Observation and Analysis for Motions of Trapped Microparticles in the TRISTAN Accumulation Ring

Hiroshi Saeki*, Takashi Momose**, and Hajime Ishimaru
National Laboratory for High Energy Physics
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

Abstract

Signals of high-energy bremsstrahlung in the TRISTAN accumulation ring was observed with lead-glass counters, accompanied by a sudden decrease in the electron beam lifetime which occurred due to microparticle trapping in the electron beam. The observation showed a trapped microparticle made a periodic oscillation; the period was 1s. The observation coincides with the result based on our newly developed theory for vertical oscillation of a trapped microparticle. Furthermore, the calculated variation in the beam lifetime also coincides with the actual variation in the beam lifetime.

I. INTRODUCTION

Observations of microparticle trapping phenomena in the TRISTAN accumulation ring with lead-glass counters have been carried out previously. It was found that microparticles in the beam chamber were actually trapped in the electron beam.[1-2] From signals of bremsstrahlung detected during microparticle trapping, the results of our theory developed giving the motion of a trapped microparticle and results of observations trapped microparticle motions with a wire simulating the electron beam, we expect that a trapped microparticle makes a periodic oscillation around the electron beam, as shown in References [2] and [3].

But it is difficult to find precisely the motion of a trapped microparticle using the complicated theory based on many assumptions. Therefore, we carried out simple theoretical analysis for a trapped microparticle motion, using our newly developed theory based on a vertical oscillation only. We also compared results of the observation and the analysis.

II. OBSERVATION OF TRAPPED MICROPARTICLE MOTIONS IN THE TRISTAN ACCUMULATION RING

Motions of trapped microparticles in the ring were observed with lead-glass counters, as shown in Reference [2]. If microparticles are trapped in the electron beam, signals of high-energy bremsstrahlung can be detected at the interacting location with intensity much greater than that of residual gases.

A. Measuring Instruments to Observe Motions of Trapped Microparticles

Four lead-glass counters were used to observe bremsstrahlung. High-energy bremsstrahlung generated at each source area corresponding to three bending magnets is detected with each of the three lead-glass counters. The other one is set at a straight chamber.

The bremsstrahlung is detected with the lead-glass counter set behind plates made of lead (thickness 10 mm). Each lead-glass counter is constructed with a lead-glass block (360 mm × 120 mm × 100 mm) and a photomultiplier. The lead-glass counters are shielded with lead blocks (thickness 100 mm) except for the detecting slit. The amplified signals from the lead-glass counters are transmitted to a digital storage oscilloscope synchronized with bunch signals from a single bunch electron beam as it passes a position monitor.

B. Observations of High-energy Bremsstrahlung Accompanying a Sudden Decrease in the Beam Lifetime

If a trapped microparticle makes a periodic oscillation, it is expected that signals of high-energy bremsstrahlung corresponding to the motions of the trapped microparticle could be observed.

Figure 1 shows signals from the lead-glass counter at the straight chamber during microparticle trapping. The initial injected beam current of the single-bunch electron beam was 30 mA and the beam energy was 6.5 GeV. The beam current suddenly decreased at 25 mA. The beam lifetime also decreased from 125 min to 72 min and did not recover. At the beam current of 21 mA, signals of high-energy bremsstrahlung synchronized with the bunch signals from the electron beam and signal of 0.15 ms duration were also observed with the other counters. From results of test of lead-glass counters using a internal target, it was found that the voltage of signals detected with the lead-glass counters was 15-17 times higher than that of an electron with 6.5 GeV. Such signals can be detected very little, during a sudden decrease in the beam lifetime.

