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BEAM POSITION MEASUREMENT IN THE PHOTON FACTORY STORAGE RING

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Abstract

A beam position monitoring system has been constructed for the 2.5 GeV electron storage ring in the Photon Factory. Since the first beam was stored at design energy on March 11, 1982, the position monitor system has been used for orbit measurements during routine operation and during machine studies. We confirmed that the accuracy and reproducibility of the system is within 0.2 mm.

Introduction

The beam position in the storage ring must be measured at a few tens of locations over the circumference of 180 m. Other parameters necessary in designing the monitoring system are the maximum beam current of 500 mA, the frequency of the r.f. accelerating cavity system of 500 MHz and the harmonic number of 312.[1]

At each of 45 separate locations, a position monitor, consisting of an array of six button-type electrodes, is used to observe the horizontal and vertical beam position. Usually it is possible to observe the beam position with 4 electrodes, however, the two additional electrodes were required to obtain a higher vertical sensitivity, on account of the shape of vacuum chamber.[2] A position monitor is installed near almost every quadrupole magnet. Since the betatron wave number is 4.25 to 6.25, this number of the position monitors is sufficient to accurately determine the closed orbit.

The position monitors are designed so as to pickup the 500 MHz component in the circulating beam. Eight control substations are placed under the ring tunnel. Each substation deals with a group of 6 position monitors. The signal from the electrodes is amplified by a super-heterodyne scheme. The output signals are then sent to the control center where a micro-computer controls the whole system.

Electrodes and installation

A button electrode of 30 mm diameter is fixed directly to a vacuum-tight BNC connector which is then welded to the vacuum chamber. Prior to installation in the ring, the position monitors are individually measured at a test bench to find the difference between mechanical and electrical centers, as well as the horizontal and vertical sensitivity. These measurements were performed automatically using a probe antenna mounted on a micro-computer-controlled X-Y stage. The data are used for correction of the raw observed beam position. The vacuum chamber is fastened to very rigid and accurately-machined frames, which are fixed to the quadrupole magnets so that the mechanical center of a position monitor and the center of a quadrupole magnet are aligned within 50 μm.

Electronics and data acquisition

The signal processing system is shown in Fig. 1. Signals from electrodes are switched sequentially by a coaxial relay placed at the foot of each position monitor. The relayed signal is sent to a substation through a low-loss coaxial cable. The signals from each position monitor are scanned sequentially by a coaxial relay and are fed to the amplifier.

Figure 2 shows the detail of the amplifier. The amplifier consists of a 500 MHz band-pass filter, a double-balanced mixer for frequency conversion, an

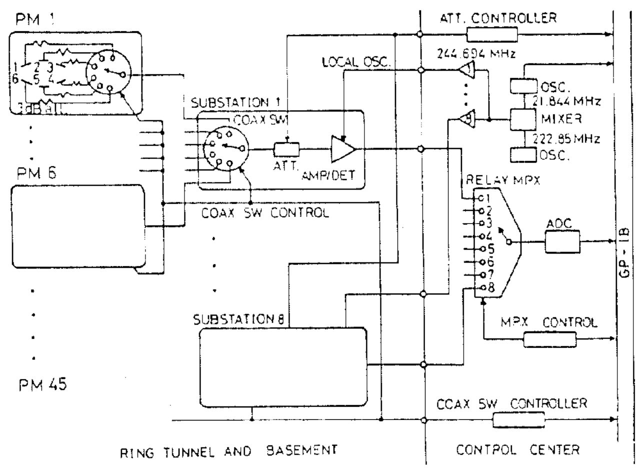

Fig.1 Beam position monitoring system.

