On the Reliability of Measured Results by Non-Destructive Beam Profile Monitor

Tadamichi Kawakubo, Eiichi Kadokura and Tadaharu Ishida*
National Laboratory for High Energy Physics, 1-1, Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan
*Mitsubishi Electric Company, 1-7-4, Iwamoto-cho, Chiyoda-ku, Tokyo-to, 101, Japan

Abstract

In KEK-PS, there is a pair of horizontal (H) and vertical (V) non-destructive beam profile monitor (NDPM) in the Booster, and two H- and one V-NDPM in the main ring. All NDPMs can measure the time dependence of beam profile within one acceleration period without beam destruction, and the combination of two H-NDPMs in the main ring can measure the time dependence of momentum spread. By the system with a scraper and orbit bump magnets we cross-checked the beam size. And by measuring the longitudinal bunch length and the RF characteristics, we also cross-checked the momentum spread. The half width by NDPM is apt to be wider than the width by the scraper method to the extent of some mm. The error becomes severe in the measurement of narrow beam width.

I. INTRODUCTION

The positive ion are produced by the collision of the circulating proton beam into residual gas in a synchrotron ring. Leading them to a sensor by a external collecting field, the position dependence of these ion currents shows circulating beam profile indirectly. We call this monitor as a non-destructive beam profile monitor (NDPM) [1]. Since the ion current signal is very low, we usually use a micro-channel plate (MCP) to amplify the signal. KEK-PS has five sets of NDPM by using a large rectangular area MCP with 32 anodes, two of which measure the time dependence of the horizontal and vertical booster beam profile, separately. In the main ring, one NDPM measures the vertical beam profile and a pare of two monitors measures not only horizontal beam profile but also momentum spread ($\Delta p/p$) [2]. When the beam intensity is high, the electric potential of the beam distorts the collecting field. Therefore, it needs to be checked by other measuring system that the measured data by NDPM is correct. The data of the horizontal and the vertical beam profile of the Booster and the vertical in the main ring were checked by the combination systems of a scraper and orbit bump magnets, and the data of the momentum spread in the main ring was checked by the calculation from the bunch length and RF characteristics [3]. The beam width measured by NDPM is apt to be wider than the width by the scraper and orbit bump magnets system, especially in the the vertical beam with narrow width and high intensity.

II. CROSS-CHECK OF BEAM PROFILE

The measurement by the system with a scraper and orbit bump magnets is shown in Fig.1. The beam orbit is deformed by the bump magnets and some part of the beam is hit by the scraper. The dependence of the beam loss on the bump current (see Fig.2) is changed by the scraper position. By taking these dependence curves, the calibration constant between the bump current and the moved distance of the beam at the scraper position is obtained. Fig.3 shows the typical vertical beam profile in the Booster measured by NDPM (white circle) and the beam loss dependence on the bump current which is equivalent to the moving scraper position (black circle). The former profile is the projection of the beam density in the phase space along Y' axis as shown in Fig.4a, on the other hand, the later beam loss dependence shows the density dependence on the radius in the phase space as shown in Fig.4b. These position dependences of the signal show different meanings of the beam density distribution in the phase space with each other, however, it is safe to say that the half width at 5% height of these two profiles should be good agreement with each other. Fig 5a and 5b show the dependence of the half vertical beam width at 5% height on the acceleration time of the Booster at low and high intensity, respectively. Fig.6 shows the horizontal case at medium intensity. The horizotal beam width by NDPM is fairly good agreement with one by the scraper and bump system (Fig.6). However, the vertical beam width by NDPM is wider than one by the scraper system, especially in the case with high intensity and narrow width (Fig.5b). All measurement were done under the sufficient high collecting field (=30kV/120mm).

