Summary. Design principles and main performance data of the electronic systems used in the Serpukhov proton synchrotron, to generate the accelerating field, to control acceleration processes, and to measure accelerated beam parameters are described.

Introduction

Previous papers on the electronic systems of the Serpukhov 70-GeV proton synchrotron gave some parameters of the electronic systems then envisaged and characteristics of these obtained in the course of development and bench tests. After being installed at the accelerator the electronic systems were tested autonomously using control signal simulators and an electronic beam model. In a month after the first turn had been obtained the highest proton energy was 76 GeV at $5 \times 10^8$ protons per pulse. This low beam intensity was due to the fact that in the daytime, final assembly of various accelerator systems was continued (works with beam were carried out in the nighttime) so that it was not possible to overcome a permitted level of residual radioactivity.

In about a month, a possibility appeared to increase the beam intensity up to $10^{10}$ protons per pulse. To make RF system to operate with the intensity as low as $5 \times 10^8$ an adjusting FM oscillator with precisely programmed frequency deviation (The precision was $\pm 2 \times 10^{-4}$ for frequency between 2.6 and 5.96 MHz and $10^{-6}$ for a frequency between 5.96 and 6.05 MHz) was specially built to provide for accelerating a low-intensity beam. With no beam-controlled feedback at the beginning of acceleration cycle (up to an energy of 5 Gev). Also, a possibility of using the beam-controlled feedback with less than $10^7$ protons per pulse was envisaged.

During tests of the RF system it was found that a delay of ferrite magnetization that took place in the cavities of accelerating stations significantly deteriorated the effective $Q$ of output circuits at the initial stage of acceleration cycle during which the rate of frequency change is highest reaching 150 MHz/s.

This effect was lowered significantly by preliminarily magnetizing ferrites for 0.5 ms before frequency deviation began. A magnetizing current of 70A is interrupted 6 ms before RF power is supplied. Under these conditions, the effective $Q$ of output circuits of accelerating stations provides for a total accelerating voltage of 380 kv.

Careful preliminary adjustment of all the accelerator electronics was important in speedy achievement of output energy.

Developed are electronic systems to control simultaneously all the acceleration processes, to provide for a required energy gain per turn, to keep beam at a mean radius inside the chamber, to damp out synchrotron oscillations, and to facilitate controlling the beam intensity, the bunch azimuthal length and the closed orbit and measuring the betatron frequency and parameters of electronic components.

The main electronic systems are:

a) Acceleration programming system.
b) RF supply system, c) Beam measuring system, and d) Electronics monitoring system.

Acceleration programing system

This system is designed to supply control pulses each corresponding to a certain moment within an acceleration cycle. It contains devices that produce pulses locked to a given magnetic field magnitude, to a given time interval or to a given number of turns referred to the time of injection.

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Locking of the reference pulse with the magnetic field is stable within $10^{-2}$ Oe which corresponds to pulse jitter of less than $3\mu$s.

Multichannel timers triggered by pulses from peaking strips are used to control processes which need not be very accurately corresponded to the magnetic field. These timers produce control pul-
Pulses referred to reset magnetic field values are obtained from a digital integrator. This integrator is triggered by pulses from a peaking strip and is controlled by the voltage from an induction pick-up coil placed in the gap of reference magnet. The output of digital integrator is set by steps of 1 0e.

To check the stability of pulses from peaking strips and to calibrate the digital integrator two ESR magnetic field probes one for 76 0e and the other for 1000 Oe.

The devices that produce pulses corresponding to a given number of turns are similar to that of a multichannel timer. They employ the accelerating frequency as a standard frequency to count the number of turns. The setting of these pulses is discrete and equal either to 0, 1 or 1 turn.

RF - System

The RF system consists of the following three interconnected subsystems:

a) A master FM oscillator programmed to deviate its frequency according to magnetic field variation. b) Tunable accelerating power stations delivering a required energy to protons. c) Beam-controlled feedback devices to correct the accelerating field with accordance to the frequency by signals proportional to the magnetic field. (Adiabatic errors must be within $2 \times 10^{-4}$ at the beginning of acceleration cycle and $10^{-6}$ when passing through the transition energy).

