Simulations of the millimeter wavelength accelerating structure excitation

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Abstract. We present the work on development of the millimeter wavelength accelerating structure (also called the W-band structure). It consists of cylindrical cavities with the operating frequency of 96 GHz. The structure will be excited by the picosecond electron beam from the photocathode RF gun. In order to define exactly both the structure and the exciting beam parameters, analytical estimations and simulations of the structure excitation were performed. For the successful propagation of the exciting beam through it, focusing system is needed. It is proposed to use the permanent magnets producing solenoidal field, their preliminary design being discussed. Prototype of the millimeter wavelength structure has been manufactured, its first measurements are presented.

1. Introduction
Accelerator facilities on the base of short beams for interdisciplinary research are under operation at different research centers [1-3]. We began to develop an accelerator facility with short electron beams at Budker Institute of Nuclear Physics. It will be based on the RF photocathode gun [4]. Substantial feature of such a gun is the production of low emittance beams compared to the conventional thermionic cathode guns. At the same time, a charge of the beam from this gun can be high enough. Thus, such beams are suitable to serve a driver for the excitation of the W-band accelerating structure. There are several motivations to develop this course:

- One may obtain higher gradient due to the higher frequency [5]. Length of the W-band accelerator may be significantly reduced compared to that of the conventional S-band structure.
- Plasma excitation with subsequent wakefield acceleration where the bunch required length is determined by the Langmuir wavelength and equals about 1-3 mm.
- The W-band structure may serve as a bunching system for a “long” beam with a spatial period of about 3 mm.

Taking into account these motivations, we will consider excitation of the structure at the $E_{010}$ mode. According to this, the parameters of the structure and the exciting beam will be chosen.
2. Geometry of the W-band structure

Inner radius of the structure cavities was defined by the operating frequency close to 96 GHz. Longitudinal parameters of the structure cavities were chosen from two points of view. Firstly, cavities of the structure should be independent by the electromagnetic field. Secondly, it should be possible to produce such a structure, that is, we have to take into account manufacturing possibilities and resources. Figure 1 presents view of two cavities of the W-band structure with its chosen dimensions being indicated.

![Figure 1: Two cavities of the millimeter wavelength structure excited at the $E_{010}$ mode.](image)

3. Excitation of the W-band structure

Amplitude of the electric field to be excited at the cavity at the $E_{010}$ mode by the beam with the gaussian charge distribution is given by

$$E_0 = \frac{q}{\pi \varepsilon_0 R^2 J_1^2(\nu_{01})} \exp \left( -\frac{\omega_0^2 \sigma_t^2}{2} \right)$$

where $q$ is the beam charge, $\varepsilon_0$ is the dielectric constant, $R$ is the cavity inner radius. $J_1$ is the 1st order Bessel function, $\nu_{01}$ is the 1st zero of the Bessel function $J_1(x)$. $\omega_0 = 2\pi f$, $f$ is the frequency of the excited mode at the cavity, $\sigma_t$ is the RMS duration of the gaussian beam. That is, in terms of obtaining the higher accelerating gradient, the exciting beam should be as short as possible. However, an extremely small beam length is undesirable because of the excitation of higher modes. If the single mode $E_{010}$ is to be excited, one should find an optimal RMS duration of the exciting beam.

Excitation of the W-band structure was performed at CST Studio [6] in order to choose an optimal exciting beam duration. Longitudinal electric field was registered by a probe in one of the structure cavities. Figure 2 shows the excited electric field by the beam with $\sigma_t = 1\text{ps}$.

![Figure 2. Electric field excited by the beam with $\sigma_t = 1\text{ps}$.](image)

![Figure 3. Fourier spectrum of the electric field excited by the beam with $\sigma_t = 1\text{ps}$.](image)
This dependence is not a single-frequency harmonic signal, that is, more than one mode is excited. Indeed, this fact is confirmed by the Fourier spectrum of the electric field (Figure 3). Beside the peak at about 96 GHz which corresponds to the mode $E_{010}$, there are higher modes being excited. That is, the beam with $\sigma_t = 1$ ps is too short to excite the $E_{010}$ mode only.

The same simulation was performed with other values of the beam RMS duration. Shown at Figure 4 is the longitudinal electric field induced in one of the cavities by the beam with $\sigma_t = 2$ ps. As one can see from the Fourier spectrum (Figure 5), higher modes are significantly mitigated compare to the $E_{010}$ mode. That is, $\sigma_t = 2$ ps is more suitable in terms of the single $E_{010}$ mode excitation.

![Figure 4: Electric field excited by the beam with $\sigma_t = 2$ ps.](image1)

![Figure 5: Fourier spectrum of the electric field excited by the beam with $\sigma_t = 2$ ps.](image2)

### 4. Focusing system on permanent magnets

We propose to use permanent magnet producing alternating solenoidal magnetic field for the beam focusing. Shown at Figure 6 is the preliminary design of magnets. This element is axisymmetric and consists of NdFeB material and permendur screen. Magnetization is longitudinal, i.e. it is directed along the element symmetry axis.

![Figure 6: Design of the single magnet element.](image3)

Distribution of the longitudinal magnetic field along the magnet axis is presented at Figure 7.
According to our estimations of the exciting beam transverse dynamics, this field is enough for the successful beam passage through the aperture of the W-band structure.

5. Fabrication of the prototype of the W-band structure
In order to develop the technology of the W-band structure production, a first experimental prototype of the structure was manufactured. Copper cavities (Figure 8) were fabricated, after that 50 of them were brazed in an upright position into the structure (Figure 9).

The structure was checked for tightness; measurements from the outside revealed misalignment of cavities from the structure axis of about 0.02 mm. A primary inspection of the cut prototype (Figure 9) did not revealed visible brazing inconsistencies. Further work comprises more precise measurements and inspections. With the next structure prototypes we also plan to perform “cold” RF measurements.

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