PULSED ELECTRON BEAM CURRENT AND FLUX MONITOR FOR THE RACE-TRACK MICROTRON

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Abstract

In electron irradiation experiments on the materials, a true current of the electron beam is to be known to calculate the electron fluence received by the sample. Therefore, a pulsed electron beam current and flux monitor alongwith electronic system for an electron accelerator called Race-Track Microtron has been designed and developed. The sensing device used was a ferrite core having suitable number of turns of copper wire wound around it, through which the electron beam was passed without loss in the intensity. With an appropriate developed electronic circuit, the instantaneous value of the induced voltage was measured which in turn provides value of the electron beam pulsed current. The total charge passed through the ferrite core per unit time was therefore recorded and an integrated value of the total charge in a given period could be derived. This system can be used to measure the electron flux in the range from 10^8 electron/cm^2 to 10^{16} electron/cm^2. Moreover, this system has been used successfully in a few electron irradiation experiments where the knowledge of the electron fluence received by the sample is required.

INTRODUCTION

Charged particle accelerators deliver particle beams either in the pulse or continuous mode. In case of continuous beam current, combination of Faraday cup and current meter can serve the purpose of flux measurement. However, in case of pulsed electron beam, analog meters are not sensitive to the small beam pulse width which may vary from nanoseconds to microseconds. In such cases, integration of the charge collected over a known period is required to obtain particle fluence received by the target.

The Microtron, an electron accelerator of the University of Pune is operated in a pulse mode with pulse width 2 μs and pulsating rate variable in the range 50 *pps* to 200 *pps*. The energy range can be set in two ranges 0.5 to 1 MeV and 6 to 8 MeV. For many applications, samples are exposed with electrons and fluence level (e$^-$/cm^2) is required to be known with accuracy around 1%. In this laboratory, for irradiation experiments, a Faraday cup is being used to measure electron fluence received by the sample. In this method, a conducting plate made of graphite or aluminum is placed in the beam path and the charge collected is measured by a current integrator. The thickness of the plate is kept much more than the range of the electrons. However, all the incident electron do not flow to the integrator because a fraction of the incident electron are lost due to backscattering. Secondary emitted electrons also reduce the charge reaching the current integrator. Due to this problem, it was difficult to estimate fluence level by measuring the charge received by the sample. To avoid this problem an induction type current transformer[1, 2, 3] and pulse integrator have been designed and fabricated to measure pulsed electron beam current and hence fluence received by a sample.

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DESIGN PRINCIPLE OF INDUCTION MONITOR

The measurement of pulse current using ferrite core is based on the principle of current transformer[2]. If ideal transformer conditions are assumed i.e. unity coupling without core losses and winding reactances much greater than respective primary and secondary resistances, the ratio of primary and secondary current inversely proportional to the turns ratio

$$\frac{i_p}{i_s} = \frac{N_s}{N_p} \quad (1)$$

Where i_p= primary current, i_s = secondary current, N_s = number of secondary turns, N_p= number of primary turns

In many cases, while the monitoring of primary current requires a voltage output from the secondary, the secondary current passes through load resistance R_L

$$V_s = i_p.\frac{N_p}{N_s}R_L \quad (2)$$

Considering N_s=50, N_p=1, then i_p=$i_s \times 50$

$$V_s = i_s R_L \therefore i_s = \frac{i_p}{50} \quad (3)$$

$$V_s = i_p \quad (4)$$

Relation 3 gives the magnitude of voltage V_s directly proportional to the primary beam current.

DESIGN PRINCIPLE OF THE CURRENT TRANSFORMER

The current monitor consists of a ferrite core type T45HP3 having OD 46 mm, ID 28.6 mm and width 13

ISBN 978-3-95450-119-9

mm. The permeability and the flux density of the ferrite core as supplied by the manufacture are 2300 Henries/m and 3900 Weber/m^2 respectively. Winding of nearly 1000 turns of fine insulated copper wire of 40 SWG are provided around the core. The measure value of the inductance and resistance of the core are 67 mH and 150 Ω respectively. When electron bunch passes through the ferrite ring, pulse voltage is generated directly proportional to the number of electrons in the bunch. The details of the system are shown in Fig. 1 and induced pulse is shown in Fig. 2.

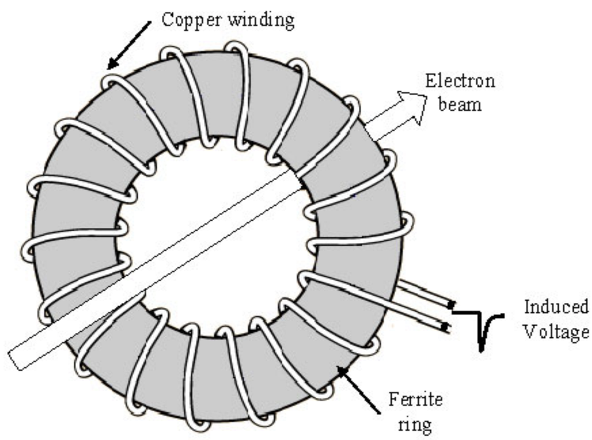

Figure 1: Induction beam current monitor.

