MEASUREMENT OF THE BEAM CURRENT IN THE COMPACT EXACT CIRCULAR STORAGE RING BASED ON THE CONSERVATION OF RF POWER

I. Sakai[a], Y. Yamamoto[b], and H. Iwasaki[a]
[a] Faculty of Science and Engineering, and [b] Synchrotron Radiation Center,
Ritsumeikan University, Kusatsu, Shiga 525-8577, Japan

Abstract

AURORA is an electron storage ring of the weak focusing type composed of a single body superconducting magnet and does not allow to adopt a conventional method for the measurement of stored beam current. A new method has been developed, in which the power conservation in the RF accelerating system and the normalized load impedance are taken into account and combined to a single equation. By measuring the beam loading through the radiation power measurement at various magnitudes of stored beam current and referring to the equation, absolute value of the beam current can be obtained.

1 INTRODUCTION

The synchrotron radiation source AURORA at Ritsumeikan University is of the weak focusing type composed of a single body superconducting magnet which produces an axially symmetric magnetic field as high as 3.8 T [1-3]. Figure 1 shows the cross section of the ring containing the RF accelerating cavity in the electron orbit of the radius of 0.5 m. The basic machine parameters are listed in Table. 1. With this ring, there is a difficulty for measuring stored beam current: the strong magnetic field does not allow to adopt a conventional method using a DC current transformer. To avoid the difficulty a practical, simple method has been adopted, in which the intensity of the radiation emitted from the ring is measured using a photomultiplier-tube. In order to find a conversion factor of the value of photocurrent into that of stored beam current, the intensity of the radiation from a single electron is measured in the operational mode of extremely low beam current and it is used in the region of high stored beam current. However, there remains a problem whether the proportionality holds in a wide range of the radiation intensity. An alternative method is developed, in which the conservation of RF power in the ring is taken into account; the simple structure of the ring allows the conservation to hold in a simple way. Principle of the method and results of measurement are described in the following.

2 PRINCIPLE OF THE METHOD

Figure 2 shows the power flow in the RF accelerating system of the ring. Conservation of the RF power is

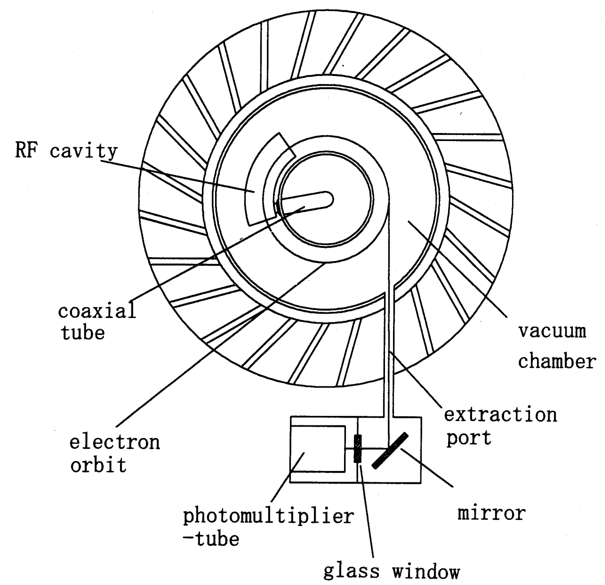

Figure 1 : Cross section of the AURORA ring showing the electron orbit and the RF cavity. The RF power is transmitted from below through the coaxial tube. Photomultiplier-tube is used to measure the power of the radiation beam.

expressed in the following form

$$P_i = P_b + P_c + P_r + P_e, \qquad (1)$$

where P_i is the supplied power, P_b the beam loading, P_c the wall loss of the RF cavity, P_r the reflection loss of the RF cavity, and P_e the transmission loss. Equation (1) holds for any values of stored electron beam current I_b at a fixed electron beam energy E. P_i and P_r can be measured using the power meter of the ring. P_e is, strictly speaking, dependent on the supplied power, but can be treated as a constant for the AURORA ring [4].

