TRAVELING WAVE ACCELERATING STRUCTURES WITH A LARGE PHASE ADVANCE

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Abstract

The Traveling Wave (TW) accelerating structures, operating with phase advance for the whole field more than 180^o per period (up to 1300^o) are considered in this report. To realize such phase advance, the structures should operate in higher branches of the Brillouine diagram for TM_{01} wave and have similar to TM_{01n} mode field distribution in the cell. RF parameters of the Disk Loaded Waveguide (DLW) cells are considered for such phase advance and some additions to improve RF efficiency are presented.

INTROSUCTION

There are a lot of papers, describing traveling wave structures with phase advance $\Theta \geq 180^o$ and particularities of particle acceleration. For example, see [1] and related references, higher current electron beams can be accelerated. If such structures operate in the first Brillouine zone for TM_{01} wave and field distribution in the cell corresponds to TM_{010} mode, it means acceleration with higher spatial harmonics. The subject of this paper is consideration of DLW structures, in which the main, dominating spatial harmonic has a phase advance $\Theta \geq 180^o$.

FIELD DISTRIBUTION

In Fig. 1 is shown well known formation of the DLW dispersion diagram from TM_{01} wave parabola in smooth waveguide, [2], and numbers of Brillouine zones are marked. For traveling wave the field distribution in the

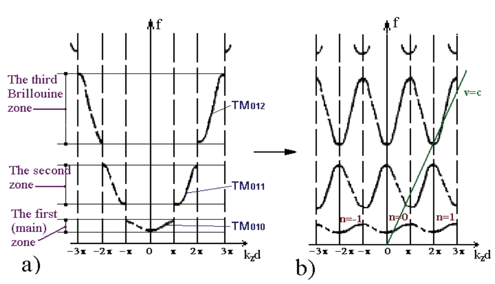

Figure 1: DLW dispersion diagram formation for TM_{01} wave.

aperture all time can be represented in complex form as:

$$E_j(r,z) = \Re E_j(r,z) - i\Im E_j(r,z) = \tag{1}$$
$$= e^{\frac{-i\Theta_0 z}{d}} \sum_{n\to-\infty}^{n\to+\infty} a_{jn}(r) e^{\frac{-i2n\pi z}{d}},$$

where d is the DLW period and $0 \leq \Theta_0 \leq 180^o$ is the phase advance. In the main zone, Fig. 1, the TM_{010} mode is implemented in DLW cell and expansion (1) starts with $n = 0$. For the second zone the field distribution is TM_{011}-like. For symmetrical DLW cell there is no $n = 0$ harmonic in the expansion (1), which starts now with $n = -1$, and field phase advance is in range $180^o \leq \Theta \leq 360^o$, including 180^o leap due to TM_{011} mode field structure.
So on, in higher zones with TM_{01N}-like field in the cell, we can provide field phase advance $N \cdot 180^o \leq \Theta \leq N \cdot 180^o + 180^o$.

DLW CELLS PARAMETERS

RF parameters of DLW cells in higher TM_{01} passbands investigated assuming operating frequency $3.0GHz$ in wide range of aperture radius a and Θ_0 similar to [3] with powerful 2D software. In each passband the cell length is defined from synchronism condition:

$$d_2 = \frac{\lambda(2\pi - \Theta_0)}{2\pi}, \quad d_3 = \frac{\lambda(2\pi + \Theta_0)}{2\pi}, \tag{2}$$

where d_2 and d_3 are the DLW cell length for the second and the third passband, respectively.
In Fig. 2 the surfaces of the group velocity β_g and effec-

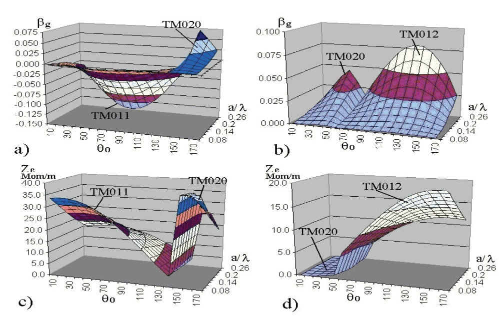

Figure 2: The surfaces $\beta_g(\frac{a}{\lambda}, \Theta_0)$, (a,b) and $Z_e(\frac{a}{\lambda}, \Theta_0)$, (c,d) for the second (a,c) and the third (b,d) passbands.

tive shunt impedance Z_e are shown with parameters $\frac{a}{\lambda}$ and Θ_0 for the second and the third TM_{01} passbands.
The regions of TM_{01} wave existence in each higher passbans are limited by interaction with TM_{02} wave, see Fig, 2. For the first and the second passbans possible Θ_0 values are in limits $0 < \Theta_0 < 140^o$ and $70^o < \Theta_0 < 180^o$, respectively. Outside these limits the cell radius R_c becomes large enough and TM_{02} wave comes in appropriate passband.
Without 2D investigations, these Θ_0 limitations were accepted and for appropriate higher passbands (the forth and so on).

