RECALIBRATION OF A WALL-CURRENT MONITOR USING A BEAM-INDUCED FIELD FOR THE KEKB INJECTOR LINAC

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Abstract

About seventy wall-current monitors (WCMs) have been newly installed along the KEKB injector linac. The WCMs are used to measure three types of the beam currents, that is, single-bunch electron (1.3nC/bunch) and positron beams (0.64nC/bunch), and primary high-current single-bunch electron beams (10nC/bunch) in order to produce the positrons. Recalibration of the WCMs using a beam-induced field has been performed in the beam tests of the linac commissioning in December 1997, and the beam charge /bunch for the primary high-current electrons has been recalibrated. The calibration coefficients measured by the recalibration are larger than 23 % of that obtained by the bench calibration. This report presents the calibration system of the WCMs by the test bench, the recalibration method using the beam-induced fields, and the beam-test results in detail.

1 INTRODUCTION

New wall-current monitors have been developed in order to reinforce the beam-monitoring system in the injector linac for the KEKB [1,2]. The performance and characteristics of a prototype WCM were reported in detail, mainly for the beam-position dependence and the frequency response, elsewhere [3]. It is furthermore important to obtain precise information concerning the amount of beam currents in order to keep the positron production and the beam-injection rate to the KEKB rings higher. The calibration of the WCM can be generally performed by the bench test. The bench calibration is done by using fast test pulses with a width of nano seconds, and the calibration coefficients are derived from the pulse-height response of the monitor depending upon the pulse width. On the other hand, it is difficult to directly measure the calibration coefficient for the single-bunch beam with a pulse width of about 10ps, because the direct generation of such short test pulses is difficult. One of the authors (T.S.) has tentatively derived the calibration coefficients for the 10-ps pulse width from the extrapolation based on the results of the bench calibration. It is, however, not sufficiently accurate to estimate them by this extrapolation method, because the WCM has a strong frequency response for the shorter pulses. A new method for the precise beam-current calibration using a beam-induced field, that is, the fundamental longitudinal wakefield, was proposed by the authors. The new calibration depends not upon the pulse characteristics of the beam, but only upon the amount of the beam charges. The beam tests have been performed in order to check the new method and the results has been compared with the results of the bench calibration.

2 HARDWARE SYSTEM

2.1 Monitor Design

Figure 1 shows a schematic cross-sectional drawing of the monitor.

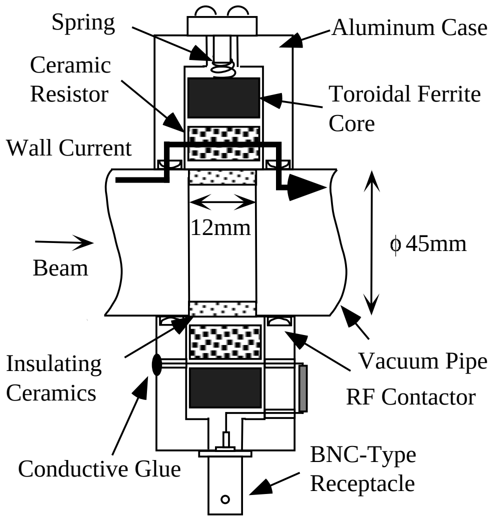

Figure: 1 Cross-sectional view of the new wall-current monitor. The induced wall current, which is spatially distributed around on the vacuum pipe, flows through the ceramic resistor at the monitor. For the sake of simplicity, the wall current is drawn by a thick solid line.

The monitor comprises a disk-shaped ceramic solid resistor, a Mn-Zn toroidal ferrite core inside an aluminum case, and four pickup BNC-type receptacles with $\pi/2$ rotational symmetry. The aluminum case needs to cover the monitor components in order not to affect the pickups by the electromagnetic noise mainly generated by high-power klystron modulators. An insulated short gap (12mm wide) in a vacuum pipe (45mmϕ) interrupts the return current on the inner surface of the pipe wall. Each component is separable into two pieces in order to be easily mounted around the pipe. The monitor is electrically in contact with the outer surface of the pipe by RF contactors. The Mn-Zn ferrite core is used to keep a high magnetic permeability (μ=4000 over a frequency range less than 1MHz) and a comparatively high Curie temperature (>140^{o}C). The resistor is made of a ceramic ($Al_2O_3+SiO_2$) mixed with carbon powders sintered at temperatures above 1000^{o}C. The resistance was selected to be 2.5Ω so as to have a good frequency response for short-pulse beams.

2.2 Data-Acquisition System

A new data-acquisition (DAQ) system has been constructed in order to get the amount of the beam-currents in real time. The software and hardware developments are described in detail elsewhere [4], and here only the hardware system is briefly summarized. Figure 2 shows a schematic drawing of the DAQ system.

