

DIFFRACTION ACCELERATING STRUCTURE FIELD DISTRIBUTION MEASUREMENTS*

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Abstract

We describe method and results of field distribution measurements for the diffraction accelerating structure consisting of two conducting gratings embedded in dielectric. This structure with operating aperture close to wavelength can be used for high gradient acceleration in millimetre-micron wavelength range.

INTRODUCTION

Diffraction accelerating structure [1], is shown schematically in Fig. 1.

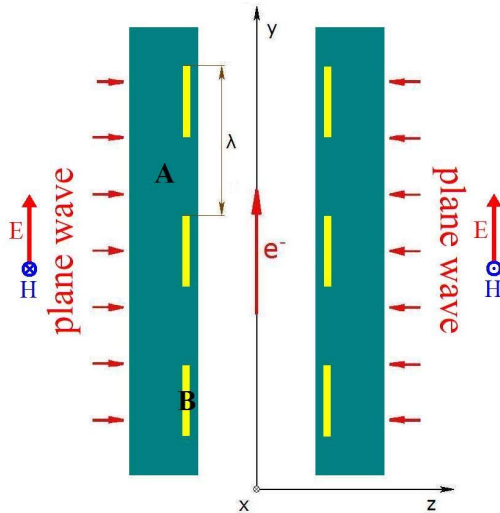


Figure 1: Diffraction accelerating structure. A – dielectric slab, B – conducting strip.

Structure consists of two mirror symmetric diffraction gratings embedded in the dielectric slab. It is irradiated from the opposite sides by two linearly polarized plane waves. Grating period is equal to the length of the irradiating plane wave. Numerical simulation demonstrates that the structure can be optimized to have longitudinal (along Y axis in Fig.1) electric field distribution similar to ordinary standing wave accelerating structure operating in π -mode. Thus, the diffraction structure can be used to accelerate a relativistic electron beam. Specific feature of the diffraction structure is low dependence of the longitudinal electric field on the transverse coordinate [2]. Optimal distance between the internal dielectric layers is close to one wavelength, so effective beam aperture of diffraction structure in z-direction is about order of magnitude higher than in ordinary accelerating structures and is practically unlimited in x- direction. Thus the diffraction structure

can be used for a beam acceleration in millimetre-micron wavelength range in which ordinary structure aperture is extremely small. Maximum accelerating gradient which can be reached with the diffraction structure is limited by the threshold of structure damage by electromagnetic field and in 10.6 μm range (CO_2 laser) can be close to 1 GeV/m [3].

The goal of present work is to provide experimental evidence of the similarity of accelerating field distribution in the diffraction structure to π -mode distribution of ordinary accelerating structure using microwave model operating at 25 mm.

MICROWAVE MODEL

Scaling of optical systems to the microwave range is convenient method for study of their electromagnetic properties, especially the field distribution in the near zone. We designed microwave analogue of the diffraction structure for 25 mm wavelength. Choice of the wavelength was done taking into account an equipment available (antennas, network analyzer) and reasonable model dimensions. Numerical optimization was done for Plexiglas taken as a dielectric. By changing the thickness of the internal dielectric layer, width and thickness of the conducting strips and the distance between the gratings we found geometry providing a longitudinal electric field distribution in the median plane with close amplitudes and opposite sign in neighboring half periods (Fig. 2).

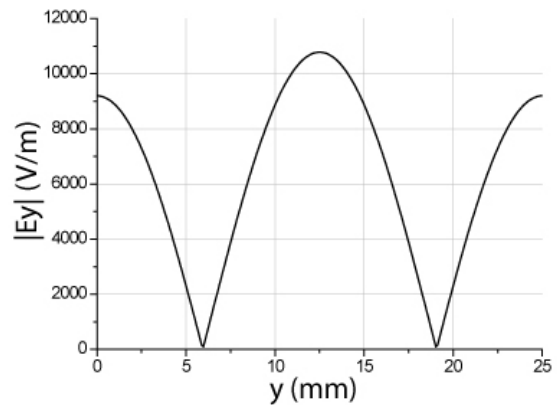


Figure 2: Electric field E_y component amplitude.

Following these calculations two gratings were manufactured with the dimensions shown in Fig. 3.

