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Flying Wire Beam Profile Monitors at the KEK PS

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Abstract

Transverse beam profile monitors called "Flying Wires" have been developed and operated for more than three years at the KEK Proton Synchrotron main ring. A carbon wire of 7 μm in diameter scans the beam with a maximum speed of 20 m/s and produces secondary particles from the beam-wire scattering. The minimum wire material and fast scanning speed has been chosen to achieve the precise profile measurement and minimum beam destruction because the requirements are critical for the low kinetic energy beam of 500 MeV. Scintillation counters located near the vacuum pipe detect the secondary particles. Signals from both the scintillation counters and the potentiometer which encodes the angle of the wire holder are digitized, recorded and analyzed to reconstruct the beam profile. It is demonstrated that the flying wire has a wide dynamic range of more than two orders of magnitude. In case of a Gaussian distribution beam profile the flying wires would be able to measure the profile up to the tail of 0.1%. The position accuracy is estimated to be 0.4 mm. Profitable information would be obtained with the monitors for the mechanism of the halo formation and beam loss.

1 Introduction

One way of measuring transverse beam profiles is to use a thin wire as a probe that crosses the beam with a high speed. Secondary particles are produced from scattering of the wire material and cross section of the beam at the wire position. The amount of the secondary particles as a function of the wire position should be the beam profile, when the wire moves in the transverse direction with respect to the beam.

If the amount of the wire material is not small enough, the beam would be disturbed during scanning and the measured profile would not be precise. The effect is more critical for low energy proton beams because the distribution of the multiple scattering is wider for the lower energy protons. The injection kinetic energy of the KEK PS main ring is 500 MeV. A thick and strong wire, however, is preferred to avoid wire breakage due to the mechanical strain or the heat from the beam scattering. The effect of the wire heating and the beam emittance are described in Reference [1]. We have chosen a carbon fiber of 7 μm in diameter.

A fast scanning as well as a thin wire is necessary to minimize the beam destruction. We have achieved a wire speed of up to 20 m/s. The wire of 70mm in length is attached to a 120 mm radius holder that rotates around a motor shaft. A controller system drives the motor so that the wire rotation follows one cycle of a sinusoidal angle profile. The wire scanning can be initiated once in an acceleration cycle of the KEK PS main ring at an arbitrary timing. One scan takes about 100 ms. The wire crosses the beam four times in one scan. The potentiometer is attached to the motor shaft and the signal is used as a feedback signal to the motor controller. It is also read out with a digitizer and analyzed to evaluate the wire position.

We have installed two flying wire monitors. One is for the horizontal profile and another is for the vertical profile. Both are near quadrupole magnets where the lattice betatron functions are maximum for the direction.

2 Potentiometer signals

The control unit is located in the access pit where the radiation is less than that in the main ring tunnel and receives a function generator signal as a designed wire rotation angle profile for one wire scan. One cycle of a sinusoidal function of the period 100 ms is chosen for the function generator signal. The amplitude is to be proportional to the wire scan range. The control unit feeds a power to the DC servo motor and receives signals of the potentiometer that encodes the motor angle. The control unit with a feedback loop comparing the potentiometer signal and the function generator signal makes the wire scan angle follow the sinusoidal angle profile.

The potentiometer signal is also sent to the control room about 100m away and read out with a wave form digitizer Tektronix RTD720A. The signal is then digitized at the rate of 4 ns or 10 ns for one million samplings. Data is summed for each of 10 thousand samplings to produce the potentiometer data array of 100 in the time domain of 4 ms or 10 ms.

The calibration of the wire position measurement was done just before the installation of flying wires. The wire position was measured with a vernier caliper at the main ring tunnel and the potentiometer response was measured with a digital multimeter at the control room. Measurements were repeated for a series of setting values of the function generator signal. Figure 1(a) shows the wire position as a function of the potentiometer response for the vertical flying wire. The data points are fitted with a sinusoidal function and deviation from the fitted function are plotted in Figure 1(b). The rms values of the distributions are 0.3 mm for both of the horizontal and vertical flying wire.

