Abstract: A broadband slow-wave structure (SWS) formed by a periodic row of rings connected by helices is considered below. The approximate analysis and measurements confirmed that the offered SWS has at least twice less "periodicity" in comparison to the helix and can operate without the backward wave oscillation at voltages exceeding 20 kV.

Keywords: TWT; slow-wave structure; dispersion; periodicity.

Introduction
One of the main disadvantages of the helix TWTs is the high "periodicity" (the phase shift per period over \( \pi \)), restricting the operating voltage by 10 kV, i.e. by deceleration \( N = 5 \) [1, 2]. It follows from this that at this deceleration the helix turn's length is just a little bit less than the half wavelength at the high-frequency boundary of the operating band, when the backward wave oscillation can appear. In this case periodicity exceeds 0.8. At periodicity equal to one, phase velocities of the zero spatial harmonic of the forward wave and the minus first harmonic of the backward wave are equal. This leads to the backward wave oscillation. Application of the bi-helix, which has twice less periodicity, is followed by the self-excitation at the opposite phase mode. The periodicity decrease in a ring-bar structure is insignificant due to the azimuth inhomogeneity introduced by the bars.

A novel, broadband SWS with significantly decreased periodicity is offered and considered below.

Rings connected by helices

The offered SWS is formed by a periodic row of metal rings connected one to another by two or three identical helices, one ring at each coil (Fig. 1). We’ll name this structure as the “Rings-Helices” SWS. Radius \( a \) of the rings at least twice exceeds radius \( b \) of the helices and is chosen to satisfy the approximate equality \( \gamma a \approx 1.5 \) in the middle of the frequency band, where \( \gamma \) is the transverse constant. For chosen operating voltage \( V \) and chosen wavelength \( \lambda \),

\[
\gamma \approx \frac{2\pi}{\lambda} \sqrt{\frac{255}{V}} - 1 ,
\]

where \( \lambda \) is in meters, \( V \) is in kV.

The transverse constant can be defined through wave deceleration \( N \), which in turn can be calculated through specific capacitance \( C_0 \) and specific inductance \( L_0 \) of a SWS [3, 4],

\[
N = \frac{C_0 L_0}{\varepsilon_0 \mu_0}.
\]

The small radiuses of the helices connecting rings, i.e. the small deceleration at a given pitch \( p \), means a small periodicity.

Let's assume that in the first approximation, the rings' specific capacitance is equal to the capacitance of the helix with the same radius \( a \) [3]:

\[
C_0 \approx \frac{\varepsilon_0 2\pi}{I_0(\gamma a) K_1(\gamma a)} .
\]

Consider also that the specific inductance can be defined as inductance of the connected in parallel helices with radius \( b \) [3]. In this approximation one may obtain for two helices

\[
L_0 \approx \mu_0 \frac{\beta^2 \pi b^2}{\gamma^2} \frac{I_1(\gamma b) K_1(\gamma b)}{p^2} .
\]

Substituting (3) and (4) into (2) gives the next dispersion equation:

\[
\gamma^2 \approx \frac{1}{2} \frac{I_1(\gamma b) K_1(\gamma b)}{I_0(\gamma a) K_1(\gamma a)} \left( \frac{2\pi b}{p} \right)^2 .
\]
offered SWS can operate at significantly higher operating voltage than the helix, \( \leq 40 kV \).

Figure 2. Dispersion characteristics calculated for the rings-helices SWS and the helix.

Measured Dispersion Characteristics

A scaled model of the rings-helices SWS had been fabricated and measured. The rings with radius \( a \) and two connecting helices with radiuses \( b \) were wound on the thin paper tubes that practically excluded the dielectric influence. The wave was excited between the rings and the ground rods with radius \( c = b/3 \) installed along the axis of the helices and connected one to another. Ratio of radiuses \( a/b \) was chosen equal to 2.3.

Figure 3. Deceleration characteristics measured for the rings-helices and the helix with the same radius.

It follows from comparison of the measured characteristics of the rings-helices and the helix that the first structure provides smaller deceleration with approximately the same slope of the dispersion characteristic. Measurements of the coupling impedances showed that they are approximately the same in the both cases. Having twice smaller periodicity than the helix, the offered SWS can operate at voltages 30…40 kV without backward wave oscillation.

Design Versions

The offered SWS can be installed in a metal shield through dielectric supports, as it is shown in Fig. 4a, or through dielectric spacers shown in Fig. 4b. Using the dielectric spacers decreases the dielectric load on the rings, providing their cooling through the connecting helices.

Figure 4. Two versions of the rings-helices SWS; 1-rings, 2 – connecting helices, 3 – dielectric supports, 4 electron beam, 5 – metal shield, 6 - dielectric spacers.

Conclusion

Novel, ring-based, SWS was offered, analyzed, and measured. Despite of the more complex in comparison to the helix SWS design, the offered SWS can be considered as a real solution for the significant increase in the operating frequency and the output power of the broadband TWTs.

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References