https://doi.org/10.46813/2023-145-112

PROBE FOR MEASURING THE LONGITUDINAL COMPONENT OF THE ELECTRIC FIELD IN A DIELECTRIC WAKEFIELD ACCELERATOR

D.Yu. Zalesky, V.I. Pristupa, V.S. Us, G.V. Sotnikov*
National Science Center
"Kharkov Institute of Physics and Technology",
Kharkiv, Ukraine
**E-mail: zdmitriy2022@gmail.com*

To conduct experiments to determine the amplitude of the electric field and the transformation ratio in the wake field accelerator based on dielectric structures excited by electron bunches of the Almaz-2 electron accelerator, a probe was developed and manufactured. The probe consists of a ¼ wavelength antenna (27 mm) and a detection circuit based on a 2A201A microwave diode. To calibrate the probe, a measuring stand was assembled, consisting of a microwave generator and a horn emitter. A SPEKTRAN spectrum analyzer (Germany) was used as a microwave power meter, and a digital oscilloscope was used as a meter of the detected signal from the probe. The results of measurements made on the stand show that at a microwave radiation power of 26 mW/m^2 and an electric microwave field strength of 2.6 V/m at the measurement point, the output signal from the probe is 1 mV.

PACS: 41.75.Lx; 07.57.Kp; 84.40.Ba; 84.40.Dc

INTRODUCTION

In wake acceleration methods, where a bunch of charged particles acts as a driver, one of the important parameters of the attractiveness of a considered acceleration scheme is the transformer ratio **T**, which determines the maximum energy gain of accelerated particles [1, 2]. In collinear devices, where the drive and accelerated bunch move along the same path, **T**<2. To increase the transformer ratio in collinear dielectric wake accelerators, it was proposed to use charge profiling inside a single bunch [3] or bunch train profiling [4, 5]. The transformer ratio can also be significantly increased by using multizone dielectric structures [6–8], where the accelerated and drive bunches move along different trajectories. Another important parameter that determines the length of the wake accelerator is the amplitude of the longitudinal component of the electric field of the electromagnetic wave E_z. These two parameters are not independent, it is impossible to simultaneously increase T and E_z, there is always a tradeoff between choosing a large value of the transformation ratio **T**>>2 and a large value of the accelerating field strength [7].

It follows from the above that it is necessary to determine the transformer ratio and the amplitude of the longitudinal electric field in a specific acceleration scheme. The transformater ratio **T** can be determined in two ways. The first is as the ratio of the maximum in the energy gain of the accelerated beam electrons to the maximum energy loss of the drive beam particles [4], the second is as the ratio of the maximum of the accelerating field to the losses of the drive beam, devided to the beam charge [1]. The second method is especially attractive for the case of multizone multichannel accelerator structures. In this case, in the experiment, the losses of the drive bunch in one channel can be determined, for example, with a mass analyzer, and the amplitude of the longitudinal electric field can be found using an electric probe.

To carry out experimental studies on measuring the transformation ratio and the accelerating field in the developed five-zone wake structure [9] and the plasma-dielectric structure with a profiled train of drive bunches [5], we created new measuring equipment, which includes the measuring probe described below.

The probe was developed and adapted for measurements on the experimental setup shown in Fig. 1.

As can be seen from Fig.1. The source of relativistic electrons with an energy of 4.5 MeV is the Almaz-2M accelerator [10, 11], from which electron bunches enter a waveguide-dielectric structure consisting of a dielectric structure 4 and a vacuum section 5 of the same waveguide.

Wake dielectric systems can be both round or rectangular cross section. The dielectric structure in the first case consists of fluoroplastic rings, and in the second of rectangular fluoroplastic plates.

The waveguide-dielectric structure is a microwave resonator tuned to the natural frequency of the dielectric structure and the repetition rate of electron bunches, which varies in the range of 2800…2806 MHz. The resonator was tuned using plunger 8.

The internal volume of the resonator is divided into the vacuum and atmospheric parts by a plug 6. To prevent the electron beam from falling on the plug, a deflecting magnet 10 is used.

The measuring probe is inserted into the hole in the plunger 8 with access to the inner region of the resonator to a predetermined length.

