MEASUREMENTS OF BEAM CURRENT FOR RELATIVISTIC ELECTRONS IN AIR BY CURRENT TRANSFORMERS

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Abstract

The investigation of current transformers for measurements of beam current for relativistic electrons in air is presented in this report. The industrial CW electron accelerator “Rhodotron” (E = 5 MeV, I = 1-16 mA) was used for experiments. The effect of scanning electron beam allows pulsed current transformers to be used for measurements of beam current. The comparison of beam current measurements in air and vacuum conditions is given. Analysis of errors is discussed.

1 INTRODUCTION

Measurement of the beam current of a relativistic electron beams (REBs) is very important from a practical aspect [1]. The standard approach requires vacuum conditions, and is not a simple task for industrial electron accelerators. The high beam power leads to problems such as heating of diagnostic equipment, large system geometries, and high cost and low reliablity due to radiation resistance of elements [2].

Thus we see that searching for new approaches and methods for measurement of beam current beyond the output window is very important for industrial applications of electron accelerators. Such an attempt to measure REB current in air from a scanning beam is presented in this report.

2 PULSED MODE OF CURRENT FOR SCANNING ELECTRON ACCELERATORS

The scanning mode of the electron beam beyond the output window leads to a pulsed regime of irradiation of sample or product, so the beam current from the collector is also pulsed in character; [3] see Figure 1. The pulsed mode of scanning electron beams allows using current transformers for measurements of beam current.

3. PROPAGATION OF REBS IN AIR

Propagation of REBs in air involves these main physical processes:

- ionization of air molecule, forming air plasma;
- heating of air and air plasma;
- resonance oscillation of air plasma;
- production of ozone.

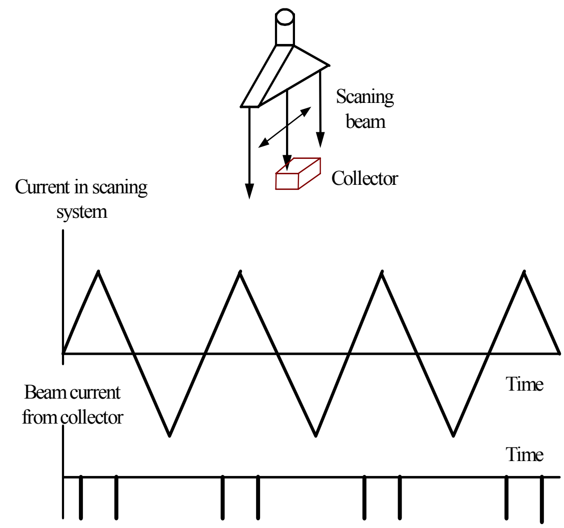

Figure 1. Pulsed mode of scanning electron beam.

During propagation of REBs in air we have radiation and ionization losses. According to the classical consideration the relationship between radiation and ionization loses is:

$$(dE/dz)_{rad} \;/\; (dE/dZ)_{ioniz} \sim EZ/800, \qquad (1)$$

where E is the energy of the electrons [MeV] and Z is the charge of the nucleus of the atom.

Analysis of ionization losses and computer simulation shows that, for the case of electrons with kinetic energy 5–10 MeV in air, ionization loss is at a low level until 4 m or so of beam propagation.

Sensors that probe the electrical conductivity of plasma were used for diagnostics of ionised air (air plasma). The scanning electron beam allows pulsed charge and discharge of a capacitor made up of thin Ti foils. The results showed low conductivity, with a resistance on the level of 100 – 300 kilohms. The current from plasma electrons was very small, indicating low ionization and thus pointing to the possibility of success for this method of measuring beam current.

Detail measurements of time structure of the beam current (by microbunch) showed the erosion of the fronts of micropulses. The same results were reported for high current electron beams in [4].

The measurements of the current of a powerful beam presents, among other problems, heating of elements of system, and also challenges their radiation resistance. The standard solution is a collimator with a small aperture [5]. The thickness of collimator needed is determined by absorption of electrons and X-rays.

The electrical circuit for beam current measurements in air is presented in Figure 2.

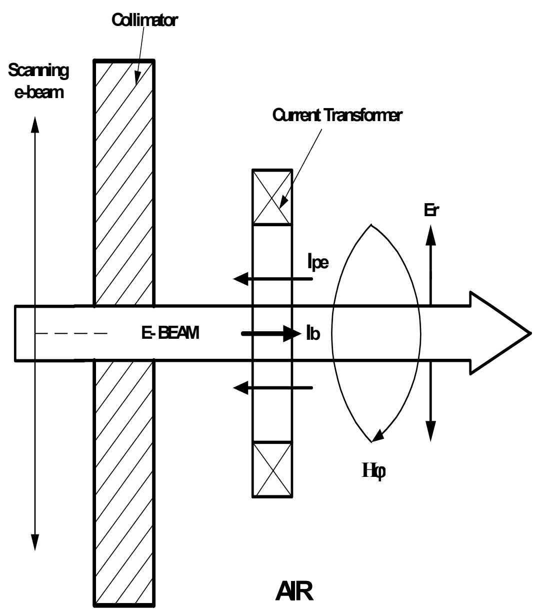

Figure 2: Electrical circuit for beam current measurements by current transformer in air: I_b is beam current and I_{pe} is current of plasma electrons.

