IOP Conf. Series: Journal of Physics: Conf. Series **830** (2017) 012044 doi:10.1088/1742-6596/830/1/012044

PIN-diode diagnostics of pulsed electron beam for high repetition rate mode

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Abstract. This work describes the operating principle and test results of the diagnostics for measuring the pulsed electron beam parameters under repetitive operation mode. The diagnostics is based on a PIN-diode, which is used as a bremsstrahlung detector. The signal from a PIN-diode was converted to a pseudo constant voltage signal which can be measured by a conventional voltmeter. Then the signal acquired by the voltmeter was compared with a reference signal indicating the normal operating regime of the accelerator, thus information about the shot-to-shot reproducibility of the electron beam parameters was given. The system was developed and tested for the ASTRA-M accelerator with the following operating parameters: 470 kV accelerating voltage, 120 ns beam duration and up to 50 pulses per second repetition rate.

1. Introduction

The field of electron beam applications is growing up rapidly [1, 2]. For applications, which require a high level of an average electron beam power [2, 3], the continuous and the linear electron accelerators are usually used. The pulsed accelerators are used for relatively lower average power applications and, meanwhile, allow for a compact facility size [4, 5]. As a rule, for pulsed systems, a higher pulse repetition rate means a higher productivity. The ASTRA-M pulsed electron accelerator [6] uses the 40 pulses per second (pps) continuous operation mode for the purpose of wastewater treatment, as well as single pulses for research applications [7 - 9]. The ASTRA-M accelerator generates electron beams with the kinetic energy of electrons of up to 470 keV and the pulse width of 120 ns at half maximum [6]. During the use of accelerator for some applications, the electron beam parameters cannot be measured directly, thus, the accelerating voltage and the total diode current are used for controlling the electron beam parameters. However, such indirect information about the beam parameters is not enough to ensure an accurate operation of the accelerator, especially when the electron beam is ejected into the atmosphere. An alternative approach to control the electron beam parameters is measuring the bremsstrahlung radiation, which occurs when the electron beam interacts with a matter. The bremsstrahlung intensity for the same measurement geometry depends on the electron beam parameters. One of the most convenient ways to measure the bremsstrahlung with a high time resolution is to use PIN-diodes [10, 11]. However, when a great number of pulses, e.g. 10^6 shots, need to be done every day, it is impossible for the operator of the accelerator to check every pulse. To control the bremsstrahlung pulses in the automatic mode, a measurement system with a nanosecond resolution and the complicated algorithms for signal processing are required. An alternative simplified method with a compact schematic, high-reliability, and a satisfactory performance is described in this paper.

2. Experimental setup

The PIN-diode based system was built to control parameters of the electron beam inside the reaction chamber for a wastewater treatment [6]. Figure 1 shows the schematic of the reaction chamber with the PIN-diode detector installed. The exit window of the ASTRA-M accelerator is located at the top of the reaction chamber (pos. 7 in Fig. 1). The PIN-diode detector was installed in an area where the most intense radiation occurs (pos. 6 in Fig.1).

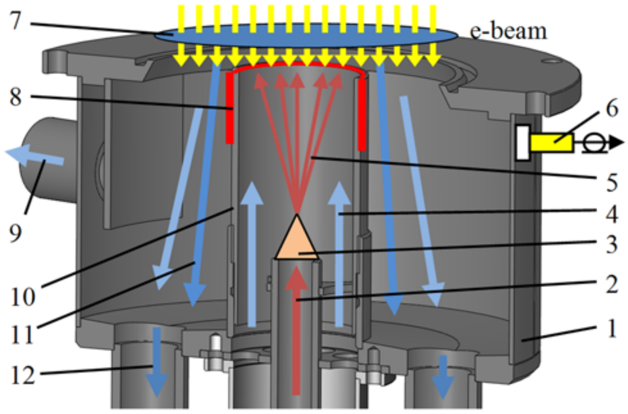

Figure 1. Schematic of the PIN-diode installation: 1 – stainless steel housing of the reaction chamber; 2 – water supply; 3 – sprayer; 4 – atmospheric air flow; 5 – sprayed water; 6 – isolated PIN-diode detector; 7 – exit window of the accelerator; 8 – area of an intensive bremsstrahlung generation; 9 – output air flow; 10 – divider; 11 – processed water; 12 – output water flow.

The electrical circuit for the PIN-diode diagnostics is shown in Figure 2. The measuring scheme consists of two main blocks. The detecting module converts a current signal of the PIN-diode detector to a voltage signal, which is further measured by an oscilloscope. The integrating circuit is used for a repetitive operation mode only and will be described below.

