Beam Diagnostics

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Introduction

The purpose of the beam diagnostic system is to obtain the information of the behavior of the electron beam in the SPring-8 Storage Ring so that the performances of the storage ring as a synchrotron light source can be assessed. The information will be used to improve the operation conditions of the ring.

The work for the beam diagnostic system covers three major items: (1) design and construction of the straight section equipped with diagnostic devices, (2) design and construction of the beam line(s) for diagnostics using the synchrotron light. (3) and the design and construction of beam position monitors to measure the beam positions around the storage ring.

The straight section, called tentatively the diagnostic straight section, is used for installing the devices to measure the stored beam current, betatron tunes, and transverse beam size. The stored beam current will be measured with current transformers. A beam shaker will excite a small amplitude coherent oscillation to measure the betatron tune. A mechanical scraper with four blades will be used for defining the transverse beam size at the diagnostic straight section.

Although every detail of the design of the straight section and the devices to be installed is yet to be done, the present status of the straight section design can be referred in this annual report[1].

At the beam line(s) for the diagnostic purpose, the following quantities will be measured by utilizing synchrotron light; the emittance of the stored beam, bunch length, transverse beam profile at a certain point, and single bunch purity during the single bunch operation. Furthermore, some information concerning to beam instabilities are expected to be extracted with synchrotron light.

The studies for some of the measuring methods using the synchrotron light is undertaken[2,3]. These results will be included in designing the beam line(s).

The third topic, the beam position monitors (BPM for short), will be described in some detail here, since the major part of the effort of the beam diagnostics work was hitherto devoted to the studies of beam position monitors.

Beam position monitors

Introduction

Three kinds of measurement are in the scope of the BPM usage: (1) closed orbit distortion measurement, (2) first turn tuning of the orbit during the storage ring commissioning, (3) measurement of the coupling between horizontal and vertical motion of the electrons. For the purpose of fulfilling the above requirements, two modes of processing will be devised for the signal processing electronics of the BPM, which are named as the COD mode and the single pass mode (abbreviated as SP mode).

As the electrons in a storage ring conducts a betatron oscillation around the closed orbit, the positions of the center of gravity of a beam observed at a certain point in the ring differ turn by turn in some cases. In other cases, the center of gravity of a beam passes the same position every turn, which is on the closed orbit.

In the SP mode processing of the signal, the turn by turn difference of the beam position can be observed at a certain storage ring operation condition.

In the COD mode, on the other hand, the signal is measured by switching electrodes one after another; each signal is averaged over thousands of turns to get a good signal to noise ratio of more than one thousand. This averaging is expected to improve the COD measurement resolution down to as small as less than ten micro-meters.

The BPMs will be placed just next to the 6 sextupole magnets out of 7 in a cell, because how close the beam passes referred to the sextupole axis is crucial to the performance of the storage ring. In the design of the SPring-8 lattice, 7 sextupole magnets are installed in a Chasman-Green cell. The sextupole which is not installed the BPM is the one placed at the symmetrical point in a cell.

The total number of the BPM is 288, since the number of the cell is 48 and each cell has 6 BPMs as described above.

The required accuracy of the beam position measurement is 0.1 mm, including all the contributions of error sources to the measurement accuracy, such as, the resolution of position measurement, sextupole axis position defined by the magnetic field measurement, BPM calibration accuracy, etc.

Mechanical structure of the BPM pickups and BPM parts of the vacuum chamber

The signal pickups of the BPM consist of four electrodes called button pickup electrodes. By the passage of the electron beam a pulse shape current is induced on the surface of the vacuum chamber inner wall. When a pulse passes one of the button pickups, a pulsed signal will be induced[4]. This signal is a function of the beam current per bunch, cross sectional position of the beam, and pulse shape. After appropriate processing of the signals, the position information can be extracted.

A pickup button has a round shape with 10.3 mm in diameter and flush mounted to the inner wall of the vacuum chamber by directly welding to the extruded aluminum chamber. The longest type of the chamber has a length of about 6 m.

A cross sectional view of the BPM part of the vacuum chamber is shown in figure 1. Two orthogonal plates are attached on a block of aluminum as reference planes for the alignment; the reference point is defined as a point having certain distances from the planes, and the axes of coordinates are the axes parallel to the planes and pass through the reference point.

