

# DISK-LOADED WAVEGUIDES FOR ACCELERATION HIGH INTENSITY SHORT PULSE ELECTON BEAMS

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One of the beam loading effects in linacs is limitation on the amount of number of particles that can be accelerated in very short beam pulses. The maximum number of particles is determined the correlation between the external accelerating field amplitude and the retarding field amplitude which particles radiate passing the waveguide. For increasing this value we suggested to use disk-loaded waveguides with period  $D$  that satisfies the condition:  $\lambda/2 < D < \lambda$ , where  $\lambda$  is the wavelength of accelerating wave. Three accelerating sections of this type have been manufactured in KFTI and installed at different linacs.

## INTRODUCTION

A most widely used technique for energy loss reduction is enlargement of the structure geometric sizes with an ensuing decrease of the accelerator operating frequency. For similar geometry structures the accelerating field amplitude in a certain cross-section at a fixed total rf-flow value depends in direct proportion on the operating frequency  $E_a \propto f_0$ , while radiation fields for similar geometry bunches vary according to the law  $E_r \propto f_0^2$ . After decreasing the operating frequency by the factor of  $n$  the ratio of the energy loss to the energy gain decreases by this value. Note that this inference is valid only for similar geometry bunches.

In a number of cases the radiation loss reduction by the way of operating frequency decrease is undesirable, because it entails making larger accelerating structure sizes, decreases the breakdown limit, etc. It is of considerable interest to seek out other ways of diminishing the slow-wave structure electrodynamic inhomogeneity for particle acceleration. We

suggested that energy losses to radiation of charge particles at constant operating frequency be decreased by the making smaller the number of inhomogeneities per unit length of a slow-wave guide [1, 2]. For a disk-loaded waveguide it was shown that in case of acceleration of short-pulsed beams containing several bunches ( $N > 10$ ), when energy losses are determined by excitation of the fundamental mode, the increasing of inter-disk spacing causes the radiated wave to decrease amplitude faster than the acceleration gradient decreases. Concurrently, beginning from a certain inter-disk value one of the wave spatial harmonics becomes the accelerating one, i.e. particle-synchronous. This conformity to natural laws opens up a possibility to increase the number of accelerating particles at a constant external source power. Besides, such structures have several other advantages, namely, a better  $Q$  and presence of rf-focusing [3, 4].

However, during single-bunch acceleration, when the exited wave spectrum considerably broadens, the possibility of loss decrease owing to a sparser inhomogeneity position becomes obscure. Really, in case of single bunch acceleration of considerable importance are both excited wave amplitudes and their frequency spectrum "density". In this connection, we carried out calculations of radiation characteristics of point charged particles in disk-loaded waveguides with different inter-disk spacing.

## BASIC EQUATIONS

As a main parameter chosen to be constant for the structures under consideration was considered the group velocity  $V_g$ . At constant  $V_g$ , section lengths  $L$  and external source power  $P$  one and the same value of rf-energy  $W$

( $W = P \tau_f$ ,  $\tau_f = L / V_g$ ) is needed to file them. The accelerating wave amplitude in a fixed cross-section of the homogeneous slow-wave structure is known to be determined by the expression

$$E_a = \sqrt{R_s P(z)} \quad (1)$$

where  $P(z)$  is the electromagnetic wave power in the given cross-section,  $R_s = E_s^2(z) / P(z)$  is the consecutive impedance of the accelerating wave synchronous spatial harmonic. The longitudinal radiation field component in the wake of axis-propagating particle without consideration of the oscillation terms is equal to the sum of all exited waveguide eigen-waves [5]

$$E_r = -q c \sum_{n=0}^{\infty} R_n \frac{|\beta_{g,n}|}{|1 - \beta_{g,n}|} \cos(\omega_n (t - \frac{z}{V_0}) - \omega_n t_0) \quad (2)$$

here  $\beta_{g,n} = V_{g,n} / c$ ,  $V_{g,n}$  is the group velocity of n-th eigen wave, particle-synchronous,  $t_0$  is the particle flight time over the cross-section considered as a start-off count marker for the longitudinal coordinate,  $q$  is the particle charge. For a value characterizing the relationship of radiation fields vs. accelerating field is taken the dimensionless value which is equal to the relationship of the radiation field in the frequency range  $\omega_n < \omega$  ( $0 \leq n \leq N$ ) in the immediate vicinity of point particle ( $t - z / V_0 \approx t_0$ ) with the charge  $q_* = 1$  nC vs. the accelerating wave amplitude that has in the cross-section under consideration the total power flow  $P_* = 1$  MW:

$$F(\omega) = \frac{q_* c \sum_{n=0}^N R_n |\beta_{g,n}| / |1 - \beta_{g,n}|}{\sqrt{R_s P_*}} \quad (4)$$

Since the eigen-waves form a discrete frequency spectrum, then the function  $F(\omega)$  is treated as a step-by-step one.

