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EXCITATION OF MILLIMETER WAVELENGTH CAVITY STRUCTURE

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Abstract

In this work excitation of W-band structure is studied. The structure consists of cylindrical cavities with the operating frequency of about 96 GHz. We plan to excite the structure by short bunches from the photocathode RF gun. In order to choose structure geometry and beam duration, we performed estimations and simulations; induced voltage was also estimated. Taking into account feasible parameters of the photocathode RF gun such as beam size and emittance, we studied exciting beam transverse dynamics to define its other characteristics (energy and charge). To lead the beam from the whole structure, focusing is needed. After estimation of required magnetic field, we considered possibility of focusing with help of permanent magnets.

INTRODUCTION

Accelerator facilities on the base of short beams for interdisciplinary research are being developed at research centers [1-3]. Radiofrequency (RF) photocathode gun is usually the source of short beams. Such a facility being developed at Budker Institute of Nuclear Physics (BINP) will provide electron beams of picosecond duration for different experimens that require short beams.

Excitation of W-band accelerating structure could be one of these experiments. Such structures are interesting from the point of view of high gradient [4] due to the higher frequency. Thus, length of the W-band accelerator may be significantly reduced compared to length of the S-band one.

Another motivation to develop W-band accelerating structures is connected with plasma excitation experiments where bunch required length is determined by the Langmuir wavelength

$$\sigma_t \sim c/\omega_p.$$

Here c is the speed of light, $\omega_p = \sqrt{4\pi n_p e^2/m}$, is the plasma frequency, e is the electron charge, n_p is the plasma density, m is the electron mass. With the plasma density of 10^{15} cm^{-3}, required bunch length is about 0.2 mm (0.6 ps). To obtain train of such short bunches, one can excite W-band structure by the "driver" beam from the photocathode gun, and then bunch there the secondary "long" beam. These bunches with spatial period of about mm are suitable for the plasma excitement and for the subsequent wakefield acceleration.

Thus, W-band structures are interesting not only in terms of accelerator fundamental physics but also for the industry where accelerator length may be significantly reduced.

RF PHOTOCATHODE GUN

After the photocathode RF gun (Fig. 1) beam is accelerated in the S-band disk-loaded accelerating structure up to tens MeV. After that it enters the W-band structure to excite it.

RF Photocathode Gun

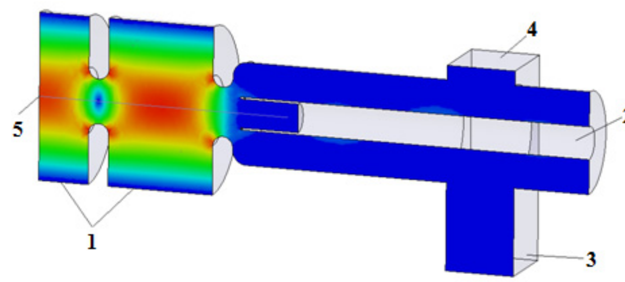

Figure 1: Layout of the photocathode gun with the electric field distribution: 1 — accelerating cavities, 2 — input for the laser beam, 3 — RF power input, 4 — vacuum pumping connection, 5 — photocathode.

Table 1: Photocathode Gun Specifications.

Parameter	Value
Operating frequency	2856 MHz
SWR at the operating mode	1.1
Unloaded quality factor of cavities	12000
Length of the first cavity	24.8 mm
Length of the second cavity	52.3 mm
Cavity diameter	82 mm
Beam duration	1-10 ps
Repetition rate	10 Hz
Beam charge	up to 2 nC
Transverse emittance	10 µm

Substantial feature of the photocathode guns is production of low emittance beams compared to conventional thermionic cathode guns [5]. Emittance evolution for the beam charge of 1nC and 2 nC at the BINP photocathode gun is shown at Fig. 2 (obtained during simulations at ASTRA [6]).

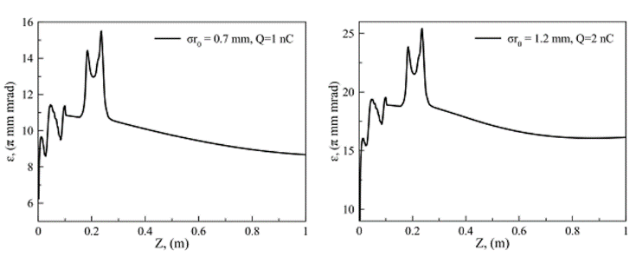

Figure 2: Emittance evolution for the beam from the photocathode gun with the charge of 1 nC (top) and 2 nC (bottom).

