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Wire Scanner Beam Size Monitor for ATF

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Abstract

A beam size monitor for emittance measurement is required to have around 10μm resolution for injector linac, and to have a few tenth μm resolution for an extracted beam from a damping ring in Accelerator Test Facility (ATF). A wire scanner is a one of the candidate of a beam size monitor with a high resolution. The design and development study of the wire scanning stage has been done for mainly wire vibration issue. A vibration of wire was studied using small spot size of laser light, and we found that vibration amplitude during off-resonance movement was less than 1μm. A detection of beam size signal was done by a scintillator gamma detector placed at downstream of the wire stage. The beam test using Tohoku 300MeV Linac was done and the emittance was measured by this wire scanner. The design and beam test results are described.

I. Introduction

The beam emittance measurement is required for 20 multi-bunched beam which has 2×10^{10} electrons in a micro-bunch with 2.8ns spacing in ATF. The required beam size monitors upstream of the damping ring should have around 10μm resolution for several hundreds μm beam size. On the other hands, the beam size at downstream of the damping ring is several μm, the resolution should have few tenth μm for it. The wire scanner beam size monitor used in SLC [1] is a candidate of such a high resolution beam size monitor to meet both of resolution requirements. The resolution is determined by a wire size and a step size of wire movement or beam movement. As a few μm wire and a few tenth μm mover are available today, the wire scanner is promising to get such a high resolution. However, it still has defects such as wire vibration, wire melting by a beam hit, lower speed to get an entire beam profile, not one-shot detector. The development study to overcome such defect was begun. We described the detail of design and the first beam test held at Tohoku University.

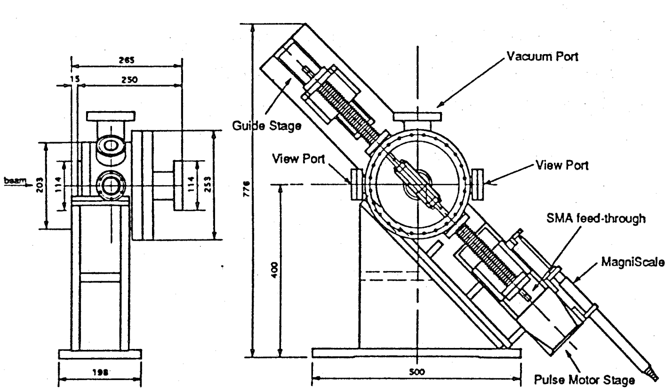

Figure 1. Wire scanner chamber and support.

II. Details of Wire Scanner

A. Wire Mover Stage

Figure 1 shows the side views of the wire mover stage and the vacuum chamber. The wire mount shown in Figure 2 is supported by the two arms in the chamber. A 50μm diameter gold plated tungsten wire is stretched simultaneously to X, Y and U directions which is 45 degree tilted from the X direction. The wire is insulated from the mount by ceramics supports, and tensioned by a screw nut. The insulation is for monitoring of secondary emission current on the wire and checking wire break. This wiring method which is the same as the SLC wire scanner has an advantage of that the only one move direction is necessary for 3 axis scans. The maximum beam size to be measured is σ=2.5mm. Assuming the full beam size is 6σ, the wire spacing should be wider than 5.55σ=13.9mm in the center of the wire mount.

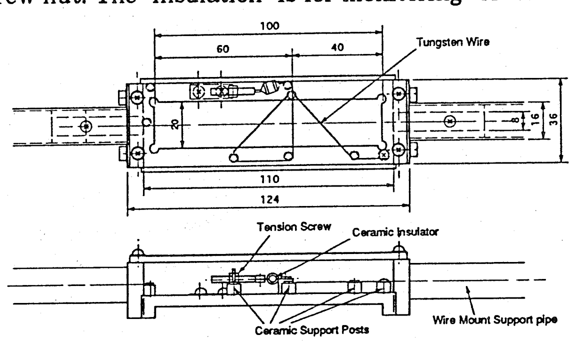

Figure 2. Close view of the wire mount.

A support of the wire mount inside the vacuum chamber is done by double stages and double bellows at both ends of support tube. The support tube is loaded by a vacuum loading and cancels it out from the mover stage loading. The load of mover stage is a spring force of the bellows only. A vibration of the wire mount is reduced by using this double stage support compared with single end support. As it has many advantages, we adopted the double stage mover. However it has disadvantages such as need precise alignment of the two sliders, need bigger stage.

The only one end of stage is powered by a 5-phase stepping motor (Physik Instrumente M-510.10). This stage is driven by a ball bearing spindle of 1mm pitch for one revolution and the stepping motor performs 2000 steps/rev. The resolution of step is 0.5 μm and repeatability is less than 0.1μm. The drive force and holding force is about 50N. The stepping motor stage is adopted because of its strong holding force and strong radiation resistant. Using fine pitch ball bearing spindle, fine gear-box, stepping motor can attain a less than 1 μm resolution easily without a micro-stepper technique. Although a maximum starting pulse rate is limited to several kHz, the fine step mover is not adequate for a long travel scan. For example, as the starting frequency is about 4 kHz for this wire scanner, it takes about 25 sec for 50 mm travel correspond to 3 wire scan. A suitable selection of a mover resolution is necessary for a quick scan.

