TRANSVERSE DEFLECTING STRUCTURE PARAMETERS STUDY

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Abstract

Parameters of a periodical traveling wave structure, based on the disk-loaded waveguide with operating HE_{11} wave, have been considered. The structure is intended for single, or several, bunch extraction from long bunch train. For stability, single mode operations is required and pass bands separation with structure axial symmetry deterioration is investigated. Both backward and forward wave regimes are considered. The aim of investigations is to define cell dimension to provide required particle deflection under limited filling time and restricted RF power. Results of the study are reported.

INTRODUCTION

Normal conducting Transverse Deflecting Structures (TDS) are used for charges particles separation [1], [2] and are well investigated [3] in parameters. In modern Free Electron Lasers (FELs), see, for example, [4], such structure is used for fast deflection of a single (or several) bunch from the beam axis for further special diagnostic of ultra short bunches. The others bunches in the bunch train should be not disturbed. For the same purpose deflecting structures are foreseen in the modern unique projects, like [5]. It stimulates the structure optimization for particularities of such applications.

GENERAL CONSIDERATION

Only several TDS units, differing in length and deflecting voltage U_d, should be installed at the linac beam line, providing normal conducting insertions into super conducting linac. The TDS length is limited by linac lattice and U_d depends on the beam energy. To deflect only one bunch, TDS should have a small filling time τ and a sufficient group velocity V_g. Large V_g means small wave attenuation α per unit length. Together with enough small TDS length it results in not so big total attenuation and constant gradient concept for TDS cells has no preference with respect constant impedance realization. RF power, dissipated in TDS, is less than travelling RF power and such structure parameter as effective shunt impedance is not of primary importance.

But extra high V_g, providing smaller τ results in extra input RF power to provide sufficient stored energy in the cell to generate required U_d. We have to find the reasonable compromise. In our consideration we strongly base on existing results of TDS parameters study [1], [3].

The cells of disk-loaded waveguide, Fig. 1, were considered for operating $2\pi/3$ mode HE_{11} wave and operating frequency 3000 MHz. Also two geometry options were considered – with the cell rounding near outer wall, Fig. 2a, and without it.

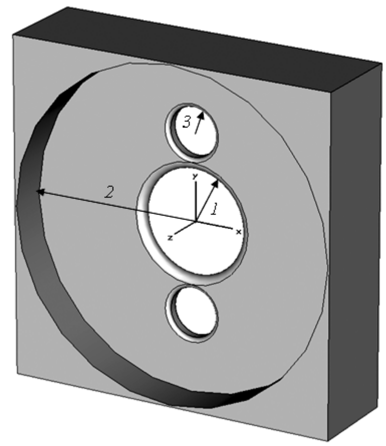

Figure 1: The cell of TDS, 1-aperture radius R_a; 2–cell radius R_c; 3-hole radius R_h

It was expected, the rounded cell should have lower RF power dissipation and better RF parameters. Further consideration have shown such expectation not correct. RF parameters of interest, V_g and α a practically the same for both options. For simpler machining the cell shape without outer rounding is chosen. The iris thickness is chosen 5.4 mm and iris is rounded with radius 2.7 mm.

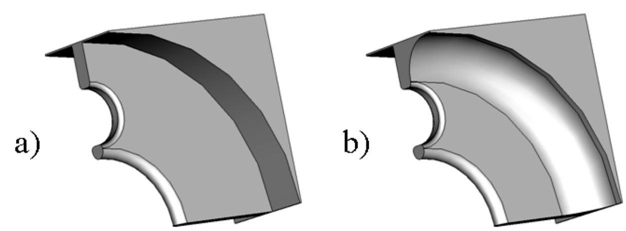

Figure 2: The cell without rounding (a) and the cell with rounding near outer radius (b).

DISPERTION PROPERTIES

The pass band of the required TE_{11} wave, with respect another lower and higher pass bands, is shown for TDS in Fig. 3. As it is known well, in circular geometry all wave with azimuth field variation, including TE_{11}, are twice degenerated. For parameters stability we need in single mode operation. To separate in frequency two TE_{11} pass bands with different field orientation, special holes, similar to [1], with radius R_h, (3) in Fig. 1, are introduced in the iris. The hole edges rounded with radius 1.35 mm. To provide a maximal effect in pass bands separation, holes should be placed as close to aperture, as it is possible from rounding matching. With the holes, introduced in the cell geometry, operating TE_{11} pass band is lower than parasitic TE_{11} one.

