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ELECTRON SPECTROMETER FOR A LOW CHARGE INTERMEDIATE ENERGY LWFA ELECTRON BEAM MEASUREMENT

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ABSTRACT

The Laser-driven Compton light source is under development in ILP SB RAS in collaboration with BINP SB RAS. Electron spectrometer with energy range 10-150 MeV for using in this project is presented. Spectrometer based on permanent magnet and phosphor screen with CCD registrar and this geometry was optimized for best measurements resolution in compromise with size limitations. Preliminary collimation of electron beam allows achieving energy resolution up to 5-10 % of top limit. System has been tested at the VEPP-5 linear electron accelerator and obtained results corresponds to design objectives. Sensitivity of beam transverse charge density was experimentally fixed at 0.03 pC/mm^2, that is practically sufficient for our LWFA experiments.

INTRODUCTION

At the present time, the impressive progress in laser wakefield acceleration (LWFA) of charged particles gives grounds to consider LWFA as a perspective method of electron beam production in the GeV energy range.

The project of laser-driven Compton light source started in ILP SB RAS in collaboration with BINP SB RAS [1]. The first stage of the project is creation and studying laser based accelerated electron beam from the supersonic gas jet. At the next stage, it is planned to obtain a high-energy gamma-ray beam by means of Compton backscattering of a probe light beam on LWFA-accelerated electrons.

General parameters of the first stage LWFA stand are:

- laser system: repetition rate is 10 Hz, pulse energy is 100÷300 mJ, pulse duration is ~20 fs, central wavelength is 810 nm;
- acceleration area: diameter is ~ 10÷15 µm, length is ~ 0.5 mm;
- supersonic He jet: diameter is ~1.2 mm, gas density is $10^{18}÷10^{19}$ cm^{-3}, Mach number is 3.5÷4, gas backpressure is 5÷10 atm;
- expected parameters of the electron beam are: up to 100-150 MeV of energy, 1-10 pC of charge, 1-10 mrad of angular divergence, ≤ 0.1 ps of beam duration.

SPECTROMETER PURPOSE AND REQUIREMENTS

Beam energy measurement is a necessary constituent of any accelerator facility. We choose the wide-used in LWFA experiments layout of spectrometer with magnetic dipole, phosphor screen and CCD camera as a signal register.

The spectrometer development is constrained by the following general demands:

- Compact size (full dimensions 20-25 cm) because of device must be placed inside limited volume of experimental vacuum chamber (Fig. 1) with diameter 70 cm and height 50 cm. It determines length and value of analizing magnetic field: 0.7-1.2 T and 30-50 mm. It follows the use of permanent magnets.
- Materials must be nonactivated and vacuum usable. It determines the use permanent magnets for dipole.
- The use of special electron beam collimator to improve energy resolution (see below).
- Taking into account a very small beam charge (several pC per pulse), registration system (phosphor screen + CCD camera) must have high quantum efficiency and sensitivity. Also we should take into account that CCD camera will be placed maximally near to screen but, from other hand, outside the vacuum volume. It means the distance between camera and screen will consist 35-40 cm, and the objective should be an appropriate angle of view to project the screen (about 10cm) on the CCD (11 mm).

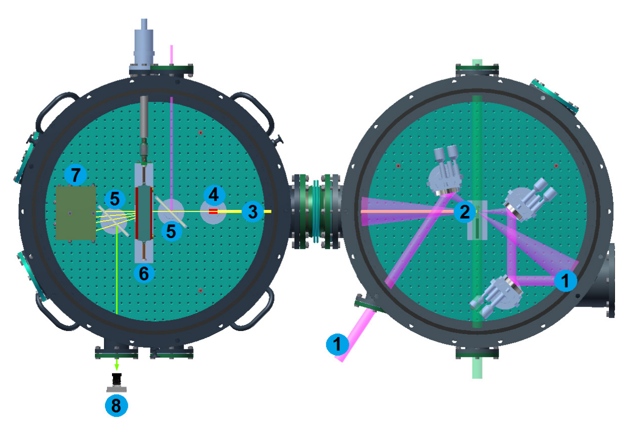

Figure 1: Experimental vacuum chamber. (1) Laser beams, (2) supersonic gas jet, (3) electronic beam, (4) collimator, (5) screens, (6) magnet dipole, (7) faraday cap, (8) CCD.

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MAGNETIC DIPOLE AND COLLIMATOR

The dipole has been designed on two permanent NdFeB magnets (Fig. 2) with magnetization 1 T. It allows to reach magnetic field inside a magnet bore close to 1 T. This field configuration provides sufficient beam deflection to place luminescent screen at 10-12 cm from the dipole. A movable mounting of the dipole allows to insert and remove it into a beam. Figures 3a and 3b show respectively the calculated and measured distribution of the magnetic field.

