BEAM PROFILE MONITOR USING ALUMINA SCREEN AND CCD CAMERA

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Abstract

A pair of beam profile monitors using alumina ceramic screens (Al_2O_3) and CCD cameras has been developed for diagnosis of a linac beam at the 1.3 GeV electron synchrotnon of the Institute for Nuclear Study, the University of Tokyo (INS-ES).

Since both the light decay-time of the screen and a shutter speed of the camera are relatively short, about 10 msec or less and 1 msec, respectively, this system is able to measure the beam profile for each pulse of the linac beam operated at a repetition rate of 21.5 Hz.

Detailed analysis of the beam profile is made using the stored data on the personal computer. On the other hand, a light spot on the screen is displayed directly on a monitor display.

Introduction

For a fine operation of the electron synchrotron, it is very important to control the beam characteristics from the injector linac. Therefore, it is highly desirable to monitor the beam position and profile as well as the intensity in the beam injection line.

So far, only two beam intensity monitors of a current transformer type had been installed. The configulation of the beam line is shown in Fig.1. The linac beam has the energy of 15 MeV, the pulse width of 2 μsec, the peak current of 100 - 200 mA and the repetition rate of 21.5 Hz. In the figure, Li and Ii are the beam intensity monitors at the exit of the linac and at the entrance of the ring, respectively. Using these monitors, the linac beam has been tuned to fit the ring acceptance.

Recently, the stable operation of the synchrotron has been highly required for the tagged-photon beam experiment. A key factor to get the small intensity fluctuation of the synchrotron beam is a fine control of the injection beam. It is found that the injection orbit is distorted by, perhaps, the eddy current due to the fringing field of the synchrotron magnet, in particular, at the high energy operation.

To monitor and investigate the quality of the linac beam, we constructed and installed a beam profile monitor system using an alumina ceramic screen and a CCD camera. This paper describes the system configuration and its performances. The preliminary results of measurements are also presented.

System Configuration

A schematic diagram of the monitor system is illustrated in Fig.2. It is made up of two fluorescent screens, two CCD cameras with a controller for each and a personal computer equipped with an video digitizer board,ADC. The screens are mounted in vacuum chambers, the first one, SCM1, is located 1.08 m downstream from the linac, and just before the triplet-type quadrupole magnet, and the second one, SCM2, 1.5 m upstream from the injection point of the synchrotron ring, as shown in Fig.1. The cameras, CCD1 for SCM1 and CCD2 for SCM2, are positioned below the screens about 60 cm away from them. Lead shields are attached to protect the cameras from radiation damage. The personal computer, which is placed in the INS-ES control room, is linked to the cameras with about 30 m long cables.

An image of light spot formed on the screen is taken in the CCD camera using a function of an external trigger mode, and converted to the video signal. The external trigger mode enables one to take a picture at the same timing in every cycle of the linac operation. A shutter speed is about one msec typically.

The video signal is transmitted to the ADC board in the computer for digitization. The digitized data is analyzed to derive the beam profile, which is easily done by using menu programs operated from the computer. These programs are also used as subroutines in an analysis