The accuracy of the wire position measurement is deteriorated by the beam induced noise on the potentiometer response. We took data of the potentiometer signals seven times. The wire scans were initiated at the time of the first bunch injection(K1) and the data

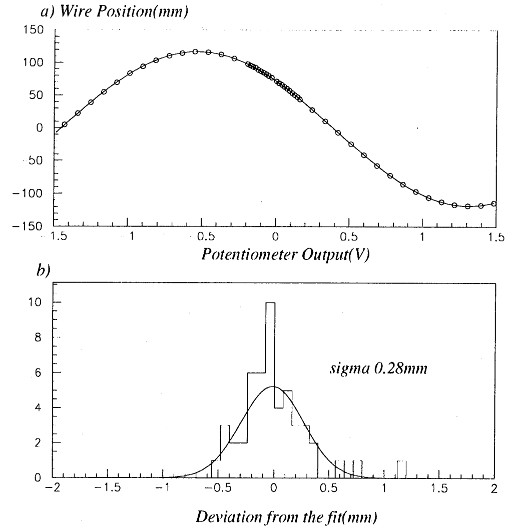

Fig. 1 (a)Vertical flying wire position as a function of potentiometer signal and (b)the deviation distribution from the fitted sinusoidal function.

acquisition started at 28.8 ms after K1. The trigger condition of this case was described as "K1+28.8 ms". We considered the average of the seven measurements as the standard function to convert the time to potentiometer signal. The variation of each measurement from the average was considered as the error of the conversion due to noise in the measurement or the variation of the motor motion. The rms of the distribution was 0.8 mV, corresponding to 0.3 mm in the wire position.

The position data array of 100 was created from the potentiometer data array with the conversion function from the wire position calibration. The array is used to reconstruct the beam profile with the scintillator data array. The accuracy of the wire position measurement is estimated to be 0.4 mm by adding the error in the conversion from the time to the potentiometer signal and the error in the conversion from the potentiometer signal to the wire position in quadrature.

3 Scintillator signals

Three scintillation counters have been installed for the horizontal profile measurement. Each counter consists of a plastic scintillator and a photomultiplier tube. Several sizes of plastic scintillators are used and one of the typical sizes is 50 mm×40 mm×7 mm. Some of the counters use a 1m long light guide to locate the photomultiplier away from the beam pipe. Two kinds of photomultipliers are used. One is Hamamatsu E4270-02X and another is Hamamatsu R1398. The photomultiplier output signal of some of the counters is amplified with an amplifier near the counter and then transferred about 100 m to the control room.

The signal is then read out and digitized with the wave form digitizer at the typical rate of 4ns for one million samplings. Data is summed for each of 10 thousand samplings to produce the scintillator data array of 100 in the time domain of 4ms. The average of the first five values of the array is considered as the offset and subtracted from the data array. The total sum of the data array is plotted as a function of the high voltage of the photomultiplier for each counter in Figure 2.

The photomultiplier signal should have a linear response within a certain region of the high voltage and the signal size as a function of the high voltage is to be linear both in logarithmic scales. If the voltage is however set too high, the photomultiplier signal would then be saturated and the reconstructed beam profile would be unphysically asymmetric. The response was confirmed with LED lights before the installation [2].

Scintillator No.2 with the photomultiplier R1398 has a narrower dynamic range and the signal saturates at the high voltage of 900 V or more. Scintillator No.1 and 3 with the photomultiplier E4270-02X have a wider dynamic range and the signal is linear up to 1200 V for both of No.1 and No.3. This is the case for the measurement during injection. The condition is a little different for the measurement during acceleration or at the flat top energy. Because the scattering angle is typically small for high energy, a scintillator located at the small angle is preferred for the measurement at the flat top energy. A scintillator located at a large angle and very close to the beam pipe, meanwhile, has a better signal to noise ratio for the measurement at the injection energy.

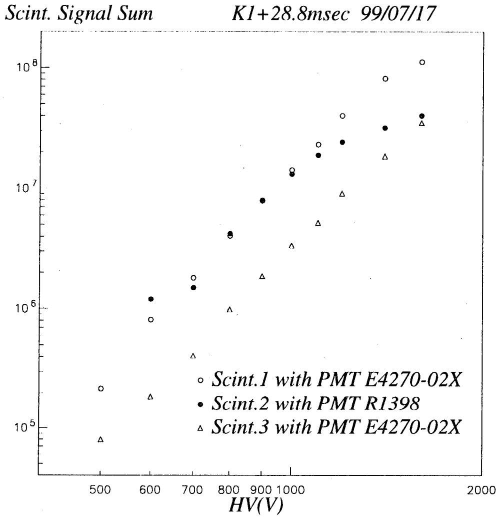

Fig. 2 The signal sum of scintillators as a function of the high voltage of the photomultipliers.

4 Profile measurements

The horizontal injection beam profiles were taken four times with the trigger of K1+350+28.8 ms after the eighth bunch injection and plotted in Figure 3. To estimate the noise level, three times of data are taken with no wire scan. The dynamic range of the profile measurement is demonstrated to be more than two orders of magnitude. Assuming that a beam profile has the Gaussian distribution, the tail of 3σ, that is the tail of up to 0.1%, would be observable.

