EFFECTIVE RF DEFLECTING STRUCTURES FOR BUNCH ROTATION AND DEFLECTION

V.V. Paramonov*, Institute for Nuclear Research of the RAS, Moscow, Russia

Abstract

The Deflecting RF Structures (DS's) find now applications for the bunch rotation with the purposes of diagnostic for the longitudinal distribution, the emittance exchange and the luminosity improvements in colliders. Results of development DS with minimized the level of aberrations in the distribution of deflecting field are described. Applied for bunch rotation along transverse axis, such DS's provide in orders smaller emittance growth, as compared to another options. In comparison with widely used deflectors, based on the Disk Loaded Waveguide, developed DS's have, depending on modification, in $2\div4$ times higher RF efficiency. Structures can operate both in Traveling Wave (TW) and in Standing Wave (SW) modes. To create longer RF cavities for SW operation, compensated DS's options are developed, adding field distribution stability and saving high RF efficiency. The main solutions are described and achieved parameters are reported.

INTRODUCTION

The periodical structures with transverse components of the electromagnetic field - DS's - were introduced for charged particle deflection and separation. The bunch cross DS synchronously with the Deflecting Field (DF) Ed, corresponding the phase $\phi = 0$ in the DS and all particles get the similar increment in the transverse momentum p_t. At present, for short and bright electron bunches DS found another applications in bunch rotation, for bunch special diagnostic, luminosity improvement and emittance exchange experiments. All directions are related to the Transformation of Particle Distribution (TPD) in the $6D$ phase space and DS operates in another mode - the Central Particle (CP) of the bunch center cross DS at zero E_d value, $\phi = 90^o$. Downstream and upstream particles get opposite increments in p_t.

The applications for TPD provide an additional requirement - a DS for TPD should provide the minimal, as possible, own distortions to the original distributions. The additional limitation to known DS's design naturally results in the reduction of the other parameters, RF efficiency and dispersion properties. Results of DS's development combining both field quality and saving another parameters are presented.

METHODICAL BASEMENT

The concept of DS's with the minimized level of own aberrations in the DF distributions was introduced in [1]. The DF distribution analysis was performed, [2], using the basis of hybrid waves HE and HM, [3]. The particles dynamic for the bunch rotation is studied and compared for different DS's in [4].

The equivalent DF is defined from the transverse component of the Lorenz force F^L, where the field components are expressed by using the basis of hybrid waves HE and HM, [3]:

$$\vec{F}^L = e(\vec{E} + [\vec{v}, \vec{B}]), F_x = eE_d = e(E_x - \beta Z_0 H_y), \quad (1)$$
$$\vec{E} = A\vec{E}_{HE} + B\vec{E}_{HM}, \vec{H} = A\vec{H}_{HE} + B\vec{H}_{HM},$$

and $Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}$.

The reasons for the emittance growth during TPD are the aberrations - the non linear additions in the E_d distribution, which take place due to not relativistic energy of particles, $\beta < 1.0$, additions from higher sextupole modes, the higher spatial harmonics in the distribution of the deflecting field. The main attention should be paid to the higher spatial harmonics, see [2], [4] for details.

In any periodical structure each field component $E_j, H_j(x, y, z)$ in the beam aperture can be represented as the set over spatial harmonics:

$$E_j, H_j(x, y, z) = E_j, \widehat{H_j(x}, y, z)e^{i\psi_j(z)} = \quad (2)$$
$$= \sum_{n\rightarrow-\infty}^{n\rightarrow+\infty} a_{jn}, b_{jn}(x, y)e^{\frac{-i(\Theta_0+2n\pi)z}{d}},$$

where $E, \widehat{H_j(x}, y, z)$ and $\psi_j(z)$ are the amplitude and the phase distributions, d is the structure period and $a, b_{jn}(x, y)$ are the transverse distribution for the n-th spatial harmonics, Θ_0 is the operating phase advance. The same representation is valid for E_d also.

In the periodical slow wave structure each component of original fields $\vec{E}, \vec{H}$ can not exist without the higher spatial harmonics, $n \geq 1$ in (2). It is the law for slow wave structures. But DF is composed from two components of original fields, (1), and this law, generally, has no force for E_d. During DS design we can manage A and B relation in (1) in such way, that spatial E_x harmonics a_{jn} will compensate the H_y harmonics b_{jn}. To provide such compensation, the opposite phasing of hybrid waves $\vec{E}_{HE}$ and $\vec{E}_{HM}$ is required, $A \cdot B < 0$ in equation (1).

For harmonics estimations in values, the parameters $\delta\psi_j(z)$ and Ψ_j at the DS axis are introduced, [2]:

$$\delta\psi_d(z) = \psi_d(z) + \frac{\Theta_0 z}{d}, \quad \Psi_d = max(|\delta\psi_d(z)|), \quad (3)$$

with the physical sense as the deviation and the maximal phase deviation of the total E_d distribution from the main synchronous harmonic in E_d. During bunch rotation, $\phi = 90^o$, CP sees the effect of higher spatial harmonics, [2], as:

$$E_{rot} \approx E_{d0} sin(\Psi_d) \approx E_{d0}\Psi_d, \quad (4)$$

* paramono@inr.ru

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where E_{d0} is the amplitude of the synchronous E_d harmonic. Minimizing Ψ_d value, we keep CP close to DS axis, in the region of low non linear additions, and simultaneously reduce the amplitudes of these additions in the total DS aperture. As the result, we have in orders smaller emittance growth after bunch rotation.