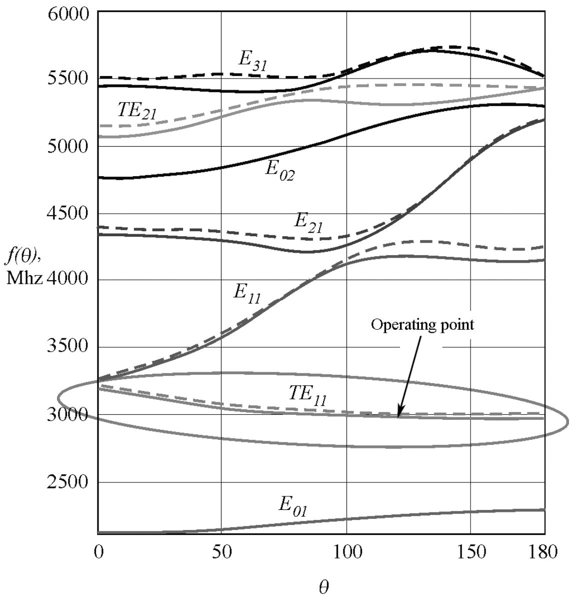

Figure 3: TDS general Brillouine diagram.

The dependence of the frequency separation Δf – difference of π–mode frequency at parasitic TE_{11} pass band and operating 2π/3-mode frequency on the hole radius R_h is shown in Fig. 4. The hole radius is fixed at R_h=8.5 mm, basing on Δf behaviour and iris rigidity reasons.

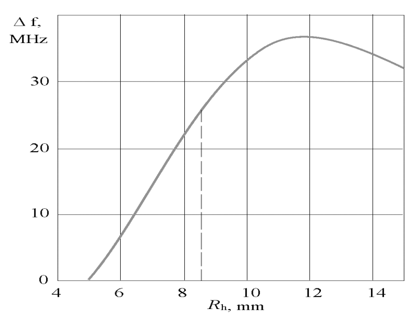

Figure 4: Δf dependence on the hole radius Rh

In Fig. 5 the frequency dependences of 0, 2π/3 and π modes for two TE_{11} pass bands on aperture radius R_a are shown for the cells with holes. For R_a<23.4 mm operating pass band is monotonous with negative dispersion and single mode operation is possible. Also single mode operation, but with positive dispersion, is possible for narrow range 24.7 mm < R_a < 25.3 mm. Another R_a values are not practical – either dispersion curve is not monotonous, or single mode operation is not possible.

RF PARAMETERS

TDS parameters, such as $\beta_g = V_g / c$, α, and χ were calculated for Ra ranges with single mode operation, both for negative and for positive dispersion. Constant operating frequency f=3000 MHz for each R_a was supported by adjusting outer cell radius R_c.

Results, obtained from calculated field distribution with well known formulas [3], are plotted in Fig. 6. As one can see from Fig. 6a, β_g tends to zero with R_a tends to ~23 mm – there is the inversion point, where dispersion changes sign.

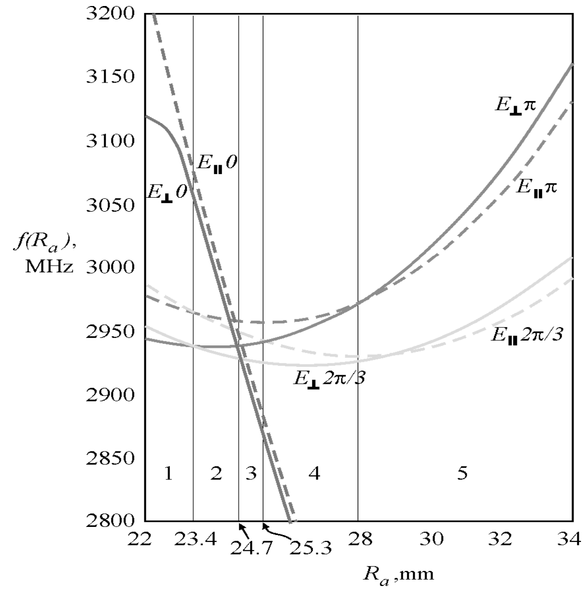

Figure 5: Frequency dependencies on aperture radius for 0, $2\pi/3$ and π modes for operating (solid lines) and parasitic (dashed lines) pass bands.