4. EXPERIMENTAL

The CW “Rhodotron” Electron Accelerator [6] made by IBA (Belgium) [7] was used. It has these main parameters:

- kinetic energy of electrons 5 MeV
- beam current 1- 16 mA
- frequency of RF accelerating structure 107.5 MHz
- Repetition rate of scanning electron beam 70 - 100 Hz

A block diagram of the experiments is given in Figure 3.

Two types of fast current transformers, FCT-=55 and FCT –082, from BERGOZ Instrumentation and GMW, [8] were used.

The thickness of collimator was calculated for full absorption of electron and controlled by film dosimeters. The collimator was made from copper, and stainless steel.

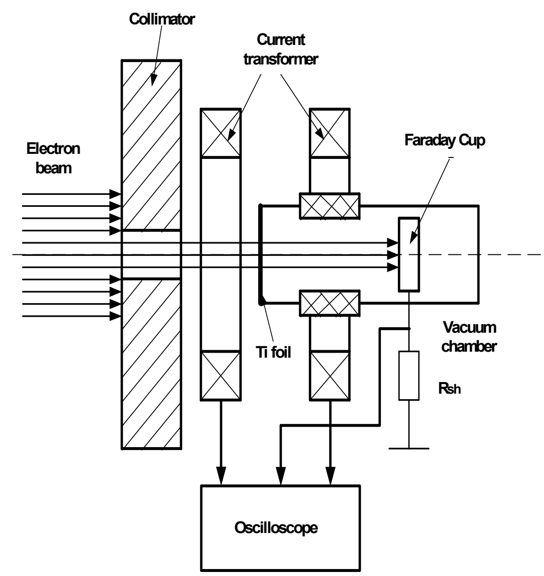

Figure 3: Block diagram of experiments.

5. RESULTS AND DISCUSSION

The measurements of beam current for 1-16 mA show good correlation between beam current in vacuum conditions and in air. The small cross section for ionization by the REB allows this.

Typical oscillograms from current transformers in air (top) and in vacuum (middle), and from a Faraday cup in vacuum (bottom), are presented in Figure 4.

The influence of current from plasma electrons is very small. The beam’s own electrical and magnetic fields are also very small, a key consideration when making current measurements of mA range. The time parameters of scanning modes also have small influence on the electrical field induced in front of the beam current.

6. CONCLUSIONS

The results of this study let us conclude that current measurements of relativistic electron beams in air from a scanning electron accelerator have low error, and compare well with measurements in vacuum.

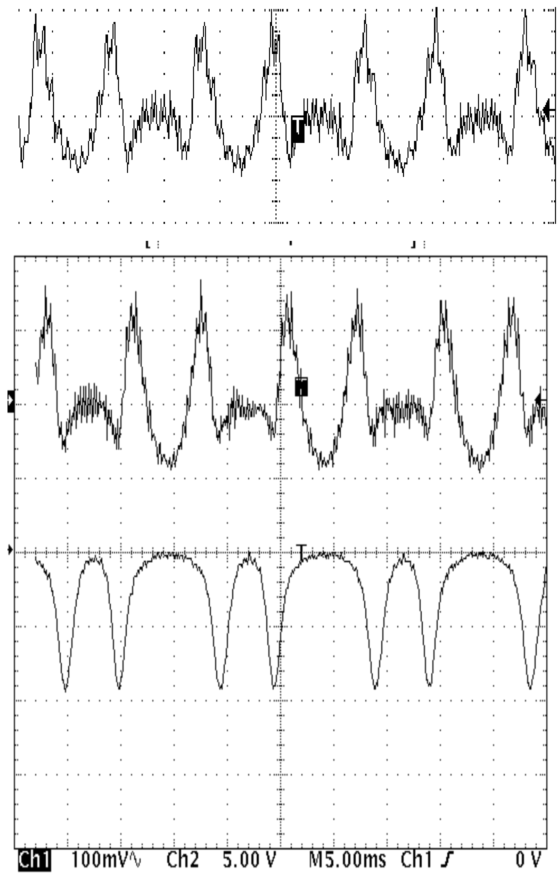

Figure 4: Typical oscillograms from current transformers in air (top) and in vacuum (middle), and from a Faraday cup in vacuum (bottom).

7. ACKNOWLEDGEMENT

I would like say thank you for help in these experiments to Robert Langley, Ivan Korenev and Jerry Kriebel, and to Frank Rich for help in this work as well.

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