THE FIRST STAGE RESULTS

The described procedure was applied to the classical DS, [3], based on DLW, Fig. 1a, resulting in the strong reduction of aberrations, $\Psi_d \leq 2^o$, but at the expense of reduction in the effective shunt impedance value $Z_e \approx 17 \frac{MOm}{m}$, [5], at $\approx 6 \frac{MOm}{m}$ lower as compared to usual DLW options.

To find a more RF effective solution, the DS with TE-

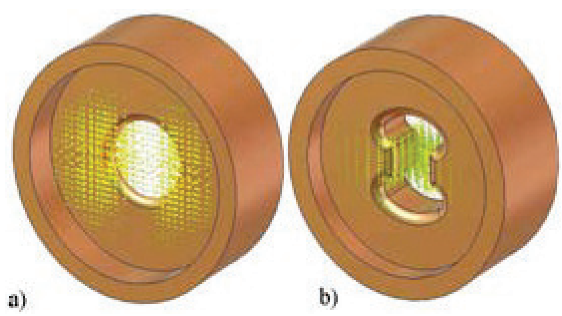

Figure 1: The DLW based DS with minimized level of aberrations, (a), and the decoupled structure, (b), [5].

like operating mode, [6], which has possible Z_e up to $\approx 80 \frac{MOm}{m}$, but, due to the same phasing of hybrid waves, $A \cdot B > 0$ in equation (1), very bad for bunch rotation field quality, $\Psi_d \approx 70^o$, was transformed, see Fig. 2, into decoupled structure, Fig. 1b, Fig. 2c. Together with the good field quality, $\Psi_d \approx 1.87^o$, much higher, as compared to DLW, Fig. 1a, $Z_e \approx 36 \frac{MOm}{m}$ value for RF efficiency was obtained, [5].

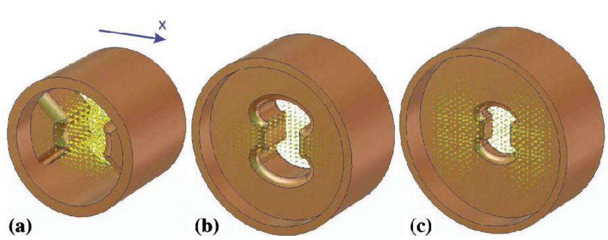

Figure 2: DS transformation from high RF efficiency and bad field quality, (a), to fine field quality and tolerable RF efficiency, (c).

EFFICIENCY IMPROVEMENT

Providing the cell shape near DS axis as a drift tube, Fig. 4a, we improve Z_e value up to $Z_e \approx 43 \frac{MOm}{m}$, while keeping $\Psi_d \approx 1.9^o$. This DS option, named with service name $V2$, due to very specific distribution of magnetic field in the middle between disks, calculated with ANSYS, has the working name "Vanja", Fig. 4b. For the $V2$ option the field balance is achieved in average, because for synchronous harmonics in E_x and H_y the balance is of $a_0 = -1.27b_0$. With the value $\Psi_d \approx 1.9^o$ CP moves near $V2$ axis, but higher spatial harmonics for E_d distribution in DS aperture are dumped in average, see [4].

Modifying the drift tube dimensions we come to $V3$ option,

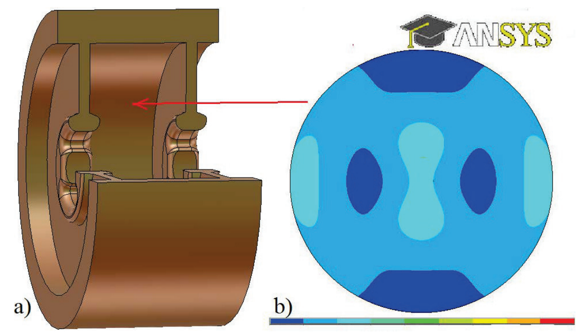

Figure 3: The shape with the drift tube - V2 option, (a), and magnetic field distribution in the plane between disks, (b).

Fig. 5a, with the fields balance in total, $a_0 = -1.007b_0$ even with higher RF efficiency, $Z_e \approx 53 \frac{MOm}{m}$ and similar field quality, $\Psi_d \approx 2.0^o$. For bunches with small, as compared to DS aperture, transverse dimensions, $V2$ and $V3$ options provide similar very small results in the emittance growth.