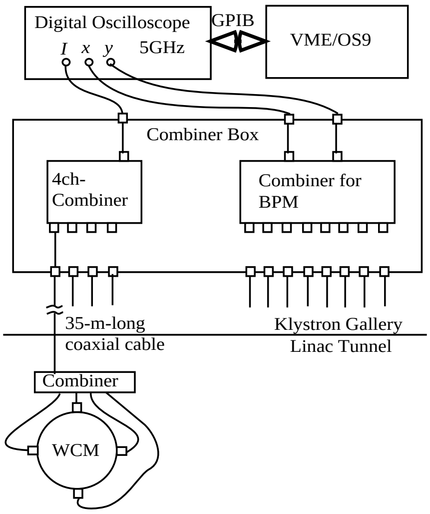

Figure: 2 New data-acquisition system of the wall-current monitors.

The four pickup signals of the WCM are combined by a signal combiner, and then the combined signal is sent up to a signal-combiner box, which combines the signal with the other WCM signals, in order to be fed to one channel of a digital oscilloscope with a sampling rate of 5 GHz. The same oscilloscope is used for the beam-position monitor system. The digital data are sent to the front-end computer (VME/OS9) through GPIB. The beam currents are calculated on this computer in real time using the calibration coefficients described later. A UNIX-based host computer is interconnected with the eighteen front-end computer through ethernet.

3 BENCH CALIBRATION

Bench calibration was performed in order to get calibration coefficients which were defined by the ratio of an unit charge to the output voltage of the WCM signal. Figure 3 shows a schematic drawing of the bench-calibration system. The monitor is installed on a 50-Ω matched-coaxial tube (calibration tube). The test pulses with the width of nano seconds are fed into the calibration tube and the output voltages of the monitor are measured by the digital oscilloscope (Tektronics TDS680B) after combining signals from the four pickups. Figure 4 shows the results of the bench calibration. It is clear that the calibration coefficients have the strong frequency dependence in the nano-second region of the pulse width. The calibration coefficient for the single-bunch beam, of which pulse width corresponds to the order of 10 ps, was estimated using an extrapolation of the straight line calculated by the least-squared fitting procedure. It is not self-evident whether or not this extrapolation is correct because the frequency response of the monitor is not clear in such a short pulse. We can derive a correct single-bunch calibration coefficient from a model calculation of the monitor; however, in practice, it is difficult to get accurately some parameters, for example, capacitance of the insulated gap and precise frequency response of the ferrite core, etc.. This is the reason why the recalibration is necessary.

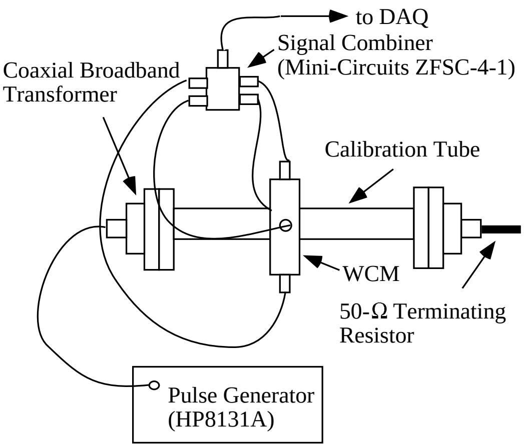

Figure: 3 Bench calibration system using a 50-Ω matched-coaxial calibration tube.

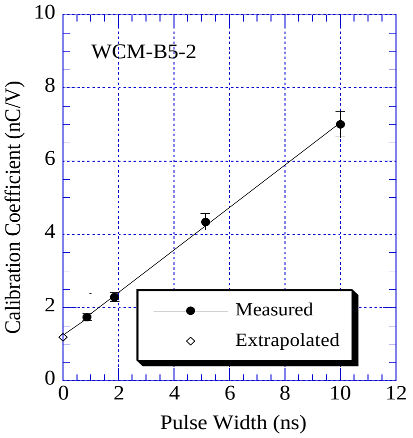

Figure: 4 Pulse-width dependence of the calibration coefficients measured by the bench calibration.

