Design of Automatic Beam Transport System at SPring-8 LINAC

Hironao Sakaki, Hiroshi Yoshikawa, Hideaki Yokomizo,
Takuya Sogo*, Kouji Kinoshita*, Norihiko Adachi*
SPring-8 Linac, Kamigori, Ako, Hyogo, 678-12, Japan
Division of Applied systems Science, Kyoto University, Kyoto, 606, Japan *

Abstract

At a new accelerator, the best operating parameters have to be found by trial and error. The operator must learn from experience, and it expends much time for operation because the accelerator has many alignments and other errors which are hard to measure. The SPring-8 Linac is also a new accelerator operated since 1996. It's a 140m long, 1GeV electron machine. The machine is used as an injector into the 8GeV synchrotron. The synchrotron demands high energy stability, so the operator must search for the parameter by trial and error. Even after the parameter is fixed, it is possible that the energy is fluctuated by the temperature and various other reasons, and the operator must engage in adjustment continually[1].

Whenever a parameter is adjusted, the beam profile is also checked on a screen which is made with alumina-ceramic (Desmarquest AF995R). Therefore we design an automatic operation system using screen monitors. Firstly, we develop an image processing system for the screen monitor. Next, we try to do a preliminary automatic control using the system. It is attempted for the electron beam transport.

This paper presents the image processing system of screen monitor, and some results of a preliminary automatic control experiment using it.

1 Data acquisition system

1.1 Linac control system and screen monitor system

For the data acquisition and low level control of devices, we adopt VME computers. The hierarchy of the control system has two layers. One is the Machine Control Process layer (VME), another is the MMIF layer (EWS) [2]. Figure 1 shows a layout of the system in the Linac. These VMEs have MVME147 boards (Motolora 68030 CPU) and run the OS-9 operating system. An EWS uses HP9000 series. The VME system is located on the second floor which is called the klystron gallery.

The 32 screen monitors are installed in the Linac. The monitor is constructed with a CCD camera that sends an image by wire to the control-room. Usually, the image processing for getting the profile is done by shuttered CCD camera[3]. However, we use non-shutter CCD Camera based on NTSC (National Television System Committee) regulation, because it is very expensive to install all screen monitors. The CCD signal is inputed to a VME, and convert to digital data.

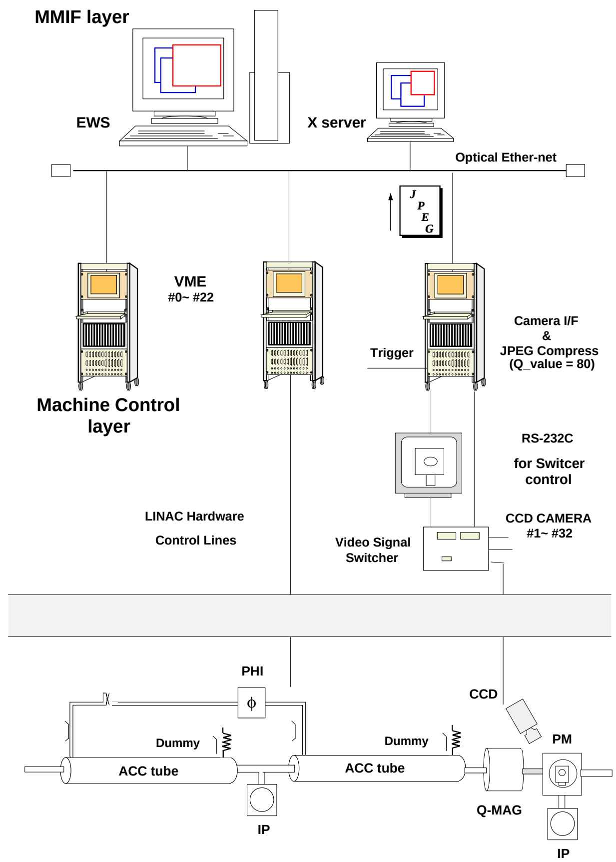

Figure. 1. Layout of Linac control system and the screen monitor system.

