AN ELECTRON BEAM PROFILE MONITOR FOR THE RACE-TRACK MICROTRON

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Abstract

In electron irradiation experiments on materials such as semiconductors, solar cells etc., an uniformity and the charge distribution in the electron beam is very important. Therefore, an electron beam current monitor and its electronic system have been designed and built to measure the distribution of a beam current either in the horizontal or vertical direction along with the beam dimensions. To obtain X-Y beam profile, a special type of Faraday Cup was designed which mainly consists of charge collecting electrodes made up of thin copper strips. Each strip having dimensions 0.5 mm wide, 4 mm thick and 20 mm long were fixed parallel to each other and separation between them was ∼ 0.5 mm. This multi electrode Faraday was mounted at the extraction port of the Race Track Microtron, where 1 MeV electron beam allowed to fall on it. The beam characterization in the form of current and uniformity were measured. The current from each strip were measured using an electronic circuit developed based on the multiplexing principle. The uniformity of the beam can be measured with an accuracy of 10%. The minimum and maximum dimensions which can be measured are 3 mm and 15 mm respectively.

INTRODUCTION

The MeV energy range electron beams have gained importance due to their applications in space technology and tailoring of device parameters. In several cases, approximate beam dimensions are required for controlled irradiation. The electron beam delivered by an electron accelerator called 'Race-Track Microtron' [1, 2] has pulse duration 1.6 s with repetition rate 50 PPS. Normally, at 1 MeV electron energy, the beam size obtained is around 6 mm × 4 mm. The beam dimension can further be increased by using scattering mechanism which is required to irradiate samples of large dimensions. The dimension of the beam may vary due to several factors such as variations in the magnetic field configuration, electron beam injection conditions, microwave cavity field, etc. Similarly, when the beam is passed through a bending magnet, the beam shape at the magnet exit is very much different from that at the magnet entrance. It is not always possible to know the uniformity of the electron beam using scintillator and therefore it was thought appropriate to design and fabricate a beam current monitor, which can provide intensity distribution over the beam area at different points along horizontal and vertical directions. Such a monitor along with an electronic system has been designed, fabricated and put into operation in the laboratory.

EXPERIMENT

Multielectrode Faraday Cup

This consist of charge collecting electrodes in the form of thin copper strips. Such fifteen numbers of copper strips, each of 0.5 mm wide, 4 mm thick and 20 mm long were fixed parallel to each other with adhesive on a Perspex sheet. The separation between two strip was kept ∼ 0.5 mm. The thickness of copper strip was calculated on the basis of range of 1 MeV electron in copper [3]. Therefore, the thickness of copper strip was chosen such that all the incident electron can stop inside the strip. The assembly was enclosed in an aluminum box having length 50 mm, width 50 mm and depth 30 mm. For charge measurement, each copper strip was connected to a BNC connector. Front side of the box is closed with a 50 μm aluminized mylar to provide shielding against external electrical noise. This beam profile measurement assembly was kept in the electron beam line and each of the BNC connector was connected to an electronic circuit specially made for this monitor.

