ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-WEPSC42

RF CAVITY BASED CHARGE DETECTOR FOR A LOW CHARGE ULTRA SORT SINGE ELECTRON BUNCH MEASUREMENT

K.V. Gubin, ILP SB RAS, Novosibirsk, Russia
A.M. Barnyakov, S.L. Samoylov, D.P. Sukhanov[1], BINP SB RAS, Novosibirsk, Russia
[1]also at Novosibirsk State University, Novosibirsk, Russia and Novosibirsk State Technical University, Novosibirsk, Russia

Abstract

Nowadays the project of laser-driven Compton light source started in ILP SB RAS in collaboration with BINP SB RAS. It was expected the production of 1-10 pC electron beams sub-ps time range duration with energies up to 100÷150 MeV as a result of the first stage of the project. It is necessary to have the non-destructive charge detector for on line measurements during experiments. We proposed the detector based on reentrant RF resonator technology. Single circular cylinder geometry of measuring RF cavity is insensitive to electron beam position and size as well as time structure of bunch (on the assumption of sufficiently short bunch). Base data of cavity are close to acceleration section elements of VEPP-5 linac.The prototype of the detector was successfully tested at VEPP-5 electron linac. Measured charge of single bunch reaches down to 1 pC and less. This paper presents the results of development and testing of diagnostics.

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.

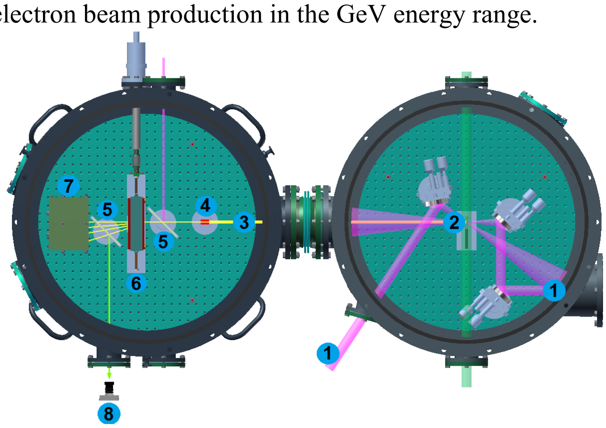

Figure 1: Experimental vacuum chamber. (1) Laser beams, (2) supersonic gas jet, (3) electronic beam, (4) RF beam charge detector, (5) screens, (6) magnet spectrometer, (7) faraday cap, (8) CCD.

The project of laser-driven Compton light source started in ILP SB RAS in collaboration with BINP SB RAS. The first stage of the project is to create a stand for obtaining and studying LWFA-accelerated electron beam inside the supersonic gas jet with energy as high as 100 MeV. 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 [1] (see Fig.1). 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.

DETECTOR PURPOSE, DESIGN AND PARAMETERS

Non-destructive beam current measurement is a necessary constituent of any accelerator facility. In our case we propose to use the wide-used diagnostics based on reentrant RF resonator. This kind of detector was realized, for example, [2] as a beam current monitor or beam position monitor [3, 4].

The development of beam charge detector is constrained by the following general demands:

- Compact size (full dimensions not more than ~10 cm) because the device will be placed inside limited volume of experimental vacuum chamber (Fig. 1) with diameter 70 cm and height 50 cm.
- Detector will operate with single bunch condition. Storage methods of measurements are unacceptable because of the electron beam has repetition rate not more 1 Hz. Moreover, expected beam parameters (as charge as beam size and position) will be very unstable between charge pulses.
- Maximum unification of detector parameters with parameters of VEPP-5 RF elements [5].
- Beam charge range is from 100÷500 fC (tuning regime of LWFA experiment) to 1÷5 nC (RF-photogun experiments).
- In any case beam structure can has as one bunch as bunch train structure. But the bunch duration inside the train will be more or less uniform.

According to the fundamental properties of beam loading we can estimate analytically induced wakefield in the cavities of the millimeterwave structure [6, 7]. A pointlike beam induces a voltage (and, therefore, signal amplitude from pickup antenna) linearly depended on beam charge

$$U_p = 2kq \quad (1)$$

For the TM_{010} mode in the cylindrical waveguide with radius R and length L final expression of the loss parameter is

$$k = \frac{LT^2}{2\varepsilon_0 R^2 J_1^2(\nu_{01})} \quad (2)$$

27th Russian Particle Acc. Conf. RuPAC2021, Alushta, Russia JACoW Publishing
ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-WEPSC42

Linear dependence between beam charge q and electrical (and magnetic) field, hence voltage on the detector antenna can us to measure the transverse beam charge.

