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

RF PARAMETERS

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

Figure 1: General view 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 \( \lambda \) is the operating wavelength and \( \beta \) 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 \( E_{\text{max}} \), safety reasons and deflecting field uniformity.

For the chosen gap distance 2a operating frequency value \( f_\pi \) 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.

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
cell volume. In the $TE_{11n}$ 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 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 3: Electric energy density $W_e$ (a) and magnetic one $W_h$, (b), distributions at the surface of the $TE_{11n}$ structure.](image)

![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 $TM_{11n}$ cavity (a,b) and the proposed $TE_{11n}$ one (c,d).](image)

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

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

In Fig. 4 distributions of transverse components $E_x$, $H_y$ along beam axis are shown for $TM_{11n}$ DLW and proposed $TE_{11n}$ 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 $TE_{11n}$ structure. Components $H_y$ in considered structures, as one can see from Fig. 4, have different phase shift with respect $E_x$. In the $TM_{11n}$ 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 $TE_{11n}$ structure is sufficiently higher, as compared to DLW. Quality factor for operating mode is higher ($\approx 5$ times) for $TM_{11n}$ 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 $TE_{11n}$ 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 $TM_{11n}$ DLW cavity.

**Passbands**

![Figure 5: Operating passband of the proposed $TE_{11n}$ structure.](image)

In the classical $TM_{11}$ 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 $TE_{11n}$ 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 $\gamma_c$ values are $\gamma_c \sim 0.11 \div 0.16$.

$$\gamma_c = \frac{f_x^2 - f_0^2}{f_x^2 + f_0^2}, \hspace{1cm} (2)$$

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 $TM_{11n}$ DLW modes at operating passband are not degenerated - second $TE_{11n}$ passband with perpendicular field polarization is placed in the region $\approx 1.5f_x$. The nearest passband to operating one is very narrow $TM_{01n}$ passband, placed near $\approx 1.1f_x$.

For $\pi$ structures the frequency separation between operating mode and nearest one at the operating passband is proportional to $(\frac{N}{\pi})^2$, where $N$ is the number of structure periods in the cavity. With significant $\gamma_c$ 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 $\approx \sqrt{2}$ is larger, than structure period length $d =$. As it was mentioned before, $TE_{11n}$ 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 $E_z$ distributions crosswise beam axis for $TM_{11n}$ structure (a) and the proposed $TE_{11n}$ one (b).](image)

For cylindrical $\beta = 1$ DLW synchronous space harmonic of the deflecting voltage is constant, ensuring aberration free deflection [4]. For essentially 3D $TE_{11n}$ 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 $TM_{11n}$ structure and the proposed $TE_{11n}$ 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, $TE_{11n}$ cavity provides smaller distortions, as compared to $TM_{11n}$ one. Due to design idea, proposed cavity has no longitudinal $E_z$ component, and, in first order, should be no distortions in the longitudinal phase space.

**CONCLUSION**

Proposed $TE_{11n}$-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.

**REFERENCES**