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The examples of phase and amplitude distributions along

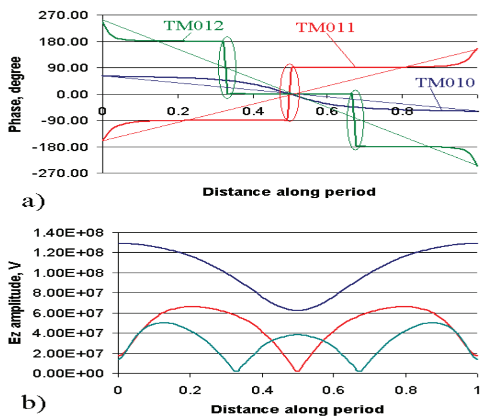

Figure 3: Phase (a) and amplitude distributions along DLW cell axis for the first ($\Theta = 120^o$), the second ($\Theta = 320^o$) and the third ($\Theta = 510^o$) passbands.

cell axis are plotted in Fig. 3 for several passbands, showing for the total field the phase advance per cell $\Theta > 180^o$ in higher passbands.

The relative dimensions of DLW cells for the first and the

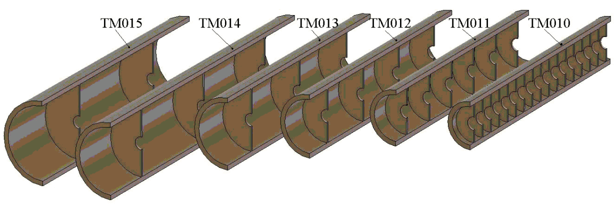

Figure 4: The relative DLW cells dimensions for operation in the first and in higher TM_{01} passbands.

higher TM_{01} wave passbands are compared in Fig. 4 and main RF parameters are listed in the Table 1.

As one can see from Fig. 4 and Table 1, the simple DLW

Table 1: The main RF parameters of DLW cells, $f_0 = 3GHz, a = 12mm$, for operation in the first and higher passbands.

Mode	Θ_0	R_c	$\beta_g \cdot 10^2$	$Q \cdot 10^{-3}$	Z_e
TM_{010}	120	39.49	2.19	14.1	60.86
TM_{011}	320	48.08	-1.36	18.7	24.93
TM_{012}	510	56.02	0.58	25.6	18.24
TM_{013}	680	65.51	-0.39	31.7	12.23
TM_{014}	840	70.73	0.22	36.4	9.48
TM_{015}	1040	79.55	-0.17	40.1	7.15
TM_{016}	1230	83.01	0.11	45.9	6.05

cells in higher passbands lose to classical DLW for the fist zone in transverse dimensions, group velocity and Z_e value.

EFFICIENCY IMPROVEMENT

Efficiency reduction of DLW cells in higher TM_{01} passbands is evident from the particularity in electric field distribution for TM_{01N} mode. In Fig. 5 electric field is shown in DLW cell for TM_{012} mode and one can see a strong E_r component along segments BE and CF.

Considering the balance

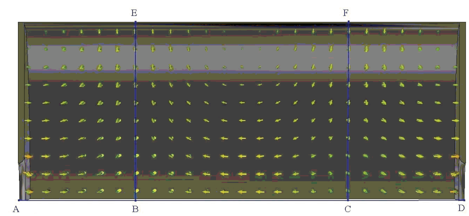

Figure 5: Electric field of TM_{012} mode in DLW cell.

$$\int_B^E E_r dr + \int_C^B E_z dz + \int_F^C E_r dr = \omega\mu\mu_0 \oint_S H_\varphi dS, \quad (3)$$

one can conclude - RF voltage along segments BE and CF spend magnetic flux, but doesn't takes a part in acceleration. It tells a way for RF efficiency improvement - we can substitute a part of segments BE and CF by conducting washers to reduce radial RF voltage part in (3). The maximum of E_r corresponds to minimum of H_φ and washers should not increase RF loss essentially.

Structures with washers in DLW cells are shown in Fig. 6 and main RF parameters are listed in the Table 2 for the same conditions as DLW cells in Fig. 3 and in the Table 1.

The washers lead to essential reduction in the cell radius

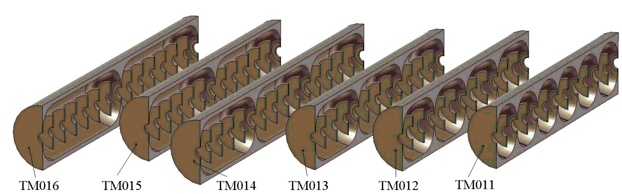

Figure 6: Structures with washers in DLW cells.

