# Monitoring the Conditions of Beam Injection into the IHEP Accelerator from the Booster

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## Introduction

The beam is injected into the IHEP accelerator 29 times per cycle, each time filling one unfilled bucket. The purpose of our work was to measure the parameters of betatron (H and V) oscillations, as well as of dipole and quadrupole synchrotron ones of the burst just injected. The measurements results are processed on-line to transform them into the machine parameters. Then the correction data and statistical information characterizing the parameter stability are displayed. These allow one to make a prompt and comprehensive tuning of the two machines with a view to minimize the oscillation amplitude.

A specific feature of the measuring equipment is the necessity to record the parameters of one bunch specified among a number of those circulating in the accelerator.

## Betatron Oscillations

The parameters are measured simultaneously for H and V coordinates using two identical channels. The results are handled and presented with the help of the same algorithm. The block diagram of the measurement circuit is shown in Fig. 1. The sum ($U\Sigma$) and difference ($U\Delta$) of the pick-up electrode signals are fed to the base line restitution circuits, $BLR_\Sigma$ and $BLR_\Delta$.[1,2] After BLR the latter is integrated within exactly one period of the accelerating voltage, ≃180 ns, and 3 $\mu$s later the integrator capacity is discharged quickly. All of it is repeated every period of the revolution frequency (5.5 $\mu$s) till the next bunch is injected. After that, the integrator strobe is shifted automatically to the next bucket to be filled. The integrator signal is fed to a fast ADC with buffer memory[3] placed in a CAMAC-type crate. By the end of injection from the booster the memory contains the data on the position of each injected bunch at the first 32 turns. The operation of all units mentioned above is synchronized by a special unit, which is fed by the appropriately phased RF voltage and injection kicker pulses determining the bucket.

Integration of the difference signal within a period of RF voltage significantly reduces interference with RF and its harmonics. Besides, the integral becomes independent of the bunch shape.

The sum signal from the BLR is integrated in the same manner in order to measure the bunch intensity and the digitized integral is loaded into the buffer memory. The intensity is measured for each bunch at the first, fiftieth and five hundredth turns.

Then the results are processed by a computer. The data on the bunches whose intensity is below the specified threshold is discarded. Then the bunch displacement from the vacuum chamber axis is calculated using the data on the sum and difference signals. Afterwards, we use the discrete Fourier transform to analyze the data on bunch oscillations. If we confined ourselves to determining the maximum harmonic only, the accuracy of local betatron frequency would be $\delta Q \leq 0.02$ which is definitely insufficient. Therefore the results of Fourier-analysis are used just to determine the starting point for the search algorithm of subsequent processing. Oscillations are assumed to be harmonic (decay during 32 turns is negligible), and the problem is solved by minimizing the RMS deviation. The following function is minimized:

$$SQ=\Sigma[Y_i-(AO+A_i*\cos(\omega t_i)+B*\sin(\omega t_i))]^2 \qquad (1)$$

where: $Y_i$ is the value of i-th experimental point, $t_i$ is its number, $\omega$, AO, A, B are the parameters to be defined.

At the first stage, the frequency $\omega$ is considered to be fixed and the values of parameters AO, A and B are estimated analytically from (1). The quantity SQ is calculated for this value.

At the second stage, $\omega$ is included into minimization. The dependence of SQ on $\omega$ is assumed to be parabolic in a small vicinity and the vertex coordinates are calculated from 3 points with the help of the Lagrange interpolation formula.

The obtained values of $\omega$, AO, A, B are the oscillation parameters for the pick-up azimuth and are transformed for the injection point one in the form of angle and position errors.

Since such calculations are done in each cycle for all 29 bunches their rate is quite important. In order to raise it, the analytic dependences and fast algorithms have been found with account of the fact that the initial data is an equidistant time series.

As a result of calculations there appears much data, which is displayed using color multi-window technique (see Fig. 2).

The left upper window shows the intensity of all bunches in the form of a histogram. Different colors correspond to different turn numbers. To the right the table contains the total intensities for the same turn numbers of their ratios. The ratio characterizes betatron capture and is an important adjustment criterion.

The right-hand upper window shows in different colors the curves of betatron oscillations over H and V for one chosen bunch and the calculated amplitudes in mm.

In the right-hand lower corner there are two windows showing the betatron frequencies $Q_h$ and $Q_v$ of each bunch. The digits show the averaged values of these frequencies, their errors not exceeding ±0.001.

The remaining four windows display the histograms of the calculated H and V mismatches in angle and position for each bunch. The mean values shown by digits characterize the adjustment accuracy and the spread in the histograms is a measure of instability.

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The mean values of mismatches are transformed into corrections to the currents in the beam transfer line elements using the relevant matrices. The operation showed that one iteration is, as a rule, sufficient to adjust these currents to the accuracy required. This means that the measurement and calculational accuracy is quite good.

## Synchrotron Oscillations

When transferring the beam from the booster into the PS it is necessary to minimize the amplitudes of dipole and quadrupole synchrotron oscillations. Therefore their parameters are also measured. For dipole oscillations the phase angle of the bunch center of mass is measured and for quadrupole ones the duration of bunch is measured for a sufficiently low density level. These measurements are synchronized in the same manner as those for betatron oscillations. For measuring the time intervals on an order of hundreds of ns to an accuracy of 1 ns we use the time-charge and charge-code conversions.

The measurement results are processed in a way similar to the aforementioned one. The difference is that Fourier-transform is not required because possible relative variations in synchrotron frequency are fairly small and the starting point for search may be specified as a constant.

A number of beam and machine parameters are calculated and displayed proceeding from the results on handling the signals (see Fig. 3). The meaning of the 3 upper windows is similar to those in Fig. 2.

The right-hand middle window shows the reconstructed values of dipole oscillation frequencies for each bunch. The digits represent the bunch averaged frequency and the effective accelerating voltage calculated from it.

The histogram in the right-hand lower window shows the length of each bunch and the digits give their mean length. Variations of these values are independent of the PS parameters and are specified by those of booster RF.

And, finally, the left lower quarter shows the amplitudes of sine and cosine constituents of dipole and quadrupole oscillations. These have a clear physical interpretation:

dipole SIN - momentum mismatch
dipole COS - phase mismatch
quadrupole SIN - presence of quadrupoles oscillations in the booster
quadrupole COS - mismatch in longitudinal phase space

These four constituents are necessary and sufficient to calculate the corrections to RF phase and orbit length in the booster as well as those to RF voltages in both machines.

This technique has been in continuous use and has become an irreplaceable tool for monitoring and adjustment of the systems determined by the beam transfer quality.

## References

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