Nuclear Instruments and Methods in Physics Research A 764 (2014) 7–10

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Development of a current monitor using a negative impedance circuit

Tetsuro Kurita

The Wakasa Wan Energy Research Center (WERC), 64-52-1, Nagatani, Tsuruga, Fukui, Japan

ARTICLE INFO

Article history:
Received 23 January 2014
Received in revised form
18 June 2014
Accepted 7 July 2014
Available online 15 July 2014

Keywords:
Beam monitor
Current monitor
Synchrotron
NIC
Negative impedance circuit

ABSTRACT

I developed a beam current transformer (CT) for monitoring the beam of a slow-cycling accelerator. The beam monitor is a new type of CT that measures the average current of a circulating beam using a negative impedance circuit (NIC). Adding an NIC can extend the low-frequency cutoff of a CT down to 0 Hz (Ninomiya et al., 2006 [1]). This report presents the detail of our proposed beam-monitoring system. The measurable band width of the CT is 30 kHz. The stability of the droop time constant of the square pulse response is ~2%/s. This beam monitor was developed for the synchrotron at the Wakasa–Wan Energy Research Center (WERC) and is currently installed there.

1. Principle

A normal current transformer (CT) consists of a primary winding, a toroidal core, and a secondary winding. For the CT of a beam current monitor, the circulating beam acts as the current in the primary winding and produces a magnetic field in the core. This field induces a current in a pickup coil, which is the secondary winding.

In general, CTs have a low-frequency cutoff ω_L given by the ratio of the load resistance R, which includes the resistance of the pickup coil, to the self-inductance L; $\omega_L = R/L$.

One of the methods to measure DC component of the beam current is extending the low-frequency cutoff by minimizing R. To minimize R, HEREWARD transformer uses the low input impedance characteristic of an operational amplifier circuit with a feedback loop coil [2]. However, in this case, R (and therefore ω_L) remains finite. A feedback technique, which cancels the flux in the core via another feedback winding, can also decrease ω_L. In this case, the pickup coil has 1000 windings to obtain a sufficiently low-frequency cutoff (e.g. 5×10^{-3} Hz) [3].

In the present case, a negative impedance circuit (NIC) was employed to obtain the perfect cancellation of the resistance R. Fig. 1 shows the principle of our beam monitor. The input impedance Z_{in} of the NIC, which is based on an operational amplifier (see Fig. 1), is given by

$$Z_{in} = -R\frac{R_i}{R_f}. \quad (1)$$

By adjusting Z_{in}, the resistance R_1 of the pickup coil can be canceled. The CT is sensitive to the DC component of the circulating beam.

DCCTs that use magnetic modulation [4] (i.e., parametric DCCTs) are widely used for measuring the DC component of the circulating beam. The parametric DCCT consists of at least three toroidal cores. Our beam monitor, with a single toroidal core, is good for small synchrotrons that do not provide enough space to insert elements.

2. System overview

A FINEMET (FT-3M by Hitachi Metals, Ltd.) was used for the magnetic core of the CT. The FT-3M has a large permeability, which makes for a pickup coil with a large inductance. Because of the finite temperature coefficient of the coil resistance, the large inductance helps for adjusting the resistances in the NIC and reduces drift in the droop time constant. The outer and inner diameters of the core are 215 mm and 158 mm, respectively, and the thickness is 25 mm. The core is divided into two pieces so that it can be installed without breaking the vacuum of the beam duct. With 110 windings in the pickup coil, its inductance is approximately 80 mH.

A droop rate of the square pulse response is given by R/L. To obtain the droop rate under a few percent with L=80 mH, the cancellation accuracy of the coil resistance R should be under a few mΩ.

An overview of the practical monitor system is shown in Fig. 2. The pickup coil installed in the synchrotron is connected to the

E-mail address: tkurita@werc.or.jp

http://dx.doi.org/10.1016/j.nima.2014.07.020
0168-9002/

frontend module which consists of an NIC and a pre-amplifier. The current signal from the frontend module is transmitted to the control room. This signal is amplified by the control module and is input into the digital signal processor (DSP) module. In the DSP module, the signal proportional to the particle number is obtained by dividing the current signal by the revolution frequency.

The current sensitivity of the frontend module is about 0.1 V/50 mA. The gain of the control module is about 10 times. In the DSP, the current sensitivity is adjusted to 1 V/50 mA. Also the sensitivity of particle number is adjusted to $1\ \mathrm{V}/5\times10^{10}$ ppp. The measurement of current sensitivity was performed by inputting test signals into an additional single-turn winding of the pickup coil.