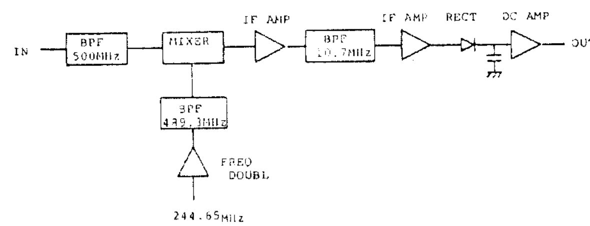

Fig.2 Detail of signal amplifier and detector.

intermediate frequency amplifier, a rectifier and a dc amplifier. The intermediate frequency is 10.7 MHz and the band-width is limited to 1.2 kHz by a crystal filter to obtain a suitable signal-to-noise ratio. The local frequency of 244.65 MHz is produced by mixing both 222.8 MHz from a crystal oscillator and 21.85 MHz from a variable frequency generator with the double balanced mixer. The output of the mixer is fed to the 8 substations where the frequency is doubled and mixed with the 500 MHz beam signal to produce the intermediate frequency. As the frequency of the r.f. cavity system is varied, the frequency of the variable frequency generator is adjusted to keep the intermediate frequency at its nominal value. A remotely-controlled variable attenuator is inserted in front of the amplifier to keep the signal level approximately the same irrespective of a change in beam intensity.

Electronic errors in position measurement are minimized as follows: First, the 21.85 MHz generator is required to be stable within a few 100 Hz. This is much less than the amplifier bandwidth of 1.2 kHz, because the frequency characteristics of the amplifier are not completely flat-topped over this bandwidth. Second, a 3 db attenuator is connected to each electrode to avoid open circuits when the electrode is not selected. Insertion errors for the attenuators may result in beam position errors, thus for each position monitor, a group of 6 attenuators were selected so that the deviation lies within 0.015 db. Thirdly, fluctuations of insertion loss in the coaxial relay are also

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a source of position error. The coaxial relay has an insertion loss of 0.1 db with a standard deviation of 0.05 db. This is acceptable, since a deviation of 0.06 db corresponds to a position error of 0.1 mm, well below our goal of 0.2 mm.

The intrinsic resolution of the signal processing system was measured on a test bench by repeatedly reading signals. Figure 3 shows the results. During the test, fluctuations and time-drifts in the oscillator frequency were kept below 100 Hz. The characteristics of the electronics guarantees that the monitor system is capable of measuring the beam position with a resolution less than 0.2 mm.

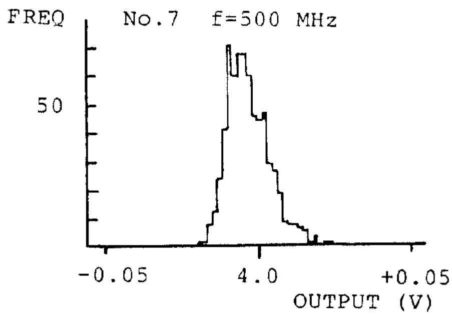

Fig.3 Intrinsic resolution of the signal processing system.

The position signals from each substation are scanned sequentially by a relay multiplexer, digitized with an A/D converter and then collected by a microcomputer. Measurements are made twice for each position monitor and if the difference is more than 0.2 mm, the data is labeled as "bad". This helps find malfunctioning coaxial relays.

All the control and data acquisition is made through an IEEE 488 bus. Horizontal and vertical closed orbits can be obtained in 90 sec. over the whole circumference. Most of time is spent in switching the coaxial relays and in the acquisition time of the digital voltmeter.

Actual performance

1. Accuracy of the measurements: The position accuracy of the monitor was cross-checked with an independent experiment measuring beam position at one straight section where the vertical wiggler was to be installed. The experiment provides information on the beam location within the vacuum chamber by gradually inserting a scraper into the chamber and measuring the beam lifetime at each location of the scraper. When the beam was shifted by making a local dc bump in the orbit, the shift read by the position monitor agreed with that of the scraper within 0.1 mm. The beam center was measured by inserting two scrapers from opposite sides.[3] The results differ from that obtained using the position monitor by 0.25 mm. Such differences can reasonably exist when comparing the two systems because installation of the two systems was made independently, with setting errors of 0.1 mm.

