BEAM POWER CALIBRATION SYSTEM FOR INDUSTRIAL ELECTRON ACCELERATORS*

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Abstract

Modern electron accelerators intended for commercial application provide a particle energy up to 10 MeV and a beam power up to ≥ 100 kW. Such a beam is ejected into the air using a scanning system. The measuring channel has been designed around a flow-type total-absorption calorimeter for beam calibration with respect to the energy flux. The processes of beam interaction with a primary measuring converter (a water-cooled beam absorber of peculiar geometry) have previously been investigated through the use of computer simulation. The measuring circuit of the channel is made as a stand-alone module with a liquid-crystal display and a control keypad. It serves to measure the temperature at both the inlet and outlet of the absorber, and also to determine the water flow rate. The absorbed power is first determined from the measured parameters, and then is displayed and stored in the channel memory using the appropriate software. The process is carried out both in the off-line mode and under the control of an external PC via a serial RS-232 interface.

INTRODUCTION

The measuring channel consists of a sensor (beam absorber) and a measuring circuit. By its type of design, the sensor corresponds to a combined calorimeter - Faraday cup unit [1]. It provides a possibility of measuring simultaneously the power and average current of the beam in order to estimate the average electron energy.

The geometry of the sensor is given in Fig.1.

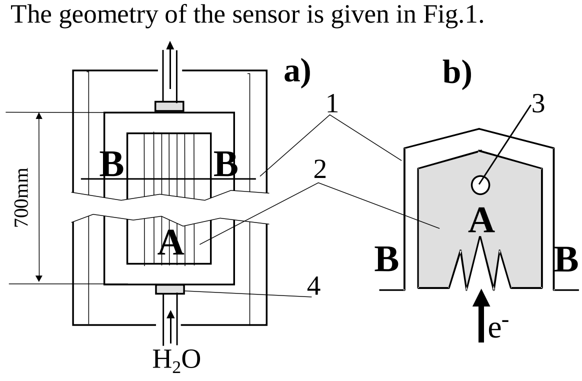

Figure 1: The sensor: a) side view of the beam; b) cross section.

It embraces the casing 1 and absorber 2. Running water cools the absorber through hole 3. The presence of ceramic insulators 4 at the sites of water delivery and tapping provides galvanic insulation of the absorber relative to the grounded casing. Owing to this, the sensor can also be used as a free-air Faraday cup.

The beam power P is determined by measuring the steady-state difference between water temperatures at the outlet and inlet of the absorber (T_2 - T_1) exposed to the scanned electron beam at a water flow rate N. In this case, the following expression is used

$$P=k_P^{-1}C\rho\,(T_2-T_1)\,N, \qquad (1)$$

where C is the water heat capacity, ρ is the water density, k_p is the absorbed power coefficient dependent on the beam parameters

$$k_P=P_{ab}/P, \qquad (2)$$

where P_{ab} is the radiation power absorbed in the sensitive area of the sensor A.

Functionally, the measuring channel includes the following modules (see Fig. 2):

- absorber A;
- module for measuring analog signals (AM);
- control module (CM);
- temperature sensors (thermoresistors T_1, T_2);
- flowmeter (F);
- power supply (PS).

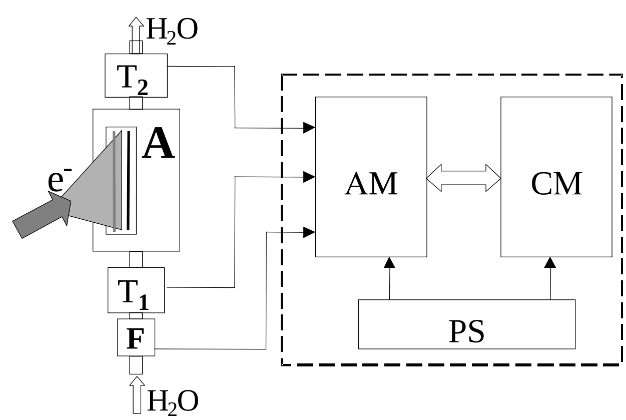

Figure 2: The functional scheme of the measuring channel.

BEAM-SENSOR INTERACTION SIMULATION

The influence of electron flux parameters (energy, transverse dimension, scanning length) on the absorption coefficients of power k_P and charge k_Q was determined by means of computer simulation with the use of the program system PENELOPE. The results of simulation for the monochromatic beam, and also, with due regard for the real beam spectrum from the accelerator LU-10 [2] are presented in Figs. 3 and 4.

