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BEAM SIZE MEASUREMENT OF 12 GeV ACCELERATOR BY FAST ROTARY SCRAPER

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Introduction

A new type of beam size measurement by a fast rotary scraper for the 12 GeV proton synchrotron has been developed. The profile of the accelerating beam was measured by a non-destructive monitor.[1] But we have a problem with the expansion of the profile by the space charge effect of a high intensity beam. A quantitative interpretation of the space charge effect, precise size measurement, and the scraped beam for accelerator studies are desirable.[2-3]

A schematic diagram of the measurement of the beam size[4] in the main synchrotron is shown in Fig.1. Beam current and beam loss are monitored by the current transformer[5] and the coaxial type ionization loss monitor.[6] The position of the scraped beam in the phase space diagram is shown in Fig.2. The scraping time for beam is the order of msec. The period of the betatron oscillation of beam is of the order of 10 μsec. The shadowed region corresponds to the output of the current transformer of the survival beam and the dotted region corresponds to the output of the beam loss monitor of the lost beam. The region of decrease curve of beam intensity gives information of beam size. The time interval of the decrease of beam intensity gives the half beam size. The beam loss by the scraper is due to energy loss and scattering. Beam scattering by the target is the main contribution. The beam loss rises slowly, so that about 5 msec transit time is suitable for beam size measurement.

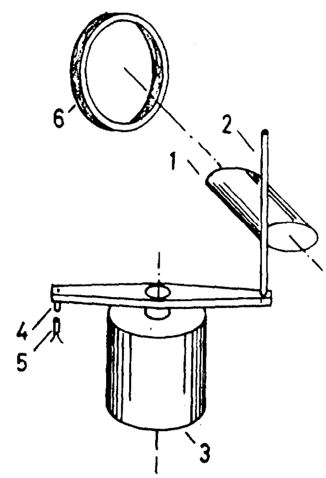

Fig.1 A schematic diagram of the measurement for the beam size in the proton synchrotron. 1. beam, 2. scraper target, 3. stepping motor, 4. parmenent magnet, 5. air core coil, 6. toroidal current transformer.

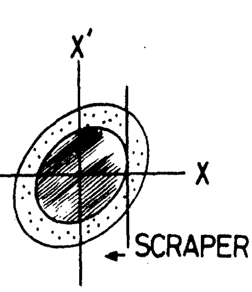

Fig.2 The position of the scraper, the survival beam and the lost beam in the pahse space diagram.

Stepping motor control

The requirements for the beam scraper are as follows. A fast rotary scraper must undergo a speed higher than 1°/msec without vibration. The scraping target is an stainless steel cylinder of diameter 3 mm and length 65 mm. The radius of the rotation is 40 mm. The timing fluctuation across the beam should be less than 10 μs. The stainless steel scraping target is directly coupled to and driven by a commercially available four-phase stepping motor.[7] The characteristics of the stepping motor are given in Table I. The stepping motor requires a dc bias to hold its rest position. The power loss is approximately 40 watts. It is preferable that there be no cooling in vacuum for a stepping motor. In order to decrease the operating temperature the dc bias for holding the position is lowered to about 4 watts (low level) and the required dc bias (high level) is turned on only for the stepping motion. Unwanted oscillations create not only mechanical vibrations but also uncertainty in position. All commercial stepping motor drivers known to the author send rectangular on-off signals to the motor. It is impossible to have smooth motion with an ordinary driving scheme. F.W. Schneider[8] made some efforts to reduce the mechanical vibration by using very fine interpolated steps in the form of a sinusoidal ladder.

Type	KP5AR15-2
Voltage	28 V dc
Current	1.4 A/Phase
Resistance per phase	20 ohm
Phase	4
Excitation	2 Phase
Step angle	15°
Dimension	50 mm dia. 64 mm length
Weight	560 gr

Table I. Characteristics of the stepping motor.