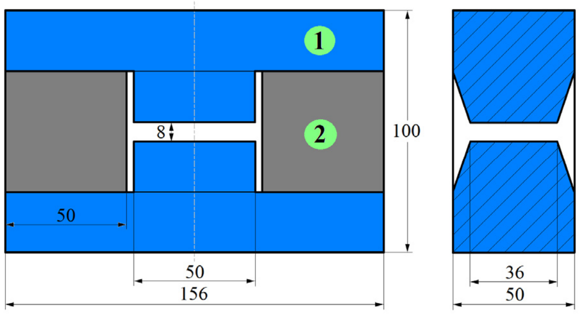

Figure 2: Magnetic dipole schematic. (1) Fe. (2) NdFeB.

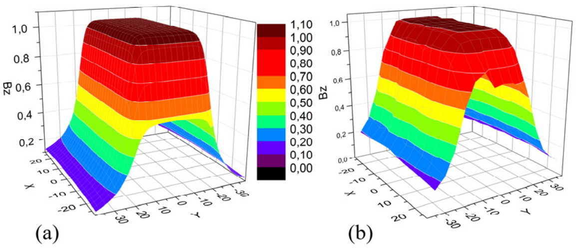

Figure 3: (a) Calculated and (b) measured magnetic field.

Laser accelerated electron beam usually has angle divergence up to 5-10 mrad and will reach a size of 5-7 mm in the experimental chamber, which will give an unsatisfactory energy resolution of 50-70% for the energy of 100 MeV and more (Fig. 4). To improve the resolution it was decided to use a special collimator that cuts the beam in the plane of rotation. Simple estimations show that reducing the size to 1 mm allows achieving a resolution of ~ 10%, to 0.5 mm - respectively ~ 5% (Fig. 4). Simulation of collimator for beam energy up to 150 MeV with use of GEANT4 program complex was performed. Results of simulations for simple slit tungsten collimator with a length of 6 cm, height of 1 cm and 1 mm width of slit are presented on Fig. 5. It is shown that this collimator geometry is sufficient for complete collimation of our electron beam. Electron beam at collimator output has width following a slit size and angle divergence close to 0.2°. Other electrons are completely stopped by collimator material.

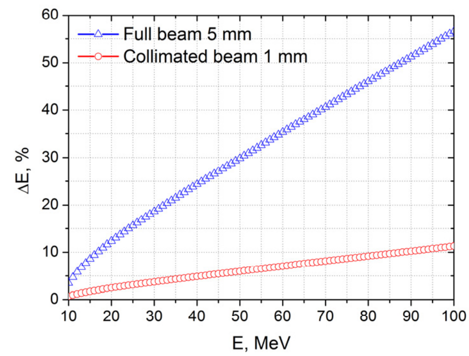

Figure 4: Energy resolution of beam energy.

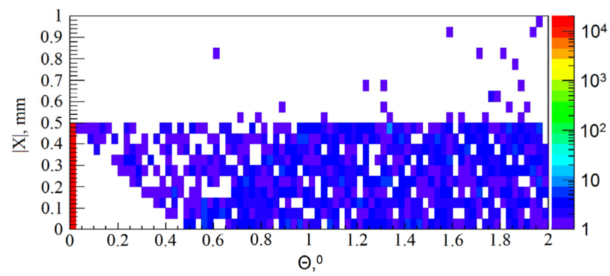

Figure 5: Collimated beam distribution.

PHOSPHOR SCREEN AND CCD CAMERA

The phosphor screen produced by Renex [2] (Novosibirsk, Russia) and the CCD camera based on SONY ICX285 are used.

The screen has Gd_2O_2S-Tb phosphor and is an analogue of wide used of Kodak-Carestream Lanex screens. This type of screen has high charge linearity and weak energy dependency [3].

CCD camera developed in INP SB RAS. The choice was determined by its availability and satisfying characteristics. To achieve high sensitivity a Jupiter-3 (focal length 50mm and aperture 1.5) objective is used. Camera has the following key parameters: 100Mbit Ethernet interface, 1.4 MPix resolution, external trigger source, 4 fps speed, 63 dB dynamic range, 42 dB signal to noise ratio.

SPECTROMETER BEAM TESTING

The general aims of test were to check up the real operation of basic elements of spectrometer: magnetic dipole, collimator and register system under real electron beam.

The spectrometer was mounted and tested at electron linac of Injection Complex VEPP-5, BINP [4,5]. Sketch of experiment is presented in Fig. 6. Beam energy at the experiment was 120 MeV, bunch duration was ~ 1 ns, tunable bunch charge was in the range between 4.8 nC ($3{\cdot}10^{10}$ e^-, nominal operational condition of VEPP-5 Injection Complex) and practically down to zero, repetition rate was 2 Hz. Beam charge was measured by high sensitive Faraday cup (FC) specially developed for LWFA experiment [6,7].

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All spectrometer elements were located at geometry closed to estimate for LWFA experiment.