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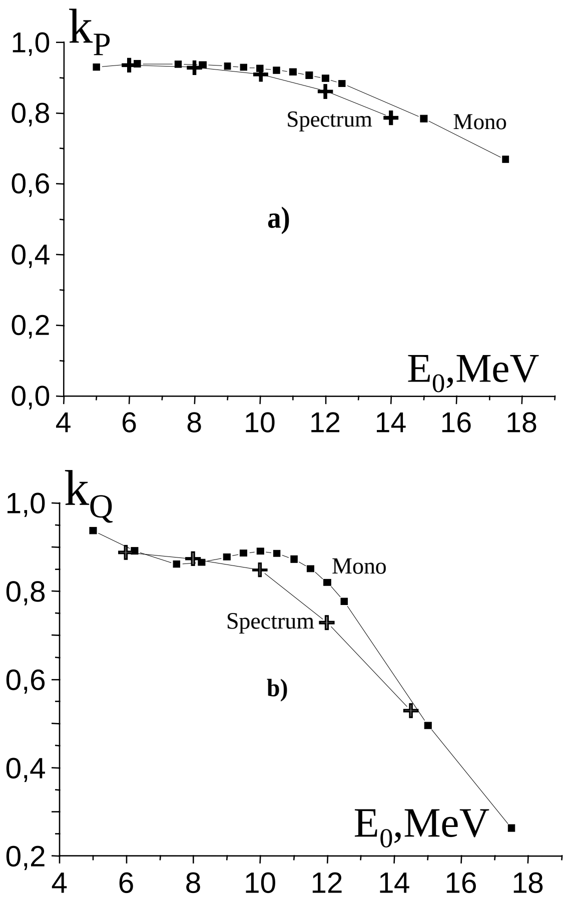

Figure 3: Power (a) and charge (b) absorption coefficients versus electron energy E_0.

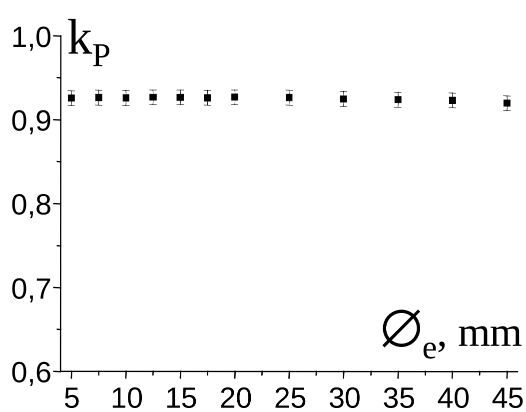

Figure 4: Power absorption coefficient k_P versus beam diameter (E_0 = 10 MeV).

HARDWARE DESIGN

The module of analog signals measuring (Fig.5) consists of:

- 2 channels for voltage measurements;
- 2 direct current sources (CS);
- frequency measuring channel (FM);
- analog-to-digital converter (ADC);
- optoisolator (OI).

The main functions of the AM are as follows:

- conversion of analog signals acting with the measuring circuits to a digital code by means of the analog-to-digital converter;
- feed of thermal probes with a direct current from the current source;
- conversion of a sine-wave signal from the flowmeter into a sequence digital pulses.

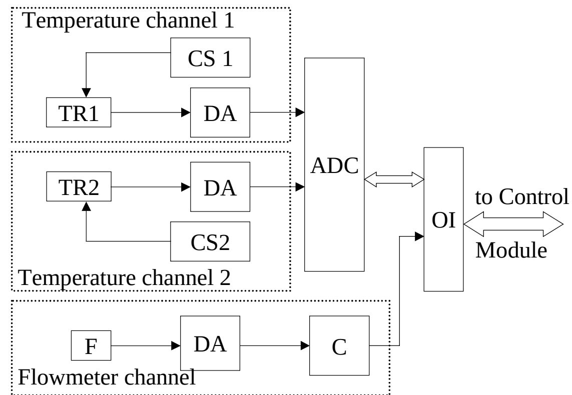

Figure. 5. The diagram of the analogy module.

The control module CM (Fig. 6) consists of :
- microcontroller (MC);
- peripheral data memory (RAM);
- programs memory (ROM);
- liquid-crystal display unit (LCD);
- control keypad (K);
- level translator of the serial interface RS-232 (LT).

