RF DEFLECTOR BASED ON STANDING WAVE AND π/3 MODE

O.A. Adonev, E.A. Savin, N.P. Sobenin, A.Yu. Smirnov
National Research Nuclear University “MEPhI”, Moscow, Russia
E-mail: oadonev@yahoo.com

For accelerating beam characteristics measurement together with travelling wave RF deflectors with E_{11} wave type, SW deflectors with π mode are used. The disadvantage of TW deflectors is the small frequency division between working and neighboring modes. SW heterogeneous structure with DLS type is proposed. The working mode is π/3.

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INTRODUCTION

One of the most important problems for the existing free electron lasers (FEL) and linear colliders is extremely short bunches measuring and controlling. The RMS length of bunches, which are used, for example, in the LCLS (Linac Coherent Light Source) and linear collider NLC (Next Linear Collider) in SLAC, are equal to 80 fs (24 mkm) [1] and 300 fs (90 mkm) [2] respectively.

The measurement of the parameters of such bunches using of optical-electron cameras are impracticable. That’s why using of transverse electrical field, which affects the electron bunch, allows, watching beam deviations during the one impulse, to obtain not only data about beam absolute length, but also to identify important time characteristics in other phase spaces and to measure beam RMS sizes in time slices. Using other words, RF field dipole wave electrical and magnetic components are deflecting the electron beam from the structure axis. The bunch absolute length, its transverse emittance and the energy spectrum time dependence are measuring using the time picture of the this deviation, obtained by monitors.

The main electrodynamics characteristic (EDC) of the SW RF deflector looks familiar with EDC of the accelerating cavities [3]:

a) $r_{\mathrm{sh}\perp\mathrm{eff}}$ – effective transverse shunt impedance per unit length:

$$r_{sh\perp eff} = \frac{\left|\int_0^L E_x - c\mu_0 H_y \;\; e^{ik_z z} dz\right|^2}{P_{loss} L} [\mathrm{Ohm/m}], \qquad (1)$$

where E_x and H_y – are transverse electric and magnetic components of the electric and magnetic fields respectively, P_{loss} – is the loss power mean value, L – is the structure length, k_z=2π/λ – is the longitudinal wave parameter;

b) Q – factor:

$$Q = \omega_{\mathrm{RF}} \frac{W}{P_{loss}}, \qquad (2)$$

where W – is the stored energy mean value;

c) τ_{store} – is the RF power filling time, defined from Q-factor as:

$$\tau_{store} = \frac{2Q}{\omega_{\mathrm{RF}}}. \qquad (3)$$

For the shunt impedance increasing it is possible to use multi-cells cavities as in the accelerating structures.

The one cell of multi-cell deflecting resonator design choose (Fig. 1), as well as mode choose (for example π or π/2), should be carried out to the same criteria as in the accelerating section design. So with π mode the cell longitudinal length (period of the structure) should be equal to $\lambda_{\mathrm{rf}}/2$, the aperture radius should have the minimum value to obtain the shunt impedance maximum, and the cell radius should be such that the cavity frequency on this mode be equal feed generator frequency.

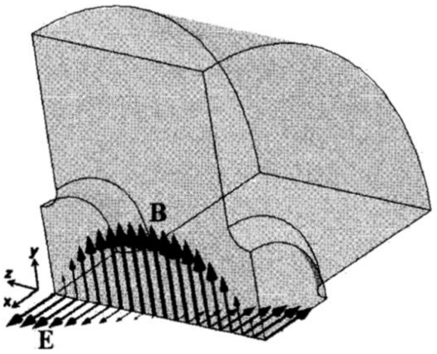

Fig. 1. The quarter of the one SW deflector cell and the electric (E) and magnetic (B) field lines of the E11 mode

In any periodical structure the each field component distribution $E_j(r,z)$ in the beam aperture can be obtained in the complex form [4]:

$$\mathbf{E}_j \;\; r,z \;\; = E_j \;\; r,z \;\; e^{i\psi_j \;\; z} \;\; = \sum_n^n a_{jn} \;\; r \;\; e^{\frac{-i \;\; \Theta_0 + 2n\pi \;\; z}{d}}. \qquad (4)$$