For the moment the gun is fabricated, measured and pumped (Fig. 3).

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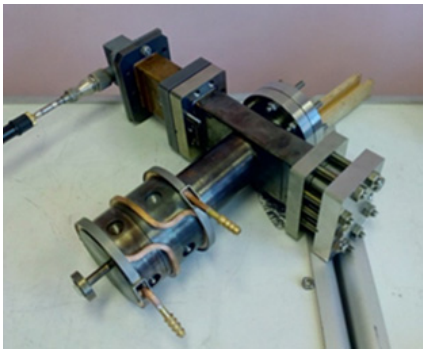

Figure 3: Fabricated photocathode RF gun.

GEOMETRY OF THE W-BAND STRUCTURE

Radius of cavities was defined by the operating frequency close to 96 GHz. Longitudinal parameters of the structure cavities were chosen in such a way that cavities were independent by the electromagnetic field (Fig. 4).

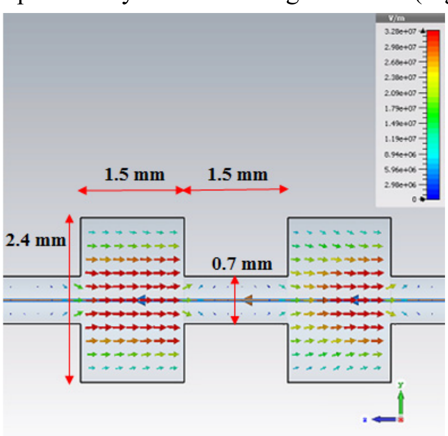

Figure 4: Two cavities of the excited W-band structure by the beam with $\sigma_t = 2$ps, $Q = 2$ nC.

EXCITATION OF THE W-BAND STRUCTURE

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

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

where q is the beam charge, ε_0 is the dielectric constant, R is the cavity radius. J_1 is the 1st order Bessel function, ν_{01} is the 1st zero of the Bessel function $J_0(x)$, $\omega_0 = 2\pi f$, f is the frequency of the excited mode at the cavity, σ_t is the RMS duration of the gaussian beam.That is, in terms of higher accelerating gradient, exciting beam should be as short as possible. However, extremely small beam length is undesirable because of higher mode excitation. Optimal beam duration of 2 ps was chosen as a result of simulations at CST Studio [7]. Figure 5 illustrates spectrum (in logarithmic scale) of the excited electric field at one of the cavities : modes with the frequency higher then 96.2 GHz are several orders of magnitude smaller.

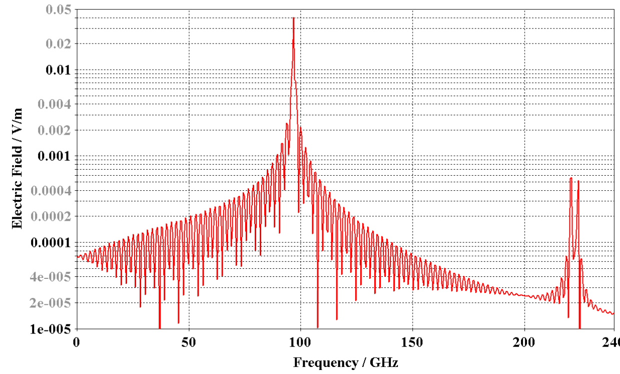

Figure 5: Spectrum of the excited electric field at one of the cavities.

Table 2: Result of Simulations of the W-band Structure Excitation

Parameter	Value
Exciting beam charge	2 nC
Exciting beam RMS duration	2 ps
Frequency of the excited mode E_{010}	96.2 GHz
Amplitude of the excited electric field	50 MV/m
Damping time	60 ns

FOCUSING SYSTEM ON PERMANENT MAGNETS

To lead the beam through the W-band cavity structure, it is necessary to focus it into its small aperture of 2 a = 0.7 mm. With Kapchinsky-Vladimirsky beam envelope equation [8] one can estimate required magnetic field B_z for the focusing of the electron beam with given parameters :

$$B_z = \frac{2\beta\gamma mc}{q}\sqrt{\frac{K}{a^2} + \frac{\varepsilon_n^2}{\beta^2\gamma^2 a^4}}.$$

Here β and γ are beam relativistic factors, ε_n is normalized emittance, $K = 2I_b/(I_0\beta^3\gamma^3)$, I_b is the beam current, $I_0 \approx 17$kA. Taking into account beam feasible parameters after the gun (Table 1), one can depict required magnetic field dependence on the beam energy (Fig. 6).