Electronic System

An electronic circuitry [4, 5, 6, 7, 8, 9] has been designed, built and assembled to obtain visual display of the charge distribution of an electron beam on a CRO as well as on a digital display. The block diagram of the circuit used for this work is shown in Figure 1, whereas the circuit details are shown in Figure 2. Eight strips of the beam current monitor were connected to multiplexer of type 4051B. This multiplexer is 8 to 1 type multiplexer, which has a facility of eight independent input bits or channels, three control bits and one output bit. This is also sometimes called as data selector, because output bit is depends on the input data bit that is selected. For instance, if the control signal ABC is 000, then the information from the first copper strip of the Faraday cup is transmitted to the output. However, if the control signal ABC is change to 111, then the information from the eight strips is transmitted to the output. From the circuit one can see that the multiplexer can be operated in the mode of transmit information, which is available at one of the eight inputs to the corresponding output terminals, sequence of which can be preset through a programme
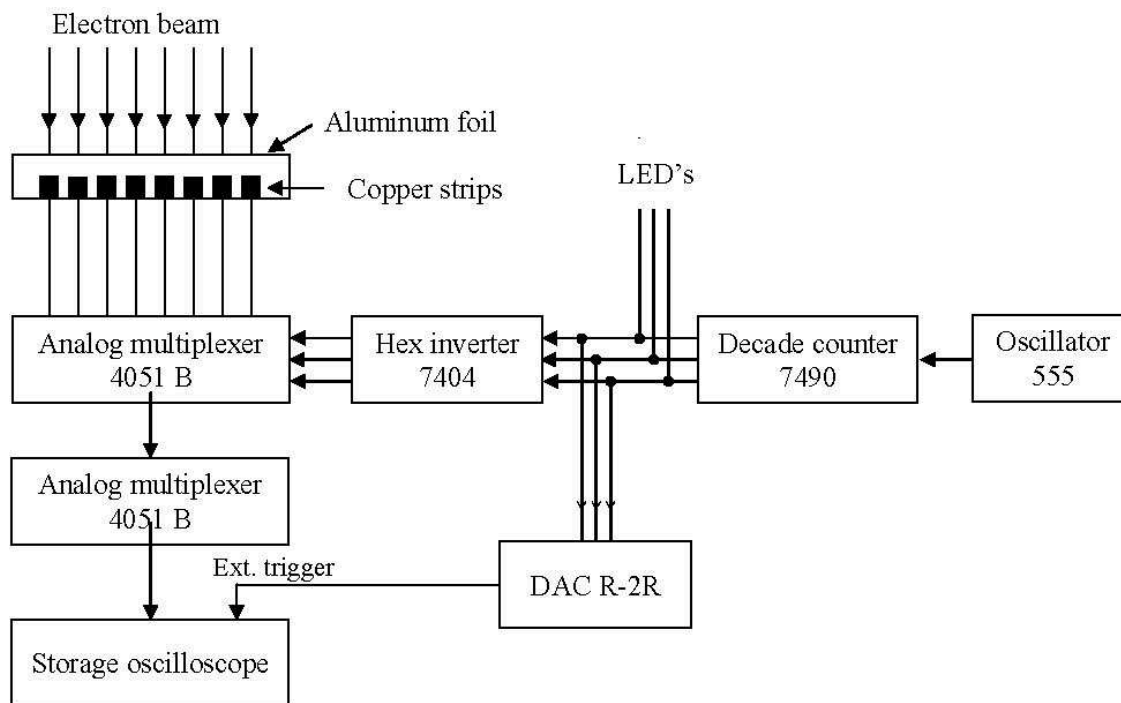
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Figure 1: Block diagram of the beam profile monitor with electronic system.

fed to its control signal. In this case, the control signal programme is made in such a way that, in sequence, the input information from the first to eight strips is transmitted to the output terminal. The control signals to the multiplexer is provided by using decade counter IC 7490, which was used in mod-8 counter system. The counter forms a three flip-flop in this mode and has eight discrete states. It counts through a street binary sequence from 000 upto 111 and then back to 000. This decade counter is driven by a simple clock generator using 555 timer, a TTL compatible integrated circuit, that can be used as an oscillator to provide a clock waveforms. It is basically a switching circuit that has two distinct output levels. As a result, the circuit oscillates and the output is periodic, rectangular waveforms. The circuit is said to astable mode. In the present circuit, the frequencies of the oscillator as well as the duty cycle are accurately controlled by two external resistor (RA and RB) and a single timing capacitor (C). The time varies from a few milliseconds to a few seconds and duty cycle varies from 10 % to 90 %. To match the output of the decade counter IC7490with multiplexer control signal, an inverter type IC7404 was used.

At the time of operation, the working of decade counter and identification of the control signal was also monitored through light emitting diodes (LED's) by connecting separately to the output terminal of the decade counter. These terminals of the counter are connected to a D/A converter made of using R-2R ladder resistive network, which converts a particular data or signal form counter to an analog voltage. With increase in the output of decade counter, the DAC output voltage also increases in magnitude that is from 0 to 4.37 V in steps with 0.625 V and the current

form 0 to 0.4227 mA in step with 0.0625 mA. This analog voltage, however, used to shift the oscilloscope beam in the horizontal direction. The multiplexer output was connected to one of the channels of the CRO through a pulse amplifier mode of IC 355 and IC 741. The gain of the amplifier was adjusted as per the intensity of the electron beam. The circuit performance has been found satisfactorily and with this it was possible to observe beam profile on a storage oscilloscope. A detail circuitry of the beam profile is also shown in Figure 2.

