IMAGE PROCESSING SYSTEM FOR ELECTRON LINAC BEAM DIAGNOSIS

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Abstract: For diagnosis of electron linac beams, image signals from a TV camera viewing a ceramic screen monitor were processed and analyzed using a waveform digitizer and a personal computer. The black-and-white TV camera used has a zoom lens with a remote-controllable iris; the automatic gain control circuit was switched off to obtain tolerable linearity of the output video signal against the brightness of the beam spot on the screen. The video signals are taken by the waveform digitizer with a sampling rate of 4 MHz; the digitized picture is transmitted to the personal computer via the GPIB and is analyzed to derive spatial intensity distribution of the beam. The sync signal of the TV camera is externally synchronized with the electron linac beam timing.

Introduction

For the operation of long electron linacs, monitoring of beam position and profile is essentially important. The use of ceramic screen monitors is one of the popular and direct methods to observe the beam position and profiles. In usual case, the image of the beam is directly observed on a TV monitor. In such a direct observation by eyes on the TV monitor, the spatial distribution of the beam density is not clear. A simple way to visualize the beam density distribution is a computer processing of video signals from a TV camera viewing the ceramic screen which is inserted in the beam line. The video signal processing is made by means of a waveform digitizer and a computer. If a sufficiently fast computer and quickly movable screens are available, it may be possible to observe the beam envelope along the linac in nearly real-time response. Such a dynamic observation of the beam in acceleration can make it easy to construct an automatic control system for beam focussing and steering. In the present system, however, the data processig is fairly slow because of the limitation of the data processing ability of the personal computer used.

This paper describes an image processing system developed for electron linac beam diagnosis. Some applications of the system to the beam monitoring are also reported.

System configuration

Hardware

The entire hardware system is illustrated in Fig.1. It consists of a ceramic screen monitor, a black-and-white TV camera, a video signal synchronizer, a waveform digitizer and a personal computer (Fujitsu FM-11). The alumina screen monitor used for the test of this system was installed 90 m downstream from the electron gun (at a point of 500 MeV) in the main beam line. The TV camera viewing the screen was of a conventional vidicon type with a remote-controllable zoom lens (focal length: 11-110 mm, aperture: F1.6-close); also the iris of the lens was remote-controllable. The horizontal scanning frequency of the camera was 15.75 kHz and vertical one was 60 Hz. The vertical and horizontal sync signals for the TV camera were externally generated so as to synchronize with the linac beam trigger. If the vertical sync signal is asynchronous with the beam trigger, the brightness of the beam image taken by the digitizer would be uncertain. In order to get linearity of the video signal against the beam screen brightness, the TV camera was used without automatic gain control.

The video signal from the camera was transmitted to the control room and digitized by a 10-bit waveform digitizer (SONY/TEKTRONIX 390AD). As compared with a conventional video frame memory, the use of this transient digitizer is advantageous to the easy gain control of the input video signal amplifier which is

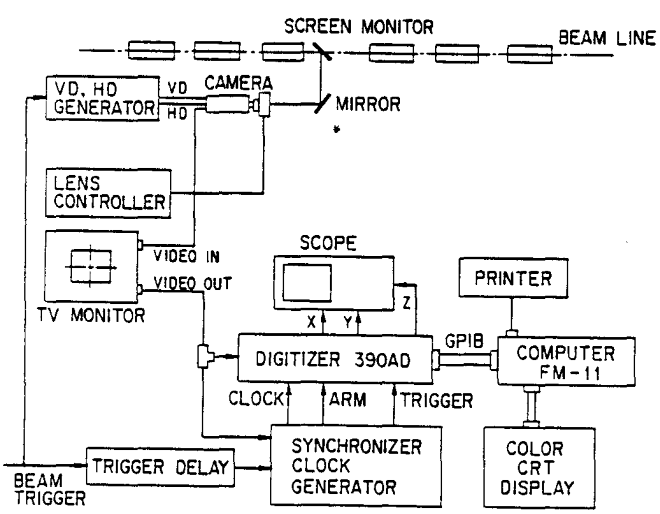

Fig. 1. Hardware configuration of the image processing system for the beam profile monitor.

