Design of a Stripline Monitor for an Orbit Feedback System

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Abstract
To avoid degradation of accuracy due to insufficient directivity of a stripline monitor for an orbit feedback system, we have worked out two countermeasures. First, the location of the monitors were carefully chosen. Second, we designed the structure of the monitors so that the characteristic impedance of the dipole mode matches to 50 Ω. Details of these countermeasures are decribed.

I. INTORODUCTION

In the future B Factory machine, an orbit feedback system is vital to keep two beams in optimum collision, since the two beams circulate in separate beam pipes. Requirements to the system and a basic design concept are described in a previous paper[1]. In this paper we concentrate on some detailed design considerations on a stripline monitor for the system. Before getting in touch with the main subject, we summarize the basic scheme and parameters of the system in the following:

(1) A pair of stripline monitors are installed in the interaction region between which the interaction point is sandwiched. These monitors detect the orbit offset of the two beams at the collision point and the crossing angle by measuring bunch positions of the two beams before and after collision. (2) Considering expected speed of the orbit change, the system should work at more than 1 Hz. Then we do not need a single pass monitor system. We can make use of the same type of the signal processor which was developed for the orbit measurement of the TRISTAN. (3) In the second step of our B Factory, we will fill all the RF buckets with a beam. Then, detection frequency must be the RF frequency times some integer number. In the present design, we chose the RF frequency itself for the detection frequency. (4) Required accuracy of the monitors is 5 micron at the bunch current of 0.2 mA. (5) The system must be able to measure the orbits of the two beams separately.

To meet the last requirement, we have adopted a stripline monitor for the system. Directivity of the monitor can help us to distinguish a signal of one beam from that of the other. The length of the stripline was chosen as 15 cm to maximize monitor sensitivity at the detection frequency of 508 MHz. Poor directivity can affect accuracy of position measurement. The main subject of this paper is how to avoid this degradation of accuracy due to insufficient directivity. For this purpose we have worked out two countermeasures. In the following two sections, we describe details of these countermeasures.

II. CHOICE OF MONITOR LOCATION

Let us consider the following simplified situation as is shown schematically in Fig. 1. Only one bunch is circulating both in an electron and in a positron rings. When one bunch, say electron bunch, reaches the upstream end (1) of the monitor, the other positron bunch is at the position the distance of which from the downstream end (2) is S. The length of the stripline electrode L is chosen as 15 cm as is mentioned above. The voltage signal obtained from the upstream (for electron) end (1) is expected to have a pattern depicted in Fig. 2. The left two pulses come from the electron and if the monitor has perfect directivity, no other signals appear. With imperfect directivity at least two more pulses induced by the positron appear. The third pulse from the left arises due to an imperfect cancelation between the image current of the positron bunch and the voltage wave which was l aunched at the upstream (for positron) end (2) and propagated through the transmission line formed by the electrode and the vacuum chamber. The rightmost pulse is induced due to the reflection of the signal observed at the upstream end (2) in the time interval $\tau_0 = 2L/c$ after the positron bunch passed by this end. We ignored reflections more than twice. The signal pattern in Fig. 2 is expressed as

$$V(t) = K(I(t) - I(t-\tau_0) - \alpha R I(t-t_0) + \alpha R I(t-t_0-\tau_0)) \qquad (1)$$

Here, K is a factor determined by the geometry of the stripline, $I(t)$ expresses a longitudinal charge distribution of the bunch and R is the ratio between the bunch currents of the electron and the positron. And α denotes directivity which is defined as the ratio between the pulse height from the electron and that from the positron, when the bunch currents are equal to each other. We are interested in the Fourier component of this signal at the detection frequency. Needless to say, the same voltage pattern is repeated in every period of the revolution time T_0. Then $V(t)$ can be expanded with a Fourier series as

$$V(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n cos(n\omega_0 t) + b_n sin(n\omega_0 t)) \qquad (2)$$

$$a_n = \frac{1}{T_0}\int_0^{T_0} V(t)cos(n\omega_0 t)dt \qquad (3)$$

$$b_n = \frac{1}{T_0}\int_0^{T_0} V(t)sin(n\omega_0 t)dt, \qquad (4)$$

where ω_0 is $2\pi/T_0$. We choose the origin of time so that the Fourier component of $I(t)$ at the detection frequency has only a cosine component. We designate this component as $I(\omega_d)$, where ω_d is the (angular) detection frequency. Using $I(\omega_d)$ the Fourier components of $V(t)$ at ω_d are given by

$$a_d = \frac{2KI(\omega_d)}{T_0}(1 - \alpha R cos(\omega_d t_0)) \qquad (5)$$

$$b_d = \frac{-2KI(\omega_d)}{T_0}\alpha R sin(\omega_d t_0). \qquad (6)$$

Here we used the relation $cos(\omega_d \tau_0) = -1$. Then the oscillation amplitude at ω_d is given by

$$V_d = \frac{2KI(\omega_d)}{T_0}\sqrt{1 - 2\alpha R cos(\omega_d t_0) + (R\alpha)^2}. \qquad (7)$$