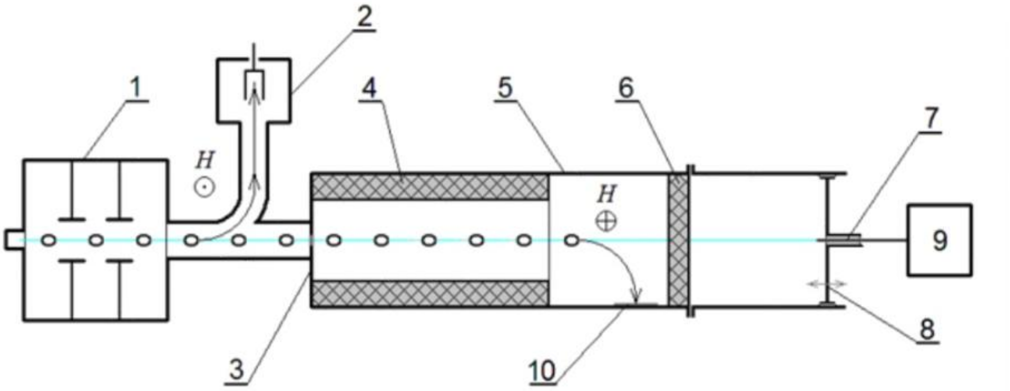


Fig. 1. An installation for measuring the longitudinal component of the electric field on a dielectric wake accelerator using the developed measuring probe, where 1 – Almaz-2M electron accelerator; 2 – magnetic analyzer; 3 – diaphragm; 4 – dielectric structure; 5 – waveguide; 6 – fluoroplastic plug; 7 – antenna; 8 – short-circuited plunger; 9 – measuring probe; 10 – deflecting magnet

DESCRIPTION OF THE DESIGN OF THE MEASURING PROBE

The appearance of the developed measuring probe is shown in Fig. 2.

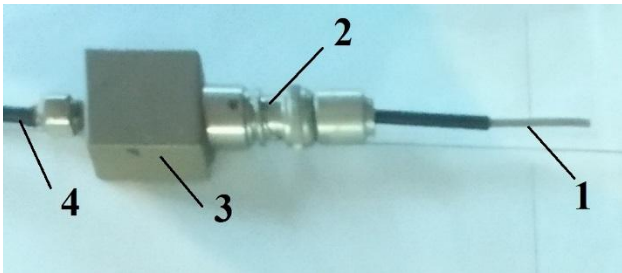


Fig. 2. External view of the measuring probe, 1 is antenna; 2 is RF connector; 3 is case; 4 is output coaxial cable

As can be seen from Fig. 2, the probe consists of antenna 1, which is a piece of coaxial cable, part of which has been stripped of the braid. The length of the bare part is 27 mm, which is equal to ¼ of the wavelength of microwave oscillations at the accelerator's operating frequency of 2.8 GHz. Item 3 in Fig. 2 is the case in which the detector circuit is located. From the probe output via cable 4, the detected signal is fed to the oscilloscope.

In Fig. 3 shows the electric circuit of the probe.

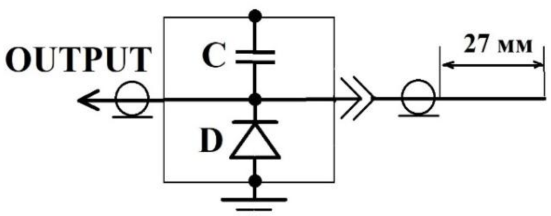


Fig. 3. Scheme of the measuring probe, where D is the detector diode; C – technological capacity

The probe circuit is located in a shielded metal case 3 (see Fig. 2) and consists of a detector diode "D" and a capacitor "C". "C" is the capacitance between the grounded case and the probe's signal wire.

A 2A201A microwave diode [12] was used as a detector diode. According to the documentation, the diode is designed to detect signals in the decimeter and centimeter wavelength ranges.

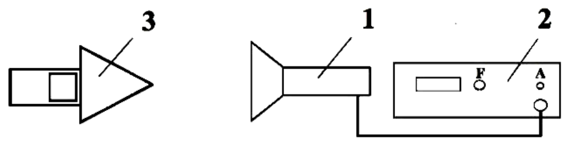
The parameters of the 2A201A diode indicated in its form are presented in Table.

Name of characteristic, mode and unit of measurement	Norm	
	less	more
Diode quality factor 2A201A, $W^{(-1/2)}$, M	80	–
Current sensitivity, A/W, BI	6.5	–
Differential resistance, Ω, rdiff	400	1000
Voltage standing wave ratio, VSWR	–	1.5

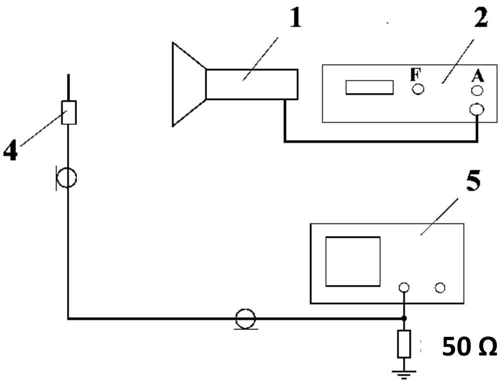
EQUIPMENT, MEASUREMENT RESULTS AND THEIR DISCUSSION

To test and calibrate the developed probe, a test stand was assembled, shown in Fig. 4.