More accurate modelling by CST Studio gives us the following main results:

- Simple cylindrical geometry of RF cavity is most useful for us. This geometry has minimal sensitivity to beam position, size, transverse angle etc.
- Cavity geometry choose the same with geometry of regular cavities of VEPP-5 linac acceleration section (see Fig. 2).
- Detector sensitivity will be enough high to sub-pC bunch registration.
- Beam charge detector can be used as for LWFA experiment, as for any VEPP-5 application.

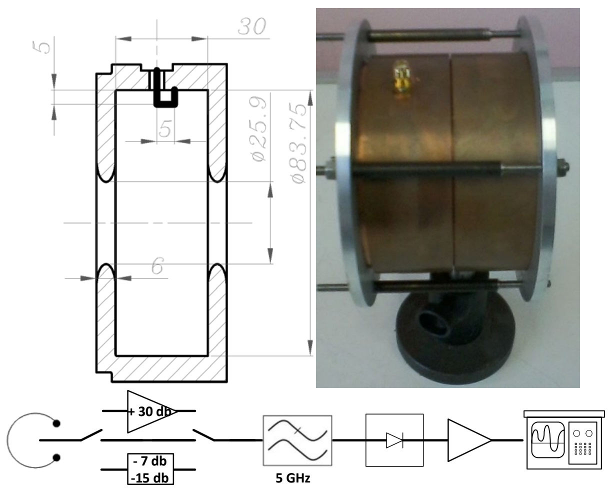

Figure 2: Maquet of cavity based charge detector and measuring circuit.

DETECTOR PROTOTYPE AND MEASURING CIRCUIT

As result of numerical modelling, the simple cylindrical reentrant cavity was chosen for further experimental realization. We use cavity geometry the same to acceleration section cavity of VEPP-5 linac in BINP (see Fig. 2). It simplifies the manufacture, measure and tuning of detector cavity. The prototype of detector based on segment of acceleration section of VEPP-5 linac was manufactured. Goal of prototype development are:

- To study RF characteristics, to choose and complete the measuring circuit.
- To excite cavity by the short electric pulse through the axial stub antenna.
- To excite cavity by VEPP-5 electron beam and to study the detector real parameters (as sensitivity, linearity of characteristics etc.).

Measuring circuit was chosen maximum simple (Fig. 2). It consists of cavity with pickup antenna; RF amplifier or attenuator with bandpass up to 30 GHz; RF filter with bandpass up to 3.2 GHz (necessary for extraction the basic cavity RF frequency of TM_{010} mode); detector head with frequency band up to 20 GHz; video amplifier with bandpass 500 MHz and register oscilloscope.

VEPP-5 LINAC BEAM TEST

Finally, charge detector was tested at electron linac of Injection Complex VEPP-5, BINP. The layout experiment is presented in Fig. 3. The injection complex has 180° magnetic spectrometer placed after the second RF structure as regular beam diagnostics. Detector cavity placed in front of the output port of the spectrometer. To test the detector operation over a wide range of the beam charge, the electron beam was intentionally extra focused/defocused by quadrupole lens/magnetic corrector in front of the first RF structure. The 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, the repetition rate was 2 Hz.

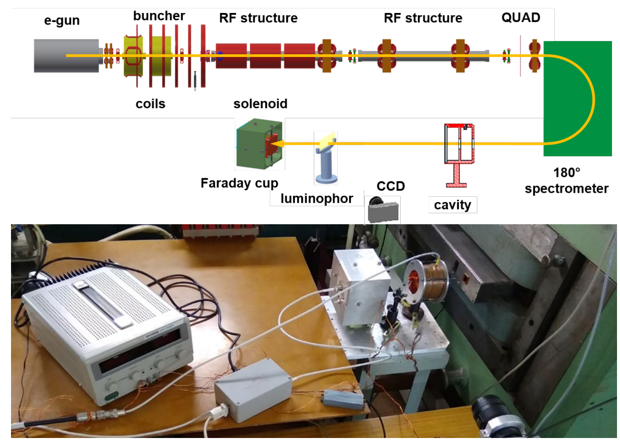

Figure 3: Electron beam line layout of VEPP-5 Injection Complex and the detector in experimental area.

