Bunch Monitor for an S-Band Electron Linear Accelerator

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Abstract

The measurement of bunch characteristics in an S-band electron linear accelerator is required in order to evaluate the quality of accelerated electron beams. A new-type bunch monitor has been developed which combines micro-stripline technology with an air insulator and wall-current monitoring technology. The obtained time resolution of the monitor was more than 150 ps. This result shows that the monitor can handle the bunch number of an S-band linac. The structure of the monitor is suitable for being installed in the vacuum area, since it is constructed of only metal and ceramic parts. I can therefore easily be employed in an actual machine.

1. Introduction

An advanced electron linear accelerator, such as a linear collider or a linac for a free-electron laser, is usually required to produce good quality electron beams, thus requiring both a low-energy spread and a low-emittance. For this reason, the measurement quality of each electron bunch is very important. The energy spread of the accelerated electron beam by a linac depends directly on its own bunch length. Bunch length measurements are necessary for the above-mentioned reasons.

A part of KEK, National Laboratory for High Energy Physics, includes the Photon Factory 2.5-GeV linac (PF Linac) which uses the S-band RF; it also has future plans, such as the JLC (Japan Linear Collider) which will use the S-band linac for both pre-acceleration and positron generation.

The bunch length of the S-band linac at the Photon Factory is less than 10ps. If we want to evaluate the electron bunch quality of the above-mentioned accelerators, the time resolution of the bunch monitor must be more than 10ps; the time resolutions of the beam monitors which already exist, however, are not sufficient for bunch length measurements. From above-mentioned reasons, a bunch monitor must be developed.

The development[1] of a bunch monitor was started using an epoxy-glass material (usually called G-ten) for the monitor's base material; a pre-experiment was carried out in the atmosphere by extracting electron beams from the positron generator of the PF Linac. The bunch monitor using G-ten achieved more than a 300ps pulse response. After obtaining reasonable results in the pre-experiment, Designing a new bunch monitor to be installed in vacuum was started.

2. Coupling Mechanism of Bunch monitor[2]

The electromagnetic field of a relativistic electron beam reduces the longitudinal electromagnetic field in proportion to $1/\gamma$. The transverse electromagnetic field of an electron beam projects its own bunch length in the extremely relativistic case, where the transverse electromagnetic field at a radial position r from the beam center can be expressed as

$$E_T = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{r},$$

where λ represents Beam Charge/unit length.

If a wall-current coupling method which is used to detect the transverse electromagnetic field of the electron beam is applied to a bunch-length measurement, we can theoretically measure the bunch length of an S-band linac. However, extra distributed inductances and stray capacitances in the pick-up resistor and transmission circuit of the monitor usually prevent circuit matching for a good pulse response. For this reason they should be reduced.

The wall current through the pick-up resistor is ideally the same as the current of the electron beam. The output voltage can be given by the following equation:

$$V = I * R,$$ where R is the pick-up resistor value, and I is the beam Current.

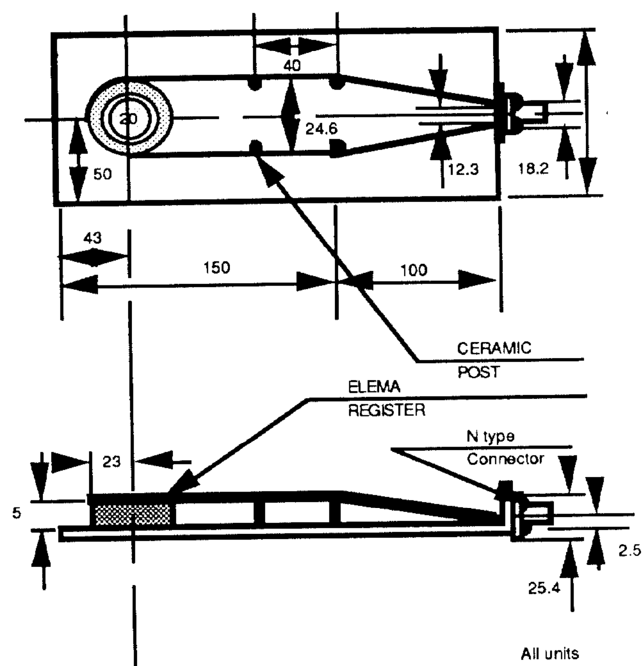

Fig. 1 Stripline-Type Bunch Monitor with an Air Insulator

3. Design and Evaluation of a Bunch monitor

A bunch monitor using stripline technology was designed, as shown in Fig.1; the matched transmission line into a characteristic impedance of 50 ohm is necessary in order to smoothly transmit the beam signal. We previously made a bunch monitor without any taper transformer in order to omit the complicated part; then, the frequency response of the monitor (looking at the output connector) was good and the main reflection component was from the resistor.

