BEAM DIAGNOSTIC SYSTEM FOR STORAGE RINGS

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Abstract.

The system described is based on a turn-by-turn processing of the electrostatic BPM signals, is controlled by computer, uses various data processing, and provides a wide range of beam diagnostic measurements. During commissioning a storage ring, the system can be used for closing the first turn. In circulating beam mode, injected beam parameters, betatron tune, closed orbit, and dispersion function are measured. Other applications are beta function and phase advance measurements, betatron motion observations on phase space diagram, a high resolution measurement of low frequency beam vibrations. The system can be completely tested and calibrated by its own means. A calibration procedure, special features of the signal and data processing are described. Experimental results of studying such systems at VEPP-3 and VEPP-4M are presented.

1 INTRODUCTION

A beam diagnostic system, using capacitive beam monitors, was developed for BINP storage rings. A modernized electron-positron 6Gev storage ring VEPP-4M [1] and its booster VEPP-3, as well as the SR-source 2GeV storage ring Siberia-2, have been equipped with the systems of that kind. The system was designed with consideration for experience of the previous VEPP-4 and has its origins in the turn-by-turn measurement approach discussed in [2].

Beam position monitors distributed along the storage ring, are incorporated in a system (SM), which is intended for closed orbit, dispersion function, beta function and betatron phase advance measurements. SM has also a limited capability for observation of the first turn of beam. Another beam diagnostic instrument (IM), which includes an individual monitor (at the VEPP-4M there are two such monitors), is meant for such purposes as: turn-by-turn current and position measurements of the injected beam; determination of betatron and synchrotron tunes; bunch-to-bunch current measurements; observation of the phase trajectory of betatron motion; low frequency beam vibration measurement.

For IM, synchronous measurements of electrodes' signals by four parallel channels are carried out. In SM, scanning the electrodes of each monitor by a single channel is used. The monitors are sampled in turns.

A built-in-system zero offset elimination procedure is employed, which results in a residual beam position zero offset of the order of the signal measurement accuracy being inherent in the instrument. This quality is a merit of the system described, as opposite to systems in which pre-measured once parameters are supposed to be invariable [3].

Both instruments use the computer as their integral parts, which controls processing electronics, calculates and displays beam parameters, as well as results of calibration. Various data processing algorithms and many algorithms of the control are used [4].

2 BEAM POSITION MONITOR AND ZERO OFFSET ERROR

Electrostatic monitors with button-like electrodes are used. Horizontal (X) or vertical (Z) beam displacements in a monitor is calculated from the expression

$$Y = M_Y \frac{k_1U_1 \mp k_2U_2 - k_3U_3 \pm k_4U_4}{\sum U_i} - Y_0 - Y_G,$$

where Y is X or Z, M_Y is the scale coefficient of this monitor; U_i is value of the output signal from BE of number i=1,2,3,4; k_i are the levelling coefficients of the BE's; Y_0 is the electrical zero offset of this monitor; and Y_G is the shift of monitor's center about the design-basic orbit.

The signals U_i are proportional to $(Q_i/C_i)G$ for measurement by scanning BE's by the same channel, and $(Q_i/C_i)G_i$ for a four parallel channel measurement, where Q_i is the charge induced by beam on BE_i , C_i is a total capacitance of the BE_i circuit, and G or G_i are the gains. Both differences between C_i and G_i , i=1,2,3,4, cause some combined zero offset which is eliminated by using levelling coefficients. To determine them, a built-in-system calibration procedure is employed, when without beam the same calibration current, imitating it, is fed into each BE circuit, producing output signal V_i , and the levelling coefficients are calculated from the expression $k_iV_i=(\Sigma V_i)/4$ and recorded in database.

The scale coefficients M_X and M_Z , and the electrical zero offsets X_0 and Z_0 were measured for each monitor on a bench and recorded in database. The beam was simulated by a thin wire antenna. The overall position reproducibility ±100μm was determined by accuracy of the bench. For each point of a coordinate grid, BE's signals were measured too with the antenna. These data can be used for linearization of monitor's characteristics.

For determination of the levelling coefficients during the single channel measurements with the antenna, the same calibration procedure was employed. For installation of the monitor on the bench, the same references were used which serve to measurements of X_G, Z_G at the storage ring.

3 SIGNAL PROCESSING.

TEST AND CALIBRATION PROCEDURE

For entering the data in the computer, the final function of the processing electronics is to be conversion of the BE signal into a signal, the form of which is suitable for measurement by ADC. The most informative measurement is the turn-by-turn one. To achieve both aims the Sample & Hold circuit (S&H) is used as the converter, the output signal of which is a quasi-DC, stepping voltage being equal to the peak values of the turn-by-turn input pulses. Strobe-pulses for the sampling are derived from the revolution frequency signal, which is taken from RF system. To lock the strobe-pulses into step with the pulses of any bunch from monitor placed at any azimuth of the ring, a digital delay circuit is used.