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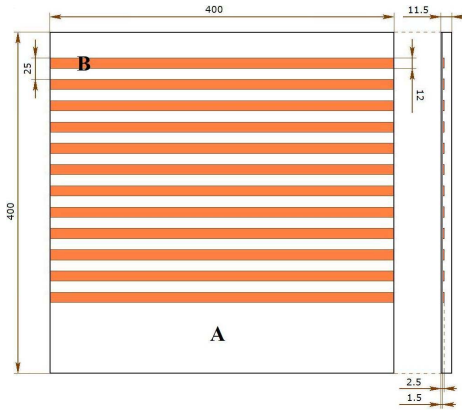


Figure 3: Scheme of the diffraction grating. A – Plexiglas as the dielectric, B - aluminum strip. All dimensions are in mm.

EXPERIMENTAL SET-UP AND METHOD

Scheme of the experimental set-up for field distribution measurements is shown in Fig. 4.

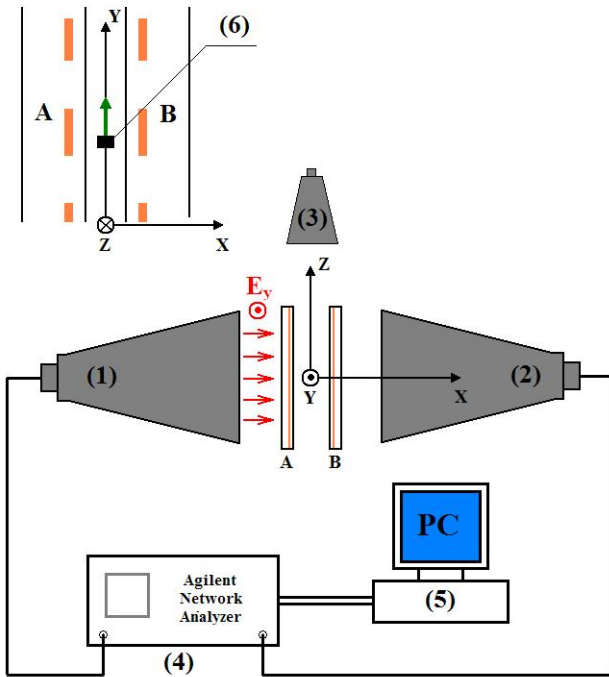


Figure 4: Experimental set-up.

Diffraction gratings A and B were located between the horn antenna (1), which radiates plane polarized wave, and receiving horn antenna (2). Additional horn antenna (3) was situated at the side with its axis perpendicular to the X axis. The network analyzer Agilent 8719 (4), connected to the computer (5) via GPIB port, was used to measure S-parameters. In order to decrease the influence of the reflections from different heterogeneities on the RF signal path, the Agilent 8719 time gating capability was utilized.

Field distribution measurements were done with the probe (6) attached to thin dielectric string, which was moved by the step motor along the Y axis. The size of the probe made of the RF absorbing material was much less than the wavelength. At each, ~1 mm, step the transmission coefficient S_{21} between the horns (1) and (2) was measured at the frequency 11.99 GHz, which corresponds to the wavelength of 25 mm. The process was automated and was controlled by the computer with the specially developed code.

Analytic formula for transmission coefficient S_{21} measured while with the probe being pulled can be represented as the following:

$$S_{21} = 20 \log \left(\frac{U_{out} - \Delta U_{out}(y)}{U_{in}} \right), \quad (1)$$

where U_{in} is the signal amplitude at the horn (1) output, U_{out} is the signal amplitude at the horn (2) input without the probe, ΔU_{out} is the amplitude change due to absorption and scattering of electromagnetic field by the probe. Assuming that $\Delta U_{out} \approx \chi |E(y)| U_{in}$, where χ is the constant defined by the probe geometry and its complex dielectric permittivity, and $E(y)$ is the electric field strength at the probe current position, the following approximate formula for electric field distribution can be obtained:

$$|E(y)| \approx \left(\frac{10^{\frac{S_{21}^0}{20}} [S_{21}^0 - S_{21}(y)]}{20\chi} \right), \quad (1)$$

where S_{21}^0 - transmission coefficient without the probe.