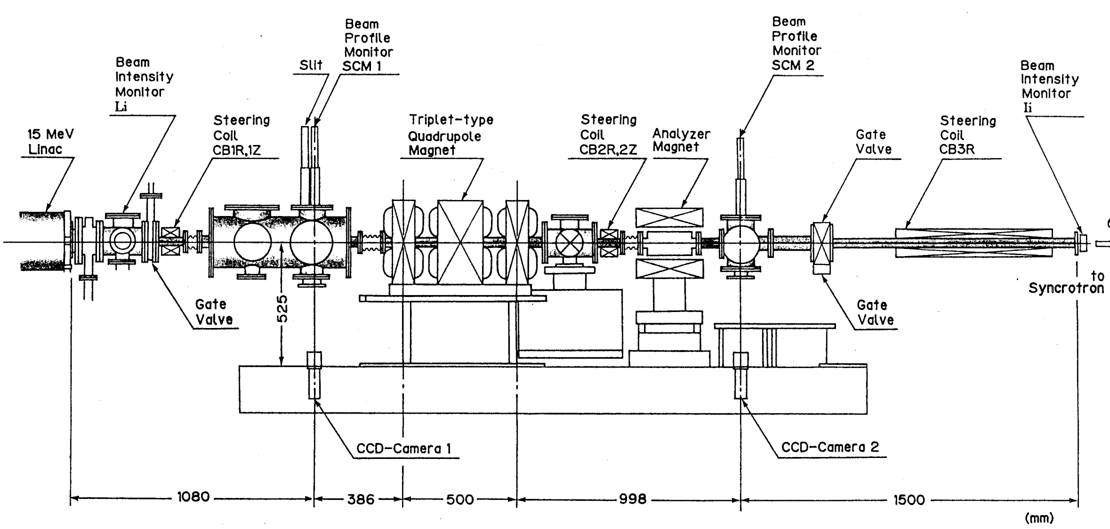


Fig.1 Configuration of the beam injection line of the INS 1.3 GeV electron synchrotron. Li and Ii are the beam intensity monitors, and SCM1 and SCM2 are the beam profile monitors.

program written by users. The intensity distributions in various dimensions are shown on the display of the computer. On the other hand, to know the beam profile visually, the raw video signal is displayed on a monitor display. Since the signal from the ADC board is displayed for every cycle of the linac operation, the system works as a real-time profile monitor.

The following sub-sections describe some main parts of the system in detail.

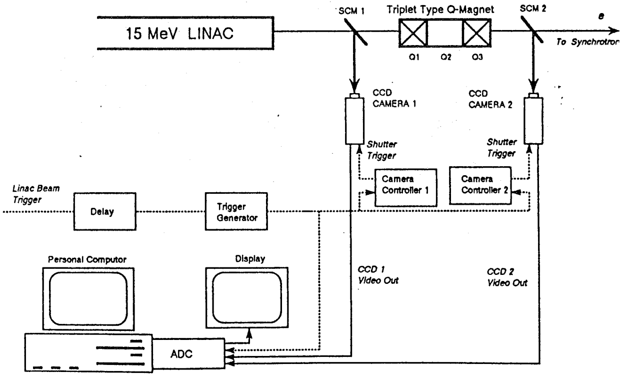


Fig.2 Schematic diagram of the monitor system.

Screen and Driving Mechanism

Fig.3 shows the mechanical construction of the screen monitor head. The screen is mounted on a holder with an angle of 45 degrees to the beam line. The holder is connected to an air cylinder fixed on the vacuum chamber with a supporting rod. The screen is usually kept at 60 mm from the beam line and, when necessary, it is moved into the beam line by the air cylinder very quickly.

The screen material is a chromium-activated alumina ceramics, AF995R from Desmarquest, with an effective area of 50x50 mm^2 and a thickness of 1 mm. This material is chosen from the view points of high resistivity against radiation and high performance in vacuum. The minimum sensitivity of the material is about 10^7 $p/mm^2.s$ when used with the CCD camera.[1)] Because the beam intensity of the linac beam is usually about 10^{11} e/mm^2.pulse, light intensity is enough to get the beam profile for each pulse. The linearity between the beam intensity and the light output of the screen was tested before the system design. Results showed no sign of saturation for the beam intensity of about 10^{10} e/mm^2.pulse.

CCD camera and Controller

The camera is a conventional video CCD camera (TM845, from Takenaka System) with the frame-transfer-type CCD device, whose active area is 8.8^H x 6.6^V mm^2 in which about 0.374 million elements are arranged, and each element has the size of 11.5 $\mu m^{(H)}$ and 13.5 $\mu m^{(V)}$. Since the CCD camera is hardly affected by the external magnetic field, it can be used around the synchrotron magnet without any problem.

The camera controller is also a commercial one. When used in the external trigger mode of the controller, the shutter speed of the camera is selected within the range of 1/5000 - 1/125 sec in a discrete step. The shutter timing is adjusted by controlling the input timing of the source trigger to the controller. The shutter is opened at the timing of 1.4 msec later from the trigger time.