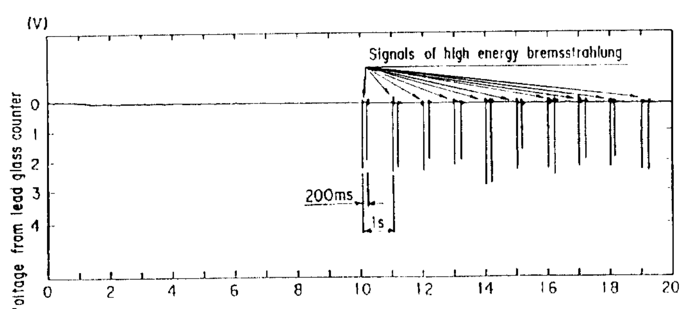

Fig. 1 Signals of high-energy bremsstrahlung caused by a microparticle oscillating around the electron beam orbit, at the beam current of 20 mA. The horizontal time scale is 1 s/division.

* Japan Synchrotron Radiation Research Institute, Minato-nakamachi 6-9-1, Chuou-ku, Kobe-shi, 650, Japan
** Miyagi National College of Technology, Miyagi, Natori-shi, 981-12, Japan

0-7803-1203-1/93$03.00 © 1993 IEEE

III. THEORETICAL ANALYSIS OF MOTIONS OF A TRAPPED MICROPARTICLE

Assuming that a microparticle to be trapped is just under the electron beam as shown in Figure 2, it is expected that the trapped microparticle makes a vertical oscillation only, in both a magnetic field and no magnetic field. In Figure 2, Z is the vertical direction and Z_0 is the distance from the bottom of the beam chamber to the center of the electron beam.

Considering the continuous vertical oscillation as shown Figure 2 and the basic equation in Reference [4], the average vertical acceleration $\ddot{Z}$, where Z is the distance between the microparticle and the bottom of the chamber wall, is given by

$$\ddot{Z} = \frac{Q\,E_z\,t_1}{m\,t_2} - g \quad . \tag{1}$$

Here Q is the charge deposited on the microparticle through the photoelectric effect, E_z the electric field in the vertical direction, m the mass of the microparticle, t_1 the time interval while the electron bunch is over the microparticle, t_2 the revolution time of the electron bunch and g the acceleration due to gravity.

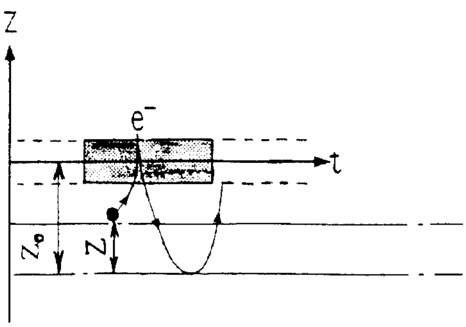

Fig. 2 A model for vertical oscillation of a trapped microparticle.

Assuming that the electrons in the bunch are formed into Gaussian distribution, the electric field E_{z0} at the vertical distance Z is given by

$$E_{z0} = \frac{Z_0\,E_z[1 - e^{-\frac{(Z_0-Z)^2}{2L_b^2}}]}{Z_0 - Z} + E_z e^{-\frac{Z_0^2}{2L_b^2}} \tag{2}$$

where E_z is the electric field at Z = 0 and L_b is the bunch length. Substituting Equation (2) into E_z in Equation (1), the vertical acceleration at Z is given by

$$\ddot{Z} = \frac{Q\,E_z\,t_1}{m\,t_2}[Z_0 \frac{1 - e^{-\frac{(Z_0-Z)^2}{2L_b^2}}}{Z_0 - Z} + e^{-\frac{Z_0^2}{2L_b^2}}] - g \tag{3}$$

Therefore, the solution of Equation (3) shows the vertical motion of the trapped microparticle.