Relaxing requirement for the field quality to $\Psi_d \approx (20^o \div$

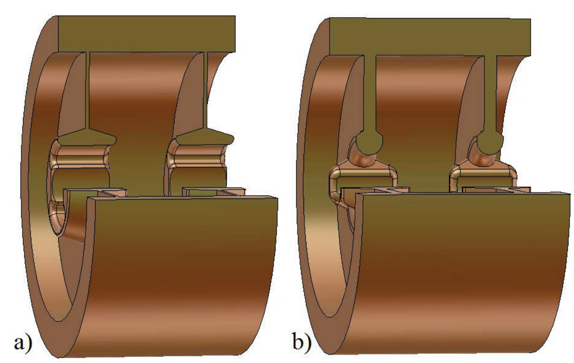

Figure 4: The cells shape for V3, (a), and V4, (b) options.

$4^o)$, which is typical for the classic DLW, not optimized for minimal aberrations, we can improve RF efficiency up to $Z_e \approx (93 \div 73) \frac{MOm}{m}$ by more complicated shape near DS axis, Fig. 5b, option $V4$. In the emittance growth option $V4$ definitely lose to $V2$ and $V3$ and is comparable to not optimized DLW, having more than 3 times higher RF efficiency.

DISPERSION PROPERTIES

The opposite phasing of hybrid waves in equation (1) defines the negative DS dispersion and for TW operation structures operate in the backward wave mode. Additionally, fields balancing in (1) $a_0 \approx -b_0$ to have a minimal Ψ_d value results in a narrow passband. For SW operation it limits the number of cells in a deflecting cavity and possible

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value of deflecting voltage V_d. For dispersion curve correction near operating π mode the resonant slots in DLW disks were considered, [5]. More simple and effective solution is developed now - compensated DS options. As it is known well, [7], compensated structures combine the high RF efficiency with the qualitatively higher stability of the field distribution for operating π mode.

Different technical solutions are possible. After comparison, we select the method, which can be applied to all considered DS's, results in a minimal Z_e reduction and can be mostly reliable and simple realized in practice. Two additional disks are partially inserted in the outer cylindrical DS wall in the middle between the original DS disks, Fig. 5a. With the appropriate adjustment of the cell radius and radius and depth of insertion for additional disk, the DLW dispersion curve becomes typical for compensated structures, Fig. 5b.

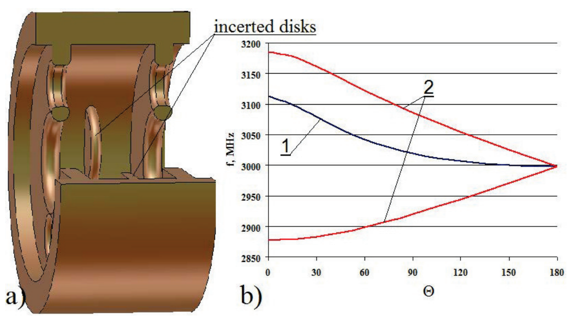

Figure 5: The compensated DLW option, (a) and corresponding dispersion curves, (b) for the simple DLW option, 1, and for the compensated one, (2).

The most important stability problem is for $V3$ option due to perfect field balance $a_0 = -b_0$. The simple $V3$ option has the passband width $\approx 100\ MHz$ only for the S band operating frequency. As one can see from Fig. 6, the compensated $V3$ option solves this problem.

In compensated DS's options we switch on for DS's the new physical property - mutual compensation for contributions of adjacent modes into operating field distribution due to deviation of cell frequencies in manufacturing or RF tuning. We can also improve the passband width, see Fig. 5, Fig. 6, and control the value of coupling coefficient.

Additional elements in the compensated DS's options naturally result in Z_e reduction, which is of $(3 \div 6)\ \frac{MOm}{m}$. For the DLW such Z_e reduction is too strong. For developed $V2$, $V3$ and $V4$ options, at the background of the high initial Z_e, this price for the new quality is tolerable.

Due to the additional set of physical limitations the shape of cells for the developed DS's are more complicated, but realistic for manufacturing with the modern numerically controlled equipment. All DS's are developed following to the concept of domination - one free geometrical parameter in cell dimensions in times more strongly effects at the corresponding physical parameter of the DS. It allows a fast dimension adjustment in DS development and simplifies cells tuning.

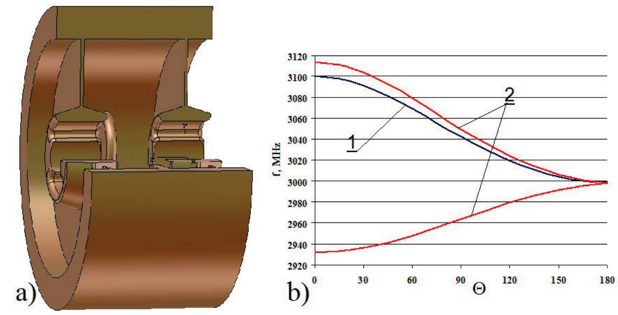

Figure 6: The compensated V3 option, (a) and corresponding dispersion curves, (b) for the simple V3 option, 1, and for the compensated one, (2).

SUMMARY

New family of deflecting structures is developed with the main feature of careful bunch handling during transformation of particle distributions due to minimized own DS aberrations. Even with this added new quality, developed structures have excellent RF efficiency and can be used for usual bunch deflection. Results of this development are requested by community and INR starts promotion of this structures now into research facilities. The first results of operation we expect soon.

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