If we know the value of α (and the ratio of the bunch current of the electron and the positron), we can avoid the effect from the counter-rotating beam completely. Lacking those knowledges, we can decrease the effect to the order of $O(\alpha^2)$ by selecting the location of the monitor so that $cos(\omega_d t_0)$ is zero. This condition can be satisfied by choosing the distance between the center of the monitor and the collision point ($L_{M.IP}$) so that

$$L_{M.IP} = N \times 30cm + 15cm, \qquad (8)$$

where N is some integer.

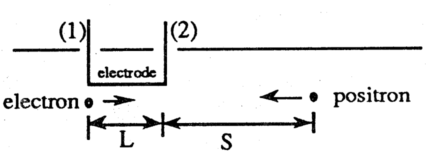

Figure 1: Schematic view of the stripline monitor

In the above discussion, we assume that there is only one bunch in each ring. In reality, the number of bunches amounts to the order of thousand. However, the above discussion does not change significantly with a multibunch beam as far as the detection frequency is chosen as the RF frequency. Let us define an effective number of bunches N_b as the ratio between the total electron beam current and the bunch current in the above discussion. we also define $\tilde{R}$ as the ratio of the total beam current of the electron and the positron. The only change in the above equations we should make is that $I(\omega_d)$ should be replaced by $N_b I(\omega_d)$ and R by $\tilde{R}$. Therefore, the essential part of the discussion is preserved in the multibunch scheme.

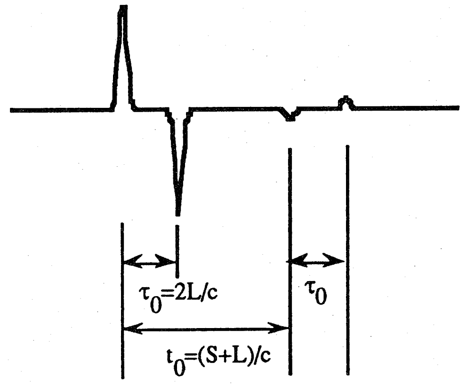

Figure 2: Voltage pattern from the stripline monitor

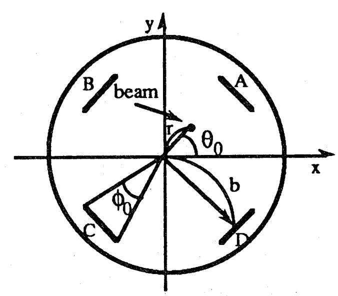

Figure 3: Cross sectional view of the stripline monitor

III. IMPEDANCE MATCHING

The next step is to get as good directivity (or a small value of α) as possible. For this purpose it is important to match the characteristic impedance of the stripline to that of the transmission line (50 Ω). The characteristic impedance is defined as the ratio between the current traveling on the electrode and the voltage of the electrode against the chamber accompanied by a TEM wave. The problem to calculate the impedance can be reduced to solve the Laplace equation in the two dimensions. This kind of problem can be dealt with computer codes such as "Poisson". However, there is a complication in the calculation connected to the interference among the electrodes. In the following we mention briefly the method to deal with the interference.

A. Mode expansion of the signal

Fig. 3 shows the schematic view of the monitor. Here, we assume that the cross section of the chamber is circular and four identical electrodes are installed symmetrically so that the monitor has a four-fold rotational symmetry in respect to the central axis. The angle between the centers of the electrodes and the x or y axis are 45 degree. The azimuthal image current density distribution on the electrode induced by beam current I_b is [2]

$$I(\theta) = -\frac{I_b}{2\pi}\left(1 + 2\sum_{m=1}^{\infty}(\frac{r}{b})^m cos(m(\theta - \theta_0))\right). \quad (9)$$