The new scheme utilizes inertia motion in order to eliminate vibration. Three pulses and a dc bias are supplied to the stepping motor to initiate the motion and the dc bias is cut off immediately after three pulses. The motor is driven by three steps 45°. The period of the three pulses is 4 msec. After cut off the dc bias, the motor rotates freely with smooth

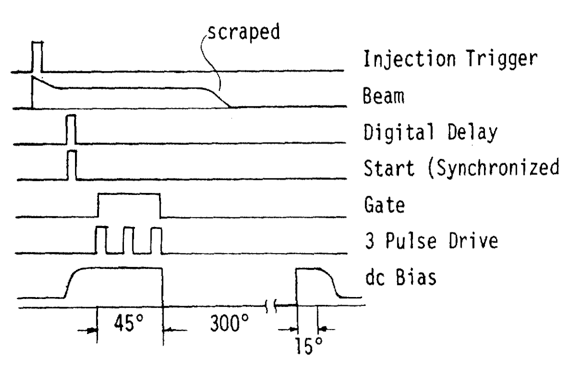

Fig.3 The timing chart of the beam scraper.

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angular velocity. Small vibration is damped to within 30°. No mechanical vibration is observed up to 270°. The rotation angle of free motion corresponds to 20 pulses which amounts to 300°. The dc bias is then applied again to stop the free motion. With such a driver system, in which vibrations are substantially reduced, one can accelerate the motor to higher frequencies. The rotation velocity is monitored using a permanent magnet and 36 air core coils, which are located along the circumference. The timing chart of the stepping motor driver is shown in Fig.3. A block diagram of the new driver circuit is shown in Fig.4. Start switch is chosen single or continuous mode synchronized to injected beam. The switch consists of a power transistor whose fall and rise time are less than 2 μsec. The dc power supply produces the step

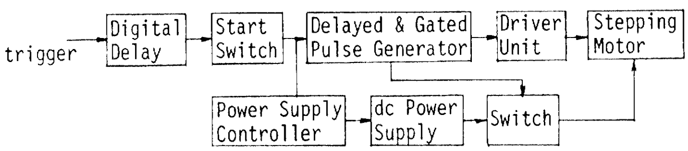

Fig.4 A block diagram of a new driver for stepping motor.

function by an externally controlled input. The scraper was mounted on an accurate driving mechanism. This mechanism consists of a dynamic bellows, a ball screw, a ball bush and a servo motor. The scraper position is monitored by a precise linear potentiometer and small digital voltmeter to an accuracy of 0.1 mm. The stepping motor and the driving mechanism are controlled by electronic logic and power units located in the control room.

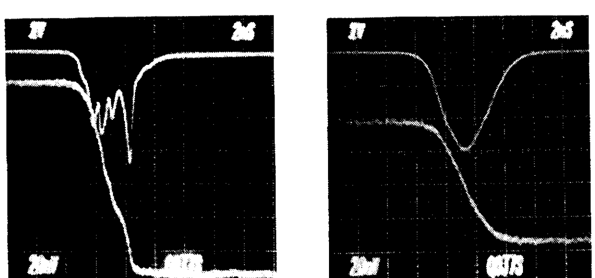

Fig.5 (a) Fig.5 (b)

Fig.5 Typical scraped beam signals with an ordinary driver and the new driver, measured by a current transformer and an ionization type beam loss monitor.
(a) Orinary driver, top: loss monitor, bottom: intensity monitor, 2 msec/div. (b) New driver, top: loss monitor, bottom: intensity monitor, 2 msec/div.

Signal processing and graphic display by computer

Typical scraped beam signals observed by a current transformer and an ionization type beam loss monitor using an ordinary driver and the new driver are shown in Fig.5. To obtain the beam size from Fig.5(b) the time interval Δt of the decrease beam intensity should be transformed to a distance. The rotating speed of the scraper is uniform but the projection is a sinusoidal function. The reduction of the beam size from the photograph must take this into account.