EXPERIMENTAL DETAILS, MEASUREMENTS AND DISCUSSION

To measure intensity distribution in the beam, the monitor was mounted at a distance of 5 cm away from the extraction port of the Microtron. Position of the monitor along the beam axis was adjusted remotely, so that electron beam could cover all the eight copper strips. The outputs of multiplexer was connected to the channel 1 of a digital oscilloscope type No. PM 3350 whereas, the DAC output was connected to the external trigger of the oscilloscope. The charge collected by each copper strip was proportional to the beam intensity in that region. The beam profile pattern was observed on the oscilloscope. In that pattern, the amount of charge collected by a particular strip was indicated by the Y-amplitude, whereas, the strip number was defined by the X position of the oscilloscope spot. The time for which the current can be recorded from a strip was kept variable in the range from 1 ms to 10 s. In this way, the whole profile of the beam could be seen on the oscilloscope. When the signal is fed to an A/D converter, it was
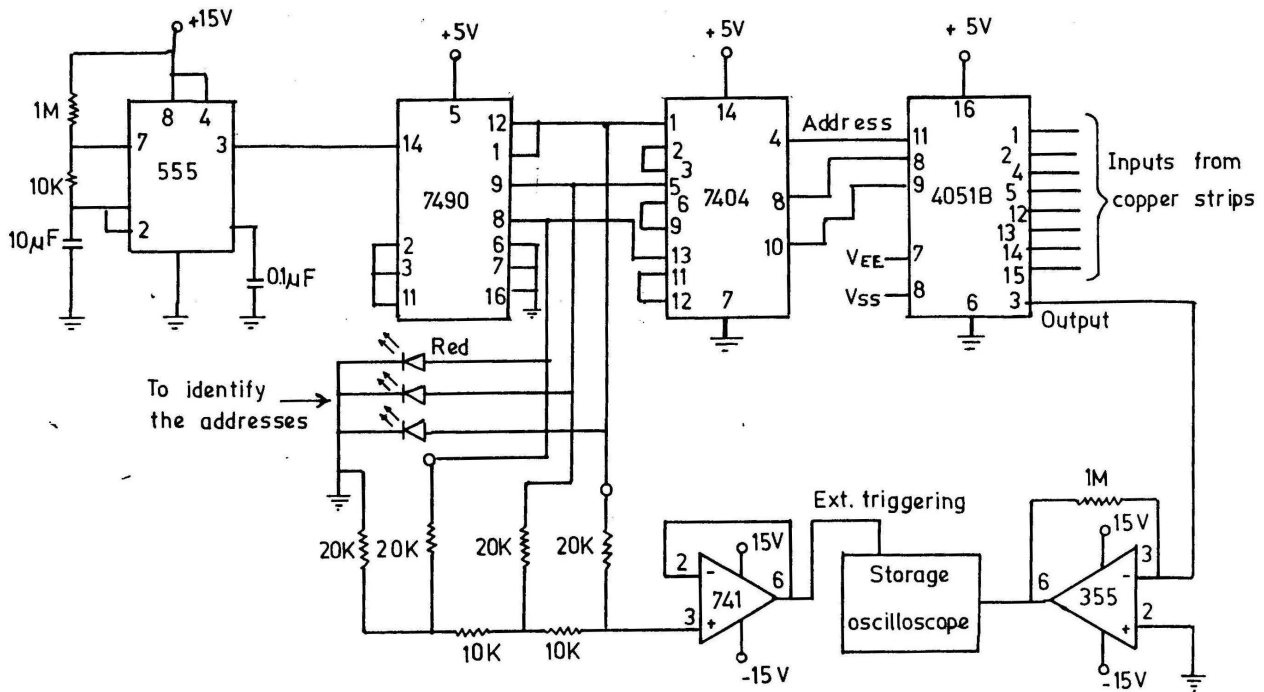
Figure 2: Detailed electronic circuitry of the beam profile monitor.

also possible to record the charge collected by a strip in digital number. This system, gives total charge in one plane only. In order to get charge distribution in the perpendicular plane, the profile monitor was rotated by 90^0 and the experiment was also repeated. Figure 3 gives charge distribution of a 1 MeV electron beam in X and Y planes respectively. From this graph, it was found that the intensity of the electron beam is large at the center and gradually decrease with an increases in X position. This indicates that the concentration of electrons in the beam is less at the edges as compared to that in the central position. The amplifier sensitivity was adjusted such that the total number of electrons in the beam could be as low as 5×10^{10} electrons/cm^2. This monitor can indicate beam dimension upto 15 mm either horizontal direction or vertical direction.
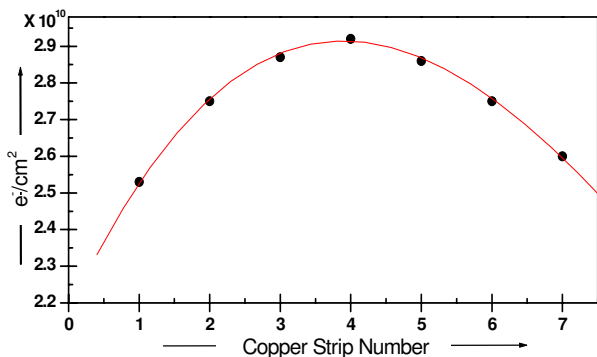

Figure 3: Nature of charge distribution of the electron beam after travelling a distance of 5 cm in air.

CONCLUSION

The beam profile monitor has been designed and used to study the beam shapes at the entrance and exit of the magnetic analyser and also beam focusing properties of a quadruple lenses. The uniformity of electron beam can also be checked by using this monitor. Uniformity of the beam plays an important role in irradiation experiments and damage induced studies in semiconductor materials and devices.

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