As can be seen from Fig. 4, the horn 1 plays the role of a source of microwave radiation of electromagnetic waves. The microwave power to the horn came from the G4-80 microwave generator. The frequency of the oscillator 1 was regulated by the potentiometer "F" and was 2.8 GHz in the experiments, and the amplitude of the signal "A" was set to a maximum of 6 mW [13].



a



b

Fig. 4. Test stand for probe calibration: a – the scheme for measuring the microwave electromagnetic field using the SPEKTRAN spectrum analyzer, and b – the scheme for measuring the microwave electromagnetic field using the developed measuring probe, where 1 – horn emitter of microwave electromagnetic waves; 2 – measuring microwave generator G4-80; 3 – spectrum analyzer SPEKTRAN; 4 – measuring probe; 5 – digital oscilloscope

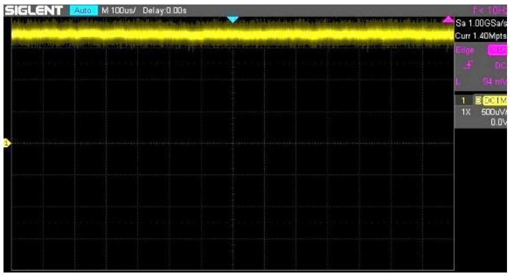
The measurements were carried out in the mode of continuous generation and pulse modulated generation with a frequency of 1 kHz and a duty cycle of 50%.

The distance from the horn both to the SPEKTRAN 3 spectrum analyzer antenna (see Fig. 4,a) and to the probe antenna (see Fig. 4,b) was 50 cm. The probe output was loaded with a resistor of 50 Ω.

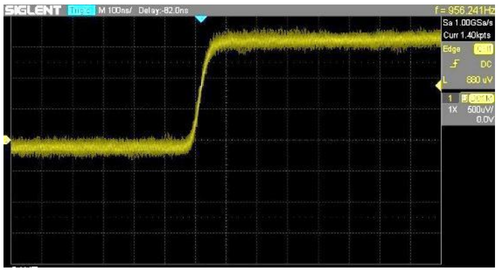
Fig. 5. The display of the spectrum analyzer SPEKTRAN, where 1 are metering values in units of microwave power density mW/m^2, 2 are metering values in units of electric field strength V/m at a frequency of 2.8 GHz

As can be seen from the metering values of the SPECTRAN device in Fig. 5 at the maximum microwave power of the generator at a distance of 50 cm from the horn to the antenna, the spectrum of the SPECTRAN analyzer is 40.08 mW/m^2, and the electric field strength is 3.886 V/m.

Fig. 6 shows the results of measuring the signal from the probe with a digital oscilloscope, in two modes of operation of the G4-80 generator – a) continuous generation mode and – b) pulsed mode at the maximum signal amplitude.



a



b

Fig. 6. Oscillograms of the signal from the output of the measuring probe measured in the modes – a – continuous and b – pulsed microwave power generation, with an oscilloscope sensitivity of 500 μV/div and a sweep of 100 ns

As can be seen from Fig. 6 at the maximum microwave power of the generator at a distance of 50 cm from the horn to the probe antenna, the amplitude of the signal from the probe was 1.5 mV, both in the continuous generation mode and in the pulsed generation mode. The pulse front of the detected signal is less than 100 ns.

Based on the results of measurements made using the SPECTRAN device and the developed probe, it can be concluded that with an output signal from the probe of 1 mV, the electric field at the measurement point will be 2.6 V/m, and the microwave power density will be 26 mW/m^2.

CONCLUSIONS

To measure the longitudinal component of the electric field in a wakefield electron accelerator, a probe was developed and manufactured.

A technique for calibrating the probe was developed and a measuring stand was assembled.

The results of the calibration showed that at a probe output voltage of 1 mV, the electric field strength at the measurement point should be – 2.6 V/m.

The measurement results showed that the transient response of the probe is no worse than 100 ns, which, with a microwave modulated pulse duration of 2 μs, is quite sufficient for correct measurements.