The stage position sensor must also have a radiation resistant. We adopted Magnescale as it because it does not include processing electronics near the sensor. The resolution of the Magnescale is 5 μm for 100mm travel, enough for the first beam test of 0.5mm beam size.

B. Vibration Measurements of Wire Mover Stage

The vibration measurements [2] were done for this stage using an accelerometer and using a laser light beam independently. The accelerometer has a sensitivity of 10mV/g ($g=9.8m/s^2$) was placed at the wire mount with its sensitive axis in the direction of motion. The stage speed was swept by the network/spectrum analyzer (HP4195A), and taken the accelerometer spectrum. The spectrum was converted to the vibration amplitude spectrum. The worst vibration is at the lowest clock speed such as 0.3 mm p/p amplitude at 10 Hz. There is a resonance at 355Hz with 20 μm p/p amplitude and below 1 μm p/p amplitude at higher clock speed of 700 Hz. These are the stage vibrations in the way of moving. In order to measure the vibration of the wire itself, the cw laser beam of σ=70μm was used to simulate stable particle beam. The vibration of wire will appear on the absorption shape of the photo-detector at downstream of the laser beam. The FFT analysis was performed to the residuals of linear fit at the steepest slope of the shape. The observed vibration of wire was always less than 0.3μm p/p for 55 Hz to 771 Hz clock speed. With higher clock speed for the stepping motor more than 150 Hz reduce the vibration amplitude to 0.2μm p/p. It is negligible small for ATF Linac application.

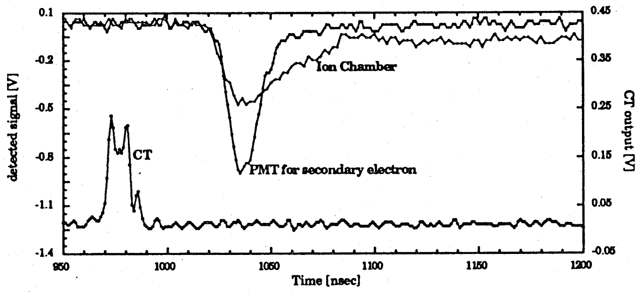

Figure 4. Beam bunch shape and gamma signals.

III. Beam Test of Wire Scanner

A. Experimental Setup

The wire scanner was tested using Tohoku 300MeV Linac beam with a high resolution screen monitor and a high resolution beam position monitor at the same time. In order to detect brems-strahlung gamma at its maximum, the beam was kicked 12.5 degree away and the gamma detectors were placed at the downstream of the gamma axis. The electron beam was 200MeV, 50Hz, 20ns width, 3 x 10^9 electrons in a burst and 0.5mm typical beam size.

The block diagram of the experimental setup is shown in Figure 3. There are a Quadrupole-magnet for emittance measurement, steering coil for beam sweep and a current trans. (CT) for making trigger and gate in the beam line at the upstream of the monitors. The screen profile monitor using 130 μm thick alumina with chromium oxide is viewed by a magnification 1:1 lens system onto CCD TV camera [3]. The beam profile on the screen was frozen by the beam trigger and sent to the video recorder. The image was analyzed by off line. The beam position monitor (BPM) is a strip-line type measures the transverse position in one shot [4]. It will be intended to use as a position reference relative to the wire and a charge reference from pulse to pulse in order to correct a wire scanner profile. As BPM was not ready to use with sufficient resolution in this test, any correction was not made for the wire scan data. In the wire scanner, 50 μm diameter of gold plated tungsten wire is stretched. The wire stage is driven by HPTG CAMAC module with 2048 pps constant speed. As a gamma

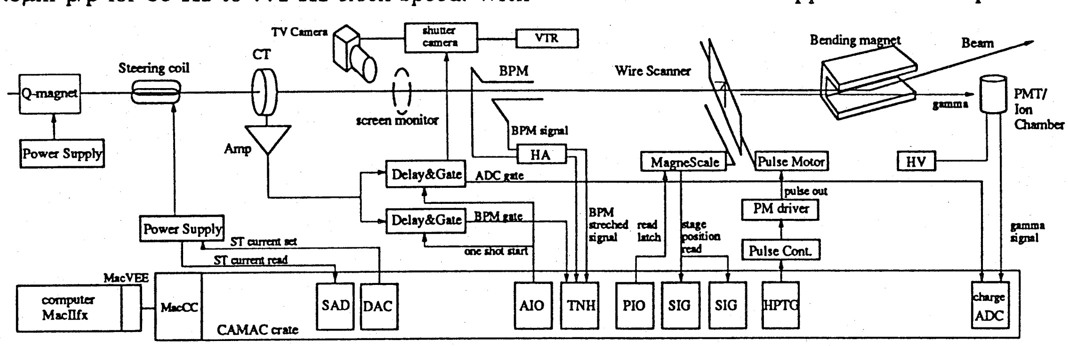

Figure 3. Block diagram of the wire scanner beam test.

