EFFECTIVE STANDING-WAVE RF STRUCTURE FOR CHARGED-PARTICLE BEAM DEFLECTOR

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Abstract

In this report we describe new standing wave π-mode rf structure for charged particles deflection. For L-band frequency range parameters of the proposed structure are compared with classical $TM110$ mode deflecting cavity ones. With originating $TE11n$ mode, our proposal has several times higher rf efficiency, one order wider pass-band and smaller (in times) transverse dimensions. The cavity design idea and typical parameters are presented. Some particularities of the beam dynamics in the proposed structure are pointed out. Preferable field of structure application is discussed.

INTRODUCTION

Charged particles deflection in accelerator facilities is some time required for different cases - particle separation, beams characterization and another special purposes. For high energy particles exist single deflecting cavities, such as well known crab cavity and CEBAF deflecting cavity [1]. As for periodical structures for particle deflection, just Disk Loaded Waveguide (DLW) [2] with operating $TM11$ wave is known. With proper cells shape, that structure is now under wide consideration for application in standing wave mode together with super-conducting realization.
In this paper we consider another periodical structure, also originated wrom DLW, but with 3D geometry and another operating mode origination.

STRUCTURE GEOMETRY

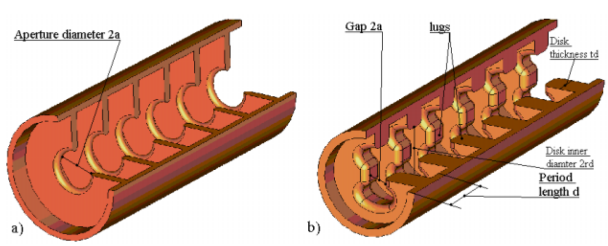

Figure 1: General wiev of the known $TM11$ deflecting cavity (a) and the proposed $TE11n$ one (b).

The shape of the proposed structure is shown in Fig. 1b in comparison with well known $TM11n$ cavity, Fig. 1a. For both cases the operating mode is π-type one and the structures period length $d = \frac{\beta\lambda}{2}$, where λ is the operating wavelength at and β is relative particle velocity.
Let us start the structure formation from DLW with disk thickness $t_d \sim 0.4d$, (see Fig. 1b for notations), and inner disk radius $r_d \sim 0.8R_c$, where R_c is the inner cell radius. Let consider the lowest π mode $TE11n$ with the transverse electric field loop at the disk. In a cylindrical geometry all modes with azimuthally field dependence are twice degenerated. Introduction of two opposite lugs at the disk cancels $TE11n$ modes degeneration and each mode splits in two. One of these modes has a transverse electric field loop at the lugs. With the lugs increasing the frequency of this mode decreases. The gap value $2a$ is the free parameter of the structure. It defines structure rf efficiency and final $2a$ value should be fixed from the reasons of rf efficiency, maximal electric field value at the surface E_{smax}, safety reasons and deflecting field uniformity.
For the chosen gap distance $2a$ operating frequency value f_π should be adjusted by changing cells radius R_c with simultaneous change in inner disk diameter r_d. With different combinations of cell elements dimension the final R_c value may be in the range $(0.26 \div 0.36)\lambda$. As compared to $TM11n$ DLW structure ($R_c \approx 0.57\lambda$), $TE11n$ one has smaller transverse dimensions.

RF PARAMETERS

RF parameters of $TM11n$ mode cavity and $TE11n$ mode one are compared at operating frequency $1300MHz$. For this purpose $TM11n$ deflecting cavity, described in [3], was scaled for $1300MHz$. and rf parameters were calculated. The electric and magnetic fields distributions for

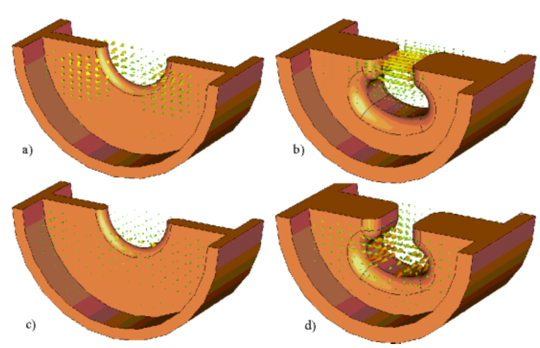

Figure 2: Electric (a,b) and magnetic (c,d) fields distribution in the $TM11n$ cavity (a,c) and the proposed one (b,d).

$TM11n$ structure and the proposed one are shown in Fig. 2. As one can see, in the $TM11n$ structure both magnetic and electric fields are enough uniformly distributed in the

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cell volume. In the $TE11n$ structure electric field is localized between opposite lugs (see Fig. 2b) and magnetic field gather round lugs.