According to the theory of microwave transmission, the normalized load impedance of a transmission system Z/Z_0 is given by $\left(1+\sqrt{P_r/P_i}\right)/\left(1-\sqrt{P_r/P_i}\right)$. On the other hand, Z/Z_0 is proportional to P_c/P_i [5], so that the three quantities in eq. (1) are related to each other. The relation can be written in the form

$$P_c = \frac{P_i}{\beta}\frac{\left(1+\sqrt{P_r/P_i}\right)}{\left(1-\sqrt{P_r/P_i}\right)}, \qquad (2)$$

where β is the proportionality constant between Z/Z_0 and

Table 1 Parameters of the AURORA ring.

Electron energy	0.575 GeV
Circumference	3.14 m
Magnet structure	Single body, weak focusing
Bending radius	0.5 m
Bending field	3.8 T
Field index	0.364
Initial stored current	300 mA
RF frequency	190.86 MHz
RF voltage	120 kV
Harmonic number	2
Horizontal tune	0.797
Vertical tune	0.604
Vertical beam size	10.5 (140*) μm
Horizontal beam size	929 (921*) μm
Bunch length	52 mm
Beam life time**	45 (500*) min.

* the value in the usual operation mode
** measured values at the beam current of I_b = 200 mA

P_c/P_i. β is nothing but the coupling coefficient at the matching section [5].

If the power of the beam loading P_b is converted to the power of radiation, it is written as $P_b = pn$, where p is the radiation power emitted from a single electron of energy E circulating in the orbit of radius ρ. According to the theory of synchrotron radiation, p is expressed as

$$p = \frac{e^2}{3\varepsilon_0\rho}\left(\frac{E}{m_0c^2}\right)^4, \tag{3}$$

e, m_0, c and ε_0 being the standard quantities used in the electron beam dynamics [6]. n is the effective electron number given by the product of the number of electrons contained in a single bunch, the harmonic number, and the revolution frequency. The stored beam current is given as $I_b = en$.

When the radiation power is measured with the help of, for example, a photomultiplier-tube, its out-put 'V' is proportional to pn. Defining the proportionality constant as α,

$$\alpha V = pn. \tag{4}$$

Using eqs. (2) and (4), eq. (1) is rewritten as

$$P_i = \alpha V + \frac{P_i}{\beta}\frac{\left(1+\sqrt{P_r/P_i}\right)}{\left(1-\sqrt{P_r/P_i}\right)} + P_r + P_e. \tag{5}$$

Putting $\varphi = P_r + P_e$, $\Phi = P_i\left(1+\sqrt{P_r/P_i}\right)/\left(1-\sqrt{P_r/P_i}\right)$, dividing the both sides in eq. (5) by V, and rearranging the terms we have

$$\frac{(P_i - \varphi)}{V} = \alpha + \frac{1}{\beta}\frac{\Phi}{V}. \tag{6}$$

If P_i, φ, Φ and V are measured at various magnitudes of the stored beam current, and $(P_i - \varphi)/V$ is plotted against Φ/V, a linear relation is obtained. α and β are given as the intersection of the straight line with the ordinate and the reciprocal of the gradient of that line, respectively. From α thus obtained, the absolute value of I_b is given as

$$I_b = e\alpha V/p. \tag{7}$$

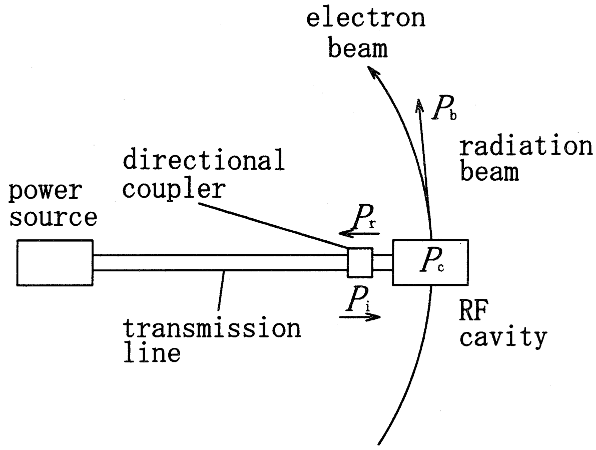

Figure 2: Power flow in the accelerating system of the AURORA ring. P_i is the supplied power, P_b the beam loading, P_c the wall loss of the RF cavity, P_r the reflection loss of the RF cavity, and P_e the transmission loss.

