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° per period (up to 1300°) are considered in this report. To realize such phase advance, the structures should operate in higher branches of the Brillouin diagram for TM01 wave and have similar to TM01n 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.

INTROUSCTION

There are a lot of papers, describing traveling wave structures with phase advance Θ ≥ 180° 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 Brillouin zone for TM01 wave and field distribution in the cell corresponds to TM010 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 Θ ≥ 180°.

FIELD DISTRIBUTION

In Fig. 1 is shown well known formation of the DLW dispersion diagram from TM01 wave parabola in smooth waveguide, [2], and numbers of Brillouine zones are marked. For traveling wave the field distribution in the aperture all time can be represented in complex form as:

\[ E_j(r, z) = \Re E_j(r, z) - i \Im E_j(r, z) = e^{-i \Omega_0 z} \sum_{n=\pm \infty} a_{j,n}(r) e^{-i \nu_{j,n} z}, \]

where \( d \) is the DLW period and \( 0 \leq \Theta_0 \leq 180° \) is the phase advance. In the main zone, Fig. 1, the TM010 mode is implemented in DLW cell and expansion (1) starts with \( n = 0 \). For the second zone the field distribution is TM011-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° ≤ Θ ≤ 360°, including 180° leap due to TM011 mode field structure.

So on, in higher zones with TM01N-like field in the cell, we can provide field phase advance \( N \cdot 180° \leq \Theta \leq N \cdot 180° + 180° \).

DLW CELLS PARAMETERS

RF parameters of DLW cells in higher TM01 passbands investigated assuming operating frequency 3.0GHz in wide range of aperture radius \( a \) and \( \Theta_0 \) similar to [3] with powerful 2D software. In each passband the cell length is defined from synchronism condition:

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

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 \( \beta_g \) and effective shunt impedance \( Z_e \) are shown with parameters \( \frac{a}{\lambda} \) and \( \Theta_0 \) for the second and the third TM01 passbands.

The regions of TM01 wave existence in each higher passbands are limited by interaction with TM02 wave, see Fig. 2. For the first and the second passbands possible \( \Theta_0 \) values are in limits 0 < \( \Theta_0 < 140° \) and 70° < \( \Theta_0 < 180° \), respectively. Outside these limits the cell radius \( R_e \) becomes large enough and TM02 wave comes in appropriate passband.

Without 2D investigations, these \( \Theta_0 \) 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 DL W cell axis for the first (Θ = 120°), the second (Θ = 320°) and the third (Θ = 510°) passbands.

The relative dimensions of DL W cells for the first and the higher TM01 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 cells in higher passbands lose to classical DL W for the first zone in transverse dimensions, group velocity and Ze value.

Efficiency reduction of DLW cells in higher TM01 passbands is evident from the particularity in electric field distribution for TM01N mode. In Fig. 5 electric field is shown in DLW cell for TM012 mode and one can see a strong Er component along segments BE and CF.

Considering the balance one can conclude - RF voltage along segments BE and CF spend magnetic flux, but doesn’t take 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 Er corresponds to minimum of Hϕ 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 Rc, which is defined now mainly by washer diameter and for all structures in Fig. 6 Rc ≈ 65mm. As one can see from the Table 2, the group velocity βg and Ze values are improved essentially due to stronger fields near axis. The DLW with washers is the structure with separated functions - βg value for TW operations depends on the aperture radius in the disk. And Ze value is defined by washers, which have similar to standing wave π mode field distribution - mostly effective with respect Ze value. As one can see from the Table 2, Ze value comes to saturation with increasing number of washers. The case N = 3÷4 (TM013, TM014) modes in the cell is a reasonable choice.

The accelerating structure with washers is known, [4], and further Ze improvement is due to the drift tubes at washers. Such structure is shown in Fig. 7 and for the fifth passband,
Table 2: The RF parameters of DLW cells with washers.

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

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

The dimensions optimization for DLW cells with washers 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 $\Theta$ 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 $\Theta = 510^\circ$ 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 $\Theta > 180^\circ$.

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 7: The structure with washers and drift tubes in DLW cell.](image)

![Figure 8: Dispersion diagram of DLW with washers.](image)

SUMMARY

Traveling wave accelerating structures with the phase advance for the total field essentially larger than $180^\circ$ per period are possible using higher passbands of $TM_{0j}$ 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.

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REFERENCES