COMPUTER CONTROLLED SYSTEM FOR RF MANIPULATION AT ITEP PROTON SYNCHROTRON

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Introduction

A rf-manipulation system for ion acceleration is developed at the proton synchrotron U-10. The synchrotron has to accelerate all ions from hydrogen to uranium, that is the ions with different Z/A ratios, so the system has to be easily switched from one ion type to another. The intensity of ions, especially of heavy ones, will be low, accordingly, beam position observation and radial feedback will be embarrassing. Therefore it is necessary to reproduce accurately the functional dependence of the accelerating field frequency on the leading magnetic field without radial feedback loop. The new system must permit the change of harmonic number in the process of ions acceleration. The frequency range of U-10 acceleration stations is from 1 to 5 MHz, i.e. their frequency variation coefficient is K_f=5. Ions may be accelerated up to the energy defined by the maximum value of $B\rho$=30 Tm. The typical injection field corresponds to $B\rho$=0.7 Tm. So the revolution frequency of unrelativistic ions may be changed by the factor K_o=40. The discrepancy between K_f and K_o is supposed to be secured by many stages scheme of acceleration, with beam recapture at intermediate flat tops of the magnetic cycle. This scheme of acceleration is not new it is used, in particular, at the JINR synchrophasotron /2/.

System structure

The main elements of the system are shown in Fig. 1. The accelerating field frequency depends on the synchrotron magnetic field according to the formula

$$f(B) = \frac{hc}{L}\cdot\left(1 + \left(\frac{Amc^2}{ZeB\rho}\right)^2 \right)^{-1/2} \qquad (1)$$

where A, Z are the atomic weight and charge number of the ion, m - the atomic mass unit, L - the orbit lenght, h - the harmonic number.

The r-f signal of changing frequency determined by Eq.(1) is produced at the output of the voltage-controlled oscillator (VCO). The dependece of the VCO output frequency on its driving voltage is defined by the modulation characteristic of the oscillator. The VCO driving voltage is formed by cascade connected modules of the function generator FG1 and the integrator.

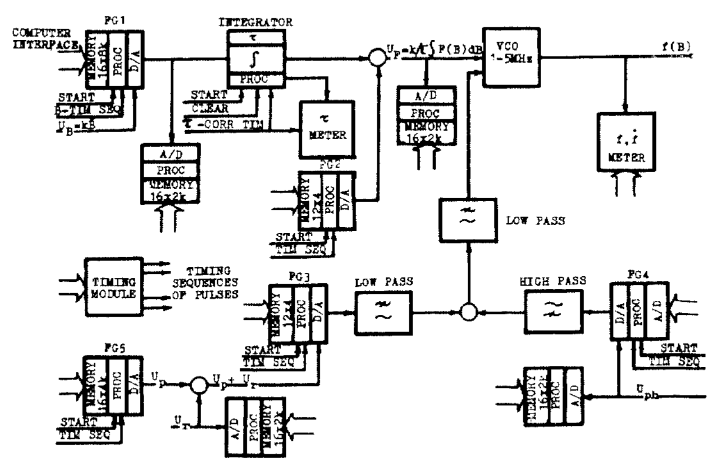

Fig. 1. Blok diagram of rf-manipulation system

The FG1 module controlled by an incorporated microprocessor produces the stepwise changing voltage

$$U_F(t,B) = U_B(t)\cdot F(B) \qquad (2)$$

where $U_B(t) = k\,\dot{B}(t)$ is the voltage as a function of time that is proportional to the derivative of the magnetic field induction, $F(B) = F_i$ (for $B \in [B_i, B_{i+1}]$, $i=1,\dots 1023$) is a stepwise changing function defined by the tables of $\{F_i\}$ and $\{B_i\}$ which are stored in the FG1 memory. The B-timing sequence of pulses synchronizes the moments of F(B) variotions. The integrator module transforms the step function Eq.(2) that depends explicitly on t and B to the piecewise-smooth function

$$U_f(B) = \frac{k}{\tau} \int F(B)\, dB \qquad (3)$$

which depends explicitly on B only and hence may be used as the driving function of VCO .