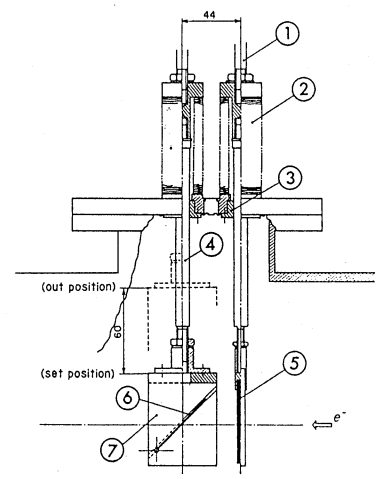
The γ-value of the TM845 has been adjusted to be 0.45. Since, generally, this value is not accurate enough to get the calibration function, we checked the γ-characteristic of the camera. The result should be refered as the calibration function between the video output signal and the light intensity. The affections due to the peculiar characteristics of the CCD camera, such as brooming, smearing and dark current noise, are tolerable for our purposes.

The optical system is made up of only one zoom lens with the focal length of 35 - 70 mm. With the focal length of 70 mm, the spatial resolution of the camera is 0.10 mm/element in the horizontal axis and 0.12 mm/element in the vertical axis.

Computer and Timing Control

The source trigger for the monitor system is derived from the beam trigger of the linac (see Fig.2). It is fed to the camera controllers and the ADC board, simultaneously. The controller generates the shutter trigger for the camera. By the shutter trigger, the camera is first reset and restarted to take only the first one field of a new picture. After finishing to take the picture, the video signal is transmitted to the ADC board at once.

The ADC board is also a commercial one (FRM2-512, from Photoron), designed so as to fit the camera, TM845. The video signal is digitized with the amplitude resolution of 8 bits. Since the sampling step of the digitizer is 1-element/step in the horizontal axis and 2-elements/step in the vertical axis, the spatial resolution of the beam profile is expected to be 0.10 mm/step and 0.24 mm/step in the horizontal and vertical axes, respectively.



Fir.3 Mechanical construction of the screen monitor head.
(1) air cylinder rod, (2) bellows, (3) bushing,
(4) supporting rod, (5) slit, (6) screen and
(7) screen holder.

System Performance

The system test was done by using the linac beam with the peak current of 20 - 111 mA and with the normal operating mode. The intensity of the linac beam was measured using the intensity monitor, Li. The video signal from the camera was converted to the light intensity using the calibration function for the γ-characteristic. The background noise included in the video signal is subtracted from the data after γ-calibration.

To suppress the affection of the smearing, the shutter speed has to be selected appropriately. The shutter speed of 1/1000 sec, being still shorter than the pulse interval of the linac beam, was chosen in this measurement, by which the smearing of about 3 % or less was expected.

Linearity and Decay Time of Light Spot

Fig.4 shows the peak light intensity in the profile as a function of the beam current of the linac measured at several trigger delay times. The delay time is defined as the delay of the source trigger from the linac beam trigger.

The figure shows that the linearity of the peak light intensity against the beam current is ensured over the whole region of the measurement. The upper end of the vertical axis corresponds to the maximum amplitude of the video signal. On the other hand, the maximum density of the linac beam is about $6.7x10^{11}$ e/mm^2.pulse in this measurement. It seems that the screen material is not saturated in light emission up to the beam intensity of that value.

Fig.5 shows the decay curve of the light emission from the screen. The light intensity decreases in proportion to about 1/t, and the half-life time is about 10 msec or less.

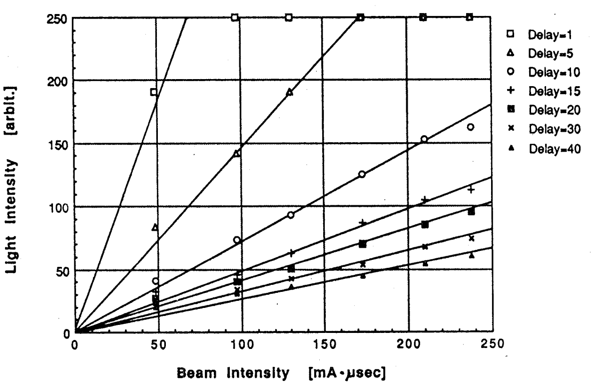


Fig.4 Light intensity vs. the linac beam current.