To obtain a pulse, shape and duration of which are suitable for S&H, the short pulse induced by bunch on BE (0.5 nsec), is fed into a series of low-pass filters and RC-circuits which stretch a passing pulse step-by-step. The output pulse looks like a sine-shaped pulse of 40 nsec duration on half-height, followed by an undershot with a decay time about 200 nsec. In the transmission band of the most narrow-band final filter the equivalent diagram of the BE circuit is capacitance C_i and resistance R in parallel, where C_i is a combined capacitance of BE and the series, R is a matched load resistance of this filter. R is chosen high (400 Ω) so that amplitude of the output pulse depends on the value C_i mainly.

To provide for S&H an optimal input voltage range independent of the beam intensity varying in a wide range, two kinds of Amplifier Gain Control are used. In IM, the gain is pre-set by the computer program accor-ding to the value of injected or stored beam current. In SM, Automatic Gain Control is used. Before the measurement of the individual BE_i signals of any moni-tor, the program increases (in steps) the gain till the S&H output signal averaged over BE's, gets a value within the range.

For turn-by-turn measurement, the resolution is resulted by noise in a full band of the input signal of S&H. To reduce noise and increase the resolution of beam parameters, discrete and analog filters are used. For betatron and synchrotron beam motions, the most suitable filter is the discrete Fourier transformation (FT) of turn-by-turn array. Low frequency beam vibrations and stationary orbits are measured with using LP analog filters. An integrating ADC itself is used as such a LP filter with a varied band, the time of integration of which can be varied in a wide range.

A basic procedure for testing the instruments and for determining the levelling coefficients and measuring the strobe pulse delay values for both beam and test signals, is as following. The S&H output signals of the four BE's of a monitor are measured in a stroboscope mode for delay values scanned within the duration of one turn. While the BE's are switched off, the S&H output offset is measured in the same mode for subsequent subtraction of it from the signals.

Analysis of the signals represented on a plot, provides testing workability of the instrument. The delay corresponding with the moment of the pulses' peaks, the peak values U_i or V_i , and the offset value are determined and registered. Four amplitudes V_i are used for calculation of the levelling coefficients. The determined parameters are displayed together with ones taken from the database for comparison. Then, the new values can be recorded there.

In all the other processing algorithms, the S&H signals and the offset for subtracting are measured with the only delay value taken from the database.

4 ARRANGEMENT

IM has a four channel pickup station (FCPS) placed near the monitor, and four parallel channels of processing electronics placed in Control Room. SM includes pickup stations (PS's, the maximal number is 64) placed near each monitor, and a single channel of processing electronics placed in Control Room. PS's are united in groups of eight, PS's of one group are distributed along the common cable. Groups (cables) are sampled by an eight-input multiplexer of the processing electronics. In a PS sampled, the BE's are scanned by switches of the PS.

One channel of FCPS consists of the stretching filters loaded on a buffer circuit, the output current stage of which is a cable driver with DC isolation. A calibration current can be fed into the input of the final filter by using a switch. In PS, the BE_i circuit includes a part of the same series and a switch for scanning. The outputs of the four switches are connected to the input of the final filter. The calibration signal can be fed into the same input through the fifth switch. The buffer circuit is the same one as in FCPS.

The processing electronics are made under CAMAC-standard. One channel consists of a wide band (50MHz) amplifier with the gain of (0÷60)dB, varied in steps of 10dB, and S&H (sampling gate is 10ns). Besides, there are digital delay circuits (step is 4ns, 7bits) and some auxiliary modules to control PS's and FCPS, to trigger fast ADC's, etc. The electronics are placed in 3 crates.

ADC's of two sorts are used: a fast ADC (two modifications: 8bits, 50ns, 1K memory or 10bits, 1µs, 4K) and a slow one ((13+n)bits and time of integration $1.25 \cdot 2^n$ msec where n=0,1,...,7 can be set, 1K memory).

Control of the system and data processing are carried out by a single computer included into the network of the multiprogram control system of the storage ring [4].

5 BETATRON OSCILLATIONS DATA PROCESSING

To determine the coherent betatron oscillation amplitude and phase for beta function measurement and to carry out a fine frequency analysis in IM, a simple and economical refinement algorithm of the standard FFT is used. Other algorithms used for betatron motion analysis are described in [4,5].