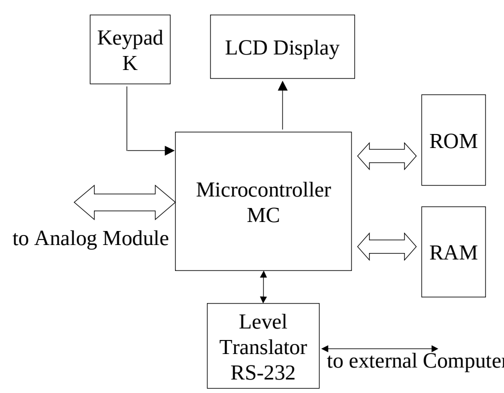

Figure 6: The diagram of the control module.

MEASURING PROCEDURE

Temperature

The platinum thermoresistors (TR) with the known transformation characteristic and calibration coefficients are used as temperature sensors.

The transformation characteristic of the TR used in the measurements is described by the following expression

$$R=R_0\ (1+A\cdot t+B\cdot t^2), \qquad (3)$$

where R is the TR resistance at temperature t; R_0 is the TR resistance at $t=0^{\circ}C$; A, B are the calibration coefficients for the given TR.

The TR is connected to the measuring channel by means of a four-wire circuit. Two conductors are used for energizing the TR by a direct current of 300 μA from a dc source, and the other two conductors are used to measure the potential drop across the TR. This connection circuit provides a full balancing of connecting wire resistance, as the TRs are placed at a sufficient distance (~50 m).

The voltage across the TR is amplified by a differential amplifier (DA) and is then transformed to a digital code by the ADC. The microcontroller reads out the digital code from the ADC output and performs the necessary calculations.

Flow rate

The industrial flow rate meter of turbine TPR-10 type is used as a flow sensor of cooling liquid. The flow rate is determined by measuring the frequency at the output of the flow sensor and recalculating it in terms of the flow rate (l/s). The measuring circuit includes a differential amplifier (DA) and a comparator (C). The sine wave signal from the flow sensor output, having a frequency of 100 to 1000 Hz and an amplitude of 20 to 50 mV, is amplified by the DA and is converted in the comparator into a sequence of digital pulses having a frequency equal to the frequency of the input signal. In the control module, the microcontroller measures the pulse repetition rate and converts it into units of the flow by the following expression:

$$N=F/B \quad (4)$$

where N is the flow rate of cooling liquid, F is the frequency at the output of the flow meter, B is the calibration coefficient.

OPERATION

The control of the mode of operation and the setting of measuring channel parameters are carried out with the help of control buttons by selecting the corresponding menu items displayed on the LCD.

The basic mode of operation consists in measuring the temperatures T1 (at the inlet) and T2 (at the outlet) of the absorber and the flow rate N of the cooling liquid. The measured T1, T2, N values are displayed on the LCD. Every 10 minutes, they get stored in the channel memory. The memory represents a nonvolatile SRAM with a feed from a lithium battery (chip DS1225AB of Dallas Semiconductor is used), that permits a long-term storage of measured data at a lack of line supply feed.

The memory of the measuring channel provides for a storage of about 600 measured TR1, TR2, F values. If necessary, the stored data may be transmitted to the external computer through the serial interface RS-232. From the beginning of the measurement, the timer is turned on for counting the duration of the measurement. The process of measuring is terminated with pressing the corresponding control button. In the course of measurement, on request of the external computer, the current values of the parameters measured and assigned may be transmitted to this computer.

All calibration coefficients for evaluations are stored in a nonvolatile memory of the microcontroller. The coefficients are assigned and changed by means of control buttons.

CONCLUSION

The present work has resulted in the creation of the measuring channel of electron radiation energy flow (power) with the following performance characteristics:

- electron energy, MeV 5...10;
- beam power, kW 0.5...100;
- temperature of cooling water, °C 0...100;
- flow rate of cooling water. l/s 0.12...0.60;
- range of electron beam scanning, cm up to 40;
- relative uncertainty of absorbed power measurements, % no more than 3.

The measuring circuit developed here can also be used for a continuous remote monitoring of absorbed radiation power in target devices of charged particle accelerators.

REFERENCES

[1] N.S. Shimanskaya, “Calorimetry of ionizing radiation” (1973), Moscow, Atomizdat publ., 328 (in Russian).

[2] K.I. Antipov, M.I. Ayzatsky, Yu.I. Akchurin, et al., Problems of Atomic Science and Technology. Series: Nuclear Physics Investigations 1 (2001) 40.