# A FARADAY CUP FOR A LOW CHARGE LWFA ELECTRON BEAM MEASUREMENT

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*Abstract*

Nowadays laser wakefield acceleration (LWFA) is considered as one a perspective method for GeV electron beam production. Combination of laser accelerated electrons and Compton backscattering of probe light beam opens possibility to create the table top source of femtosecond light beam in x-ray and gamma range. Project of laser-driven Compton light source started in ILP SB RAS in collaboration with BINP SB RAS. Production of 1-10 pC electron beams sub-ps time range duration with energies up to 100 MeV is expected as a result of the first stage of the project. Since energy of electrons does not exceed of 100 MeV, it allows using Faraday cup (FC) with reasonable dimensions, instead of commonly used integrating current transformer (ICT). Geometry of the FC was optimized taking into account of beam stopping simulation as well as low capacity requirement. RF properties, simulation of the system operation were carried out. System has been tested at the VEPP-5 electron linac. Results of development and testing of this FC are presented.

## 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 [1,2].

LWFA experiments are currently prepared at the Institute of Laser Physics (ILP) in collaboration with Budker INP. The experiments are based on the two-channel multi-terawatt femtosecond high contrast, high angle stability laser system with the pulse repetition rate of 10 Hz, which is developed at ILP [3].

To pursue further studies of laser-based acceleration techniques, a specialized experimental facility was designed. A sketch of the experimental stand is shown in Fig. 1. Scenario and design of stand are traditional for LWFA devices: sub-PW high-contrast femtosecond laser pulse will be responsible for gas ionization and formation of the plasma channel inside the supersonic gas jet, wakefield excitation, and trapping of plasma electrons by the wave.

General parameters of the LWFA stand are [4]:

- 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 50-100 MeV of energy, 1-10 pC of charge, 1-10 mrad of angular divergence, ≤ 0.1 ps of beam duration.

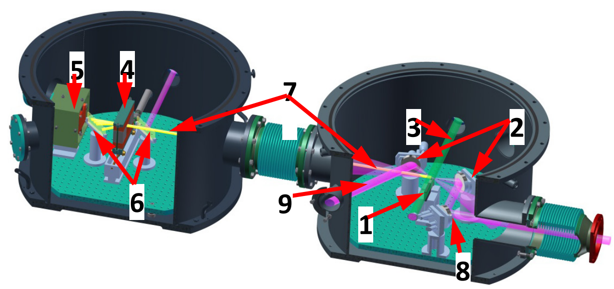


Figure 1: Two experimental chambers (without the compressor chamber): 1 – supersonic gas jet, 2 – focusing mirrors, 3 – laser beam for diagnosing the jet density, 4 – electron spectrometer magnet, 5 – Faraday cup, 6 – luminophor screens, 7 – electron beam, 8 – driving laser beam, 9 – scattered laser beam.

## FC PURPOSE AND REQUIREMENTS

Beam current measurement is a necessary constituent of any accelerator facility. Usually the ICT (Integrating Current Transformer) device is used as a detector of charge in LWFA electron bunch [2,5-7]. This method has the principal difficulties:

- ICT is indirect diagnostic;
- ICT demands periodic recalibration of complicated equipment set;
- ICT system is expensive (tens of thousands euro).

However, in our case of intermediate energy range (10÷100 MeV) we can use alternative variant of diagnostic. It is Faraday cup (FC). FC gives us a possibility to have direct current measurements with high accuracy and reliability without any additional complicated electronics and does not need special recalibration procedures. Moreover, FC can be used for calibration of more complicated systems in future.

The FC development is constrained by the conflicting demands:

- Compact size (boundary dimensions 20-25 cm). Device must be placed inside limited volume of experimental vacuum chamber.
- Small capacity, not more than 10-30 pF (several tens pF including output circuit). It is caused by small

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bunch charge and by requirement to register the signal with sufficiently high precision.

- FC materials have to be nonactivated, nonmagnetic, vacuum usable.
- FC has to provide full stopping of primary beam as well as secondary charged particles. It means the total charge and particle losses should be less than 1%.

In this way, for FC development the following tasks have to be solved:

- Electron beam stopping simulation for energy up to 100 MeV taking into account electron scattering, absorption, reflection and electromagnetic showers.
- FC design and optimization subject to minimize FC size as well as FC capacity simultaneously.
- Final testing of fabricated device under real electron beam with closed to necessary parameters.