For FFT, frequency resolution, i.e. accuracy, is equal to $1/N$ where $N>>1$ is the number of samples in the array. Amplitude and phase of some spectral component are determined with much lower accuracies if its frequency does not coincide with any frequency from the discrete set of FFT. To increase these accuracies as well as frequency resolution, for the harmonic found by the standard FFT, the discrete FT of the same array is carried out for a new set which is generated by the dichotomy algorithm of questing for maximum of amplitude value in vicinity of the harmonic. The process of dichotomy is stopped when the dichotomy step becomes smaller than a frequency tolerance preset. If the frequency accuracy provided by this algorithm is higher, for instance, by a factor of 10 than the FFT accuracy, the amplitude and phase accuracies amount up to 0.1% and 2° respectively (N=1K).

6 EXPERIMENTAL RESULTS

To measure resolution and stability of SM, average "coordinates" and their dispersions for each monitor can be measured using the calibration signal imitating beam. The deviations springing due to noise of PS's determine the resolution of the system. Local offsets of such an average "orbit" from the straight line are caused by a long time drift of PS's' characteristics. Re-measurement of levelling coefficients eliminates these offsets. To keep the accuracy of SM in the range of ±100μm, it is sufficient to re-measure the coefficients once in month. The averaged over monitors resolution $<\sigma>$ of SM is less than 4μm (the calibration signal is equivalent to the beam current of $4\cdot10^{10}$ e; the integrating time of ADC is 10msec).

For a real beam, the average orbit and dispersion of each monitor can be measured too. Resolution of the beam orbit measurement is close to the same value 4μm (10ms, $4\cdot10^{10}$ e) and was measured for few PS's at the VEPP-3 by connecting the inputs of PS together to get a signal independent of beam vibrations. With the beam current decreasing, the same resolution can be achieved by increasing the number of orbits stored for averaging or/and by increasing the integrating time of ADC. For the same integrating time 10ms, the errors of single orbit measurement come to the value of monitor's half-aperture when the particle number amounts up to $1\cdot10^7$ e.

Position error due to changing the beam current does not exceed ±30μm for the range ($2\cdot10^9 \div 3\cdot10^{11}$) e, the error due to changing the bunch pulse duration is less than ±50μm for the range (0.5÷2)nsec and $1\cdot10^{11}$ e (both were measured at VEPP-3).

Other performances of statistic analysis are used in beam position measurements and for studying SM itself.

Procedure and results of beta function measurement by SM at the VEPP-4M is described in [5].

Plots of the turn-by-turn beam current, vertical and horizontal coordinates measured by IM, are routinely displayed for every injection in the storage ring. These pictures are informative when the intensity of injected beam is more than $1\cdot10^9$ e. A procedure of beam injection optimization based on analysis of injected beam parameters, has been developing.

For the betatron tune measurement of a circulating beam by IM, the betatron oscillations are excited by kick. Tune accuracy is less than $2\cdot10^{-4}$ (N=1K).

IM is used for a high resolution measurement of low frequency beam vibrations [5].

7 RELIABILITY

In the VEPP-3, VEPP-4M systems, all CAMAC-modules, PCB's of the pickup-stations (a total number of PS's is about 80), etc. are released from repair with registration of the failures rectified. There are statistic data of the failures, stored in the years 91-95. On the average, one failure happens in a week of systems' work.

Components of the systems include transistors of various types, coaxial HF relays, digital IC's, etc. manufactured in Russia. The most unreliable component is the HF relays which are used for scanning BE's. Relay contact resistance happens to increase up to few Ohms and becomes unstable. HF transistors are more reliable, roughly 3 times. A total number of them is more than the relays, because of that, if the relays were substituted by some ideal switches, a general reliability would increase by 1/4 only.

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9 REFERENCES

1. V.V.Anashin, O.V.Anchugov, A.E.Bondar' e.a. - In: Proc. of the XII USSR Conf. on Particle Accelerators (Moscow, 1992) - JINR, Dubna, 1992, V.1, p.295.

2. A.M.Batrakov, A.S.Kalinin e.a. - Preprint 80-167 of INP, Novosibirsk, 1980. (in Russian)

3. J.A.Hinkson and K.B.Unser. - In: Proc. of Second Europ. Workshop on Beam Diagnostics and Instrumentation for Particle Accelerators (Travemunde, Germany, 1995) - DESY M-9507 (June 1995), p.124.

4. A.S.Kalinin, D.N.Shatilov, E.A.Simonov, V.V.Smaluk. - In: Proc. of the XIV Russian Conf. on Particle Accelerators (Protvino, 1994) - IHEP, 1995, (to be printed in Russian)

5 A.N.Dubrovin, A.S.Kalinin, D.N.Shatilov, E.A.Simonov, V.V. Smaluk. - In: These Proceedings.