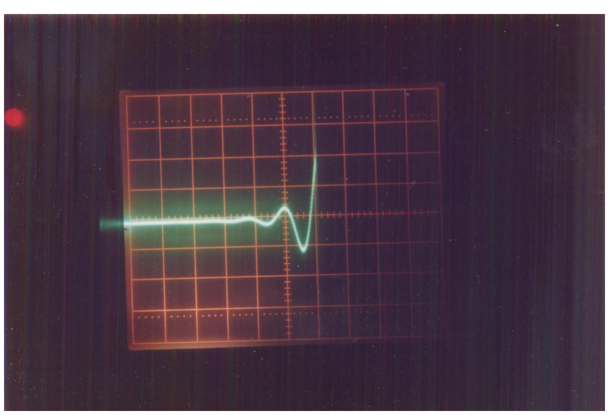

Figure 2: Photograph of induced pulse from induction monitor.

DESIGN OF THE PULSE INTEGRATOR

As the machine pulse beam current is available in the range 0.1 mA to 10 mA, the output voltage of the induction current monitor was small in amplitude. The pulse voltage was therefore amplified, integrated and then given to an A/D converter and subsequently to a counter [4, 5, 6, 7, 8, 9, 10]. Block diagram of the pulse integrator is shown in Fig. 3. A FET input preamplifier was used to amplify the induced current pulse. The amplifier output was fed to ultra low pulse peak detector. A damping resistor R is added in the peak detector to get recovery time variable in the range 0.01 to 0.1 second. DC voltage was given to an amplifier having variable gain. The amplifier DC output was fed to a 3 and $1/2$ digit A/D converter. An IC7107 is used to convert the analog signal into digital form, magnitude of which can be directly seen on display. Instantaneous value of the pulse current of the electron beam was therefore observed in terms of voltage.

Second stage of this circuit is an integrator. In this, a precession amplifier was used to increase the amplitude of the DC level, which was fed to a precision voltage to frequency converter. In this way, by measuring the frequency accurately, small variation in the input voltage and hence in pulse current can be observed. The IC used is type LM331 with 100kHz full scale ± 0.03 nonlinearity with overall conversion accuracy around 0.1 %. Output of this converter was fed to a multiplexed counter MM74C926 and its carry-out terminal was used to cascade the counters. On the display, the pulse current can be seen in digital form. The system was calibrated using a re-entrant type Faraday cup in which all the backscattered and secondary emitted electron were also collected. The total electron charge of the Faraday cup was measured by a separate commercially available current integrator having based level of 10^{-8} coulomb. Facilities such, presetting (1 sec to 10^4 sec) and present count (10^8) were also incorporated.

The time scaling factor was used to obtain a number of counts in a fixed time period. For this purpose, a 60 Hz frequency signal was obtained using a crystal oscillator type IC5369, having frequency 3.579 MHz. The 60 Hz signal is given to a decade counter type 7490. The circuits are used in different mode such that time period from 1 second to 10^4 seconds can be set. The outputs of the counters are connected to multiplexed switch and the selected time mode pulse is further used to gate and latch signals of the counter 74C926. In this way for any period from 1 second to hundreds of seconds, the total integrated charge value in terms of count can be obtained on the display.

PRECISION AUTO DOSE CONTROL SYSTEM

Further to control either irradiation period of electron dose, an additional feedback circuit was designed and fabricated. A separate counter was used to set the time using time scaling circuit and counts from V/F converter. The counter can be set to work either in time mode or in count mode through mode selector switch. The output of this counter is given to (A input) magnitude comparator which compares the data (B input) in counter with the data set on a thumbwheel BCD switch and generates three outputs $A < B, A > B$ and $A = B$. The IC74LS85 is used as a comparator in the present case to set the counts or time. The output of this comparator (A >B) is used to control mastercontrol triggering circuit of the modulators of the Microtron. After completion of the desired dose or irradiation time, the circuit puts off the trigger pulse generator.