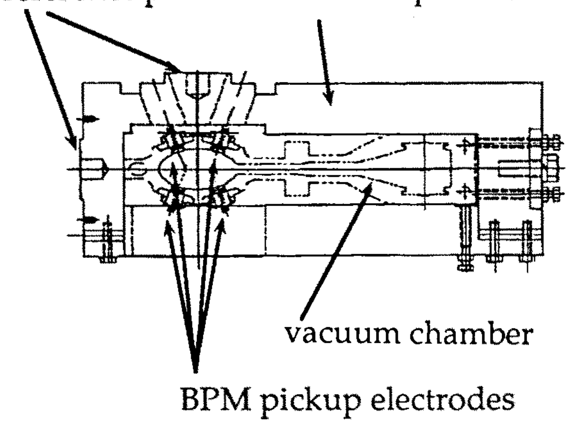

Fig.1. A cross sectional view of a BPM part of the vacuum chamber

Two aluminum blocks are attached up- and downstream of the reference plane block. These blocks work as supports against the deformation of the cross sectional shape of the chamber caused by the evacuation of the chamber. According to structure analysis calculations the deformation is expected to be as small as about 30 μm at the BPM points. Preliminary measurements show the deformations were all within 26 μm, which agree with the calculation.

Each BPM needs to be calibrated for the electric offset and the sensitivity, because the button pickup electrodes are directly welded on the vacuum chamber made of extruded aluminum[5].

COD mode electronics

As described above, the signal processing electronics has two modes, which are performed with separate modules.

Tests of a prototype of the COD mode electronics are undergoing. The circuit consists of a front end multiplexer and a rear end detector with heterodyne type frequency down conversion. The detection frequency was chosen to be 508.58 MHz, which is the same frequency as RF acceleration frequency.

The signals from four buttons of one BPM is processed by a single set of circuit so that an additional offset coming from the differences of electronics characteristics is avoided.

The front end multiplexer consists of four 3-dB attenuators, 508.58 MHz-band pass filters, one to two RF switches to select the SP mode or COD mode and a four to one switch to select one of the four electrodes for the COD mode.

Further multiplexers are equipped at the input part of the rear end circuit to select one out of twelve BPMs in order for one set of the circuit to cover two cells. After passing the multiplexer, the RF component of the signal is down converted to the 50-MHz IF (Intermediate Frequency), followed by further down conversion to 455 kHz. The detection will be performed by an RMS-DC converter. The final bandwidth of the output of the rear end detector is designed to be 3 kHz. The actual data taking will be done with integrating type ADC, and further reduction of noises are expected.

The repeatability of the front end multiplexer switches was tested and found to be within ±0.005 dB, which corresponds to the position accuracy of ±5 mm. The linearity between the input and output of the rear end detector was also tested and found to be ±3% in the range from 0.316-V output to 10 V. The linearity can be calibrated within the precision of ±0.05% in the range from 2-V output to 10 V, which is sufficient to our scope of designed specifications. The noise level was estimated by terminating the input connector, and this configuration is regarded as equivalent to the thermal noise input. The signal to noise ratio with the equivalent thermal noise input was 4.5 mV rms for 10-V output and well beyond our designed value.

SP mode electronics

The four button signals are processed parallelly with four sets of circuits for the SP mode signal processing to make simultaneous data taking possible. The detection by a synchronous detector is done at 55-MHz IF with a single step down conversion for the carrier frequency to be high enough for the bandwidth of about 5 MHz so that the amplitude of the ringing wave form decays well enough within the revolution period (4.8 μs).

The first set of the SP mode circuit is to be completed, and will be tested. Furthermore, tests of the circuits of both kinds will be done with combining control interfaces to the VME system, which will be a part of the control system of the storage ring.

Summary

The scope of the beam diagnostic related work for coming fiscal year covers the followings; (1) investigate the performances of the BPM electronics for the actual use for both COD and SP modes, (2) fixing the details of the straight section design and its manufacturing, (3) further studies of the diagnostic beam line(s).

References

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