Here, θ and θ_0 denote the azimuthal positions of the electrodes and the beam, respectively. And r is the radial beam position. If we ignore the components more than $m = 2$, the integrated image current on the electrodes A, B,C and D are given by

$$\begin{pmatrix} I_A \\ I_B \\ I_C \\ I_D \end{pmatrix} = -\frac{I_b\phi_0}{2\pi}\times$$

$$\left[\begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \end{pmatrix} + \frac{2\sqrt{2}sin\frac{\phi_0}{2}}{b\phi_0}\left[\Delta x\begin{pmatrix} 1 \\ -1 \\ -1 \\ 1 \end{pmatrix} + \Delta y\begin{pmatrix} 1 \\ 1 \\ -1 \\ -1 \end{pmatrix}\right]\right],$$

where, $\Delta x = rcos\theta_0$ and $\Delta y = rsin\theta_0$. And ϕ_0 is an angle subtended by each electrode. The first term in the right hand side is called the monopole mode, while the other two are the dipole modes. From this equation, we obtain the beam position as

$$\Delta x \simeq \frac{\phi_0 b}{2\sqrt{2}sin\frac{\phi_0}{2}}\frac{I_A - I_B - I_C + I_D}{I_A + I_B + I_C + I_D} \quad (10)$$

A similar relation is valid for the vertical position detection. As is understood from the above discussion the dipole modes are responsible for the position detection and the monopole mode does not affect the measurement almost at all. Then, we should make efforts to match the dipole mode impedance to 50 Ω.

B. Calculation of the impedance

When there are couplings among the electrodes, the impedance Z takes a matrix form;

$$\begin{pmatrix} V_A \\ V_B \\ V_C \\ V_D \end{pmatrix} = Z\begin{pmatrix} I_A \\ I_B \\ I_C \\ I_D \end{pmatrix},$$

where the currents and the voltage are those accompanied by a TEM wave. With vectors defined as $\vec{x}_m = (1,1,1,1)$, $\vec{x}_{dh} = (1,-1,-1,1)$ and $\vec{x}_{dv} = (1,1,-1,-1)$, the impedances of the monopole mode and the dipole mode (Z_m and Z_d) are defined as

$$Z_m = \frac{1}{4}\vec{x}_m Z(\vec{x}_m)^t, \quad Z_d = \frac{1}{4}\vec{x}_{dh} Z(\vec{x}_{dh})^t = \frac{1}{4}\vec{x}_{dv} Z(\vec{x}_{dv})^t.$$

By using the code "Poisson", the electric field can be calculated with given voltages of the electrode. Assuming a TEM wave, the magnetic field in the chamber and then the current going through the electrodes can be obtained from the electric field. In this way, we can calculate the impedances of each mode for a given geometry. In a trial and error method, we can determine the geometric structure of the stripline. To make sure if the method presented above works well or not, we designed a test monitor. We chose the diameter of the chamber, the distance of the electrode surface from the chamber center, the electrode width and the electrode thickness as 92.0mm, 38.3mm, 19mm, and 2mm, respectively as is shown schematically in Fig. 4. A calculated impedance of the dipole mode was 49.9 Ω, while that of the monopole mode was 52.5 Ω. The test monitors are now under construction. A bench test of the monitor is going to be done shortly. We have a plan to do a beam test in the TRISTAN Main ring this autumn.

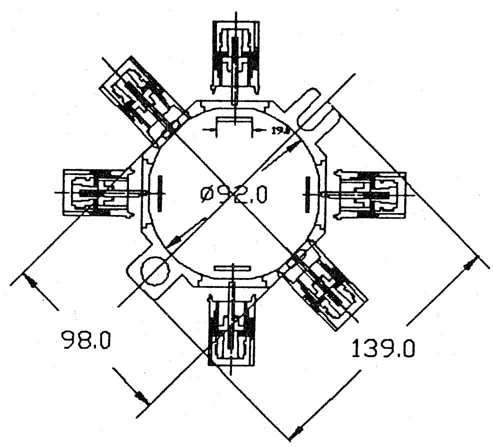

Figure 4: Geometry of a test monitor

IV. SUMMARY

To avoid degradation of accuracy due to insufficient directivity of a stripline monitor, we have worked out two countermeasures. First, the location of the monitors were carefully chosen so that voltage signals from electrodes at the detection frequency are not disturbed very much by the counter-rotating beam. Second, we designed the structure of the monitors so that the characteristic impedance of the dipole mode matches to 50 Ω taking the coupling among the electrodes into account. According to the above guideline, we designed a test monitor. A bench test and a beam test of the test monitor will be done shortly.

V. REFERENCES

[1] Y. Funakoshi, KEK Preprint 92-113 (1992).
[2] R. E. Shafer, IEEE Trans. on Nucl. Sci. NS-32, 1933 (1985).