The wire position measurement was confirmed using

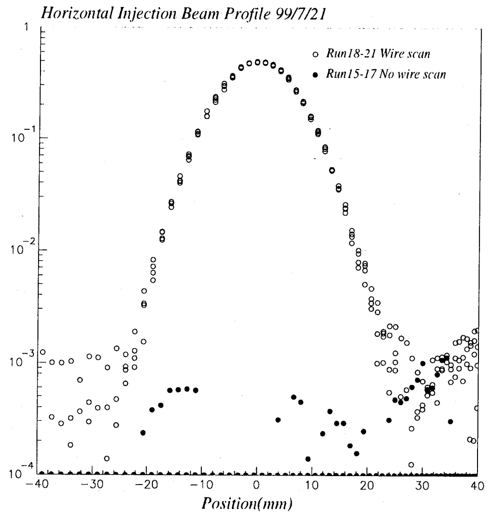

Fig. 3 Four measurements of the horizontal profiles (open circles) and three background measurements without scanning the wire (solid circles) at 28.8 ms after the eighth bunch injection.

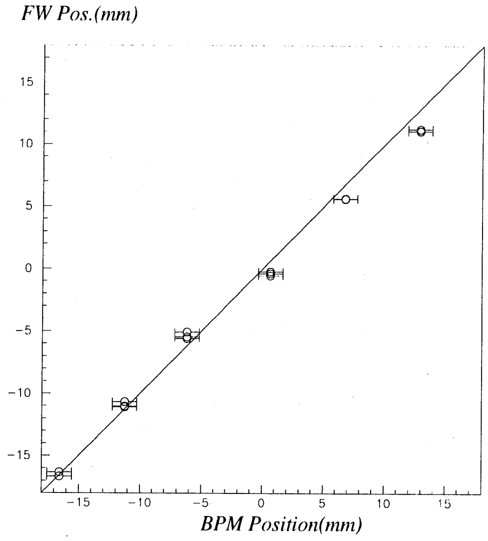

Fig. 4 The measured beam centers of the flying wire as a function of the estimated beam centers from the BPM measurements.

the beam position monitor (BPM) which detects the coordinate of the beam center from the ratio of the induced charge of two plates [3]. Steering magnets patterns of six sets were created to intentionally make the closed orbit distortion (COD) at the position of the horizontal flying wire during the injection period. The beam loss situation was unchanged if the COD was less than ±16 mm. Profile measurements were done three times for each pattern of steering magnets. Each profile were fitted with the Gaussian function. No significant change in the width of the profiles was observed.

The closest BPM is located 1 m away from the flying wire. Using the betatron functions and phase advances, the measured COD values of the BPM were corrected to estimate the COD values at the flying wire. The estimated COD values and the fitted center of the flying wire profile are compared and shown in Figure 4. The agreement is good within the resolution of the BPM.

The flying wire crosses the beam four times for one scan. The profile from the first cross and that from the fourth cross were compared. We should be able to test the effect of the response time of the potentiometer and the multiple scattering from the comparison. If there is a delay for the response time of the potentiometer, the center of the two profiles would be different. If the effect of the multiple scattering of the beam by the wire is not negligibly small, then the width of the two profiles would be different. Because it takes 50 ms for the wire to scan from the first cross positon to the fourth cross position, the start time of the wire scan for the fourth cross profile was set 50 ms earlier so that the trigger of the fourth cross profile measurement is same as that of the first cross. The average of the three measurements of the center of the first cross profiles is -0.31±0.17 mm, and that of the fourth cross profiles is -0.58±0.22 mm. The difference is less than 0.3mm and the response time of the potentiometer is proved to be small. The average of the three values of the width of the first cross profiles is 9.69±0.17 mm and in a good agreement with that of the fourth cross profiles of 9.67±0.02 mm. The destruction of the beam by the wire scan could not be detected. The noise level at the tail of the profile, however, is observed to be a little higher for the fourth cross profiles and it might be from the scattered protons.

5 Conclusions

Flying wire beam profile monitors have been developed and operated for more than three years at the KEK PS main ring. The reconstructed beam profiles demonstrate a wide dynamic range of more than two orders of magnitude. In case of a Gaussian distribution beam profile the flying wires would be able to measure the profile up to the tail of 0.1%. The position accuracy is estimated to be 0.4 mm. Profitable information would be obtained with the monitors for the mechanism of the halo formation and beam loss.

Acknowledgements

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