode. The classical DLW realization in TW $\theta_0 = 120^\circ$ mode are LOLA [1] structures. For operating frequency $f_o = 3000 MHz$ the LOLA structure was adopted in [2] and dispersion curves for the axisymmetric case are shown in Fig. 1a for aperture radius $r_a = 21.4 mm$, cell radius $r_b = 55.45 mm$ and iris thickness $t_w = 5.4 mm$. For SW $\theta_0 = 180^\circ$ mode application DLW is considered in [3] and dispersion curves are shown in Fig. 1b for $r_a = 12.5 mm$, $r_b = 59.73 mm$, $t_w = 8.0 mm$. Usually DLW with negative dispersion of the hybrid $HE_{11}$ wave is used due to higher RF efficiency.

To ensure single mode operation and stabilize the position for the plane of deflection with respect manufacturing errors and another perturbations, one should separate in frequency dispersion curves for operating DFP and PFP $HE_{11}$ waves. There are solutions with moderate geometry deterioration with the effect of separation described by perturbation theorem - LOLA structure with stabilizing holes, Fig. 2a and the structure with two peripheral recesses [4], Fig. 2b. The mutual position of dispersion curves for DFP and PFP modes is shown in Fig. c for adopted LOLA structure [2] assuming stabilizing holes radius $r_s = 9.5 mm$ and hole center position $L_s = r_a + 13.1 mm$ and for structure with recesses, assuming cell dimension given in [4].

The shorting rods in the optimized "Langeler structure" [5] provide strong field deterioration for PFP modes and essentially large separation in frequency.

DEFLECTION PLANE STABILITY

Let us consider stability of the plane of deflection in SW mode. The deviation of plane of deflection takes place due to addition of PFP modes $\vec{E}_{pn}$, excited at the cavity imperfections, to the unperturbed DFP mode $\vec{E}_{d0}$. The field distribution $\vec{E}_{q}$ in the cavity with a small dimension deviation

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\( \Delta V \) can be described as [6]:

\[
\vec{E}_d = \vec{E}_{d0} + \sum_n \vec{E}_{pn} \int_{\Delta V} (Z_0^2 \vec{H}_{d0} \vec{H}_{pn}^* - \vec{E}_{d0} \vec{E}_{pn}^*) dV/W_0(f_0^2 - f_n^2),
\]

where \( Z_0 = \sqrt{\epsilon_0} \), \( f_V Z_0^2 \vec{H}_n \vec{H}_m^* dV = f_V \vec{E}_n \vec{E}_m^* dV = \delta_{nm} W_0 \) and \( V \) is the cavity volume, \( f_0 \) and \( f_n \) are the frequencies of modes \( \vec{E}_{d0} \) and \( \vec{E}_{pn} \). The similar relation for description of a field perturbation in the chain of coupled cavities is given in [7] with a matrix form.

The most dangerous is the contribution in the total field (1) from PFP mode \( \vec{E}_{pns} \) with the phase advance \( \Theta = \Theta_0 \), because it provides the synchronous interaction with the beam. Keeping in (1) only \( \vec{E}_{pns} \) mode contribution, one can estimate this addition to the unperturbed DFP operating field \( \delta \vec{E}_d = \vec{E}_d - \vec{E}_{d0} \) as:

\[
\delta \vec{E}_d \approx \vec{E}_{pns} \int_{\Delta V} (Z_0^2 \vec{H}_{d0} \vec{H}_{pns}^* - \vec{E}_{d0} \vec{E}_{pns}^*) dV/W_0(f_0^2 - f_{pns}^2),
\]

assuming the small separation in frequency \( |f_{pns} - f_0| \ll f_{pns} \) between DFP and PFP branches of dispersion curves.

For the case of a simple separation of dispersion curves for DFP and PFP modes a possible rotation for plane of deflection is proportional to the DFP and PFP modes coupling at the imperfections of the cavity and is inverse proportional to the value of frequency separation \( (f_0 - f_{pns})^{-1} \).

\[
\Delta \vec{E} = \vec{E}_c + b \vec{E}_s, \quad \vec{E}_{uc} = \vec{E}_{pn} = a \vec{E}_s, \quad (3)
\]

where \( a^2 + b^2 = 1 \).