4 RECALIBRATION USING A BEAM-INDUCED FIELD

The basic conception of the recalibration using a fundamental beam-induced field is that a square of the amount of the beam charge is proportional to a power amount generated by the beam-induced field in an accelerator tube [5]. The beam-induced power P is represented as follows:

$$P = (eN_b)^2 \int_{-\infty}^{\infty} \lambda(\tilde{z})d\tilde{z} \int_{\tilde{z}}^{\infty} \lambda(z)W_{\parallel}(z-\tilde{z})dz, \int_{-\infty}^{\infty} \lambda(z)dz = 1,$$

where e is the charge of a particle, N_b the total number of particles in the bunch, $\lambda(z)$ the normalized linear distribution of a beam to the beam axis, and $W_{||}$ the longitudinal wake function. If the fundamental (2856 MHz in our accelerator tube) beam-induced fields generated by both the single-bunch and nano-second-pulse beams are precisely measured, assuming no variation of the bunch distribution, the recalibration for the single-bunch beam can be performed by using the proportional relation of the square-root power ratio, that is, $Q_s=\sqrt{(P_s/P_p)}\times Q_p$, where P_s and P_p are the measured powers for the single-bunch and pulsed beam, respectively, and Q_s and Q_p are the beam charges of the single-bunch and of the pulsed beam, respectively. Figure 5 shows a schematic drawing of the measurement system of the beam-induced field. The beam-induced field can be measured by a bethe-hole coupler [6] attached to a waveguide coupled to an output port of a 2-m-long accelerator tube. The pickup power is send to a subcontrol room through a 37-m-long coaxial cable, and is detected by a peak-power measurement system.

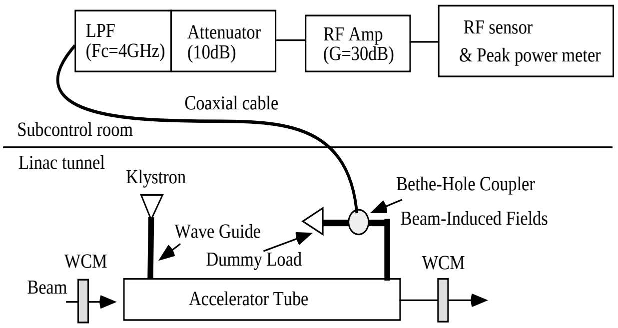

Figure: 5 Recalibration system of the WCM using the beam-induced field.

5 BEAM-TEST RESULTS

The single-bunch electron beams can be generated by the new pre-injector [7] which is composed of two sub-harmonic bunchers, a prebuncher and a buncher. The electron gun can generate the amount of the beam charge of about 18 nC/pulse, and the single-bunch electron beams greater than 10nC/bunch were stably accelerated from the outlet of the buncher until to the end of the sector B without any observable beam loss. The beam energy was about 1.5 GeV at this end. The beam tests for the single-bunch electron beams and several pulsed beams with the width of 2 (short), 5 (long1) and 10 (long2) ns have been performed in order to check the new method. The obtained beam charges/bunch were summarized in table 1. The beam-induced fields were measured by feeding the signals picked up from a bethe-hole coupler mounted in the acceleration tube B5-2 which is located at a distance of about 93 m after the electron gun. The two WCM signals (B4-2 and B5-2) were simultaneously measured, which were installed before and behind this accelerator tube, respectively. The power of the beam-induced field was stably measured by the peak-power meter within the error of 1 %. Figure 6 shows the result of the beam tests. A solid line shows the average beam charge measured by the nano-second-pulse beams. The difference of the beam charge based on the recalibration was 23 % compared with that estimated by the bench calibration.

Table 1 Recalibration result for the 10nC beam.

	single	short	long1	long2
pulse width (ns)	16ps	2.1	5	10
power (mW)	49.5	47.3	55.8	13.7
power ratio	-	1.02	0.942	1.90
WM-B4-2 (nC)	10.9	13.0	13.3	14.2
WM-B5-2 (nC)	10.4	13.0	13.2	14.4

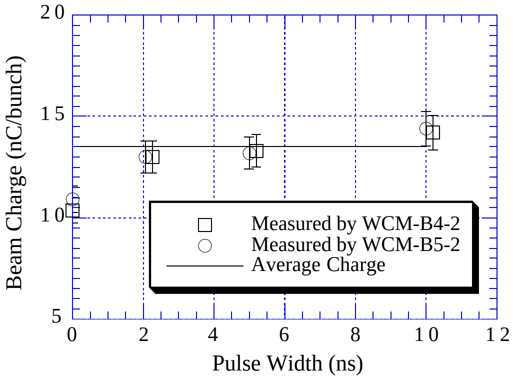

Figure: 6 Recalibration result by using the beam-induced fields.

6 CONCLUSIONS

The new wall-current monitors has been recalibrated by using the beam-induced fields for the primary high-current single-bunch electron beams. The calibration coefficient measured by the recalibration was larger than 23% of that given by the bench test. It is very useful method for the beam-current recalibration because the stability of the power measurement is very well within the error of 1 %.

7 ACKNOWLEDGMENTS

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