The characteristic impedance of the stripline can be calculated by [3]

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}}\left[\frac{w}{h} + 1.393 + 0.667 \ln\left(\frac{w}{h} + 1.444\right)\right]^{-1}$$

and $$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{w}{h}\right)^{\frac{1}{2}} \quad \text{for } w/h > 1,$$

where w is the width of the stripline, and h is the height of the stripline from the ground plane. This equation shows that the w/h ratio is important in determining the characteristic impedance.

The monitor requires a taper transformer which gradually decreases in height while maintaining the characteristic impedance for obtaining a good matching between the stripline and the output connector. The taper electrically rejects the big dimensional difference between the stripline and the output connector.

The value of the pick-up resistor is determined according to the following procedure. The evaluation circuit[2] of the pick-up part is shown in Fig. 2, and the time constant of the bunch monitor can be expressed by

$\tau = C * R$, where R is the pick-up resistor, C is the stray capacitance, and L is the distributed inductances.

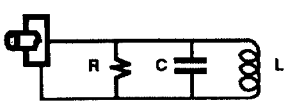

Fig. 2 Evaluation Circuit for Bunch Monitor

At first, a 50-ohm resistor was chosen, since the matching of the stripline can be easily evaluated in the opposite direction from the output connector. Furthermore if the transmission circuit of the bunch monitor has reflection at any point, the reflection signal is absorbed by the resistor. On the other hand, if a better pulse response is required and the transmission line has a good frequency response, the value of the resistor can be reduced for decreasing the time constant of the pick-up circuit.

Frequency domain measurements (scattering parameters) using a microwave network analyzer and time domain measurements using TDR (Time Domain Reflectometer) were carried out in order to evaluate the stripline circuit of the bunch monitor. Fig. 3 shows the frequency response of the monitor; time domain reflection data are shown in Fig, 4. Fig. 4 shows that the 50-ohm pick-up resistor (elema resistor) of the monitor is not very good. The frequency response shown in Fig.3 is also not very good, since the stripline width of the monitor is not optimized, and the resistor does not have a good frequency response. The main effect of the reflection loss might be attributed to the resistor.

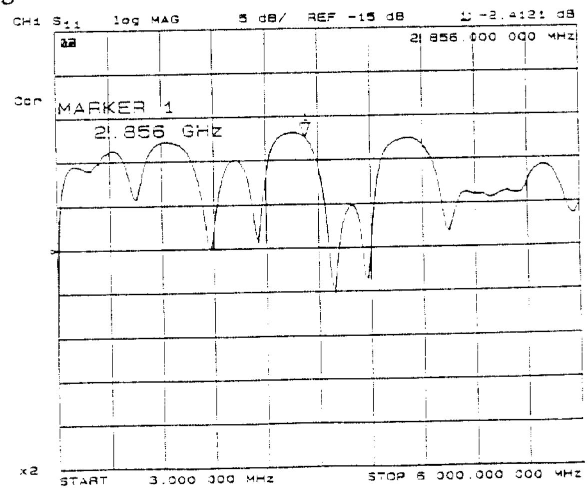

Fig. 3 Frequency Response of Bunch Monitor from the Output Connector

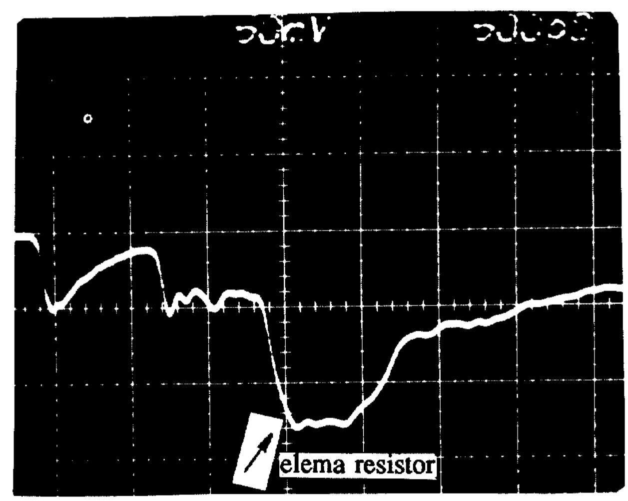

Fig. 4 Data of Time Domain Measurements from the Output Connector

4. Experiment and Result

The beam signal from the bunch monitor with a 50-ohm pick-up resistor has been observed at the end part of the KEK positron generator. The experimental setup is shown in Fig.5.[4] The primary high-intensity electron beam for generating positrons was guided to the monitor. For measurements of the fast signal (more than 100 ps), a 6-GHz transient digitizer (Tektronix, 7250) was used. The RF cable corresponding to 20D was provided between the monitor and the digitizer in order to prevent any distortion of the signal waveform.