The programmer provides for the required accuracy of correspondence of $2 \times 10^{-4}$ only during the first millisecond of acceleration cycle until the beam-controlled feedback is operated; the accuracy of correspondence being about one per cent during the other part of cycle.

Beam-controlled frequency-correction signals are formed by suitably processing the beam-induced output of pick-up electrodes. The beam is positioned by varying the capacity of pick-up electrodes through a remotely controlled differential capacitor. Output of two radial position pick-ups separated by a betatron half-wave distance can be used to eliminate the effect of free betatron oscillations. The two signals, one proportional to the radial beam displacement and the other to the phase one are added up with certain weights to be fed to the modulation input of FM oscillator.

A beam-controlled correction signal can be switched on at any time of acceleration cycle. The switching time is less than 10 $\mu$s. When crossing the transition energy the sign of radial pick-up output and the phase in the accelerating voltage channel of phase discriminator are switched over by a timer pulse. The highest admissible deviation of the actual switching-over time from the required accuracy of correspondence of $2 \times 10^{-4}$ has been experimentally found to be 1 ms. Switching-over takes place in less than 100 $\mu$s. Over the entire accelerating frequency range, the inherent error of beam-controlled feedback is about 1 $\mu$m for the radial pick-up and 0.2 and 0.05 rad for the phase pick-up for adiabatic and fast change of beam phase, respectively, with $10^{10}$ to $10^{12}$ protons per pulse.
Beam measuring system

Three separate systems have been developed to measure beam parameters:
a) A bunch intensity and azimuthal length measuring system, b) An orbit position measuring system. c) A frequency of free betatron oscillations measuring system.

Beam-induced signals at a cylindrical electrode are used to determine the intensity and azimuthal length of bunch. To measure the latter, beam-induced signals are fed to an oscilloscope through an amplifier having a bandwidth of 18 MHz and a maximum gain of 5 x 10^4. To measure the beam intensity the d.c. component is drawn out from an amplifier output signal and is applied to another oscilloscope through a low-pass filter.

Thus a panoramic view of intensity variation in the course of acceleration is displayed at the oscilloscope screen. At any time this voltage can be measured with a fast (100 µs) time-of-measurement digital voltmeter calibrated in protons per pulse. Intensity measurements are accurate within ±10 per cent at 10^10 to 10^13 protons per pulse.

The position measuring system contains 85 pairs of beam-position pick-ups. In each pair one of the pick-ups measures the vertical beam displacement and the other the horizontal one. Two to four pick-up pairs can be connected separately to one of the 30 measurement channels. Connection of a desired pick-up with a measurement channel as well as selection of the channel transfer ratio is performed through a remote control console.

The amplified signals of sum and difference circuits of the chosen pick-ups go through RF cables to the accelerator control room where they can be supplied through a relay switch and additional amplifiers to a two-beam oscilloscope. The ratio between the sum signal and the difference one makes it possible to determine beam displacement from the chamber axis. The maximum gain of each channel is 5000; the measurement channel bandwidth extends from 1 KHz up to 17 MHz; the accuracy of beam position measurement is ±0.1 mm at 10^10 to 10^13 protons per pulse. Where ∆r is beam displacement. The system measuring the frequency of free betatron oscillations makes use of signal proportional to beam displacement. From these spectra, the component with a frequency \( f = Q \Delta \nu_{\text{rev}} \) is derived by means of a low-pass filter, where \( \nu_{\text{rev}} \) is beam revolution frequency and \( Q \) is the difference between the number of betatron oscillations per turn and the nearest integer. The number of accelerating field cycles \( N \) in a time interval equal to one or more cycles of the frequency \( f \), \( N = 30 n / AQ \), is measured and appears at a digital display.

Electronics monitoring system

The system is designed to measure parameters of each individual electronic component and includes digital frequency/microsecond-meters measuring the instantaneous accelerating frequency at any time of acceleration cycle and the time interval between any two chosen control pulses. When investigating the long-term stability the frequency/microsecond-meter read-outs are type-printed, each of the printers operating in a reset cycling mode.

Included into this system are also special large screen oscilloscopes to observe and take photographs of slow processes in circuits of electronic components, cycle counters, automatic alarms, simulators of control signals, etc.

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References