Thus, the measured dependence of the value S_{21} on the probe coordinate along the Y axis corresponds to the distribution of the electric field strength absolute value along the same axis. Since the horn antennas are sensitive only to the radiation polarized along the Y axis, the E_y field component makes the main contribution to the measured electric field distribution.

MEASUREMENT RESULTS

The dependence of the transmission coefficient between horns (1) and (2) on the location of the probe along the Y axis is shown in Fig. 5. To exclude influence of the edge effects only data obtained for the central part of grating are presented.

The period with which the coefficient S_{21} maxima are observed, and, consequently, the period with which electric field E_y component amplitude maxima are observed, is equal to the half of the diffraction grating

period. Maxima are located opposite the centers of the aluminum strips and opposite the centers of the gaps. S_{21} maxima are nearly equal in amplitude. This distribution of the E_Y field component amplitude is close to expected from calculations (Fig. 2).

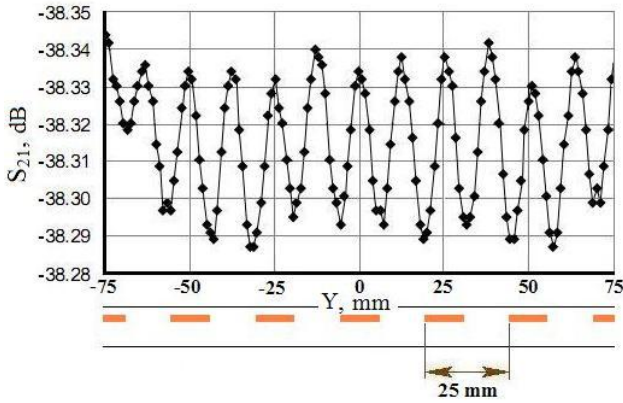


Figure 5: The dependence of the transmission coefficient between horns (1) and (2) on the probe location along Y.

The transmission coefficient between the horns (1) and (3) with the probe being pulled is presented in Fig. 6.

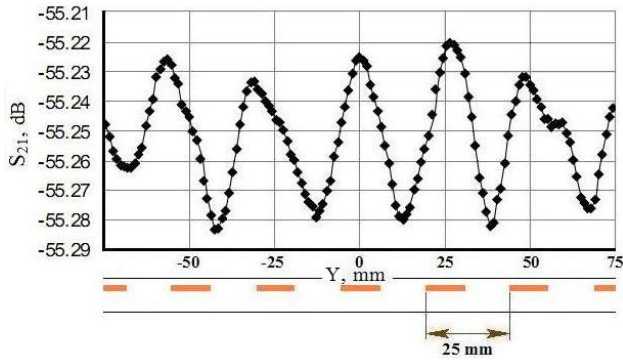


Figure 6: The dependence of the transmission coefficient between horns (1) and (3) on the probe location along Y.

The period with which the coefficient S_{21} maxima are observed in this case is equal to the diffraction grating period. Maxima are located opposite to the centers of the aluminum strips. The difference between maxima spacing period in Fig. 5 and Fig. 6 can be explained in the following way. The signal amplitude at the horn (3) input is the result of interference of radiation scattered by the probe and background radiation coming out from the inter horns space, including the space between the gratings. Background radiation field phase and amplitude are constant while probe is pulled. Scattered radiation field

phase depends on phase of the electric field at the probe position. So, as a result of scattered and background radiation interference, when the probe is located in one of the half-periods the signal amplitude received by the horn (3) increases, whereas when the body is in the neighboring half-period, the signal amplitude decreases. So, the results presented in Fig. 6 are direct evidence of opposite sign of the electric field in the neighboring half periods.

Thus, the results of the experiments described confirm that the longitudinal field distribution along the Y axis of the structure (Fig. 1) is similar to π -mode field distribution of ordinary standing wave accelerating structures used in L-, S – and C- bands: nearly equal by absolute values amplitudes in the neighboring half-periods of the grating with the phase shift between the half-periods being 180° . Such a distribution of the field accelerating component provides the relativistic charged particle acceleration in each of the half-periods provided that the particle injection phase was chosen correctly.

CONCLUSION

Presented in this paper experimental results confirm that the field distribution of the diffraction structure is appropriate for charged particles acceleration. This structure can be used for high gradient acceleration in millimetre-micron wavelength range.

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