By changing slot length (by adjusting slot resonant frequency), one can change the frequencies of composed modes \( f_{uns}, f_{lns} \). Finally one should place composed modes, with the phase advance \( \Theta \), with respect operating as:

\[
\delta \vec{E}_d \approx \sqrt{2} f_{uns} \int_{\Delta V} (Z_0^2 \vec{H}_{d0} \vec{H}_{uns}^* - \vec{E}_{d0} \vec{E}_{uns}^*) dV/W_0(f_0^2 - f_{uns}^2).
\]

As one can see, the contribution of synchronous PFP mode is cancelled, and replaced at the contribution of the field from resonant element - slot field \( \vec{E}_{uns} \), which is concentrated in the slot and a nearest vicinity. Modes coupling in (4) between operating DFP mode \( \vec{E}_{d0} \) and slot mode \( \vec{E}_{uns} \) takes place on the cavity-slot imperfections near slot and is smaller than coupling of operating DFP \( \vec{E}_{d0} \) mode with PFP \( \vec{E}_{pns} \) mode in (2). Moreover, this coupling is stronger damped by larger frequency separation. At the cavity axis the slot-related field addition in (4) is practically absent.

### SLOTS PLACEMENT AND DIMENSIONS

Just one slot should be placed in one iris. If several slots are placed in one iris, mutual slot interaction provides additional branches of dispersion curve and makes single mode DLW operation impossible. If one slot for several DLW periods is used, it strongly restricts a flexibility in the movement of branches for composed modes and results in deterioration of the compensation effect in (4). Two options of the slot placement are reasonable. In the first option, Fig. 4a, the slots in the adjacent irises are ‘face to face’. The slot-structure coupling is partially cancelled due to such slot position. Together with Translation (T) symmetry, this case the structure has the mirror symmetry planes and can

figure 3: The DLW cell with the resonant slot (a) and created dispersion curves (b).

figure 4: Possible slot placement in the irises - (a) - Translation (T) and (b) - Translation with Rotation (TR).
be modeled easy in SW model. The field addition $\delta E_d$ in (4) has the same phase advance $\Theta_0$ as operating DFP $E_{d0}$ mode.

In the second option, Fig. 4b, slots at the adjacent irises are rotated at $180^\circ$. For the same slot distance $r_s$ from the axis, the slot - structure coupling $k_s$ is higher, than for T case. The structure has symmetry of Translation with Rotation (TR) - symmetry group is $C_{2z}$, [8]. Field addition $\delta E_d$ in (4) gets additional phase shift $\theta = \Theta_0 + \pi$ in adjacent cells [8] and synchronous interaction with the beam for $\delta E_d$ is deteriorated.

Frequencies of composed modes depend on the slot resonant frequency $f_s$, which is mainly defined by the slot length $l_s = r_s \phi$, and slot-structure coupling $k_s$, which is defined by slot dimensions $h_s, t_w$, slot frequency $f_s$ and phase advance $\theta$. PFP modes with $\theta = 0$ do not excite the slot. Applying approach, developed in [9], one can have analytical estimation for composed modes frequencies. Simpler way is to calculate frequencies numerically, using modern software with periodical boundary conditions. The results of such calculations are given in Fig. 5. Modes frequencies for $\theta = 0^\circ, 60^\circ, 120^\circ, 180^\circ$ are required to control generally position of branches for composed modes with respect DFP dispersion curve.

RESULTS AND SUMMARY

With the described procedure were defined approximately dimensions of slots for DLW in SW and TW modes, both for T and TR slot positions. The calculated dispersion curves for DLW in these options are shown in Fig. 6. For TR slot position $k_s$ value was reduced by $r_s$ increasing in investigation and not maximal separation between composed and DFP modes is shown in Fig. 6c,d. As one can see from Fig. 7, the resonant method ensures single mode operation, provides large frequency separation between operating DFP modes and composed modes. This method is the flexible and powerful solution for deflection plane stabilization.

REFERENCES

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