1.2 Digital converting

The image processing board works on VME bus, and the image convert timing is shown figure 2. First, the image measurement message is sent from EWS to the board. If we want to get a few frame delay time, because of intensity saturation on the screen monitor, we can set the NTSC frame delay time. The NTSC frame pulse is constantly generate every 16.6msec (60Hz). When the message and NTSC frame delay time coincides with the injection beam trigger, the conversion is started by the board. It needs a few hundred msec. Secondary, the VME board compresses the obtained image data into a JPEG (Joint Photographic Expert Group)

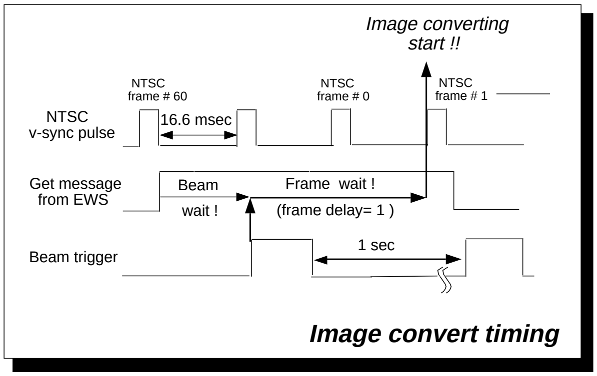

Figure. 2. Digital convert timing on VME bus. This timing coincide with the beam emission trigger.

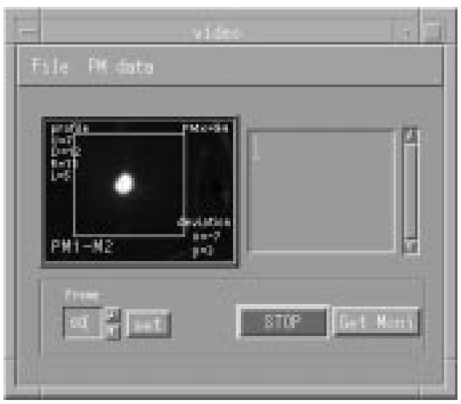

Figure. 3. Human interface of the screen monitor.

data. It needs also a few hundred msec. The JPEG Q-value is 80, and it compresses 491k byte image data into a 3k byte JPEG data. The compression is important for the LAN traffic. These all processes are written in OS-9 C-language on VME bus. Figure 3 shows the human interface of the screen monitor system. The image process on EWS was made from JPEG library and OSF-MOTIF. JPEG data from the VME is analyzed using this process, and shows the digital beam position and profile.

1.3 Measurement data

An orbit of the electron beam is changed by the strength of the magnetic field. When a steering magnet just before the screen monitor is adjusted, the beam move on the screen. To use it, we can confirm whether the screen monitor works with precision.

A steering magnet which is installed at the end of the Linac is 0.00123 (T·m), 17Ampere, and the distance between the monitor and the magnet is 892.8mm. Therefore, when the magnet operates at 15Ampere, the beam moves about 2.9mm on the screen. Figure 4 shows these measurement results. It is clear that the beam moves about 3.0mm on the screen (at 15Ampere). As the system's resolution is about 0.3mm/pixel, this shows the high performance of the system. This system can measure not only the position but also the beam profile.

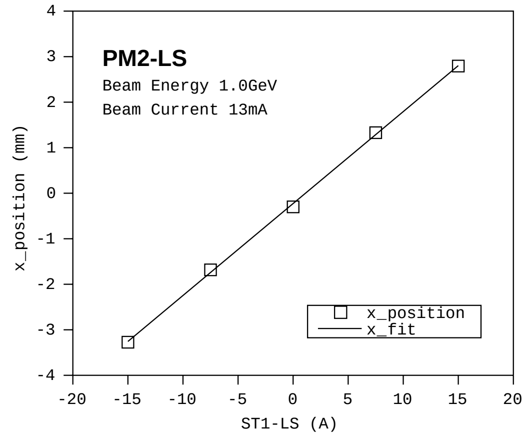

Figure. 4. Movement of electron beam position using a steering magnet.

2 Transport modeling

Mathematical modeling of the accelerator can be used to calculate the optimum parameters. Generally speaking, there are two types of modeling methods.

- **Statistical approach**
  The regression model built from statistics, and the present condition is simulated by using it.
- **Analytic approach**
  The accelerator is resulted by the model obtained theoretically.