detector, we used an ion chamber filled with P10 gas [5] and 10 x 20 mm plastic scintillator with 1200 mm light guide and HAMAMATSU H1161 PMT tube. As a secondary electron detector, the same H1161 PMT was used with and without plastic scintillator (diameter 50 mm, thickness 25.4 mm). The detection of secondary electron was made by cherenkov radiation in the scintillator or in the PMT window. These wire signals are digitized by charge ADC (LeCroy 2249A) with 11 bits range. The 160 ns gate of charge integration for the ADC was generated by the CT signal.

B. Results of Beam Test

The beam pulse detected by the CT and the gamma signals are shown in Figure 4 in the same scale. The beam was scanned by the wire and the profile signal at each wire position was gotten by integrating the gamma signal over 160 ns gate. The scanning procedure is as follows; the wire is set at the starting position at first. Then the request signal is set to the gate generator. It generates the only one gate initiated by the CT beam signal. The BPM and the charge ADC latches the signal by the gate at the same pulse. The program must wait the completion of data acquisition at least 20 ms because of 50Hz repetition. Then the wire is set to the next position, and so on.

Figure 5 is an example of beam profile by using the scintillator, the ion chamber and the secondary electron PMT. The scan range was 40 mm and the step size was 0.5 mm for the scintillator profile and 0.2 mm for the others. The scanning time, for example, was 55 sec for 0.5 mm step and 50 mm stroke. The lack of Y-profile in the case of secondary electron PMT was caused by ceramic post shadowing.

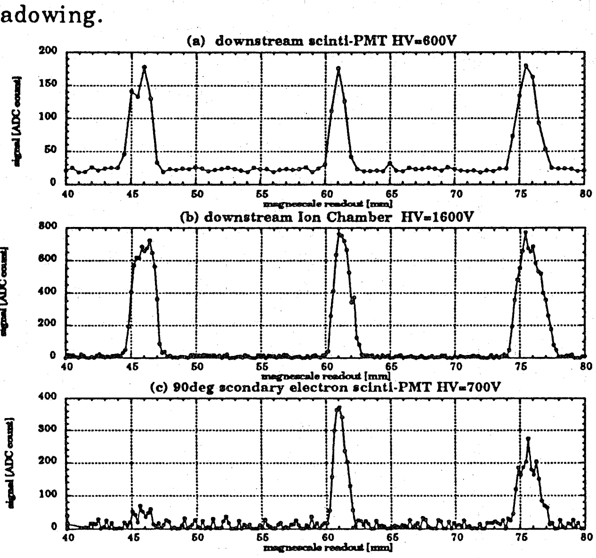

Figure 5. Wire scanner profiles by (a) scintillator gamma detector, (b) ion chamber gamma detector, (c) PMT secondary electron detector.

The comparison of beam profile with the screen monitor is shown in Figure 6. Though the shape is different in the X-profile, the fitting results to a gaussian function are in good agreement. The results were σx = 0.49mm, σy = 0.65mm for the wire scanner and σx = 0.50mm, σy = 0.62mm for the screen monitor.

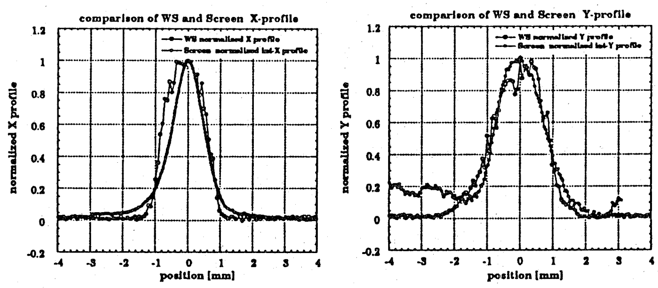

Figure 6. Comparison of bunch shape between wire scan and screen profile.

The emittance was measured by changing the strength of the Q-magnet at the upstream of the monitors. The variations of beam sizes depending on the Q-magnet strength are fitted to a parabola function. The measured normalized emittances by these fittings were 7.3 x 10^{-5} m.rad for ε_{nx} and 5.5 x 10^{-5} m.rad for ε_{ny}. On the other hand, the emittances by the screen monitor were 8.5 x 10^{-5} m.rad for ε_{nx} and 4.1 x 10^{-5} m.rad for ε_{ny}. They are in fairly good agreement.

IV. Acknowledgments

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V. References

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