Typical bunch train structure shown in Fig. 4. Beam energy at the FC point was 120-125 MeV, bunch train duration was ~ 5 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.

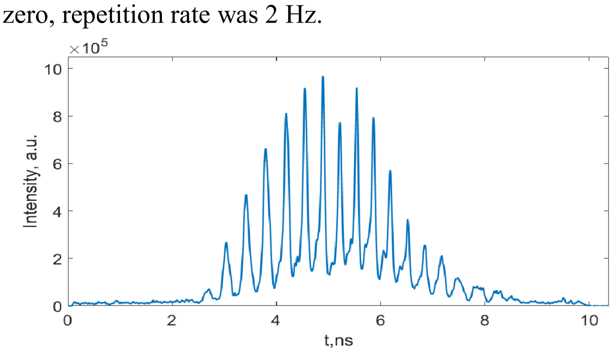

Figure 4: Bunch train structure inside VEPP-5 linac [8].

Detector signal is calibrates by Faraday cup [9]. Luminophor screen with CCD camera [10] use in order visual observation of electron beam. Cavity and FC signals were processed by specially developed amplifiers with wide-variable amplification factor.

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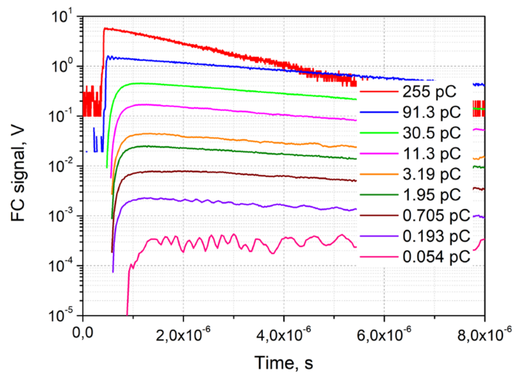

Figure 5: Signals of FC for different charge of electron beam.

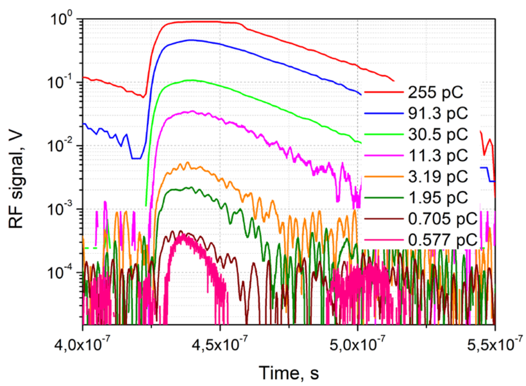

Figure 6: Signals of RF cavity based charge detector for different charge of electron beam.

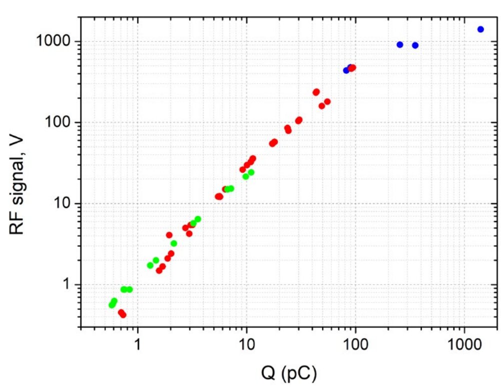

Figure 7: Dependence between detector signal and beam pulse charge.

Typical RF and FC signals from experiment are shown in Figs. 5-6. Final calibration curve of detector - dependence between detector signal and beam pulse charge is presented in Fig. 7.

The stable work of the device with bunch charge from ~ 1 nC down to ~ 0.5 pC was observed, which practically equals to the expected parameters. The experimental data are in good agreement with those of the standard beam diagnostics in Injection Complex VEPP-5. Dependence between detector signal and beam pulse charge is linear, as it was expected. Low charge limit consists ~ 500 fC and is conditioned by the radio- disturbance.

CONCLUSION

Developed charge detector allows measuring the charge of ultrashort ($\tau \leq 1$ ps) low charge (~ 1 pC) electron bunch with high precision without any additional complicated electronics and does not need special calibration procedures. The prototype of beam charge detector manufactured and successfully tested under 120 MeV beam of VEPP-5 accelerator complex at Budker INP, Novosibirsk. Proposed diagnostics can be used in wide range of linear accelerated experiments.

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