R_c, which is defined now mainly by washer diameter and for all structures in Fig. 6 $R_c \approx 65mm$. As one can see from the Table 2, the group velocity β_g and Z_e values are improved essentially due to stronger fields near axis. The DLW with washers is the structure with separated functions - β_g value for TW operations depends on the aperture radius in the disk. And Z_e value is defined by washers, which have similar to standing wave π mode field distribution - mostly effective with respect Z_e value. As one can see from the Table 2, Z_e value comes to saturation with increasing number of washers. The case $N = 3 \div 4$ (TM_{013}, TM_{014}) modes in the cell is a reasonable choice.

The accelerating structure with washers is known, [4], and further Z_e improvement is due to the drift tubes at washers. Such structure is shown in Fig. 7 and for the fifth passband,

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Table 2: The RF parameters of DLW cells with washers.

Mode	$\beta_g \cdot 10^2$	$Q \cdot 10^{-3}$	Z_e
TM_{010}	2.19	14.1	60.86
TM_{011}	-0.91	24.4	50.32
TM_{012}	0.87	33.5	60.29
TM_{013}	-0.83	37.4	61.91
TM_{014}	0.77	40.2	64.01
TM_{015}	-0.76	42.4	65.85
TM_{016}	0.73	43.6	65.56

TM_{014} - like mode in the DLW cell has for bore hole diameter in drift tubes $2 \cdot a_b = 24mm$ calculated parameteres $Q = 34300, \beta_g = 0.822 \cdot 10^{-2}, Z_e = 75.5MOm/m$ and $Q = 35800, \beta_g = 0.812 \cdot 10^{-2}, Z_e = 99.1MOm/m$ for $2 \cdot a_b = 10mm$, showing essentially higher Z_e value, as compared to classical DLW.

The dimensions optimization for DLW cells with washers

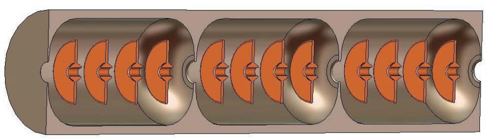

Figure 7: The structure with washers and drift tubes in DLW cell.

and drift tubes for further Z_e increasing was not performed and Z_e values, listed in the Table 2 and given for the structure in Fig. 7 may be not maximal.

DISPERSION PROPERTIES

Due to the design idea, the operating branch of the dispersion diagram is not fundamental. Depending on the Θ value, below operating branch there are several lower branches of TM_{01j} modes and branches of modes with an azimuthal field variations. As an example, in Fig. 8 is shown the dispersion diagram for the structure with washers in the cell, operating with $\Theta = 510^o$ in the third TM_{01} passband with TM_{012}-like mode in the DLW cells. Instead of differences in details, there are common features for dispersion diagrams of all structures, considered in this report. All these structures are narrow band with strong dispersion and relatively small passband width for all branches.

The washers, or washers with drift tubes, do not change dispersion diagram significantly, as compared to diagrams for simple DLW cells, shown in Fig. 4. The lowest branch is all time for modes with one azimuthal field variation.

The line of synchronous interaction $v = c$ cross the lowest branch, and, therefore, upper branches, for $\Theta > 180^o$.

In the vicinity of operating point there are branches, with separation in frequency $(30 \div 100)MHz)$, for modes with one and three azimuthal field variations. In this topic the situation with high order modes in the vicinity of operating point is the same as for the structure [4] and well known

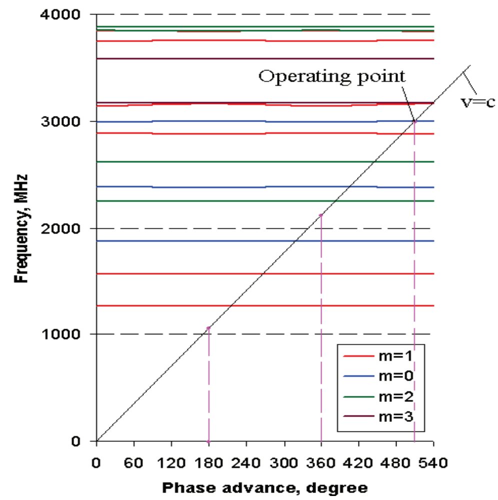

Figure 8: Dispersion diagram of DLW with washers, TM_{02}-like operating mode in the cell, $\Theta = 510^o$, m - number of azimuthal variations.

Disk And Washer (DAW) accelerating structure.

The density and placement of branches for high order modes in the vicinity of operating point is the limitation for washers number increasing in the cell.

SUMMARY

Traveling wave accelerating structures with the phase advance for the total field essentially larger than 180^o per period are possible using higher passbands of TM_{01} wave. It allows longer period length, but the simple DLW cell will lose to the classical case in RF efficiency. With washers and washers with drift tubes in DLW cells RF efficiency for higher passbands is improved in times, overlapping the classical case. The washer support, high order modes influence are the subjects for further consideration.

ACKNOWLEDGMENT

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