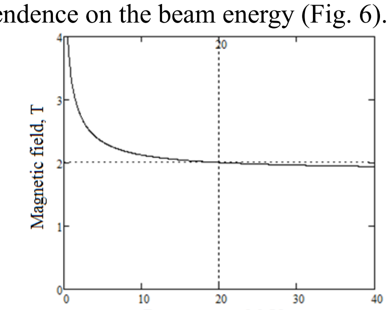

Figure 6: Dependence of focusing magnetic field on the beam energy.

Beam energy of 20 MeV is optimal; focusing magnetic field is about 2 T.

We propose to use permanent magnets producing solenoidal field. This type of magnet has some advantages compared with solenoids, i.e., no need in cooling. Design

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of one magnet module is depicted at Fig. 7; Fig. 8 shows its longitudinal field.

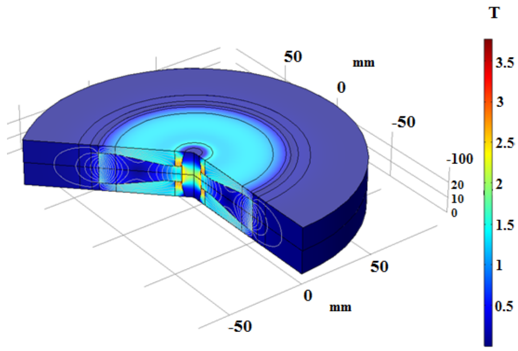

Figure 7: Magnet module with field lines.

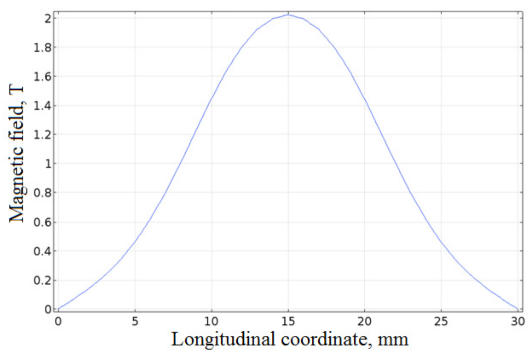

Figure 8: Longitudinal field of the magnet module.

Beam Dynamics Simulations at the Field of Permanent Magnets

Dynamics simulations for the beam with parameters form Table 1 were performed using ASTRA code. Resulting beam envelope is shown at Fig. 9. Many magnet modules (about 20) are used here to form solenoidal field at the whole W-band structure length, field amplitude of a single module of 2 T is enough to maintain beam radius of about 0.27 mm.

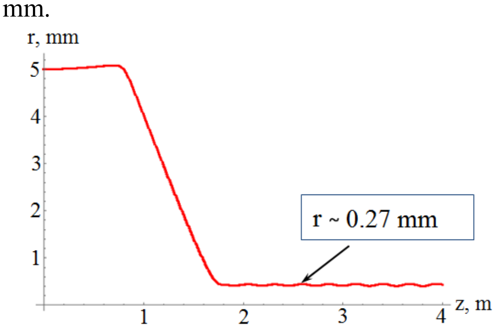

Figure 9: Beam envelope in the field of permanent magnets.

FABRICATION OF THE W-BAND STRUCTURE

Cavities were fabricated (Fig. 10), after that 50 of them were brazed into the structure (Fig. 11).

The structure was checked for tightness; measurements from the outside revealed misalignment of cavities from the structure axis of about 0.02 mm. Future work comprise

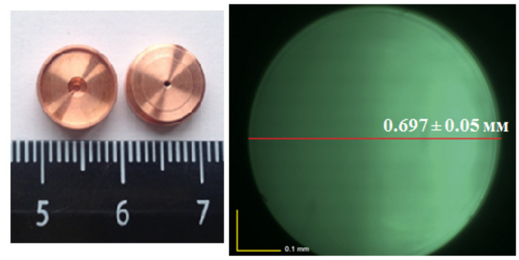

Figure 10: On the left – cavities, on the right – depiction of the aperture obtained with help of microscope.

Figure 11: Brazed W-band structure.

more precise measurements that will be possible after the structure sawing.

CONCLUSION

We began to develop W-band accelerating structures at BINP. To excite the structure, we plan to use electron beam from the photocathode RF gun.

At result of simulations of the structure excitation, we defined optimal exciting beam parameters. To focus the exciting beam into the small structure aperture, we propose to use permanent magnets; their design is prepared.

W-band cavity structure was successfully manufactured, measurements from the outside showd satisfactory results. The structure precise measurement are in progress.

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