## RESEARCH RESULTS

The calculations of eigen-wave characteristics for disk-loaded waveguide were performed according to a program

developed by the authors of this technique [6,7] in consideration of 20 eigen-oscillations in the inter-disk spacing and 101 spatial field harmonics over the flight region. Results of  $F(\omega)$ -function calculations for various slow-wave structure geometries are shown in Fig.1.

As indicated above, the value of accelerating wave group velocity at the operating frequency ( $f_0 = 2797,2$  MHz) is chosen to be constant

$\beta_{g,s} \approx 0,01$ . Geometrical

dimensions of the waveguides under consideration are given in Table 1 (a is the radius

Type	a (mm)	t (mm)	D (mm)
B <sub>1</sub>	11,8	6	35,73
B <sub>2</sub>	11,8	6	71,45
B <sub>3</sub>	50	50	71,45

of the aperture in the disk, D is the structure period, t is the disk thickness).

The first-type accelerating structure ( $R_s = 2245 \Omega/\text{cm}^2$ ,  $\alpha = 0,002$  1/cm,  $\beta_{g,s} = 0,0101$ ,  $\theta = 2\pi/3$ ,  $n_s = 0$ ) resembles in its average waveguide characteristics that a constant gradient section at SLAC [8]. The second-type accelerating structure ( $R_s = 878 \Omega/\text{cm}^2$ ,  $\alpha = 0,0015$  1/cm,  $\beta_{g,s} = 0,0096$ ,  $\theta = -2\pi/3$ ,  $n_s = 1$ ) is analogous to the structure used in a high-current section of the linear accelerator LUE-300 at KFTI [1]. To date two accelerating sections of this type have been manufactured with the length  $L \approx 160$  cm and group velocity  $\beta_g = 0,036$  installed with the fieldback loop. Electron acceleration in this waveguide is performed by the first spatial harmonic of the counter-propagating wave. Slow-wave structures of this type were designated STRAM which stands for STRucture Accelerating Modified. The third-type structure ( $R_s = 552 \Omega/\text{cm}^2$ ,  $\alpha = 0,0024$  1/cm,  $\beta_{g,s} = 0,0099$ ,  $\theta = -2\pi/3$ ,  $n_s = 1$ ), which has non-standard parameters, has been developed, and on its base an accelerating section has been manufactured for LIC-accelerator, which stands for Laser Injector Complex designed to accelerate intense electron bunches [9].

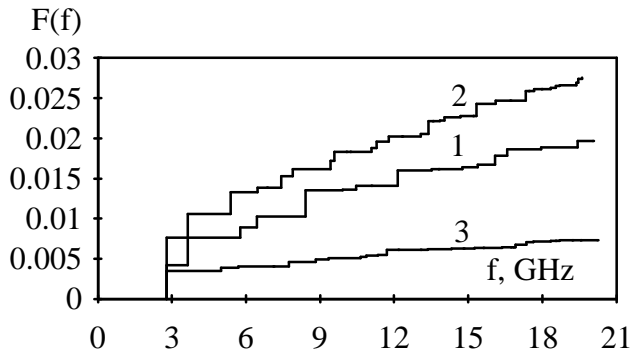


Fig.1

As follows from Table 1, disks in the waveguide  $B_2$  are spaced twice as rare the in the waveguide  $B_1$ . Comparison of the  $F(\omega)$ -function relationships for these two structures indicates that the radiation field value in the fundamental pass band decreases faster upon increasing the inter-disk spacing than the accelerating field amplitude [1,2]. Yet, upon frequency increasing the  $F(\omega)$ -function for the waveguide  $B_2$  rises faster than for the waveguide  $B_1$ . This is accounted for by the fact that owing to increasing of the cavity longitudinal dimension, as formed by two adjacent disks, the frequency spacing between excited eigen-waves decreases. As a result, structures of this type are no better for acceleration of single bunches than standard disk-loaded waveguides.

The third-type structure, designed and manufactured at KFTI, is much alike in its operation to the waveguide  $B_2$ . Particle acceleration in it is also done by the first spatial harmonic of the counter-propagating wave. However, as can be seen from Fig.1, it has considerably lower losses to radiation across the entire frequency spectrum. This is achieved due to three reasons. Firstly, owing to the increased structure period the number of electrodynamic inhomogeneities overflowed by particle per unit length is decreased by a factor of two. Secondly, resulting from an increase disk thickness the cavity dimensions remained practically the same as in the structure  $B_1$ , leaving the "spectrum density" of eigen-waves unchanged. Thirdly, removal of inhomogeneities off from the axis (increasing the

radius of the flight-through aperture) led to an additional decrease of the amplitudes of particle-excited waves. Thus, the above results of studies on charge particle radiation field relationships in periodic waveguides show that without changing the operating frequency one can decrease the losses to radiation by way of increasing the inter-spacing between electrodynamic inhomogeneities both in the fundamental band pass and in the wide frequency spectrum.

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