The Longitudinal Motion Simulation in the Control System of U-1.5 and U-70 Accelerators

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Abstract

During the accelerating cycle various parameters of acceleration RF, magnetic fields and beam intensity are measured at the predestined times. On the basis of measured values a number of parameters such as synchrotron frequency, synchronous phase, bucket dimensions, average radial position, etc. are calculated. The data obtained are presented on-line in various forms: tables, color graphics and histograms. There is the provision for long term statistics and saving the result. Using manual variations of the original data one can simulate different regimes in order to optimize the beam parameters. The hardware and applied software for both accelerators are described. The block diagram and results are presented.

1 INTRODUCTION

At present the IHEP complex consists of the main 70 GeV slow ring and fast 1.5 GeV cycling booster, which includes 30 MeV RFQ linac. This complex after its reconstruction will be used as an injector for the 3 TeV UNK. The effective work with high beam intensity greatly depends on maintaining optimal acceleration regimes. If the reseach and control staff have a measured data about primary parameters of the acceleration cycle and on-line calculated longitudinal motion characteristics then they are able to easily maintain the required regime. In the paper mentioned below describes subsystem which allows one to solve this problem with **an accuracy sufficient for practical work** as well as to simulates longitudinal motion in accordance with the measured data.

2 MEASUREMENTS AND CONTROL

Although the difference between the acceleration repetition cycles (16.7 cps for U-1.5 and about 0.1 cps for U-70) and accordingly the rate of changing of all parameters is very high, indentical equipment is used for measurements. It meets the requirements for the accuracy both of the booster synchrotron and the main ring.

The block-diagram of the measuring part of the subsystem is shown in Fig.1. During the acceleration cycle the following values are measured:

Value of the magnetic field. For this purpose standart acceleration B-trains were used. Their precision is 0.3 Gs and 0.1 Gs for the booster and U-70 respectively. The measurements are made with 24-capacity up/down counter units (BCNT) with buffer storage.

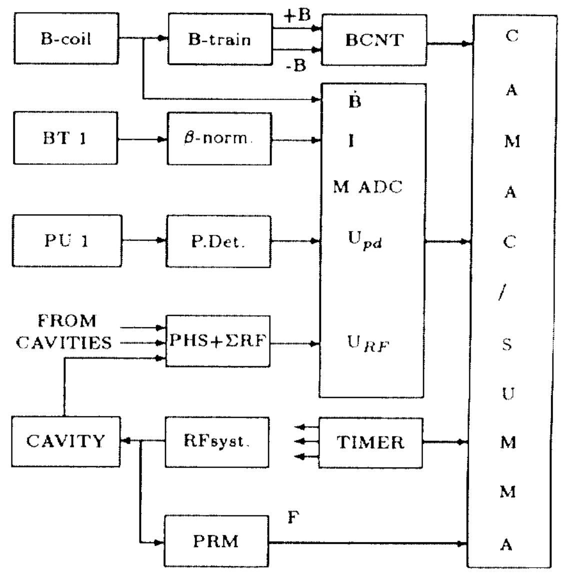

Figure 1. Block-diagram of measuring parts of the subsystem

Magnetic field derivative. After normalization the signal from the induction B-coil, which is disposed in the individual magnet block of the main magnet, is applied to the multichannel ADC unit (MADC). The maximum value dB/dt for the booster is 100 kGs/s and of summed error in this case is less than 0.2 kGs/s. For the slow main ring this error is not more than 0.01 kGs/s.

Accelerating voltage frequency. The change rate of accelerating voltage frequency in the booster achieves 150 MHz/s and frequency changes from 0.7 to 2.8 MHz [1]. Special unit measures the period of the RF voltage (PRM). The reference frequency in this unit is 50 MHz. The number of measured periods is set independently for each timer point. This allowes to choose the optimal regime of the unit and reduce measurement errors to a minimum. Moreover, frequency change during the measurement time is corrected by the program way. Thus is the frequency accuracy is such that the error no more than ∓ 1mm when calculating average radial position of beam (DR/DF is equal to 1mm/kHz in the begining and 4 mm/kHz of the end of the accelerating cycle).