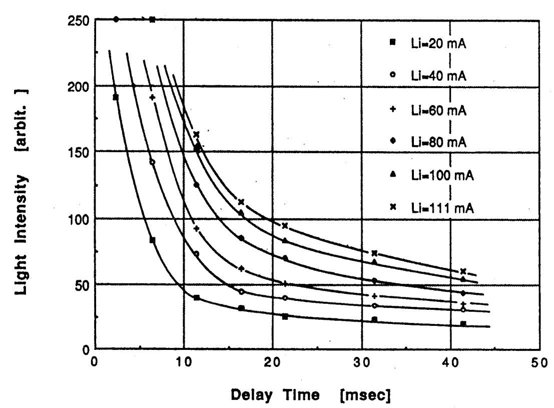


Fig.5 Decay curve of the light emission from the screen.

Profile and Emittance of Linac Beam

Some qualities of the linac beam were measured using this new profile monitor.

Fig.6 shows the typical examples of the beam distribution projected on the horizontal plane in (a), and the 2-dimensional beam distribution in (b), measured by SCM1 with the beam current of 111 mA. Though the figure (a) shows that the projected profile has the Gaussian-like distribution with σ_x of 3.12 mm, the figure (b) shows that the beam has the small structure around the mountain slope. At present, the cause of this small structure is not clear.

The beam emittance was measured with the SCM2 and the upstream quadrupole magnet by means of measuring the beam widths as a function of the strength of the quadrupole magnet.[2] Fig.7(a) shows the change of σ_x^2 as a function of the quadrupole field strength. From this curve, the beam emittance ε_x is calculated to be 1.75 πmm-mrad. With the same method, ε_y is measured to be 1.52 πmm-mrad. The beam emettance ellipse of the horizontal direction measured at the entrance of the qusdrupole magnet is shown in Fig.7(b).

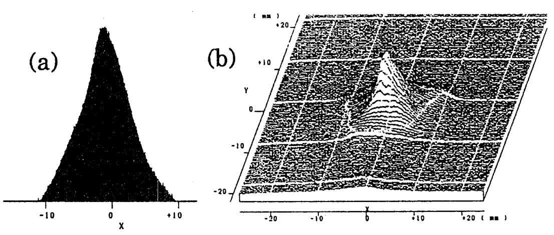


Fig.6 Beam intensity distribution.
(a) projected distribution on the horizontal plane and
(b) 2-dimentional beam distribution.

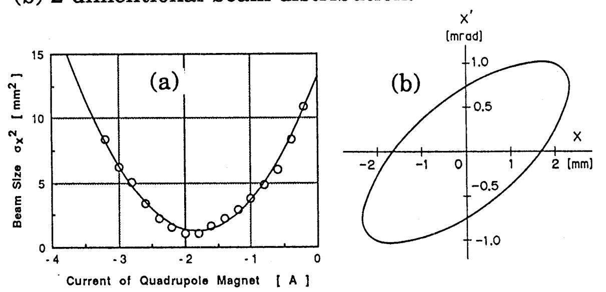


Fig.7 Beam emittance.
(a) σ_x^2 vs. the current of the quadrupole magnet
and (b) beam emittance of the horizontal direction.

Conclusion

We have developed and installed the beam profile monitor system using the cromium-activated alumina ceramic screen and the CCD camera for diagnosis of the linac beam at the INS-ES electron synchrotron. The performance test of the system confirmed the design characteristics.

The system has worked very well in measuring the size, position and profile of the linac beam. Also it has offered the very simple means for controlling the linac beam as a routine work.

As a next step, we are going to investigate the quality of the linac beam in more detail using this monitor and to find the way to get more stable operation of the synchrotron.

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