## ELECTRON BEAM STOPPING SIMULATION

Charge losses of a beam stopping region were simulated using GEANT4 code. Charge losses can occur due to electron backscattering and penetration of electromagnetic shower or incident beam through the beam dump. Electron beam has normal direction to target, point size and monoenergetic.

Fig. 2 presents results of backscattering simulations for long tungsten beam dump with front face aluminium layer of different thickness. Simulations were performed for electrons with energy 10, 50 and 100 MeV. As it is shown, part of backscattered particles reaches the acceptable level ~ 0.5 % at layer thickness 10 mm. Further increase of Al is meaningless.

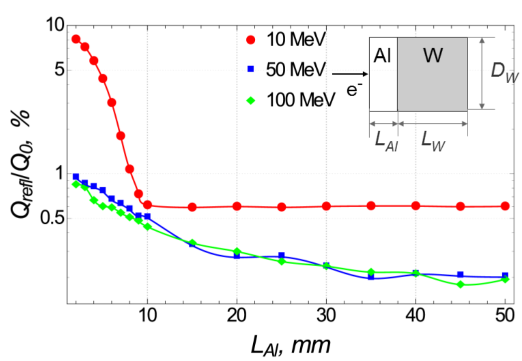


Figure 2: Dependence of charge reflection on thickness of Al layer for 10, 50, 100 MeV electron beam.

In order to optimize the total size of FC central part (subsequently beam dump) it was performed simulation of charged particles passed through the rear and lateral surfaces of beam dump with different proportions. Simulations were carried out for 100 MeV electron energy as maximum possible, since maximum electron energy defines beam dump size. Particles with lower energies will be fully stopped all the more.

Fig. 3 presents results of performed beam stopping simulations for long tungsten beam dump of different sizes. Simulations were performed for electrons energy 10, 50 and 100 MeV. It is shown, using of FC with simple cylindrical geometry of 60 mm diameter and 60 mm of length, particles losses are less than 1 %.

According to the calculations, the FC geometry was chosen to be a 90x60x60 mm$^3$ tungsten parallelepiped with a 10 mm thick aluminum layer at front to minimize electron backscattering. Beam dump width of 90 mm is due to large horizontal beam size after spectrometer magnet.

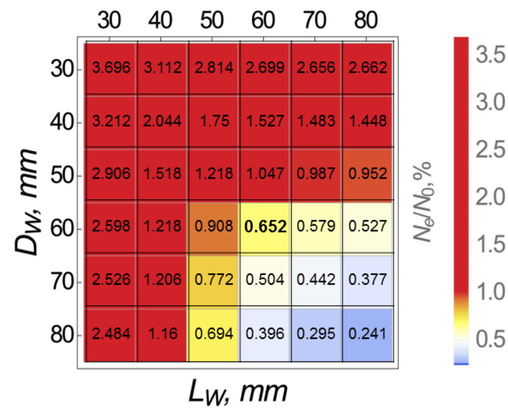


Figure 3: Number of penetrated particles for different W cylinder sizes, %. Primary beam energy is 100 MeV.

## FC DESIGN AND PARAMETERS

Based on the simulations the FC construction has the following parameters (see Fig. 4):

- Beam dump is tungsten parallelepiped with thickness 60 mm, width 90 mm, height 60 mm assembled from 10 mm slices. Front face aluminium layer has 10 mm thickness.
- Grounded external shield made from duralumin, vacuum gap between the target and external shield equals to 30 mm.
- FC has self-capacity of 14.5 pF that is optimal for given problem.
- Charge drain and signal output are made through the R ~ 100 kOhm and low-capacitance connectors. It follows time of discharge τ = RC ~ 1-3 μs.
- Possible excitation of RF electromagnetic fields attenuates output signal duration less than 100-200 ns (<< τ) and can be unconsidered.

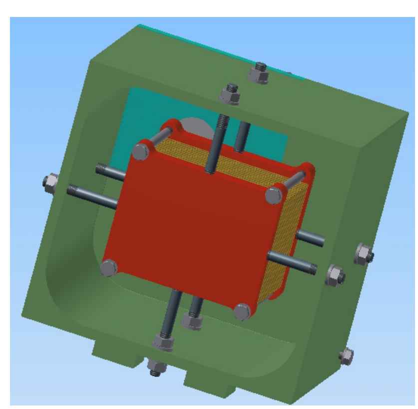

Figure 4: Construction of the FC



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## FC BEAM TEST

The FC was tested at electron linac of Injection Complex VEPP-5, BINP [8-10]. Sketch of experiment is presented in Fig. 5. Beam energy at the FC point was 120-125 MeV, bunch duration was ~ 1 ns, tunable bunch charge was in the range between 4.8 nC ($3\cdot10^{10}$ $e^-$, nominal operational condition of VEPP-5 Injection Complex) and practically down to zero, repetition rate was 2 Hz.