Figure 3 shows a result of approximation for the vertical oscillation of the trapped microparticle corresponding to time duration, when QE_z/m is 1.85×10^5 Newton/kg of the trapping condition in the TRISTAN accumulation ring shown in Reference [1], $t_1 = 6.67 \times 10^{-11}$ s, $t_2 = 1.26 \times 10^{-6}$ s, $Z_0 = 0.024$ m, $L_b = 0.02$ m and the initial vertical velocity of the microparticle at the initial position is set to be 0.00005 m/s. As shown in Figure 3, the time interval of the vertical oscillation is about 0.7 s. Considering that the calculated vertical velocity at the electron orbit is about 1.1 m/s, the transit time of the microparticle passed through the electron beam is calculated as about 1.3 ms.

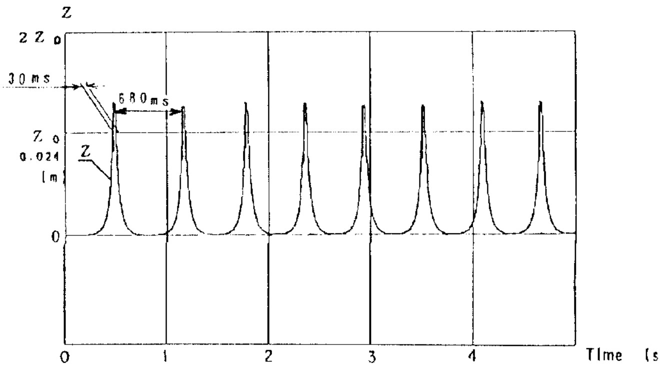

Fig. 3 A result of approximation for the vertical oscillation of the trapped microparticle. The horizontal time scale is 1 s/division.

IV. DISCUSSION

If a trapped microparticle makes a vertical oscillation as shown in Section III, it can be said that Figure 1 shows that the microparticle made the vertical oscillation and that the time interval is 1 s. It can be also said that signal of 0.15 ms duration shows the interaction time per pass of the microparticle. It can be seen that the observation coinside with the calculated result based on our newly developed theory, in spite of the simplified electric field and simplified motion of the trapped microparticle.

When the energy loss caused by a trapped microparticle becomes more than 0.1 % of the energy of an accelerated electron, it is assumed that the electron is lost. Generally, the beam lifetime τ is given by

$$\frac{1}{\tau} = \frac{Np\,\sigma\,f\,\Delta t}{4\pi\,\sigma_x\,\sigma_y} \quad , \tag{4}$$

where Np is the total number of atom in the microparticle, s the total cross-section, f the revolution frequency, Δt the transit time in a second, σ_x the width of the electron beam and σ_y the bunch length. Setting the diameter of the trapped microparticle made of Al is to be 0.1 mm, as shown in Reference [1], the calculated beam lifetime is 72 min. When the microparticle is made of Ti, the lifetime is calculated as 61 min. Compared results of the observation and the theoretical analysis show that our theory for motions of a trapped microparticle is useful.

In near future, three dimensional precise analysis for motions of a trapped microparticle will be carried out. Furthermore, precise observations in the TRISTAN accumulation ring will be carried out using an automatic observation system with lead-glass counters.

V. ACKNOWLEDGEMENTS

The authors would like to thank Professor Y. Kimura and Professor H. Kobayakawa for their helpful suggestions. The authors also wish to thank Technicians Mr. M. Shimamoto, Mr. M. Sato, and Mr. M. Nakagawa for their generous support.

VI. REFERENCES

[1] H. Saeki, T. Momose, and H. Ishimaru, "Observations of dust trapping phenomena in the TRISTAN accumulation ring and a study of dust removal in a beam chamber", Rev. Sci. Instrum. 62, 874 (1991).

[2] H. Saeki, T. Momose, and H. Ishimaru, "Motions of trapped dust particles around the electron beam in the TRISTAN accumulation ring", Rev. Sci. Instrum. 62, 2558 (1991).

[3] H. Saeki, T. Momose, and H. Ishimaru, "Experiments to trap dust particles by a wire simulating an electron beam", Rev. Sci. Instrum. 62, 2568 (1991).

[4] P. Marin, LURE, RT/90-01, Orsay (1990).