

DESIGN AND PERFORMANCES OF PHASE MONITOR IN J-PARC LINAC

A. Miura^{*},

J-PARC Linac, Japan Atomic Energy Agency, Tokai, Ibaraki, 319-1195, Japan

T. Miyao, Z. Igarashi,

J-PARC Linac, High Energy Accelerator Organization, Oho, Tsukuba, 305-0801, Japan

Abstract

J-PARC linac employs a fast current transformer (FCT) as a beam phase monitor to calculate the beam energy by time-of-flight method, and the 4-stripline beam position monitors (BPMs) for the beam position measurement. We designed, fabricated and have been used them to the beam operation. Performances of fabricated monitors and their calibration data have been measured. Here, we will discuss the structure and frequency performance of the FCT monitor. At the great earthquake occurred off the Pacific coast of Tohoku, some CT monitors, such as a phase monitor and beam current monitor had damage and the vacuum leakage was observed. But no damage of BPMs was found. It has been considered that the signals from striplines of BPM would be useful for a phase measurement. A phase measurement using a BPM has been successfully conducted. Above the lessons learnt from the damage by the quake, we consider to employ the BPM for the FCT backups after evaluation of the performances of BPM as the phase measurement device. Finally, these performances of BPM are compared with those of FCT. Based on the results of the evaluations, we will discuss the performance to measure the beam phase both FCT and BPM.

INTRODUCTION

Energy upgrade project is now progressed in J-PARC linac. Currently, J-PARC linac accelerates the negative hydrogen beam up to 181 MeV, but 400 MeV accelerated beam can be obtained with 21 ACS cavities^[1]. We designed and fabricated the beam monitors, such as BPM (beam position monitor), SCT (slow current transfer) as the beam current monitor, FCT (fast current transfer) as the beam phase monitor, WSM (wire scanner monitor) as the beam profile monitor) for this project^[2]. After fabricated BPM and CT monitors, the performance of each monitor had been obtained to confirm the design parameters and for calibration^[3].

There was big damage in J-PARC caused by the Tohoku earthquake in March 2011^[4-5]. As for the beam monitors in J-PARC Linac, there was no damage of BPMs and WSMs, but deformation of CT monitors (SCT and FCT) was found and vacuum leak occurred. Damage was mainly observed at the part where the ceramics and metal parts were brazed. BPM has a strong structure for shaking by quakes, on the other hand, FCT monitor has a such structural weak point for shaking. Because the BPM also can measure the beam phase using an electrical

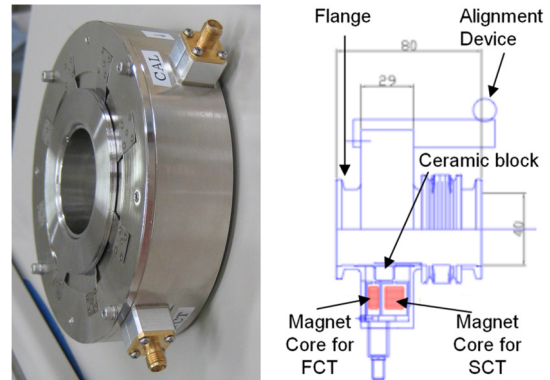


Figure 1: Overview and drawing of FCT and SCT monitor. In the drawing figure, cross-section is described in the bottom half.

circuit for phase detection, it has been considered to use the BPM for the backup of FCT.

FCT is well calibrated to detect the beam phase for 324 MHz acceleration frequency. If the BPM is employed for phase measurement, it is thought that it also needs to calibrate to 324 MHz. Then, we obtained the performance of BPM as the phase monitor. And the data are compared with the data obtained from FCT monitor.

In this paper, we describe the design parameters and performances of FCT and compared results obtained from BPM.

DESIGN OF FCT MONITOR

The beam phase monitor is the other kind of beam current monitor, which is specially designed for high frequency response. The beam phase measurement related to the RF signal provides key information in order to tune the acceleration RF phase. So that the most important information should be extracted from the fundamental RF component, 324MHz. The beam phase monitor has to have an efficient response to this RF fundamental component.

The conventional current transformer is difficult to extend its high frequency cut-off, $1/CR=\omega_H$, because of the stray-capacitance. Using crystallized magnetic alloy makes the beam phase monitor transformer, and a single winding is taken to reduce the stray-capacitance. The frequency response of the Fast-Current-Transformer (FCT) has been sufficiently extended up to GHz region.