Signal processing and display for the beam size has been performed using a 12 bits transient recorder (Kawasaki Electronica Ltd HR-1200) which is interfaced

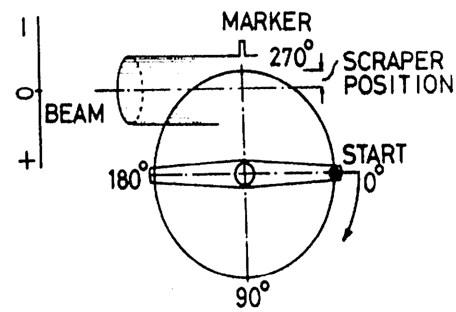

Fig.7 A schematic figure of the scraper target, beam and the position marker of the scraper.

to mini-computer[9] (Melcom-70) as shown in Fig.6. The transient recorder has 1024 words memory. The sampling interval of the transient recorder is 20 μsec. The scraped beam current, the beam loss and the position marker of the scraper are displayed on a graphic terminal. Data transfer time from the transient memory to the computer through the interface is about 20 msec using direct memory access channel. Various amplitude signal comes to the transient memory but the gain and offset adjustments are not required. Position marker from air core coil is chosen the position of zero velocity as the scraper as shown in Fig.7. Negative scraper position is chosen for the beam size measurement. Positive scraper position is chosen for thin beam production. Scraped beam intensity vs. scraper position is agreed with this beam size measurement. A typical horizontal half beam size and vertical half beam size display are shown in Fig.8 and Fig.9. Raw data shows the beam intensity curve by the scraper and the position marker signal from the air core coil. Beam size shows half beam size vs percent intensity in this figure. The material and the size of the scraper target are suitable for 12 GeV proton beam according to

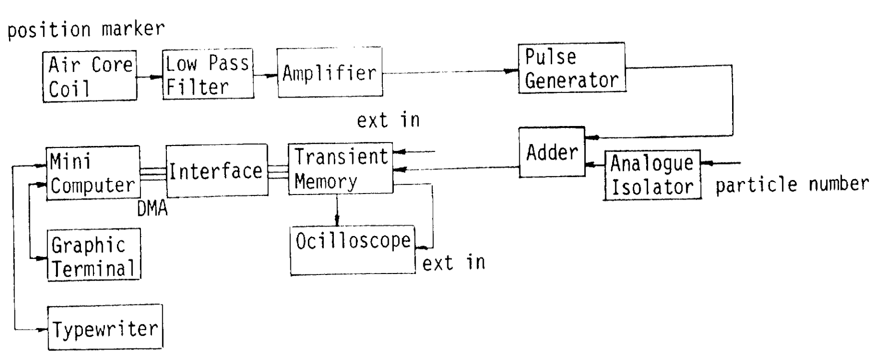

Fig.6 A block diagram of the computer controlled signal processing and display.

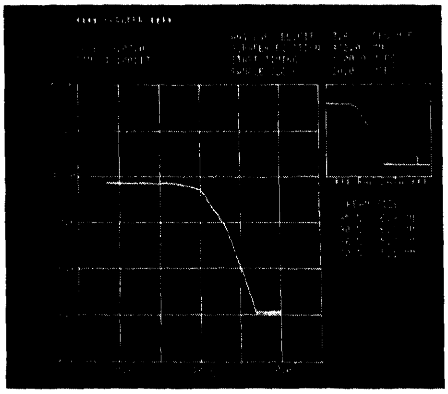

Fig.8 A typical horizontal half beam size display. Raw data shows the beam intensity curve by the scraper and the position marker signal from the aire core coil.

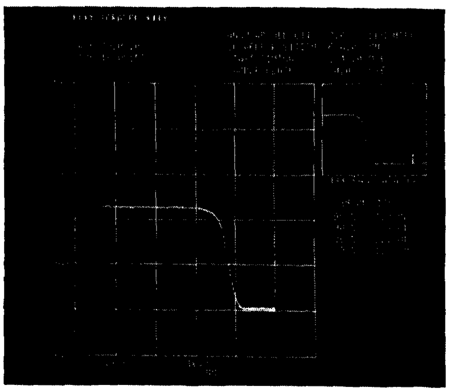

Fig.9 A typical vertical half beam size display.

the experimental data of beam loss pattern with the ionization loss monitor on circumference of the accelerator. This beam size measurement is destructive but precise, fast and simple. The fast rotary scrapers are useful in the beam size measurements. It is also useful to make a thin beam horizontally or vertically for beam studies.

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