The distributions of the electric energy density W_e and

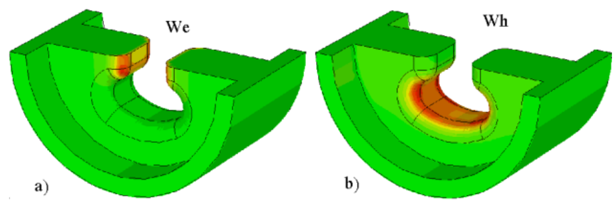

Figure 3: Electric energy density W_e (a) and magnetic one W_h, (b), distributions at the surface of the $TE11n$ structure.

magnetic one (W_h) are shown in Fig. 3. As one can see, high values both for electric and magnetic fields are at the disk and lugs facets and appropriate rounding is necessary.

RF Efficiency

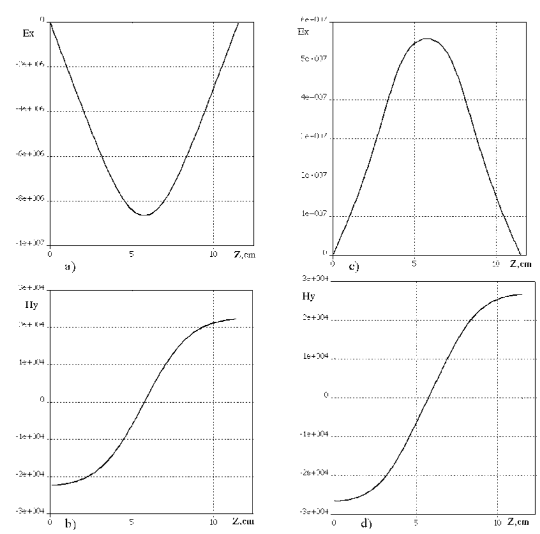

Figure 4: Transverse electric E_x component distributions (a,c) and magnetic H_y ones (b,d) along beam axis (from $-\frac{d}{2}$ to $\frac{d}{2}$) for $TM11n$ cavity (a,b) and the proposed $TE11n$ one (c,d).

In particle deflection participate transverse components both electric (E_x) and magnetic (H_y) fields. Deflecting voltage U_{def} for one period is:

$$U_{def} = \int_{-d/2}^{d/2} (E_x(z)cos(\frac{\pi z}{d}) + \beta c \mu_0 H_y(z) sin(\frac{\pi z}{d}))dz. \quad (1)$$

In Fig. 4 distributions of transverse components E_x, H_y along beam axis are shown for $TM11n$ DLW and proposed $TE11n$ structure, supposing the same energy in the structures period. As one can see, longitudinal distributions of the same components are qualitatively similar. More over, H_y values are practically the same for both structures. It results practically in the same contributions of magnetic component H_y in deflecting voltage U_{def} (1). But value of E_x component and, electric part in deflecting voltage, is several times, see Fig. 4a, 4c, higher in $TE11n$ structure. Components H_y in considered structures, as one can see from Fig. 4, have different phase shift with respect E_x. In the $TM11n$ DLW deflecting effect of magnetic field sums up with electric one. In our proposal transverse magnetic field partially cancels deflection by electric one. But, due to drastically larger E_x contribution, final U_{def} value (for the same stored energy) in $TE11n$ structure is sufficiently higher, as compared to DLW. Quality factor for operating mode is higher (≈ 1.5 times) for $TM11n$ structure. Nevertheless, the value of shunt impedance $Z_{def} = \frac{U_{def}^2}{P_s}$, where P_s is the rf losses power in the structure period, is higher for $TE11n$ structure.

Mainly Z_{def} value depends on the gap distance $2a$. But dimensions of another cell elements also have an influence. Changing t_d and r_d values, one can slightly reduce magnetic cancellation in deflecting voltage U_{def}. Together with reasonably small gap distance $2a$, for practical cases one can get advantage in Z_{def} value $\approx (6 \div 12)$ times, as compared to $TM11n$ DLW cavity.

Passbands

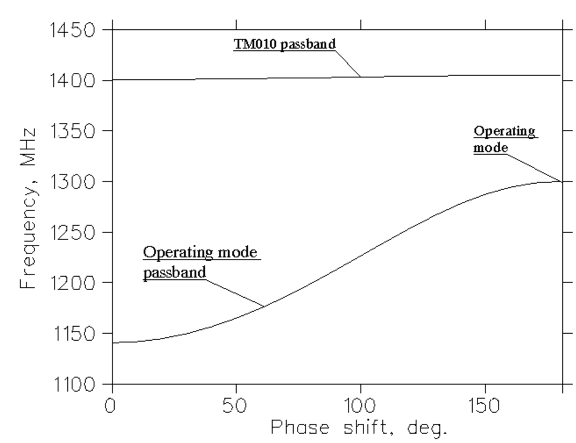

Figure 5: Operating passband of the proposed $TE11n$ structure.