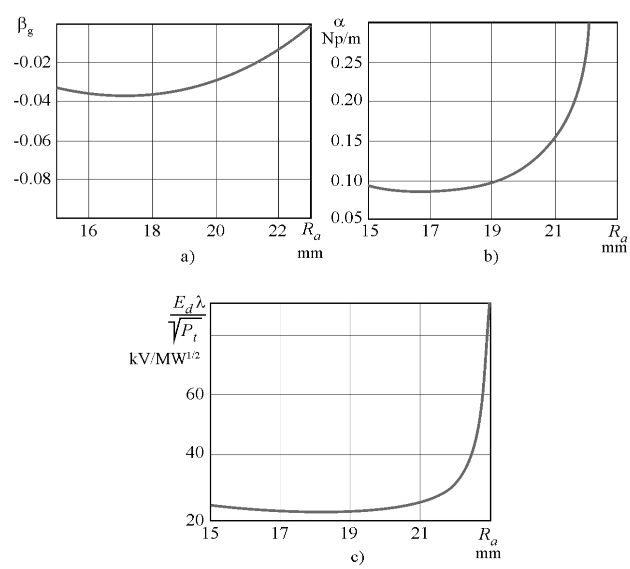

Figure 6: RF parameters dependencies on R_a for negative dispersion: (a) – β_g; (b) – attenuation α; (c) parameter $\chi = \frac{E_d \lambda}{\sqrt{P_t}}$

It means strong increasing of stored energy in the cell for the given value of the travelling RF power and fast increasing of the wave attenuation α (Fig. 6b) and parameter χ. One can see it in Fig. 6b and Fig. 6c.

Similar dependencies were obtained for R_a region with TDS positive dispersion. As further TDS parameters consideration shown, the TDS with positive dispersion has worse RF parameters, as compared to the TDS with negative dispersion. Similar to RF separator applications [1], [2] TDS with negative dispersion (with backward travelling wave) should be used for our purpose.

TDS PARAMETERS ESTIMATION

For the specified structure length L RF input power P_t and required deflecting voltage U_d, by using obtained dependencies for β_g, α and χ, we can estimate possible R_a regions for specified TDS parameters. Required deflecting field strength at the TDS section input can be defined from:

$$U_d = \int_0^L E_d(z)dz = \frac{E_d}{\alpha}(1 - e^{-\alpha L}) \cdot$$

For practical estimations we assume the safety margins for construction supposing the real quality factor Q will be 0.8 from the calculated one due to surface roughness. Going with R_a, for each R_a value we define the filling time τ, required input power P_t to get specified U_d. This way we defined Ra range in which we can totally fulfil required TDS section specification. Left limit for Ra range appears from P_t limitation. Right R_a limit is from τ limitation.

Considering several TDS section options with different L and U_d we can find several regions for R_a and specify common region for all considered options. As our estimation shows, the centre of the common region is R_a=21.39 mm, which can satisfy to different TDS specifications with appropriate P_t choice. For this aperture radius R_a=21.39 mm, the calculated parameters are:

$\alpha = 0.17334 Np/m$, $\beta_g = -0.0191$, $\chi = 249.35$ kV/MW$^{1/2}$.

Frequency sensitivity

To specify tolerances for TDS cell machining we have to know the sensitivity of the operating mode frequency to the small deviations in the cell dimensions. For this purpose simulations for cells with slightly different (~0.01mm) dimensions have been performed. The frequency sensitivities, scaled to 1.0 mm dimension deviation, are summarised in the Table 1. As one can see from Table1, enough rigid tolerances should be applied to the iris thickness, aperture rounding radius and outer cell radius

Table 1: Frequency sensitivity values

Parameters	$\frac{\partial f}{\partial x}, \frac{MHz}{mm}$
Iris thickness	83.27
Aperture rounding radius	55.56
Aperture radius	15.02
Cell radius	49.16
Hole radius	4.12
Hole rounding	4.45
Distance between holes	2.99

ANOTHER TDS TOPIC

Due to small RF pulse duration (several μs) and low repetition rate, average RF power dissipated section is not so high. There is no serious cooling problem and expected temperature rise, with respect cooling water input temperature, is several C° . Water flow is required mainly for TDS temperature stabilisation. Number of cooling channels should be defined considering TDS frequency response time for cooling water temperature change.

SUMMARY

TDS parameters were studied for special destination – fast deflection of single bunch from the long bunch train in FELs. It requires the reasonable compromise between short feeling time and required input RF power. The procedure of cell dimensions choice to satisfy the given TDS specification is described. As the result, the range of cell dimension is found which satisfies to the set of reasonable TDS specifications. Operating frequencies sensitivity to small cell dimensions deviations is defined to specify tolerances for cells machining.

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