FinemetTM core (Hitachi Metals, Ltd.) with high magnetic permeability is employed for the FCT, a single turn coil is combined with the Finemet core with 5 mm thickness is for a coil (fig. 1). Except for MEBT and DTL subsection, each current transformer has its inductive core

^{*}miura.akihiko@jaea.go.jp

outside of the vacuum chamber in order to avoid any outgas from the monitor parts. Therefore a small ceramic block is employed for RF signal to be transmitted through (toward the inductive core) while a vacuum enclosure is tightly kept (fig. 1).

A signal can be picked up with the reference frequency as ω , and the output is described below.

$$V = \frac{j\omega L/Z}{1+j\omega L/Z} \cdot \frac{RI}{N} \quad (1)$$

Here, I shows a beam current, Z shows the characteristic impedance, N shows the number of coil and L shows self-inductance.

DESIGN OF BPM

J-PARC Linac employs the strip-line type beam position monitor to avoid the space problem (fig. 2). The diameter and the length depend on the aperture size and the accelerated energy.

Accuracy of the position is stably maintained at 0.1 mm using a test bench. Because new BPMs are also required the same accuracy, we designed the pickups and the body. Basic design is taken over from the present BPMs and in order to define the design of the pickup, two-dimensional electro-magnetic simulation is conducted. After obtained the simulation results, we fabricate the prototype one for the measurement. A variety of the width of pickup are tried to match the corresponding impedance (50 ohm) and finally decide the pickup and body design. Calibration of the BPMs has already completed.



Figure 2: Beam Position Monitor (BPM).

BPM signal which is induced from the electrical charge of beam pulse on the strip-line is obtained. When we consider the equivalent circuit of BPM based on the induction principal, inducted output signal is described below.

$$V = \frac{I\theta/2\pi}{1/R+1/Z} \quad (2)$$

Here, Z is the characteristic impedance and it is adjusted to 50 ohms. θ is a composed angle from the beam centre to each strip-line. This is proportional to the width of a strip-line.

BENCH TEST OF FCT AND BPM

Setups at Test Bench

Figure 3 shows the overview of the test bench to measure the characteristic features of phase measurement devices. In the case of figure 3 on the left side, FCT is set on the bench. Waveguides are connected with both flanges and the one side (top) is terminated. From the other side (bottom), RF conductor with $\phi 17$ mm diameter is inserted to supply the RF signal using network analyzer. Reflected signal and output signal from FCT terminal are measured (fig. 4).

About the characteristic measurement of BPM (fig. 3 right side), BPM is set as same as the FCT. But in this



Figure 3: Overview of the test bench. An FCT is set on left side and a BPM is set on right side.

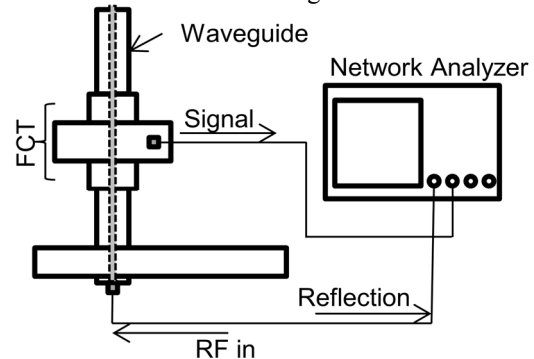


Figure 4: Signal network of characteristic measurement of FCT.

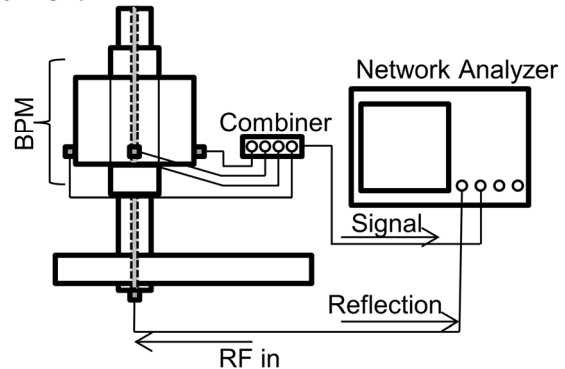


Figure 5: Signal network of characteristic measurement of BPM. Because four strip-lines feel the beam pulse, a combiner is employed for taking the sum of output signal.

case, because four strip-lines feel the beam pulse, a combiner is employed for taking the sum of output signal from all strip-lines. And there are two pick-ups as upstream and downstream for each strip-line. One is used in this measurement to obtain the signal, the other side is terminated. When the BPM is installed in the beam line, because the impedance of each cable is matched 50 ohms, one is used for beam position measurement and the other one can be used for the phase measurement.