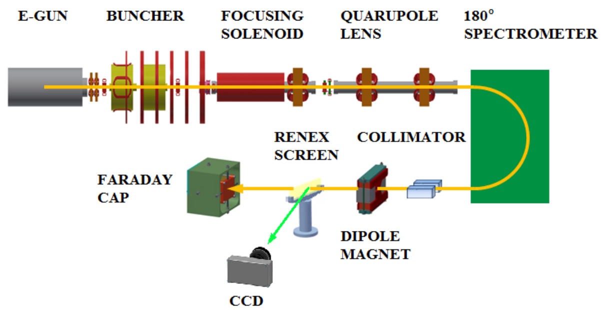

Figure 6: Test stand.

The first part of the experiment aimed to determine of real beam charge operation range of this equipment. The signals from CCD and FC were registered for some levels of beam charge. Analyzing the obtained data, we found the lower and upper limits of the operating range. Beam profile for low and middle charge values shown on Fig. 7a and Fig. 7b consequently.

Calculating the ratio of the maximum CCD signal (the center of the beam) to the FC signal for several points in the operating range gives the dependence of the signal from the CCD of the beam charge (Fig. 8).

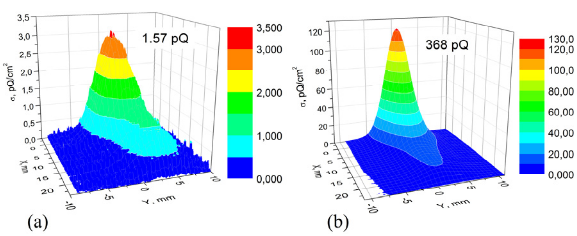

Figure 7: CCD signal for beam charge 1.57 pC (a) and 368 pC (b).

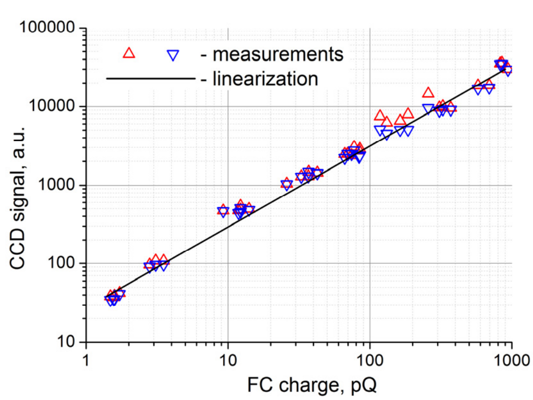

Figure 8: Dependence of CCD signal from the electron beam charge.

The final stage consisted in checking the work of the collimator and the magnetic dipole. The beams angular spread at the exit of the collimator by calculations (Fig. 5) is less than 0.025 degrees and the beam size at a distance of 40 cm should be less than 1.3mm. Test measurements were carried out at normal pressure, not in vacuum chamber, it is also necessary to take into account the spreading of the beam in the atmosphere. Measured beam size (Fig. 9a) agrees well with the computed blur (Fig. 9b).

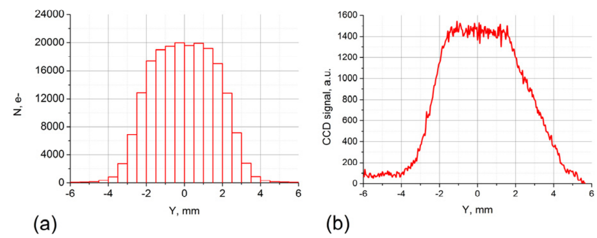

Figure 9: (a) Calculated and (b) measured beam size.

The measured beam deflection after magnetic dipole is equal 7.5cm (Fig. 10) and it agrees for calculations to 120MeV.

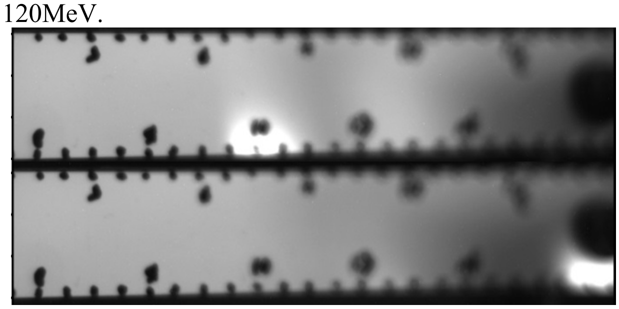

Figure 10: Beam position without dipole (above) and with dipole (below). Distance to the screen 40 cm, strokes on the screen every 5mm.

CONCLUSIONS

Magnetic spectrometer for measurement of LWFA electrons energy was developed, fabricated and successfully tested under 120 MeV beam of VEPP-5 accelerator complex at Budker INP, Novosibirsk. Spectrometer allows measuring the energy of ultrashort ($\tau \leq 0.1$ ps) low charge (~ several pC) electron bunch with energy resolution better than 10 % in the range 10-150 MeV. Linearity of properties of spectrometer registration system allows using of it for beam density distribution measurement also.

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