In the classical $TM11$ DLW one parameter - disk aperture radius a, see Fig. 1a, defines both rf efficiency, and operating passband width. Requirements of high efficiency and wide passband are conflicting. In the $TE11n$ structure we have several more or less independent parameters.

The operating passband width depends mainly on r_d and t_d values, see Fig. 1b. For practical cases, the coupling coefficient γ_c values are $\gamma_c \sim 0.11 \div 0.16$.

$$\gamma_c = \frac{f_\pi^2 - f_0^2}{f_\pi^2 + f_0^2}, \quad (2)$$

where f_0 is the frequency of 0 mode, which can not be re-

alized in the finite structure length.
The operating passband is fundamental one in the proposed structure. Differing from $TM11n$ DLW, modes at operating passband are not degenerated - second $TE11n$ passband with perpendicular field polarization is placed in the region $\approx 1.5 f_{\pi}$. The nearest passband to operating one is very narrow $TM01n$ passband, placed near $\sim 1.1 f_{\pi}$.
For π structures the frequency separation between operating mode and nearest one at the operating passband is proportional to $(\frac{\gamma_c}{N})^2$, where N is the number of structure periods in the cavity. With significant γ_c value this separation is $\approx 1MHz$ for $N \leq 22$.

RF Input

To provide fields matching, as it is clear from the fields distribution in Fig. 2, driving waveguide should be oriented with wide wall along the structure axis. The width of standard waveguide $\approx \frac{\lambda}{\sqrt{2}}$ is larger, than structure period length $d =$. As it was mentioned before, $TE11n$ structure has also small transverse dimension. In this case short taper matching section, like [5], is necessary between regular waveguide and the cavity.

BEAM DYNAMICS

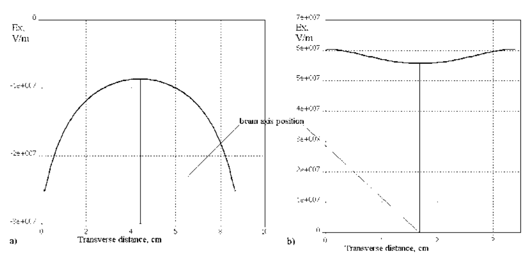

Figure 6: Transverse electric field component E_x distributions crosswise beam axis for $TM11n$ structure (a) and the proposed $TE11n$ one (b).

For cylindrical $\beta = 1$ DLW synchronous space harmonic of the deflecting voltage is constant, ensuring aberration free deflection [4]. For essentially 3D $TE11n$ cavity we can not affirm it. In the vicinity of the beam axis transverse distributions of deflecting field components for considered structures are different. For example, in Fig. 6 E_x component distributions crosswise beam axis for $TM11n$ structure and the proposed $TE11n$ one are shown.
Beam dynamics simulations have been performed in comparison of different deflecting cavities for Photo Injector Test (DESY, Zeuthen) beam characterization. One can find more details in [6]. Longitudinal and transverse momentum distributions before and after particles deflection for considered cavities are shown in Fig. 7. One can see no visible difference in the transverse momentum distributions (Fig. 7c,d) between two options. As for longitudinal momentum distribution, $TE11n$ cavity provides smaller distortions, as compared to $TM11n$ one. Due to design idea,

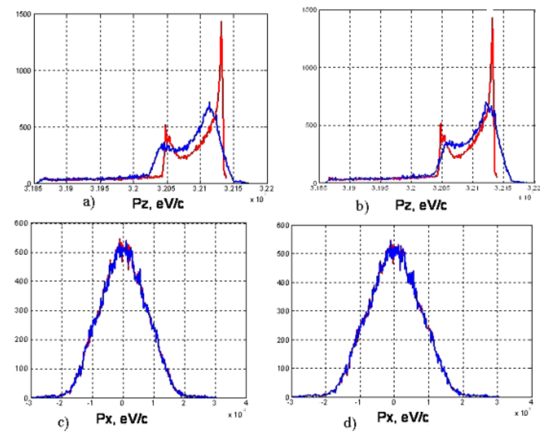

Figure 7: Longitudinal (a,b) and transverse (c,d) momentum distributions (blue line) after deflection for $TM11n$ cavity (a,c) and $TE11n$ one (b,d). Red line - initial beam.

proposed cavity has no longitudinal E_z component, and, in first order, should be no distortions in the longitudinal phase space.

CONCLUSION

Proposed $TE11n$-like cavity looks as a competitive option for high energy particles deflection. We consider, as the preferable, frequency range for cavity applications L-band and lower. Assuming $E_{smax} \approx 40MV/m$, in this frequency range effective deflecting field $\approx 15MV/m$ is possible. For higher frequencies the cavity becomes too compact and realization of all advantages of the design idea requires more study.
Now we consider this cavity for normal conducting case. For application in super conducting option the cavity should be optimized in another style. But our present NC results shows reasonably low H_{smax} value at the surface.

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