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

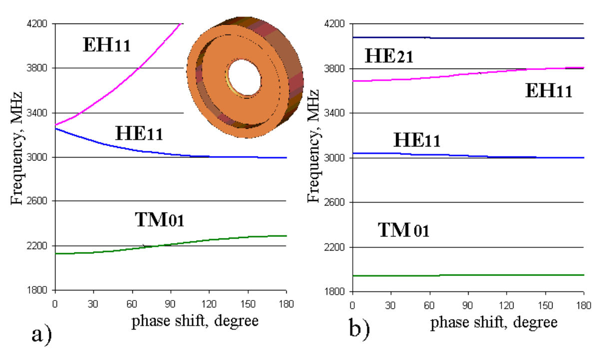

Figure 1: Dispersion curves for axisymmetric DLW for TW (a) and SW (b) operating mode.

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 $\theta_0 = 120^o$ mode are LOLA [1] structures. For operating frequency $f_o = 3000MHz$ the LOLA structure was adopted in [2] and dispersion curves for the axisymmetric case are shown in Fig. 1a for aperture radius $r_a = 21.4mm$, cell radius $r_b = 55.54mm$ and iris thickness $t_w = 5.4mm$. For SW $\theta_0 = 180^o$ mode application DLW is considered in [3] and dispersion curves are shown in Fig. 1b for $r_a = 12.5mm, r_b = 59.73mm, t_w = 8.0mm$. 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

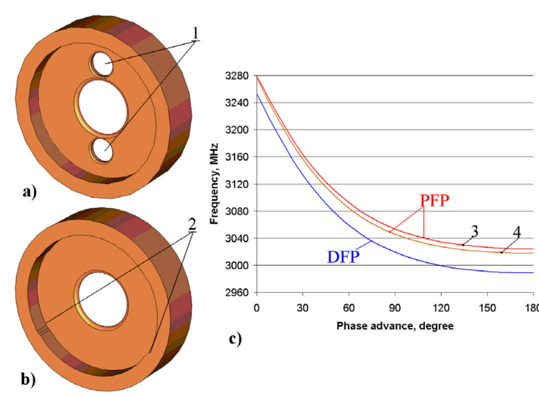

Figure 2: LOLA structure (a), structure with two peripheral recesses (b), dispersion curves for DFP and PFP modes (c). 1 -stabilizing holes, 2 - recesses, 3 - PFP for (a), 4 - PFP for (b).

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 $r_s = 9.5mm$ and hole center position $L_s = r_a + 13.1mm$ 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 $\vec{E}_{pn}$, exited at the cavity imperfections, to the unperturbed DFP mode $\vec{E}_{d0}$. The field distribution $\vec{E}_d$ in the cavity with a small dimension deviation

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ΔV can be described as [6]:

$$\vec{E}_d = \vec{E}_{d0} + \sum_n \frac{\vec{E}_{pn} f_{pn}^2 \int_{\Delta V} (Z_0^2 \vec{H}_{d0} \vec{H}_{pn}^* - \vec{E}_{d0} \vec{E}_{pn}^*) dV}{W_0 (f_{d0}^2 - f_{pn}^2)}, \quad (1)$$

where $Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}$, $\int_V Z_0^2 \vec{H}_n \vec{H}_m^* dV = \int_V \vec{E}_n \vec{E}_m^* dV = \delta_{nm} W_0$ and V is the cavity volume, f_{d0} and f_{pn} 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:

$$\delta\vec{E}_d \approx \vec{E}_{pns} \frac{f_{pns} \int_{\Delta V} (Z_0^2 \vec{H}_{d0} \vec{H}_{pns}^* - \vec{E}_{d0} \vec{E}_{pns}^*) dV}{W_0 (f_{d0} - f_{pns})}, \quad (2)$$

assuming the small separation in frequency $|f_{pns} - f_{d0}| << f_{pns}$ between DFP and PFP branches of dispersion curve.

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 $(f_{d0} - f_{pns})^{-1}$.

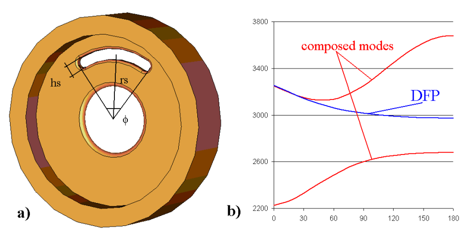

Figure 3: The DLW cell with the resonant slot (a) and created dispersion curves (b).

The idea of resonant stabilization is well known for longitudinal stabilization of accelerating field distribution is so called "compensated" or "bi-periodical" [7] or "$\pi/2$" accelerating structures and here is applied for deflecting field. We place in the structure an element, which is decoupled with DFP modes and the dispersion curve for these modes remains unchanged. The most practical solution for such element in DLW is a slot in the iris, shown in Fig. 3a. With PFP modes this element is strongly coupled. The dispersion curve for PFP modes splits into lower and upper branches, Fig. 3b. The fields distributions for modes at the lower branch $\vec{E}_{lc}$ and at the upper branch $\vec{E}_{uc}$ are composed, according regulations for coupled elements, from the fields of modes $\vec{E}_{pn}$ and fields of modes in the resonant element - slot fields $\vec{E}_{sn}$ as:

$$\vec{E}_{lc} \approx a\vec{E}_{pn} + b\vec{E}_{sn}, \quad \vec{E}_{uc} \approx b\vec{E}_{pn} - a\vec{E}_{sn}, \quad (3)$$

where $a^2 + b^2 = 1$.