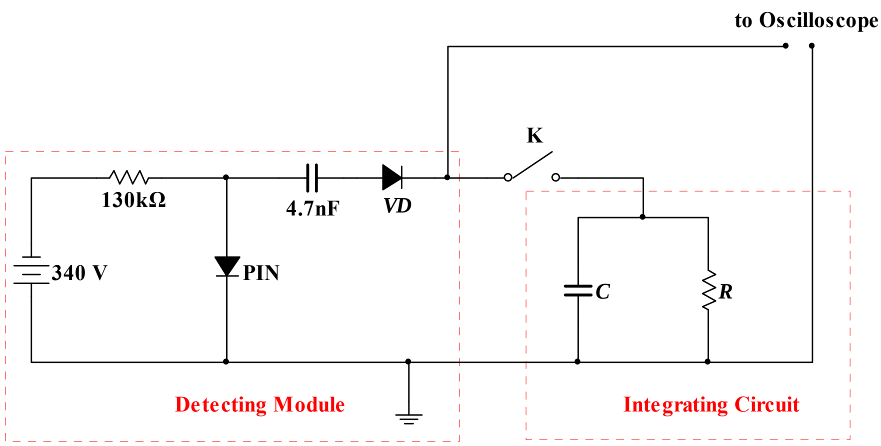

Figure 2 Electrical circuit of the PIN-diode diagnostics.

The basic principle of the operation of the PIN-diode bremsstrahlung detector can be described as follows. When the intrinsic zone of the PIN-diode is irradiated by the bremsstrahlung photons, the electron-hole pairs are excited. The generated charges are driven by the external electrical field and then a pulsed signal is generated. The described design (Fig. 2) was assembled in a single case and fixed in the accelerator base. The signals from the detecting module were transmitted to an oscilloscope in the operator room using 8-m long cables.

3. Results and discussion

Figure 3 shows the waveforms of the accelerating voltage, the electron beam current measured by a capacitive voltage divider and Faraday cup, respectively. The low-load operation regime of the accelerator has been chosen for tests to monitor the lowest value of the electron beam current. Such regime is accompanied by a delay of 150 ns between the emission current and the post pulses of voltage due to the mismatching of the generator and the diode impedances. Figure 3 also shows the calculated waveform of the electron beam power and a signal obtained from a PIN diode detector. The output voltage signal of the detecting module is proportional to the calculated electron beam power. The time resolution of the PIN-diode measurement system, typically of about 10 ns under the biased mode, satisfies the control function for the pulses of the hundreds nanosecond duration with a reasonable accuracy.

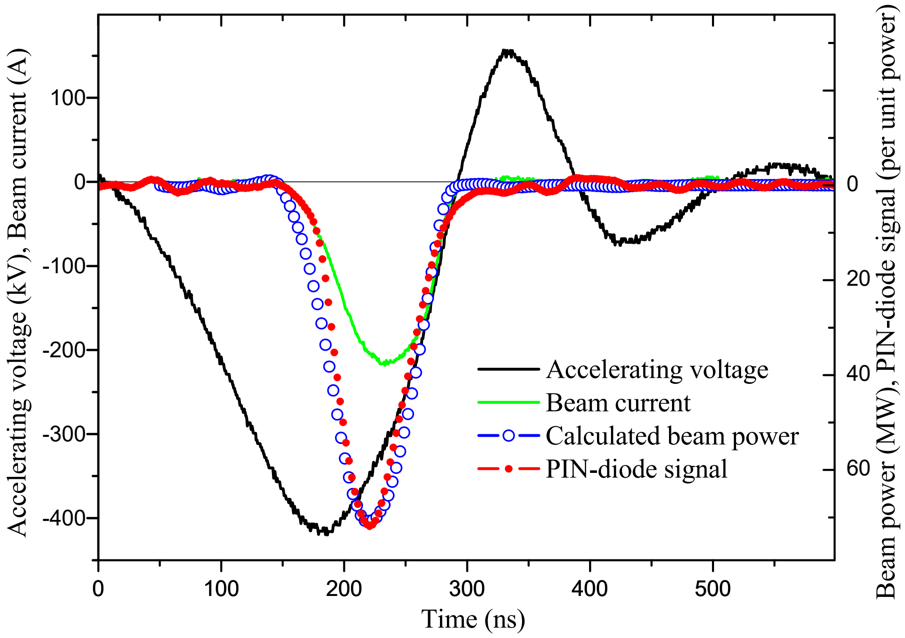

Figure 3 Typical waveforms of the accelerating voltage, electron beam current and a signal from the PIN-diode detector compared with the calculated beam power.