2. Dynamic range: Considering the initial commisioning period of the storage ring, the gain of the amplifier was set so that the beam position can be measured with a beam current as low as 0.1 mA. Actually, we observed the closed orbit at a beam current of 0.14 mA and found no difference when compared to a beam current of order 100 mA, within the system resolution.

3. Closed orbit measurement and reproducibility: Figure 4 shows the deviation of the closed orbit when the r.f. frequency is increased or decreased by 5kHz. The solid line shows the expected deviation calculated by $\Delta x = \eta\alpha^{-1}\,\Delta f/f$, where η is the horizontal momentum dispersion at each location, α is the momentum compaction factor, for which the design value is 0.04, and $\Delta f/f$ is the proportion of the frequency change. The dots are the observed deviations in the orbit. Figure 5 shows a closed orbit before and after correction made with information of the beam position. During routine operation, the closed orbit stays at the same position without any correction. To insure the reproducibility of the orbit, the magnet system must be initialized prior to routine operation.

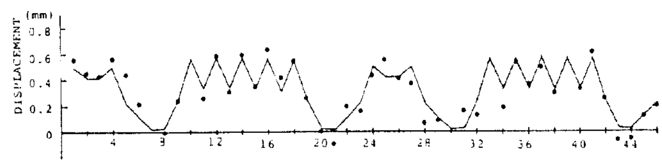

Fig.4 Closed orbit deviation corresponding to a RF frequency change of 5 kHz; abscissas are position monitor number, ordinated are beam displacement in mm. Solid line indicates expectation, dots are measured data.

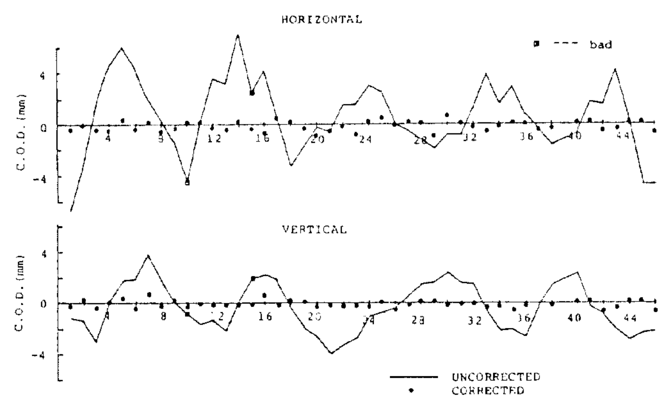

Fig.5 Closed orbit before and after correction; abssissas are position monitor number, ordinates are beam position in mm.

4. Life of coax relay and attenuator: In the last 12 months of operation, 15 out of 53 coax relays were replaced for one of the following reasons: 1) one or more dead switch positions, 2) switching with excessive insertion loss (~6 dB), or 3) producing "bad" too often. Two out of 8 variable attenuators became defective at one of their four sections and were replaced.

Results on position resolution

In real beam operation, the beam position was measured with the system and proved to be within the intrisic resolution previously guaranteed for the electronics. Figure 6 shows the results of the beam position measurement, which gives a standard deviation of 0.1 mm for both horizontal and vertical beam positions.

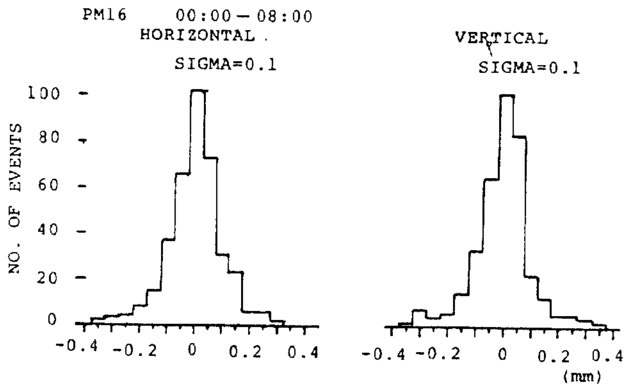

Fig.6 Position resolution with actual beam.

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