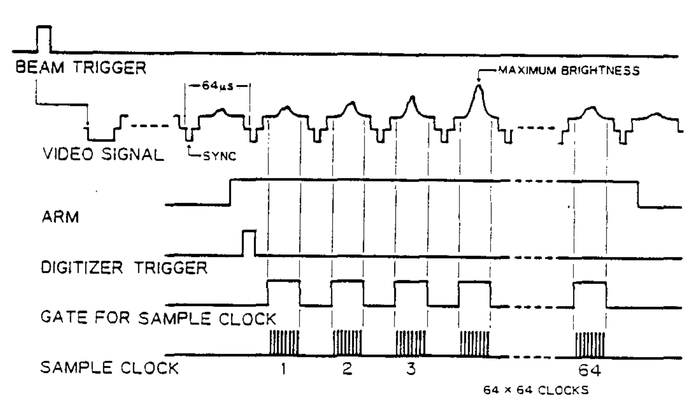

Fig. 2. Gate timing for digitizing the video signal from a TV camera viewing the beam on the screen. Only a narrow area of the screen image effective to observe the beam is digitized and stored in the buffer memory of the transient digitizer.

needed, in particular, for low-intensity beam observation. The trigger for the digitizer was generated from the beam trigger and composit video signal of the TV camera. The delay time of the digitizer trigger from the beam trigger is adjustable. Since the memory size of the digitizer was only 4096 words, the area of the picture was limited to 64x64 pixels; moreover an external sampling frequency of 4 MHz was given to the digitizer to get sufficient resolution of the beam profile image. A digital window, therefore, was set on the frame by controlling the external sampling clock input to the digitizer; the clock input was controlled by counting the horizontal sync pulse with TTL preset counters.

The image data taken by the digitizer are transfered to the personal computer FM-11 through the GPIB and processed as described below. The spatial distribution of the beam intensity can be displayed on a color CRT.

Software

The program for the beam image data handling was written in BASIC and ran under the interpreter. The program can be divided into the following blocks:

(a) Data transfer from the digitizer to FM-11.
(b) Two dimensional beam profile display.
(c) Data summation and display. After data summation along x and y axes, normalyzed curves of the beam profile are displayed on a CRT.
(d) Three dimensional display of the beam profile.

System test

Scale calibration

Prior to the beam profile measurement, the viewable area of the beam screen was set by adjusting the zoom lens of the camera so that a beam profile can be measured with a sufficient resolution. The sampling frequency of the digitizer was fixed at 4 MHz. The scale of the picture taken by the digitizer was calibrated as follows: (a) First, the TV camera is set in a test bench to view vertical (x) and horizontal (y) reference lines drawn in black at intervals of 10 mm on white paper. The video signal of the vertical reference lines and sampling clocks for the digitizer are observed with an oscilloscope; the zoom lens of the camera is adjusted to a suitable focal length so thant the period of 10 sampling clocks just corresponds to a 10 mm interval in the horizontal axis. At this setting of the camera, the pixel interval is 1.0 mm on the horizontal (x-) axis and 0.64 mm on the vertical (y-) axis. The image reference lines are marked on a TV monitor screen. (b) Second, the TV camera is installed at the screen monitor in the linac beam line. The zoom lens can quickly be adjusted for the image size of the thin reference lines marked on the screen of the profile monitor to fit those marked on the TV monitor screen. The final pixel interval in this system test was set to be 0.5 mm on the horizontal axis and 0.32 mm on the vertical axis.