By changing slot length (by adjusting slot resonant frequency), one can change the frequencies of composed modes f_{ln}, f_{un}. Finally one should place composed modes, with the phase advance Θ_0, with respect operating frequency as $\frac{f_{uns}^2}{f_{d0}^2 - f_{uns}^2} = -\frac{f_{lns}^2}{f_{d0}^2 - f_{lns}^2}$. For a small slot-structure coupling, which results in a small frequency separation $f_{uns} - f_{d0} << f_{d0}$, it means practically symmetrical position for branches of composed modes $f_{uns} - f_{d0} \approx f_{d0} - f_{lns}$. For this condition the field balance in (3) becomes $a \approx b$. Similar to (2), but taking now into account two branches with composed according (3) modes, one can get, after transformations, the synchronous field addition in the cavity :

$$\delta E_d \approx \vec{E}_{sns} \frac{\sqrt{2} f_{uns}^2 \int_{\Delta V} (Z_0^2 \vec{H}_{d0} \vec{H}_{sns}^* - \vec{E}_{d0} \vec{E}_{sns}^*) dV}{W_0 (f_{d0}^2 - f_{uns}^2)} \quad (4)$$

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 $\vec{E}_{sns}$, which is concentrated in the slot and a nearest vicinity. Modes coupling in (4) between operating DFP mode $\vec{E}_{d0}$ and slot mode $\vec{E}_{sns}$ 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

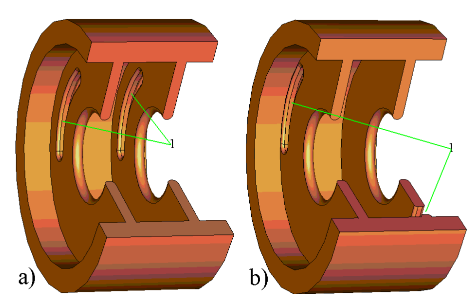

Figure 4: Possible slot placement in the irises - (a) - Translation (T) and (b) - Translation with Rotation (TR).

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 be modeled easy in SW model. The field addition $\vec{\delta E_d}$ in (4) has the same phase advance Θ_0 as operating DFP $\vec{E}_{d0}$ mode.

In the second option, Fig. 4b, slots at the adjacent irises are rotated at 180^o. 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_{2_2}, [8]. Field addition $\vec{\delta E_d}$ in (4) gets additional phase shift $\theta = \Theta_0 + \pi$ in adjacent cells [8] and synchronous interaction with the beam for $\vec{\delta E_d}$ 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 θ. PFP modes with $\theta = 0$ do not excite the slot. Applying approach, developed in [9], one can

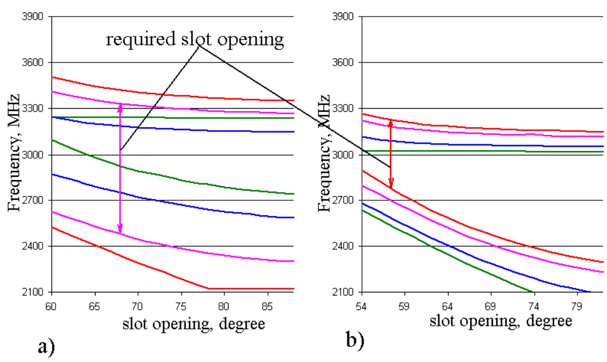

Figure 5: Dependencies of composed modes frequencies on the slot opening for TR slots position. (a) TW mode, $r_s = 50.04mm$, (b) SW mode, $r_s = 54.23mm$. Green - $\theta = 0$, blue - $\theta = 60^o$, magenta - $\theta = 120^o$, red - $\theta = 180^0$.

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 $\theta = 0, 60^o, 120^o, 180^o$ 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.

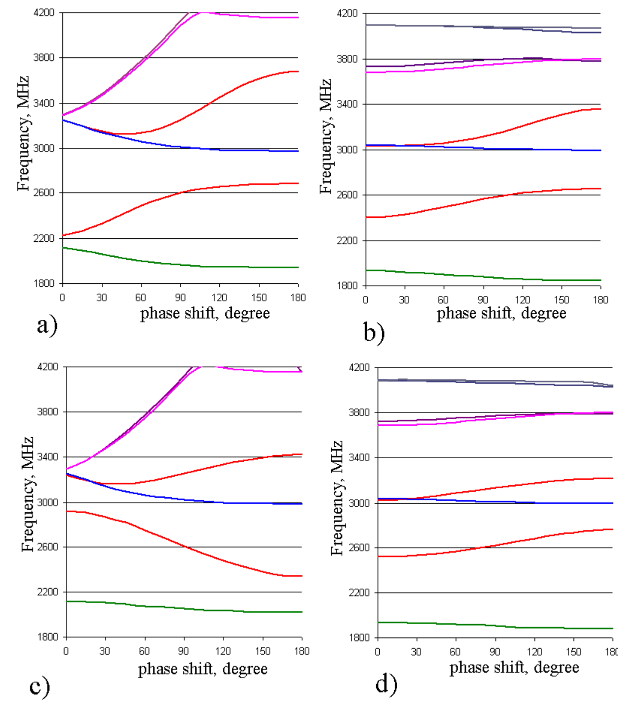

Figure 6: Calculated dispersion curves for DLW with resonant slots for (a) - TW mode, $\theta_0 = 120^o$, T slot position; (b) SW, $\theta_0 = 180^o$, T; (c) - TW, $\theta_0 = 120^o$, TR; (b) SW, $\theta_0 = 180^o$, TR. Green - TM_{01} modes, blue - operating DFP modes, red - composed modes.

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