It is difficult for the huge scale accelerator to use the Analycal approach, because of many kinds of complex error. If we use this model for the optimization, it is hard to calculate the optimum parameters. We aim principally at the calculation efficiency, and we select the statistical approach. The statistical approach is usually expressed by using the low level polynomial expression. So we assume that the beam transport is expressed by the following quadratic expression.

$$f(I) = \beta_0 + \beta_1 I_1 + ... + \beta_p I_p + \beta_{11} I_1^2 + ... + \beta_{pp} I_p^2$$
$$+\beta_{12} I_1 I_2 + ... + \beta_{p-1,p} I_{p-1} I_p + \varepsilon \qquad (1).$$

where,
$\beta_0, \beta_{11}, \beta_{12}, ..., \beta_{p-1,p}$ and ε are constants, $I_1, I_2 ... I_p$ are the current parameters.

For getting this model expression, the displacement of electron beam position was measured by using 20 magnets. And these data are approximated with the quadric model by least square fitting based on singular value decomposition

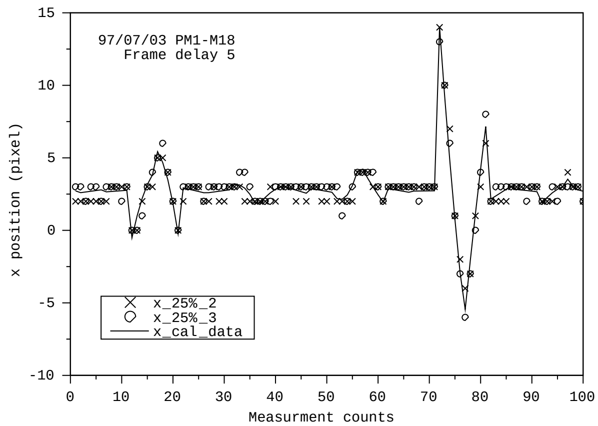

Figure. 5. The prediction data from the quadric expression model and measurement data.

(SVD)[4]. Figure 5 shows measurement data and the prediction data from the quadric expression model. Measurement data is horizontal displacement that the current value has manipulated respectively 5 times in 20 magnets. It has good agreement, and the correlation coefficient is 0.927. This model must be good for the optimization.

3 Optimization

Successive quadratic programming (SQP) is one of the best methods for solving the nonlinear programming problem. For solving the problem, a lot of numerical calculation software is avalible on market. One of these, MATLAB is a high-performance numerical calculation software, and it has an SQP-library in the optimization tool-box[5]. We use the library for solving the our transport model.

When we want to move the electron beam to the center of screen, x=0 and y=0, we solve the following minimization problem with SQP.

$$minimize : (0 - f(I)_x)^2 + (0 - f(I)_y)^2 \qquad (2).$$

And if x=0 only,

$$minimize : (0 - f(I)_x)^2 \qquad (3).$$

Figure 6 shows the results of the optimization. The solid line is the electric current value when it is adjusted manually by the operator. This value is used as a starting point of the SQP calculation. The solid line with circles is a result of SQP that fires the electron beam to a center of the horizontal position on the screen, and the solid line with box is a result of the center of vertical position. The results point out that the eighth magnet is adjusted to make each a zero. When we would like to make each a zero in the human operation, we image that the magnet which is close to the monitor is adjusted. This result shows that the optimized calculation takes an objective view of the situation. It confirms that the optimized parameter puts the beam to the screen center.

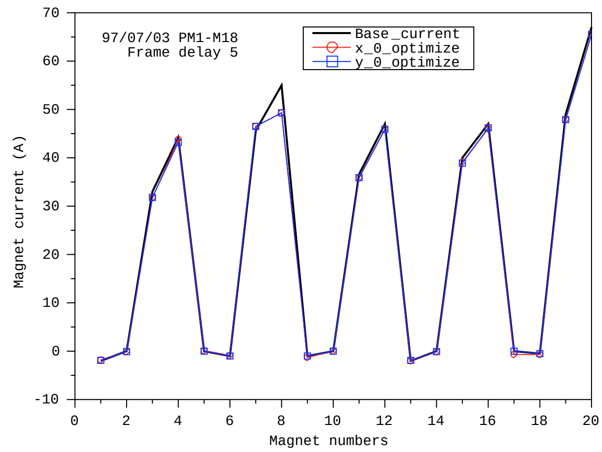

Figure. 6. Result of the optimization. A vertical axis is the magnet current value, a horizontal axis is equivalent to the electromagnet which installed on the lower reach from ST1-M8.

4 Conclusion

For automatic operation, a screen monitor system has been developed with image processing. The system works very well, we can get precise beam profiles. To use this system, the prospects which could be used for the optimized adjustment of the beam transport were given. We will proceed with the full automatic transport using this concept.

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