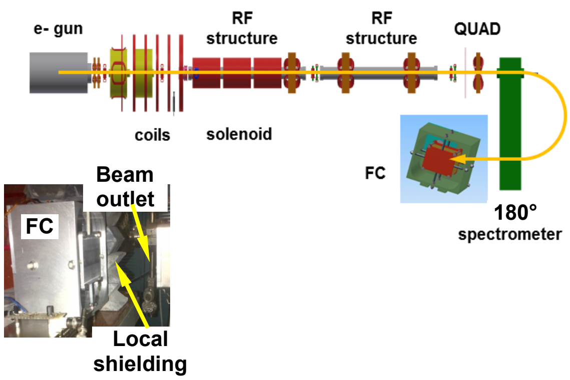

Figure 5: Electron beam line layout of VEPP-5 Injection Complex and the FC in experimental area.

Experimental results are presented in Fig. 6. Measured signal was provided from VEPP-5 beam line to control room and was registrated by the usual oscilloscope without any additive amplifiers. The stable work of the device with low bunch charge ~ 10 pC, was observed that practically equals to expected parameters.

Experimental data are in a good agreement with one of the standard beam diagnostics in Injection Complex VEPP-5.

## CONCLUSION

This FC allows measuring the charge of ultrashort electron bunch ($\tau \leq 0.1$ ps) with high precision ($\leq 1$ pC) without any additional complicated electronics and does not need special calibration procedures.

The Faraday cup is fabricated and successfully tested under 120 MeV beam of VEPP-5 accelerator complex at Budker INP, Novosibirsk.

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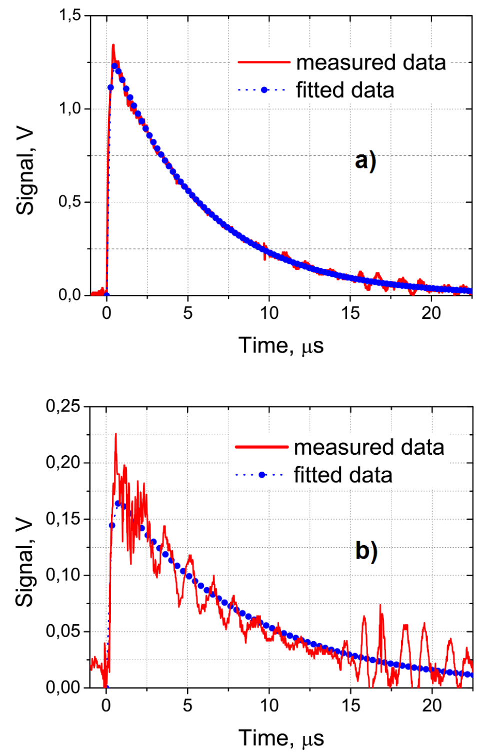

Figure 6: Beam charge measurements at e-linac. (a) is 72.3 pC ($4.52\cdot10^8$ $e^-$), (b) is 16.0 pC ($1\cdot10^8$ $e^-$).

## REFERENCES

[1] W. P. Leemans et al. *Phys. Rev. Lett.* 113 245002, (2014).
[2] Hyung Taek Kim et al. *Phys. Rev. Lett.* 111 165002, (2013).
[3] V E Leshchenko et al. *Laser Phys. Lett.* 11 095301, (2014).
[4] V.I.Trunov et al. Proc. of VII International Symposium and School for Young Scientists “MPLP-2016”, August 22-27, 2016, Novosibirsk, Russia.
[5] K. Nakamura et al. *Phys. Plasmas* 14, 056708, (2007).
[6] Mengze Tao et al. *Phys. Plasmas* 21, 073102 (2014).
[7] www.bergoz.com
[8] A.V. Alexandrov et al. Proc. LINAC96, Geneva, Switzerland, August 26- 30, 1996, pp.821-823 (CERN-1996-007).
[9] M.S. Avilov et al. *Atomic Energy* 94.No.1 (Jan 2003): 50-55.
[10]M.S. Avilov et al. Proc. of LINAC2002, Gyeongju, Korea.

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