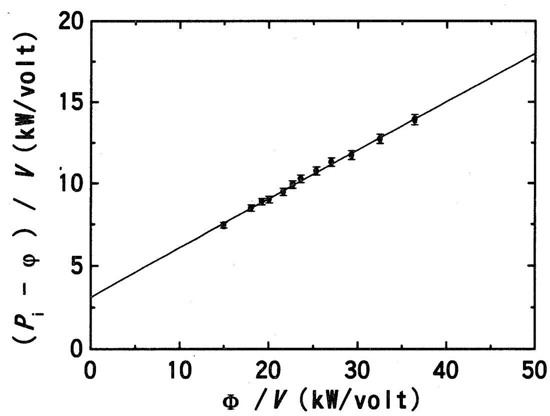

Figure 3: Plot of $(P_i - \varphi) / V$ against Φ/V with changing the magnitude of stored beam current. A linear relation holds, showing that the assumption on the conservation of the RF power is correct. Magnitudes of error are indicated by the error bar. The error in Φ/V is smaller than the diameter of the solid circle.

3 EXPERIMENTALS AND RESULTS

Experiment was carried out in the usual operation mode of the ring. RF power propagates along the transmission line made of a coaxial tube (WX 120 D), as seen in Fig. 2. P_i and P_r were measured using the RF power meter at the position of the directional coupler. Typical values of P_i and P_r are 17.0 kW and 1.36 kW, respectively, at the maximum stored beam current. P_e is 0.5 kW [4]. For the AURORA ring, p is calculated to be 3.098×10^{-18} kW for E = 0.575 GeV and ρ = 0.5 m.

The radiation emitted from the electron beam was taken out through the extraction port and introduced into the photomltiplier-tube (HAMAMATSU R268), (Fig. 1). The out-put V was measured in units of volt.

4 DISCUSSION

The results described well show that conservation of the RF power holds surprising well in the AURORA ring and, taking advantage of this fact, the conversion factor α has been determined. There may be another way of estimating P_b. For example, if it is completely converted into a thermal energy, I_b will be obtained from the temperature increase in the radiation absorber without recourse to the power conservation relation. Comparison of the results of the present method with this photocalorimetric method will be of interest, and attempts are being made to search an appropriate material for the radiation absorber.

ACKNOWLEDGMENT

We wish to thank Mr. M. Yamamoto for his assistance.

REFERENCES

[1] N. Takahashi, Nucl. Instrum. Methods A **24/25**, 425 (1987).

[2] H. Iwasaki, Y. Nakayama, K. Ozutsumi, Y. Yamamoto, Y. Tokunaga, H. Saisho, T. Matsubara and S. Ikeda, J.Synchrotron Rad. **5**, 1162 (1998).

[3] Memoirs of the SR center, Ritsumeikan university No. 3, 2001.

[4] Y. Toba and K. Ohtomo, Sumitomo Heavy Industries TECHNICAL REVIEW, vol. 39 No. 116, 24 (1991).

[5] Y.Yamazaki, OHO'84–*Proc. High Energy Accelerator Seminer*–, (KEK, Tsukuba, 1984), IV pp. 1-30.

[6] S. Krinsky, M.L. Perlman and R.E. Watson, *Handbook on Synchrotron Radiation.* Vol. 1. edited by E.E. Koch, (North-Holland Publishing Company,1983), pp.73-77.