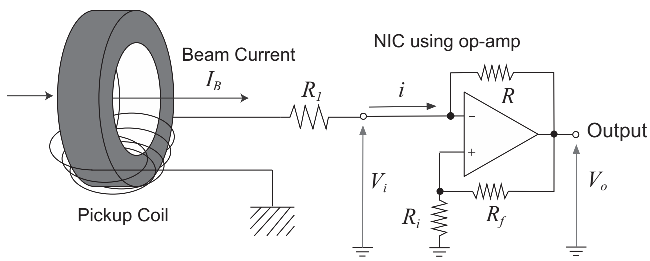

Fig. 1. Principle of current monitor using negative impedance circuit.

The signal from the pickup coil is induced not only by the magnetic flux of the beam current but also by leakage magnetic flux from synchrotron magnets near the CT, which varies with time. To reduce the influence of the leakage magnetic flux, the pickup coil is enclosed in a magnetic shield, however, the magnetic flux of about 5×10^{-5} T remains near the pickup coil. The amplitude of the signal because of the leakage magnetic flux is equivalent to about 0.5 mA of the beam current, which is not negligible typical beam current of about 10 mA in our synchrotron. The signal induced by the leakage magnetic flux is recorded in the memory of the DSP module prior to beam injection. The recorded signal is then subtracted from the current signal when the beam is injected.

Because of the temperature coefficient of the operational amplifier, the output of the NIC is sensitive to temperature changes in the environment. To stabilize the offset voltage, the output voltage is sampled when the beam current is zero. The sampled voltage is fed back to the offset-adjustment terminal of the operational amplifier in the NIC. Also the frontend module is contained in a temperature-controlled chamber for further stabilization. By enclosing the frontend module in this chamber, the fluctuation of the offset voltage of the output of the frontend module decreases from tens of mV/10 s, which is equivalent to several mA of the beam current, to 10 mV/10 s or less.

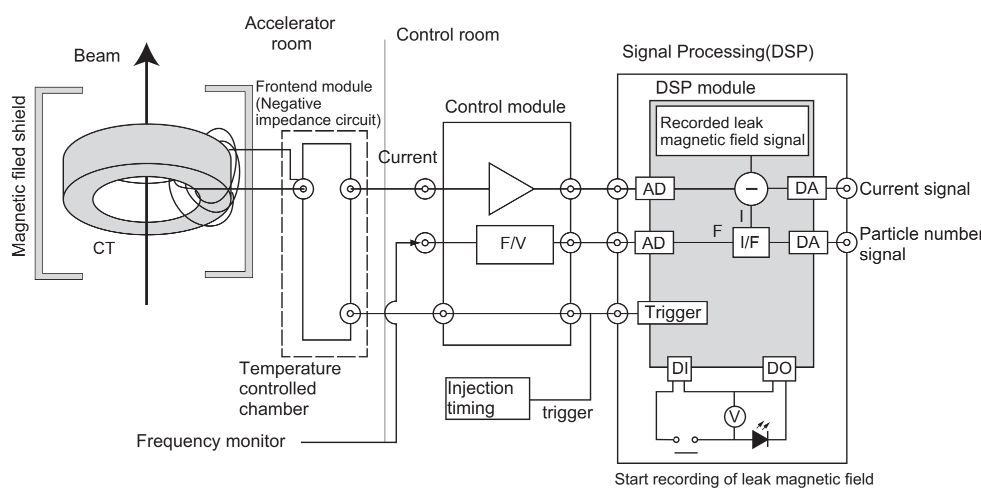

Fig. 2. Overview of beam-monitoring system.

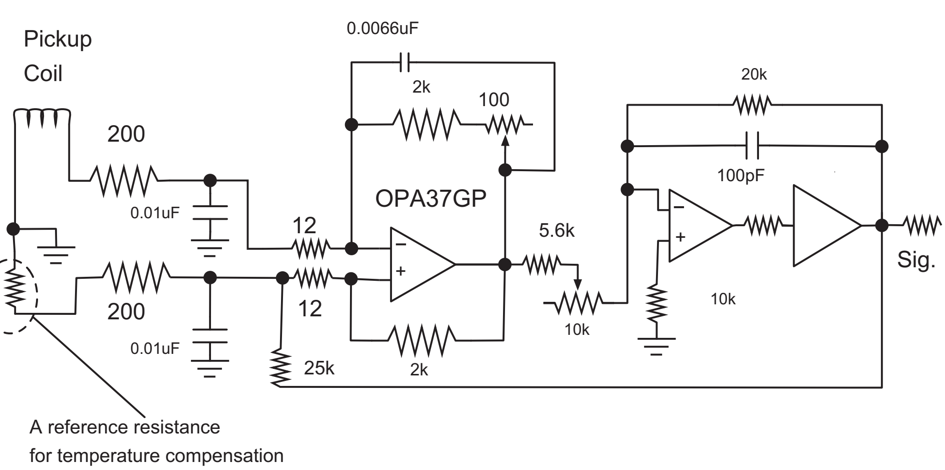

Fig. 3. Circuit of frontend module.