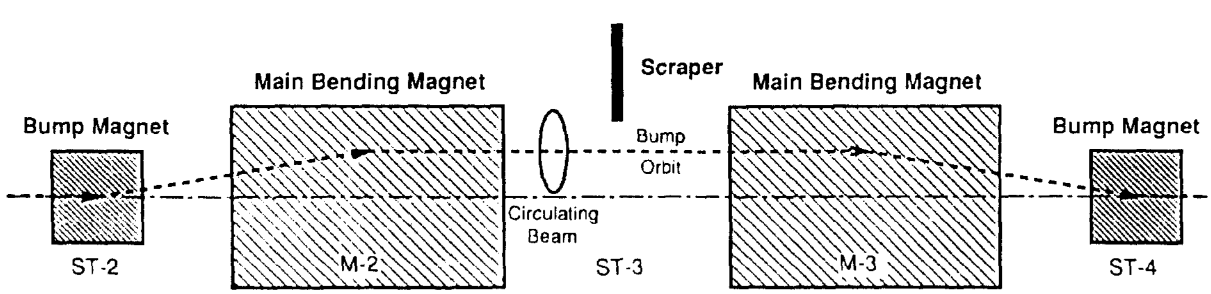

Fig.1 A scraper and two orbit bump magnets system.

0-7803-1203-1/93$03.00 © 1993 IEEE

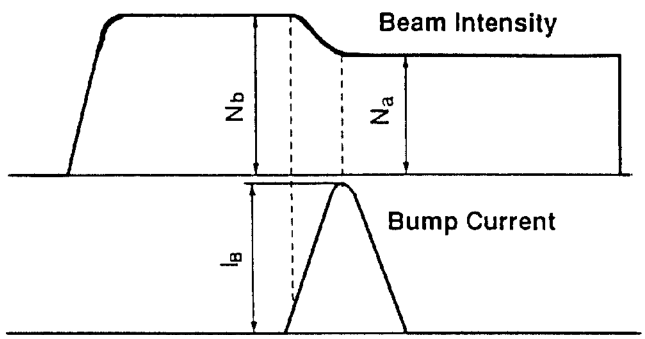

Fig.2 Beam loss generated by orbit bump current

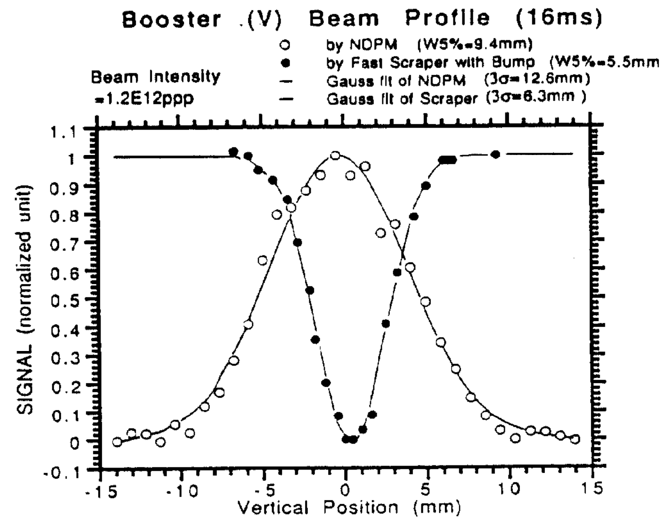

Fig.3 Typical Booster vertical beam profile by NDPM (white circle) and beam loss dependence on effective scraper position (black circle)

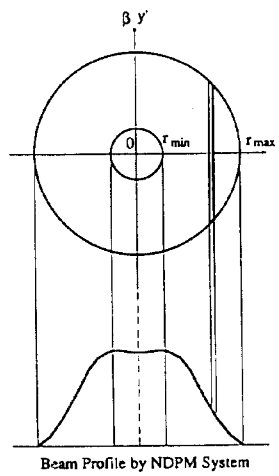

Fig.4a Relationship between output of NDPM and density distribution in phase space

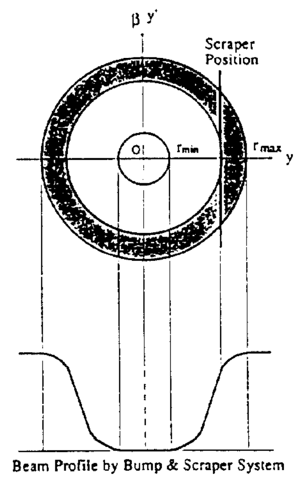

Fig.4b Relationship between output by scraper & bump system and density distribution in phase space