Image decay time and linearity

The system test was performed using electron beams with the following parameters: Energy 500 MeV, peak current 10-50 mA, pulse width 1 us and pulse repetition rate 1 pps. The iris of the TV camera was adjusted to an aperture suitable to get video signal outputs relevant to the test. The image of a bright beam spot observed with the TV monitor does not vanish immediately after the beam hits the screen of the profile monitor. The relation between the peak amplitude of the video signal and the decay time of the residual image was measured at several beam currents, where the iris of the camera was fixed. The result is shown in Fig. 3. Figure 4 represents the peak amplitude of the video signal as a function of the peak current of the beam at several delay times from the beam trigger; the data points are the same as those shown in Fig. 3. As can be seen in Fig. 4, the linearity of the video signal amplitude against the brightness of the beam spot is tolerable only for the amplitude below 0.3 V; therefore, the iris of the camera should be adjusted according to the brightness of the beam spot.

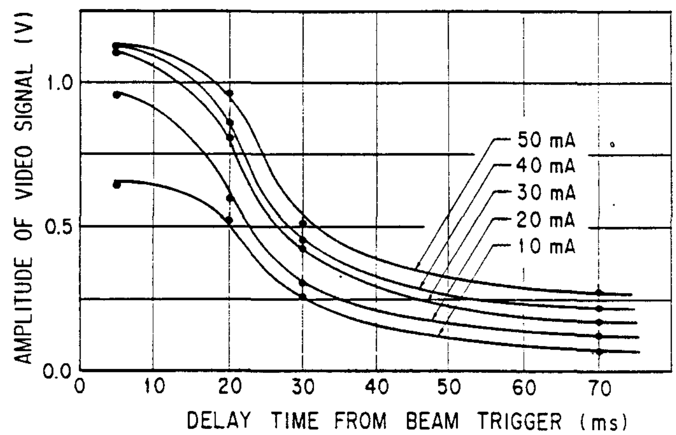

Fig. 3. Peak amplitude of the video signal as a function of the delay time from the beam trigger. Measurement was carried out at the peak current of the beam: 10, 20, 30, 40 and 50 mA. Beam pulse width: 0.8 us. Beam repetetion rate: 1 pulse per second.

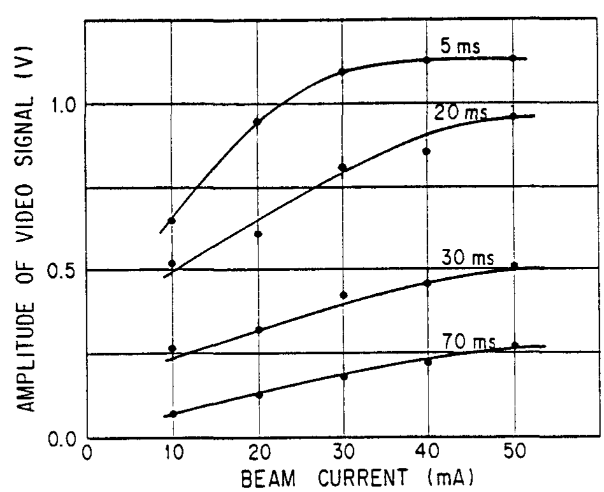

Fig. 4. Peak amplitude of the video signal as a function of the peak current of the beam at delay times from the beam trigger 5, 20, 30 and 70 ms. The data points are the same as those in Fig. 3.

Examples of the beam profile display

Figure 5 shows an example of 2-dimensional display of the beam profile. The spatial distribution of the beam current along the x-axis (y-axis) is displayed after integration of the beam current density with respect to the y-axis (x-axis); the beam size can easily be derived from this procedure. Figure 6 is a typical 3-dimensional display of a beam profile.

Application

Possible applications of this system are: (a) Measurement of the beam emittance, (b) simple observation of the beam energy distribution and (c) automatic adjustment of the beam focusing and steering system.

Easy derivation of the beam size by this system makes it easy to measure the beam emittance. A preliminary measurement of the emittance was performed, but it is not yet completed.