Although the rate of frequency changes in the main ring is nearly one hundred times more than in the booster, the calculated deviations of the average radial beam position is not valid around transition energy.

RF amplitude. The rate of the RF voltage change in the booster achieves 15 kV/ms, when the maximum amplitude is 60 kV. The range of acceleration voltage change during the cycle is exceeds 40 dB. The 9 cavities located in the beam orbit at quontities 30 degrees intervals. Since the harmonic number equals one (h=1) to obtain summary accelerating voltage signals from all cavities gap are applied the special wide-band shifters (PSH). They are summed after that and detected by the synchronous detector. All measuring channels have dynamic range of more than 40 dB [2]. Output signal is applied to the MADC.

In the main ring h=30 and cavities located at 180 electrical degrees to azimuth. The dynamic range of the RF voltage is now more than 20 dB and therefore measuring summary signal is of no problem.

Beam intensity. For the intensity measurement a signal is used from the beam transformer (BT1). After β - normalization it is applied to the MADC. One discrete is $5 \cdot 10^{10}$ protons per cycle and 10^{11} for the main ring.

Peak detector signal. In order to obtain large bandwitch and low noise the peak detector (PD) located in the ring room at a few meters from the electrostatic pickup (PU1). The output voltage from the detector over twist-pair line is transmitted to the control room and applied to the MADC.

Before measurements the operator sets the one of 31 booster cycles and 32 timer points during the accelerating cycle (for booster and main ring). All electronics units have buffer memory for 32 measurements. Between the accelerator cycles of the main ring data from the memory a read to computer and longitudinal motion parameters are calculated.

All electronics units are in SUMMA/CAMAC standart. A mini-computer EC-1010 which is included into the main control system is used for calculation and control equipment. On the main ring a similar system was used, but at present all calculations and measurements are being made with the CM-1810 computer with BOS-1810 (iRMX-86) operating system.

3 CALCULATION OF LONGITUDINAL MOTION

On the basis of the measured values the following parameters are calculated.

Synchronous phase and synchrotron frequency are represented by the following equations [3]

$$\varphi_s = \frac{180}{\pi} \cdot \arcsin \frac{\rho L \dot{B}}{U_{RF}} [deg] \tag{1}$$

$$\nu_s = \frac{c}{10^3 \cdot L} \cdot \frac{\sqrt{\frac{U_{rf}}{E_0} \cdot h \cdot \cos\varphi_s}}{2\pi \cdot \frac{\gamma}{|\eta|}} [kHz] \tag{2}$$

$\gamma = \sqrt{1 + \left(\frac{ec\rho B}{E_0}\right)^2}$ where ρ, α, L, h, e, E_0 are certain constants and B, $\dot{B}$, U_{rf} are the measured values. After this the value $E = E_0 \cdot \gamma$, $\eta = \alpha - 1/\gamma^2$ are found and $\beta = \sqrt{1 - 1/\gamma^2}$.

With [4] the bucket dimensions are calculated.

Bucket area:

$$A = \frac{\sqrt{heU_{rf}} \cdot \alpha(\Gamma) \cdot \frac{16\gamma}{h}}{\sqrt{2\pi \cdot E \cdot |\eta|}} \tag{3}$$

Bucket height:

$$H = \frac{\sqrt{heU_{rf}} \cdot Y(\Gamma) \cdot \frac{\gamma}{h}}{\sqrt{2 \cdot E \cdot |\eta|}} \tag{4}$$

$$\frac{\Delta P}{P} = \frac{\sqrt{heU_{rf}} \cdot Y(\Gamma) \cdot \frac{\gamma}{h}}{\beta \cdot \gamma \cdot \sqrt{2 \cdot E \cdot |\eta|}} \cdot 100[\%] \tag{5}$$

where $\Gamma = \sin\varphi_s$

$$\alpha(\Gamma) = \frac{A(\Gamma)}{A(O)}, A - \text{ bucket area;}$$

$Y(\Gamma)$ – one half bucket height.

The values for H, X and Y for some Γ are tabulated in [4] and they are interpolated during calculations for concrete Γ.

The deviation of the average radial position is computed as a difference beetween the measured frequency and to one calculated for synchronous particles frequency, which is based on the magnetic field data [4].