ACKNOWLEDGEMENTS

The study is supported by NAS of Ukraine Program "Plasma physics and plasma electronics: basic researches and applications", Project P-4/60-2022.

REFERENCES

1. R.D. Ruth, A.W. Chao, P.L. Morton, and P.B. Wilson. A plasma wake field accelerator // *Particle Accelerators*. 1985, v. 17, № 3-4, p. 171-189.

2. G.A. Voss and T. Weiland. *Particle acceleration by wakefields:* Report No. DESY M-82-10, 1982.
3. B. Jiang, C. Jing, P. Schoessow, J. Power, and W. Gai. Formation of a novel shaped bunch to enhance transformer ratio in collinear wakefield accelerators // *Phys. Rev. ST Accel. Beams*. 2011, v. 15, p. 011301.
4. C. Jing, J.G. Power, M. Conde, et al. Increasing the transformer ratio at the Argonne wakefield accelerator // *Phys. Rev. ST Accel. Beams*. 2011, v. 14, 021302.
5. K.V. Galaydych, G.V. Sotnikov, I.N. Onishchenko. Wakefield excitation by a ramped electron bunch train in a plasma-dielectric waveguide // *Problems of Atomic Science and Technology. Series "Plasma Electronics and New Methods Acceleration"*. 2021, No 4(134), p. 55-59.
6. G.V. Sotnikov, T.C. Marshall, S.V. Shchelkunov, A. Didenko, and J. L. Hirshfield. Two-Channel Rectangular Dielectric Wake Field Accelerator Structure Experiment // *AIP Conference Proceedings*. 2009, v. 1086, p. 415. https://doi.org/10.1063/1.3080943.
7. G.V. Sotnikov, T.C. Marshall, and J.L. Hirshfield. Coaxial two-channel high-gradient dielectric wakefield accelerator // *Phys. Rev. ST Accel. Beams*. 2009, v. 12, p. 061302.
8. G.V. Sotnikov, and T.C. Marshall. Improved ramped bunch train to increase the transformer ratio of a two-channel multimode dielectric wakefield accelerator // *Phys. Rev. ST Accel. Beams*. 2011, v. 14, p. 031302.
9. D. Yu. Zaleskyi, G.V. Sotnikov. Parameters of two-channel five-zone dielectric structure for experiments on wakefield acceleration in KIPT // *Problems of Atomic Science and Technology. Series "Plasma Physics"*. 2018, No 6(118), p. 168-171.
10. I.N. Onishchenko, V.A. Kiselev, A.F. Linnik, et al. Investigations of the concept of a multibunch dielectric wakefield accelerator // *Nucl. Instrum. Meth. A.* 2016, v. 829, p. 199-205.
11. G.P. Berezina, A.F. Linnik, V.I. Maslov, et al. Transformation ratio increase at wakefields excitation in the dielectric structure by a shaped sequence of relativistic electron bunches // *Problems of Atomic Science and Technology.* 2016, No 3(103), p. 69-73.
12. https://standart-pribor.com.ua/product/2a201a-diod-svch/
13. https://elaso.com.ua/products/0-kontrolno-izmeritelnye-pribory/10-generatory-signalov/name/8533-g4-80

Article received 03.04.2023

ЗОНД ДЛЯ ВИМІРЮВАННЯ ПОВЗДОВЖНЬОЇ СКЛАДОВОЇ ЕЛЕКТРИЧНОГО ПОЛЯ В ДІЕЛЕКТРИЧНОМУ КІЛЬВАТЕРНОМУ ПРИСКОРЮВАЧІ

Д.Ю. Залеський, В.І. Приступа, В.С. Ус, Г.В. Сотніков

Для проведення експериментів щодо визначення амплітуди електричного поля та коефіцієнта трансформації в кільватерному прискорювачі на основі діелектричних структур, що збуджуються електронними згустками електронного прискорювача «Алмаз-2», був розроблений та виготовлений зонд. Зонд складається з антени ¼ довжини хвилі (27 мм) та схеми детектування на базі НВЧ-діода 2А201А. Для калібрування зонда було зібрано вимірювальний стенд, що складається з НВЧ-генератора та рупорного випромінювача. Як вимірювач НВЧ-потужності використовувався спектр-аналізатор SPEKTRAN (Німеччина), а як вимірювач детектованого сигналу з зонда – цифровий осцилограф. Результати вимірювань, які виконані на стенді, показують, що при потужності НВЧ-випромінювання 26 мВт/м^2 і напруженості електричного НВЧ-поля 2,6 В/м вихідний сигнал у точці вимірювання із зонда становить 1 мВ.