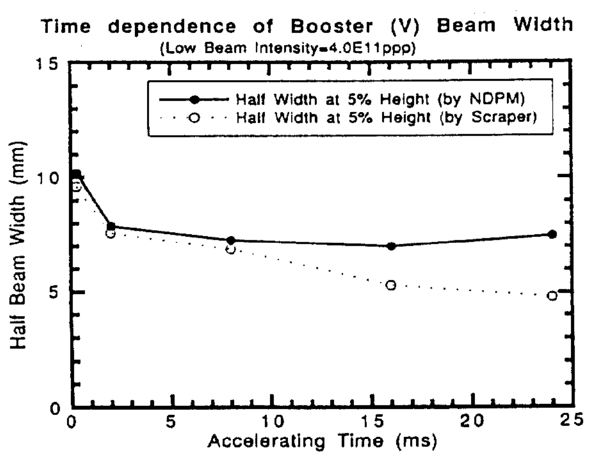

Fig.5a Time variation of half width at 5% height in Booster vertical beam profile (at low intensity)

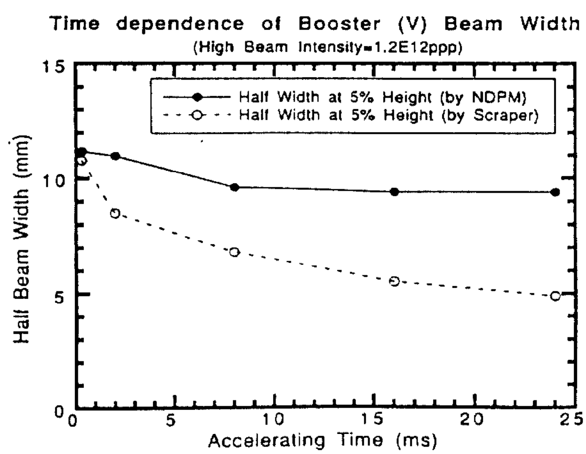

Fig.5b Time variation of half width at 5% height in Booster vertical beam profile (at high intensity)

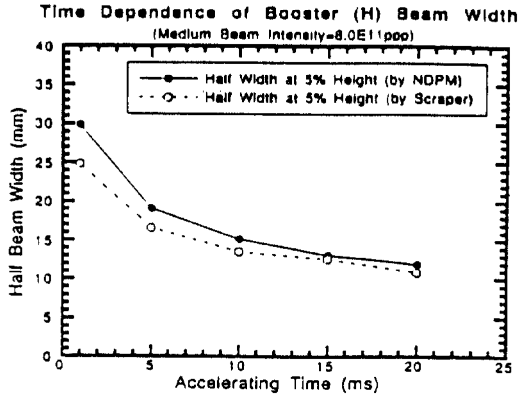

Fig.6 Time variation of half width at 5% height in Booster horizontal beam profile (at medium intensity)

III. CROSS-CHECK OF MOMENTUM SPREAD

A. Measurement by NDPM

Assuming that the intrinsic beam profile and momentum distribution have Gausian shapes, the total half beam width (x) is,

$$x = \left(\beta\varepsilon + (\eta \cdot \Delta P / P)^2\right)^{1/2}, \tag{1}$$

where β the Twiss parameter, ε the beam emittance, η the dispersion function, and ΔP the momentum spread. If two NDPMs are installed at locations with the Twiss parameter and dispersion function of (β_1, η_1) and (β_2, η_2), respectively, the momentum spread is deduced from the above-mentioned equation to

$$\Delta P/_P = \left(\frac{x_1{}^2/\beta_1 - x_2{}^2/\beta_2}{\eta_1{}^2/\beta_1 - \eta_2{}^2/\beta_2}\right)^{1/2}, \tag{2}$$

where x_1 and x_2 are the half beam width at the position of 1 and 2, respectively. The solid line in Fig. 7 shows the time dependence of the momentum spread in the main ring calculated by the half width at 5% height of beam profiles measured by two horizontal NDPMs.