Relative widening of the bunch along the cycle for adiabatic damping case is also computed [3]. Having the relationship between the peak detector voltage and bunch width value are can qualitatively estimate the tuning of the acceleration regime.

Applicational programs and graphic package for EC-1010 computer are made in FORTRAN and all application software for CM-1810 in the C86 language. In oder to computed bucket dimensions analitic expressions for a sinusoidal RF voltage was used [5].

Bucket width ($\phi_e - \phi_u$) where

$$tg(\phi_e - \phi_u - 3\varphi_s) = \frac{1}{10} tg^3\varphi_s \left[1 + \frac{110}{140} tg^2\varphi_s - O(tg^4\varphi_s)\right]^{-1} \tag{6}$$

φ — phase measured from the crest of the RF voltage.

Bucket area:

$$A_s = 16 \frac{E_0}{h\omega_0} \left| \frac{\beta^2\gamma}{h\eta} \cdot \frac{eU_{rf}}{2\pi E_0} \right|^{\frac{1}{2}} \cdot \alpha(\Gamma) [eV.s] \text{ per bunch} \tag{7}$$

where

$$\alpha(\Gamma) = \frac{3}{10} |\varphi_s|^{\frac{5}{2}} \cdot \left[1 - \frac{1}{60} \cdot \varphi_s^2 + O(\varphi_s^4)\right] \tag{8}$$

ω_0 — revolution angular frequency.

Bucket height

$$\left(\frac{\delta \hat{E}}{h\omega_0}\right) = \frac{R}{h} \cdot \delta\hat{p} = \frac{E_0}{h\omega_0} \cdot 2 \left| \frac{\beta^2\gamma}{h\eta} \cdot \frac{eU_{rf}\sin\varphi_s}{2\pi E_0} \right|^{\frac{1}{2}} \cdot [1 - \varphi_s cotg\varphi_s]^{\frac{1}{2}} [eV.s] \tag{9}$$

where $\hat{E}$ and $\hat{p}$ — maximum values.

Table 1:

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U-70 : RF control : Measurements: Page 1

		1	2	3	4	5
1.	Time from B2(ms)	500.	1800.	2700.	3300.	3800.
2.	Interval (ms)	500.	1300.	900.	600.	500.
3.	B field (Gs)	353.2	353.2	559.2	3487.2	5892.2
4.	dB/dt (Gs/ms)	0.	-.0157	3.8726	5.0532	4.5023
5.	RF amplitude(kV)	181.6	180.05	322.89	352.01	277.62
6.	Intensity·E11	13.103	31.53	30.711	30.711	30.711
7.	Peak det. (bit)	93.	98.	213.	309.	309.
8.	Frequency($10 \cdot Hz$)	551128	551131	583356	605493	605933
9.	Energy (GeV)	1.3213	1.3213	2.4487	19.378	33.366
10.	Syhc.phase (deg)	-90.	-90.14	-69.79	-65.53	-62.15
11.	Sync.freq. (kHz)	1.5873	1.5829	1.0698	.16626	.12028
12.	Δ P/P (%)	.3569	.35521	.41578	.42350	.25013
13.	Bucket wid.(deg)	360.	357.88	225.12	208.96	196.43
14.	Bucket area	.06255	.06203	.07828	.46196	.43355

3.1 The longitudinal motion simulation

The results of measurements and computations are presented on-line on the screen in the tabular form. Its fragment is shown in Table 1.

The obtained data can be printed in graphics form and histogram also. This is possible have two any function on the color graphic display if assignment both lines numbers and line number when has to abcissa axis. Data in the table will be able to modification every cycle. There is the provision for long term statistics and saving the result [6].

Using manual variations to some extend such data in the table as magnetic field value, field rate, frequency and amplitude of RF accelerating voltage one can simulate longitudinal motion parameters. The application program permits to make four arithmetical function both with one or few elements of the line in the table or with the whole line simultaniously. After optimization of the necessery parameters by means of this program one may set a new acceleration regime.

The subsystem for measurements and on-line calculations of longitudinal motion characteristics has been used actively by the operation staff for a few last years at IHEP acceleration complex and lately at the main ring in the modern configuration.

4 REFERENCES

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