Where $E_j(r,z)$ and $\psi_j(z)$ – are the amplitude and phase distributions; $d = \Theta_0\beta\lambda/2\pi$ – structure period; $a_{jn}(r)$ – transverse distribution of the n space harmonics, and Θ_0 – is the phase shift per the one cell. Space harmonics are significantly at the distance $r = a$ (a – the aperture radius) while high order modes are attenuating near the deflecting structure axis as:

$$a_{jn} \;\; 0 \;\; \sim a_{jn} \;\; a \;\; \cdot \exp\left(-\frac{4\pi^2 n}{\beta\Theta_0} \cdot \frac{a}{\lambda}\right), |n| << 1, \qquad (5)$$

where λ – is the operating wave length. For the harmonics evaluation parameters $\delta\psi_j(z)$ and Ψ are used on the axis $0 \le z \le d$, $r = 0$ [5]:

$$\delta\psi_j \;\; z \;\; = \psi_j \;\; z \;\; + \frac{\Theta_0 z}{d}, \; \Psi_j = max \left|\delta\psi_j \;\; z \;\right|. \qquad (6)$$

The total force acting on the charged particle is the Lorenz force $\mathbf{F}^L_{z,x}$. It can be decomposed in the Cartesian coordinates into the longitudinal eE_z and transverse eE_d components. Considering the deflecting voltage directed along the x axis, we will get:

$$\mathbf{F}^L_{z,x} = eE_z\mathbf{e}_z + eE_d\mathbf{e}_x, \; E_d = E_x - \beta Z_0 H_y, Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}. \qquad (7)$$

The parameter Ψ_j can be used for the harmonics level estimation (aberrations) both in longitudinal $eE_z(\Psi_z)$ and in the transverse eE_d (Ψ_d) force components.

1. REGULAR CELLS DESIGNING AND TUNING

For the deflecting structure operating at different modes EDC researches the 9 cells cavity excited by E_{11} wave (Fig. 2) on 3 GHz frequency was used.

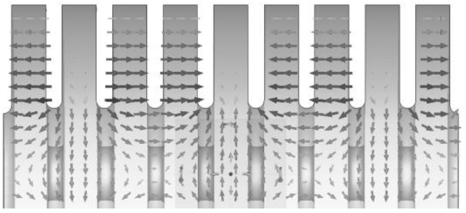

Fig. 2. $\pi/3$ mode of E_{11} wave in 9-cells cavity

$\pi/3$ mode is characterized by field absence in several cells, which enables to decrease cells lengths wherein strongly decrease the full structure length.

During the cells without field tuning process (coupling cells), their length was shorted to 3 mm. In this connection it were dispersion characteristic heterogeneity associated with resonant frequencies differences between regular and coupling cells. This heterogeneity was eliminating by the coupling cells radius changing. The main and perpendicular polarizations dispersion characteristics are shown at Fig. 3.

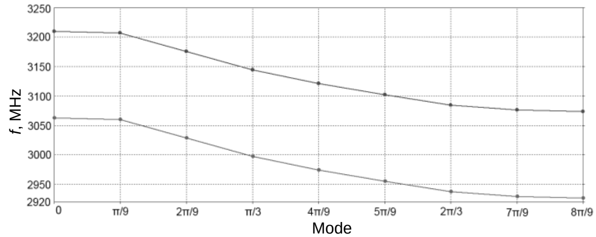

Fig. 3. Operating (lower curve) and perpendicular (upper curve) SW RF Deflector with $\pi/3$ mode polarizations

As seen from dispersion characteristics, this structure has good frequency deviations between neighboring modes and the perpendicular polarization.

The study of the fields in the structure found that the field distribution along the structure axis is uneven, and there are fields in coupling cells. This problem was solved by the geometry tuning. On the Fig. 4 are shown distributions of the electric and magnetic field transverse components E_x and H_y, and on the Fig. 5 – the longitudinal electric field distribution with the R/2 offset from the structure axis (R-is a accelerating cells radius).