Fig. 6 shows the signal from the bunch monitor; the bunch number of the electron beam can be counted by a streak camera, as shown in Fig. 7. The signal of the streak camera was saturated in order to obtain a small bunch signal;

therefore, the signal amplitude is not proportional to each bunch intensity. The rise time of the monitor's signal is almost 100 ps; we can count 7 bunches from Fig. 6. This bunch number is the same as data obtained from the streak camera.

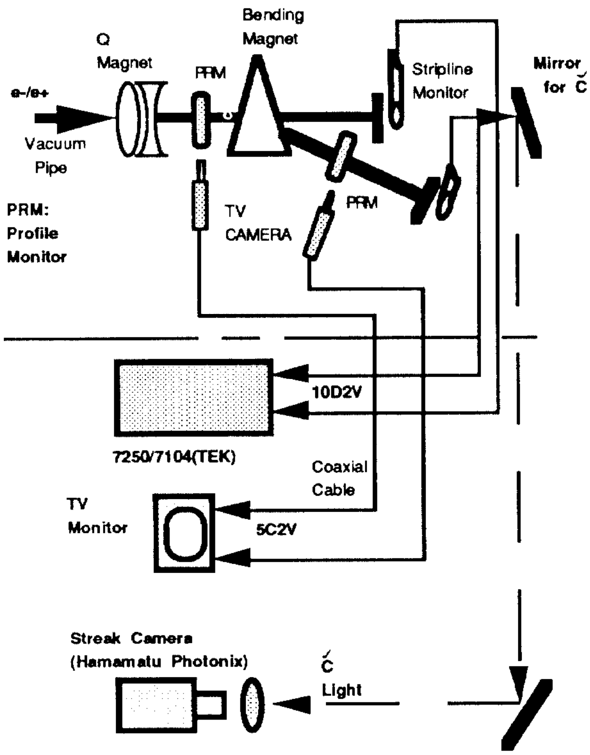

Fig. 5 Experimental Setup for Stripline Typre Bunch Monitor

5. Conclusion

The bunch monitor almost achieved a rise time of 100ps. This value is not sufficient for bunch-length measurements in an S-band linac, although the bunch monitor can count the bunch number of the electron beams. Data from the bunch monitor are still useful for evaluating the characteristics of the accelerated electron beams in S-band linacs.

We think that the characteristics of the bunch monitor can be even more improved by optimizing the stripline width, decreasing the resistor's value and using a good pick-up resistor which has a wide-band frequency response.

6, Acknowledgments

We appreciate Dr. Atsushi Enomoto's help in the experiment of the bunch monitor, and Dr. Takao Urano's help in setting up the trigger system.

Reference

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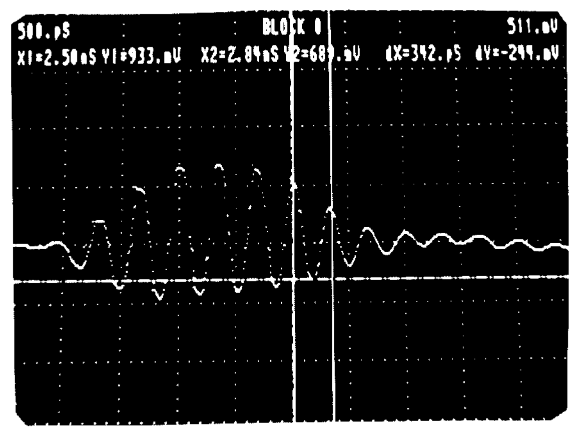

Fig. 6 Signal of Bunch Monitor

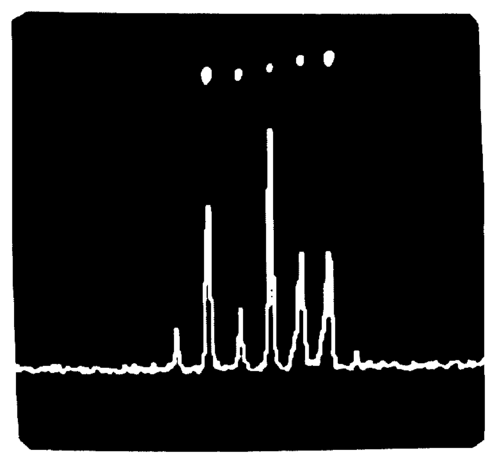

Fig. 7 Signal of Streak Camera