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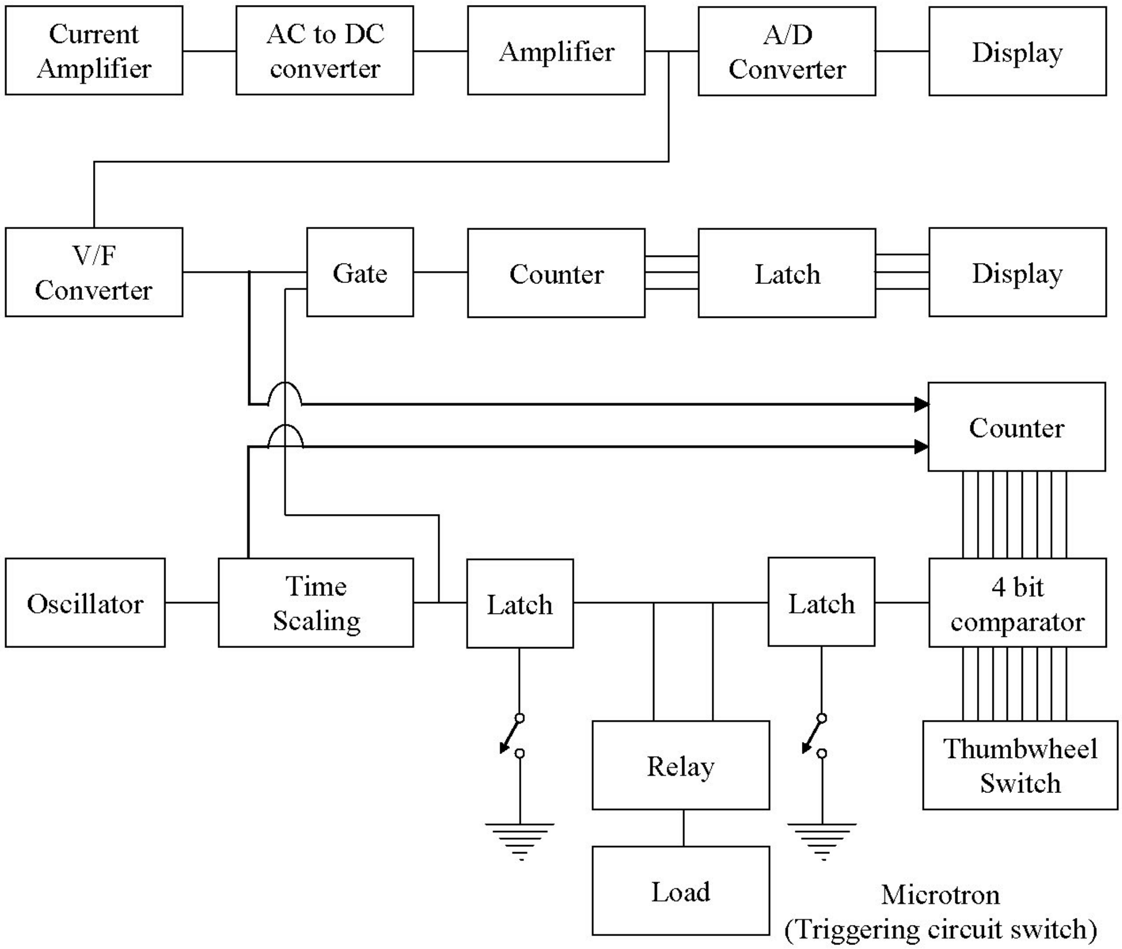

Figure 3: Block diagram of the pulse integrator used with ferrite induction current monitor.

In this way the electron beam is stopped from coming out of the machine.

CALIBRATION OF THE MONITOR

For the calibration of the induction current monitor, the re-entrant type Faraday cup as mentioned earlier was used to collect all the electrons of the beam. The output from this Farady cup was connected to charging condenser (tantalum, 1 μF) through 50 ohm co-axial cable and thus the integrated charge was measured by digital multimeter per unit time. Simultaneously, the signal from the induction monitor was fed to the pulse current integrator circuit made in this laboratory. The charge shown by the condenser was found to vary linearly with that shown by the present induction current integrator system. In this way, the pulse output of the induction monitor was calibrated in terms of the charge collected by the re-entrant Faraday cup calibration curve is shown in Fig. 4. It is observed from the figure that the flux increases with increase in the induced voltage.

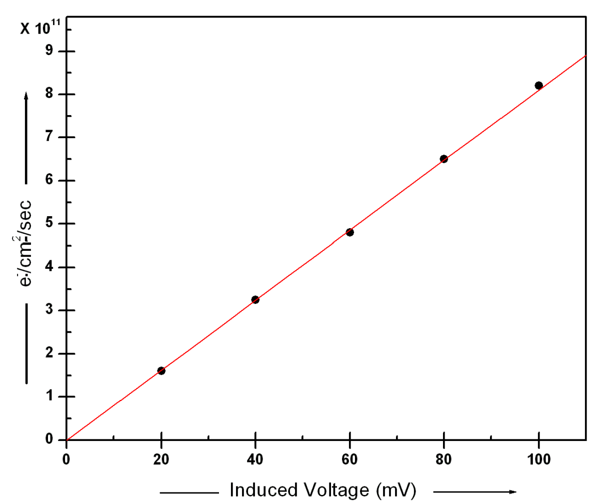

Figure 4: Calibration curve for the induced current monitor.

CONCLUSION

The current monitor consists of a ferrite core having OD 46 mm, ID 26.6 mm, width 13 mm and wound 1000 turns

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copper wire around it. When electron beam pass through the axis of the core, induced pulse generated which is directly proportional to the electron beam current. Further this pulse is given to the pulse integrator designed indigenously where the induced voltage pulse shows directly proportional to the flux of the electron beam.

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