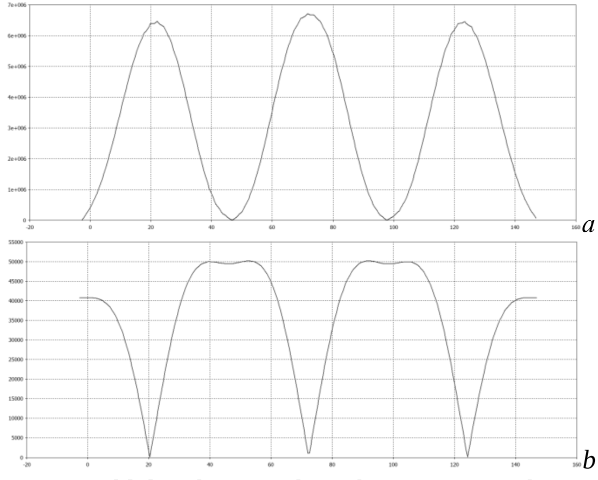

Fig. 4. Field distributions along the axis: a – E_x; b – H_y.

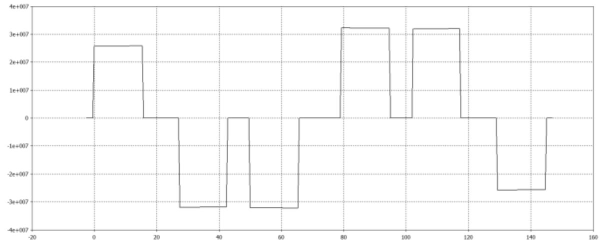

Fig. 5. Longitudinal electric field $E_z(z)$ distribution with the R/2 offset from the structure axis

As a result of the above geometry tuning is a regular structure whose sizes are shown on the Fig. 6.

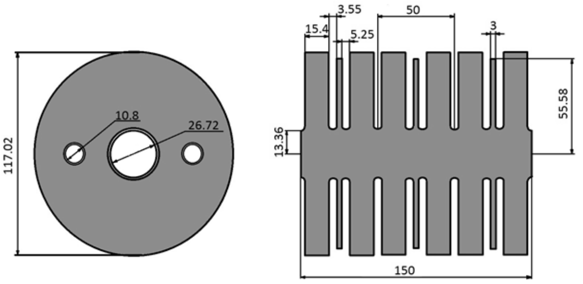

Fig. 6. The inhomogeneous structure with $\pi/3$ mode geometry

2. EDC RESEARCHES

After the final geometry obtaining its EDC was studied and compared with the deflecting structure working on π mode on 3 GHz frequency. The table with the results comparison is shown below:

EDC comparison between RF deflectors working on π and $\pi/3$ modes

EDC	Structure type	
	π	π/3
$r_{sh\perp eff}$	13.1	9.7
Q	14700	9500
$f_0 - f_{0\perp}$	30	150
$f_0 - f_{nearest}$	1.5	25

As can be seen from the table, the inhomogeneous deflecting structure working on $\pi/3$ mode with the same geometry (aperture radius ad diaphragm thickness) as deflecting structure working on π mode has a little bit worse shunt impedance, but has a bigger frequency separation between neighboring modes.

Results of the researches of the EDC and deflecting field phase aberrations in inhomogeneous structure dependence from the aperture radius (from 0.05λ to 0.25λ, where λ=10 cm) and diaphragm thickness (from 2 to 10 cm) (Figs. 7, 8).

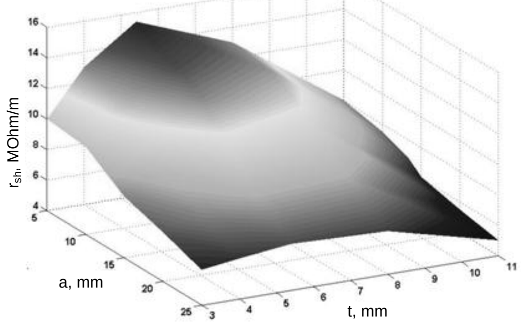

Fig. 7. Transverse effective shunt impedance dependence from the aperture radius and diaphragm thickness