Performances of FCT and BPM for Phase Measurement

Measured performance data of FCT and BPM using network analyser are shown in figure 6 and 7. Measured signal level at 324 MHz are -15.742 dB for FCT and -25.967 dB for BPM. If the signal loss is calculated using following formula, we can discuss the signal level.

$$\text{Signal Loss(dB)} = -20\log(V_{\text{out}}/V_{\text{in}}) \quad (3)$$

Input signal level from network analyser is corresponding to 0.5 V, and estimated signal from FCT is

82 mV and that from BPM is 25 mV. By this estimation, the signal from FCT is three times higher than that from BPM.

Three times higher frequency (972MHz) is used for the ACS accelerator cavity. Because the characteristic response of FCT is kept for the higher frequency and cut-off frequency is very high, FCT will be employed up to GHz region. But the characteristic response of BPM is periodical for the higher frequency, BPM will have a good performance at 324 MHz. If we employ the BPM for phase measurement at higher frequency, we need to consider the obtained data.

SUMMARY

We have measured the performances of FCT which is designed for energy upgraded linac. Signal level of FCT is so high to be transferred to a phase detection circuit that it achieved good performance at the acceleration frequency. And it would be used for the higher frequency, because the output level is stable up to 3.0 GHz. Signal level of BPM designed for the energy upgraded linac is also acceptable to be used for the phase measurement. But, when these monitors are compared in the phase measurement, FCT has a superiority at the acceleration frequency.

Because the width and length of strip-line is depending on the beam energy, signal level is also depending on the beam energy. Then, this consideration is not general, it can be only referred for both FCT and BPM designed for energy upgraded linac. But FCT is confirmed to be sufficiently used for the higher frequency region.

When the ACS cavities are installed for energy upgrade, both FCTs and BPMs are installed at the same time. We will confirm above performance and compare them.

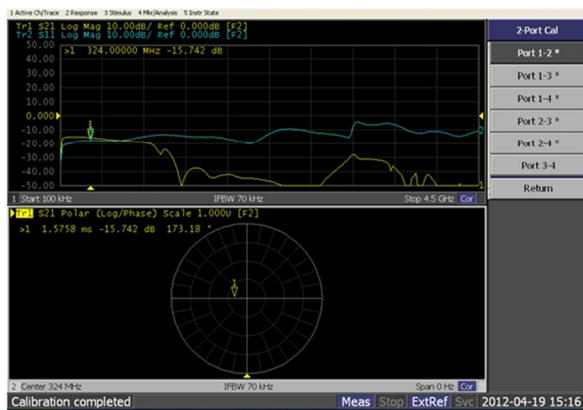


Figure 6: Measured performance of FCT using network analyzer.

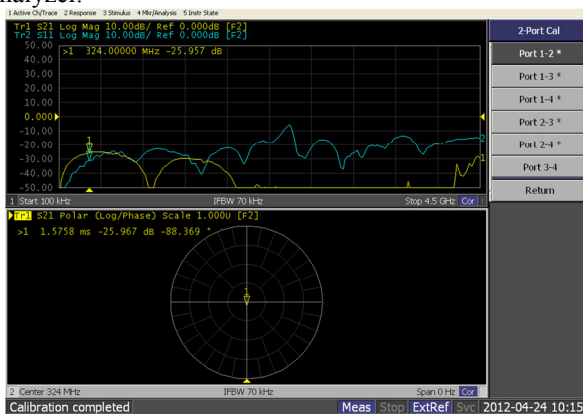


Figure 7: Measured performance of BPM. For the figure 6 and 7, in the upper box, yellow line shows the reflection of the input RF. And water color shows the characteristic response from FCT and BPM respectively. Arrow sign shows the 324 MHz which is the acceleration frequency in J-PARC accelerator cavities. In the lower box, shifted phase is measured through the FCT/BPM head, flanges, cables connectors.

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