When the switch *K* is closing, the signal at the output of the detecting module charges the capacitance *C* of the integrating circuit (see Fig. 2). It is necessary to use the diode *VD* to avoid the influence of the detecting module on the discharge parameters of the integrating circuit. A discharge time constant of the integrating circuit can be adjusted by changing the capacitance *C* and the resistance *R* (Fig. 2). The parameters of the cables and the oscilloscope should also be taken into account.

The optimal value of the discharge time constant was chosen in accordance with the pulse repetition rate of the electron beam during repetitive operation of the accelerator. Figure 4 explains the principle of the signal formation at the output of the integrating circuit (U_{out}) for a chosen discharge time constant. The fluctuations of the output voltage (U_{out}) depend on the ratio of the discharge time constant and the time interval between two pulses. The range for a normal operation of the accelerator was chosen to fit in between the maximum and the minimum values of U_{out} (Fig. 4c).

The voltage pulses of a milliseconds scale on every accelerator shot (Fig. 4) were converted into a digital form. Then, they were transmitted to a master controller of the accelerator for comparison with the value of a chosen operation range. This procedure has been automated for the continuous operation of the accelerator.

There are two undesirable incidents which should be controlled during accelerator running in the high repetition mode. These incidents can be easily detected using the developed diagnostics. The first one is the missing of one electron beam pulse, in the case of which U_{out} will drop down significantly, as it is shown in Figure 4 (c, 1). The reasons of the missing of the beam pulse can be critical for a further operation, for example, it can indicate the shortcut of the electron diode, so the accelerator operation should be stopped immediately. The second is when U_{out} slightly exceeds the operation range as shown in Figure 4 (c, 2). If it happens periodically, it means that the electron beam parameters are gradually changing. The shot-to-shot variation of the electron beam parameters during the repetitive operation occurs due to, for example, the running-in of the cathode at the beginning of the operation and the degradation of the emission properties at its end. The operation range can be varied for different operation modes.

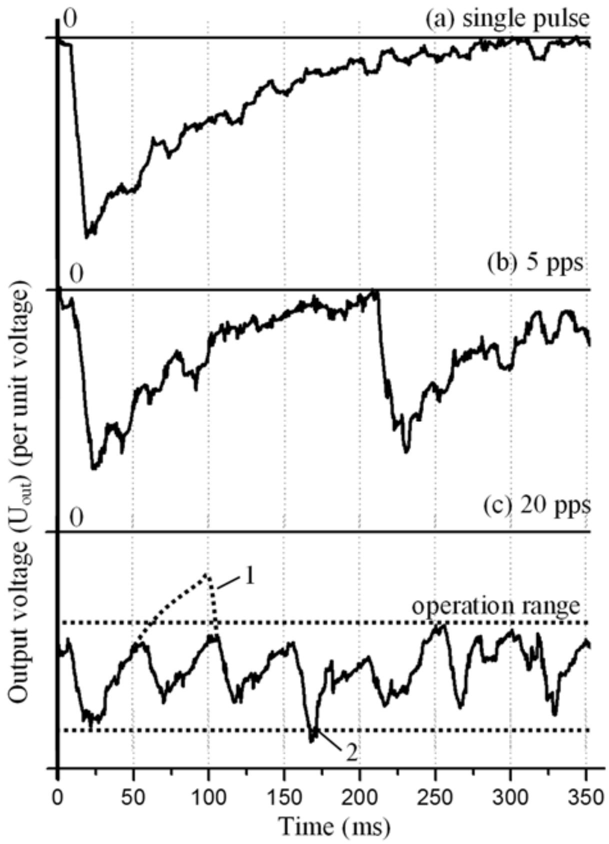

Figure 4 Typical waveforms of the signal at the output of integrating circuit for different pulse repetition rate of the accelerator.

4. Conclusion

The high-frequency electron beam diagnostics for the repetitive pulse electron accelerator has been developed and tested. The diagnostics allows for an automated control of the electron beam parameters by means of measurement and analysis of the bremsstrahlung pulses (with a high repetition rate). The diagnostics can be used to detect both the events of missing pulses in a pulse train and slowly changing parameters of the generated electron beam in the continuous mode.

Acknowledgments
The authors would like to thank Tomsk Polytechnic University for technical support in performing experiments. This work was partially supported by RFBR grant No 16-32-00287mol_a. Xiao Yu would like to thank China Scholarship Council (Grant No.201206020099) for support to visit Tomsk Polytechnic University in Russia and contribute to this work.

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