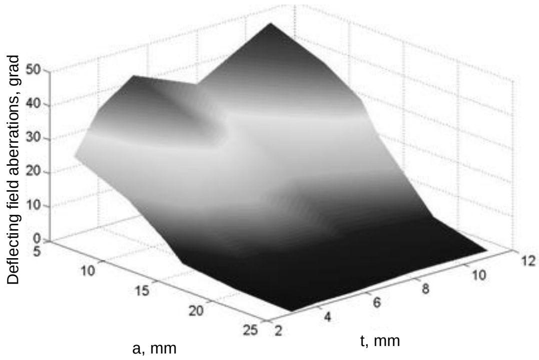

Fig. 8. Deflecting field aberrations dependence from the aperture radius and diaphragm thickness

Pictures shows that use a smaller aperture radius can increase the shunt impedance value, and the deflecting electric field axis distribution becomes close to linear.

3. POWER INPUT TUNING

The power input geometry is shown on Fig. 9. The first cell was chosen as a coupling cell. As a coupling waveguide was chosen a rectangular waveguide 72×34 mm. The tuning was carried out by the variation of the coupling window between coupling cell and coupling waveguide width.

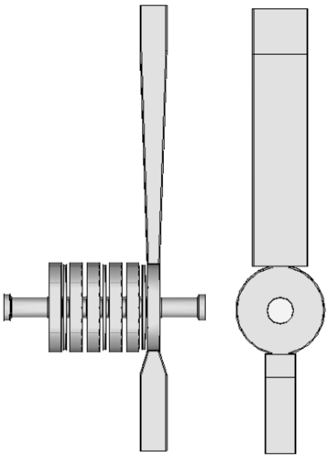

Fig. 9. Inhomogeneous deflector with the power input

As a result the power input has tuned on the 2997.2 MHz frequency (Fig. 10).

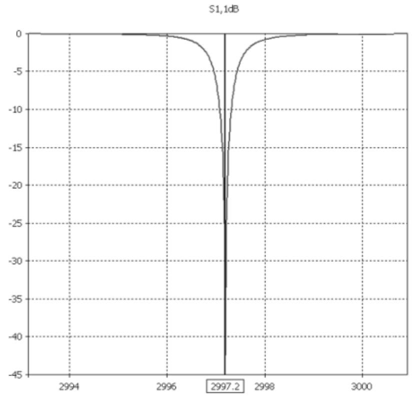

Fig. 10. The reflecting coefficient dependence from the frequency

CONCLUSIONS

In this paper are presented the results of the inhomogeneous RF deflector structure working on π/3 mode researches. Dependences of the main electrodynamics characteristics from the structure geometry are presented. The comparison of the proposed structure EDC with widely used structures working on π mode characteristics shows that the main purpose of the inhomogeneous structure applications – is the cases, where the high frequency separation between neighboring modes is required.

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ВЫСОКОЧАСТОТНЫЙ ДЕФЛЕКТОР НА СТОЯЧЕЙ ВОЛНЕ С ВИДОМ КОЛЕБАНИЙ π/3

О.А. Адоньев, Е.А. Савин, Н.П. Собенин, А.Ю. Смирнов

Для метрики характеристик ускоренного пучка наряду с высокочастотными дефлекторами (ВЧД) на волне E_{11} в режиме бегущей волны используются и ВЧД, работающие в режиме стоячей волны на виде колебаний π. Недостатком их является плохое частотное разделение рабочего вида колебаний с соседними видами. Предложена неоднородная структура в виде круглого диафрагмированного волновода на стоячей волне и виде колебаний π/3.

ВИСОКОЧАСТОТНИЙ ДЕФЛЕКТОР НА СТОЯЧІЙ ХВИЛІ З ВИДОМ КОЛИВАНЬ π/3

О.А. Адоньєв, Є.А. Савін, Н.П. Собєнін, А.Ю. Смірнов

Для метрики характеристик прискореного пучка поряд з високочастотними дефлекторами (ВЧД) на хвилі E_{11} в режимі бігучої хвилі використовуються і ВЧД, що працюють у режимі стоячої хвилі на виді коливань π. Недоліком їх є поганий частотний поділ робочого виду коливань з сусідніми видами. Запропоновано неоднорідну структуру у вигляді круглого диафрагмованого хвилеводу на стоячій хвилі і виді коливань π/3.