B. Measurement by bunch length and RF characteristics

When the minimum longitudinal phase (ϕ_1) of the bunch circulating in a synchrotron ring is near $-\pi/2$ and the maximum (ϕ_2) is near $\pi/2$, the following equation is obtained approximately [3],

$$\Delta W \approx \left(\frac{eVPR}{\pi h \eta \Omega}\phi_B\right)^{\frac{1}{2}} \cos\phi_S \left(1 + \frac{\cos\phi_S - \frac{\pi}{2} + \phi_S \sin\phi_S}{\phi_B \cos^2\phi_S}\right)^{\frac{1}{2}}, \tag{3}$$

where $\Delta W = \Delta E/\Omega$, eV is RF voltage (eV), cP is proton momentum (eV), R is radius of ring (=54m), $\Omega = 2\pi f$ (f is rotating frequency of proton beam in the ring), ϕ_B is the half bunch length, ϕ_S is the phase of the synchronous proton (r) and $\eta = \left| (1/\gamma_{tr})^2 - (1/\gamma)^2 \right|$.

Momentum spread is deduced by above and following equations;

$$\Delta P/_P = \frac{\Omega}{\beta^2 \gamma \cdot E_0} \cdot \Delta W, \tag{4}$$

where $E_0 = 9.38 * 10^8$(eV). The result is shown by cross mark in Fig.7. It can be said that the results by two different methods almost agree.

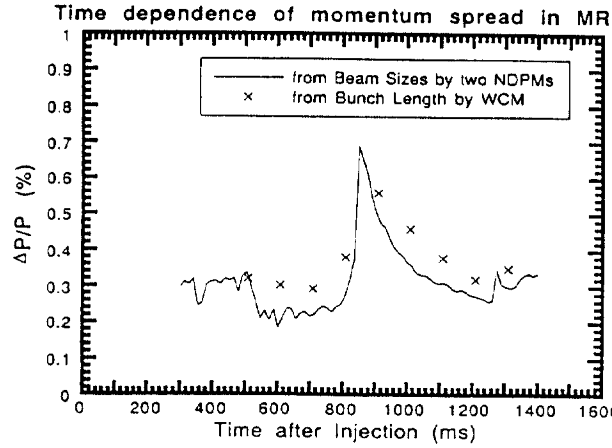

Fig.7 Time dependence of momentum spread in main ring by two horizontal NDPMs (solid line) by calculation from bunch length and RF characteristics (cross marks)

IV. CONCLUSION

It might be thought that the beam width measured by the system with a scraper and orbit bump magnets shows the real value. The half beam width obtained by NDPM is wider than real value to the extent of 3, 4 mm. The error is severe when the beam intensity is high and the with is narrow. As far as beam width is wide, the momentum spread measured by NDPM agrees well with the approximate calculation from the bunch length and RF characteristics.

V. ACKNOWLEDGMENT

The authors would like to acknowledge Dr.S.Ninomiya for his good comments to calculate the momentum spread from bunch length and RF characteristics. Thanks to him, we could cross-check the results measured by NDPM.

VI. REFERENCES

[1] T.Kawakubo, T.Ishida, E.Kadokura, Y.Ajima and T.Adachi , "Fast data acquisition system of a non-destructive profile monitor for a synchrotron beam by using a micro channel plate with multi-anodes", N.I.M., A302 (1991), pp.397.

[2] T.Kawakubo, E.Kadokura, T.Ishida, Y.Ajima and T.Adachi, "Non-destructive fast data taking system of beam profile and momentum spread in KEK-PS", Proceedings of the International Conference on Accelerator and Large Experimental Physics Control Systems, Nov., 11-15, 1991, KEK, Tsukuba, Japan, pp.399

[3] private communication by Dr.S.Ninomiya.