A beam energy distribution can be observed in such a way that a beam screen is installed at the focal plane of the magnetic energy analyzer, where usually an energy defining slit is installed. Operator of the linac may easily observe the energy distribution on a CRT display.

Using many screens in the beam line, quickly movable screen drivers and a high speed computer, an automatic beam handling will be possible. At present, eleven screen monitors with quickly movable air cylinder are distributed along the 400 m long linac in KEK; however, a computer with data handling ability sufficient for image processing is not yet available.

When the beam intensity is so weak that the beam profile can not be observed on a TV monitor, it may be cleary seen on the graphic display after eliminating background noises from the image data taken repeatedly. Figure 7 shows an example of a low-intensity beam profile with noises; after integration along the x- or y-axis, the intensity distribution becomes clear.

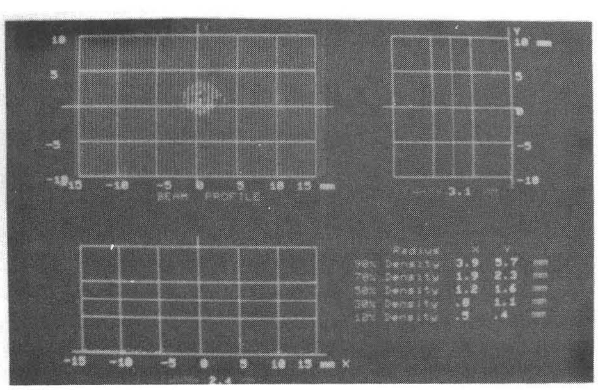

Fig. 5. Example of 2-dimensional display of the beam profile. The spatial distribution of the beam current along the x-axis (y-axis) is displayed after integration of the beam current density with respect to the y-axis(x-axis).

Conclusion

The image processing by the computer makes the beam profile observation easy and clear. This kind of system can be used for measurements of the beam position, profile, emittance and energy distribution. This image processing system is also applicable to the synchrotron radiation observation after bending magnets.

To use this system in daily operation of the linac, it should be improved by replacing the 8-bit personal computer FM-11 with a more powerful computer. An improved image processing system will be a useful tool for beam diagnosis.

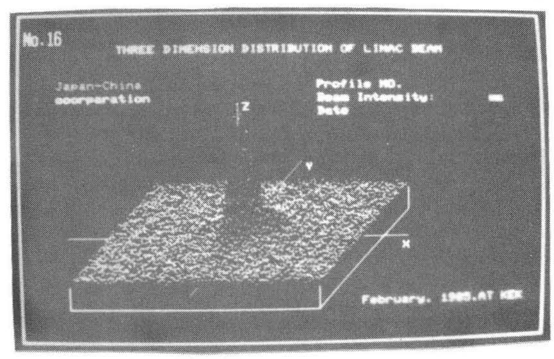

Fig. 6. Example of a 3-dimensional display of the beam profile.

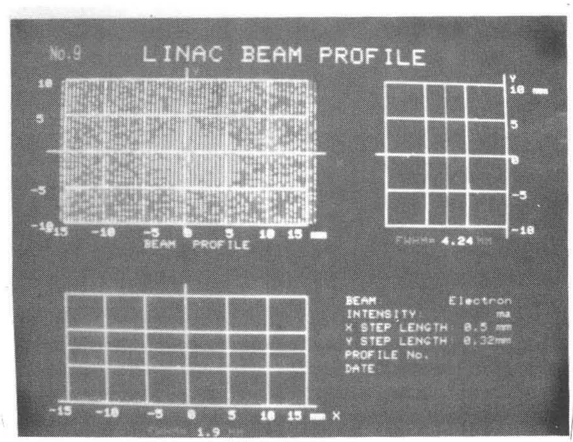

Fig. 7. A low-intensity beam profile with noises; after integration along x- (y-) axis, the y- (x-) intensity distribution becomes clear.