The tuning of the frequency control channel has the aim to adjust the function F(B) to get f(B) in accordance with Eq.(1) .

For many stages acceleration scheme, the difinition region of F(B) is divided into a series of segments. The initial values of frequencies for the segments are established by the module FG2, and the function F(B) is defined by changes of harmonic number in Eq.(1). The phase and radial feedback loops, if used, are initiated at the start of each acceleration stage. The modules FG3, FG4 are used for feedback factors regulation. The timing module generates sequences of synchronization pulses for all system modules.

Programs

A practical way to calculate F(B) for any type of ions is to express it as a function of $F_o(B)$ - the same function for one chosen type of ions :

$$F(B) = F_o(B) \frac{h}{h_o} \left(\frac{A\ Z_o}{A_o Z}\right)^2 \left(\frac{1+(A_o mc^2/Z_o eB\rho)^2}{1+(A\ mc^2/Z\ eB\rho)^2}\right)^{3/2}$$

As well, the function F(B) can be well approximated by the formula

$$F(B) = -\frac{dU_f}{k\ df} \frac{hc}{L} \left(\frac{Amc^2}{ZeB\rho}\right) \frac{1}{B} \left(1+\left(\frac{Amc^2}{ZeB\rho}\right)^2\right)^{-3/2}$$

which can be obtain from Eq.(3) by differentiation with respect to B.

The calculation and control programs are written in NODAL and execute four groups of functions: initial system tuning; optimization of parameters to get maximum value of beam intensity; measuring and stabilization of system parameters; saving, loading and check-up of their operational values for all types of accelerated ions.

The initial tuning of the system includes measuring and handy approximation of the oscillator voltage-frequency characteristic, calculation of F(B) table, forming of control words and operational data tables for the FG1 and the integrator.

For our oscilator it was found to be possible to get high precision approximation of the $U_f(f)$ function by the sum of four items

$$U_f(f) = \sum_{k=0}^{3} A_k f^{\alpha k} \qquad (6)$$

where the coefficients A_k are found by least-square analysis of information obtained from the voltage-frequency characteristic measurements, and the optimal value of α is found by small variation near unity.

Using the expression (6) we got for our oscillator that

$$U_f(f) = -0.4634 + 0.5574 \cdot f^{1.35} + 0.0191 \cdot f^{2.7} + 0.682\ 10^{-3} \cdot f^{4.05} \qquad (7)$$

approximates the oscillator driving function with 10^{-5} accuracy. Differentiating Eq.(7) and subsistuting it into Eq. (5) , one gets the expression for F(B) table calculation. The scale coefficient τ /k in Eq.(5) is chosen to use the whole dinamic range of the FG1 digital-to-analog converter.

The integration constant τ is chosen to get the given value of df/dB at some point of the magnetic cycle. The initial frequency f_o for each acceleration stage is corrected by the FG2 module.

Optimization of the system parameters to get maximum beam intensity is based on additional information that can be got from theoretical and experimental investigations. The optimization process includes delicate tuning of the timing module and F(B) tables correction to get predefined value of $\Psi(B_o) = (\frac{\Delta p}{p})_o$ of initial mismatchihg of the particle momentum and the magnetic field induction, to match the initial frequency with the average momentum of particles and with $\Psi(B_o)$, and to optimize the initial value of $\Psi' = \frac{d\Psi}{dB}\Big|_{B_o}$. The function $\Psi'(B)$ has to become zero at the optimum (for the given accelerator) value of $\Psi(B)$. If the intensity of the beam is high enough to give reliable signals of beam position and phase oscillation, the optimization is finished by activating and tuning of radial and phase feedback loops. In the case of low intensity, we need to correct F(B) to get the operational value of $\Psi(B)$ throughout the acceleration cycle. The size of the tables needed to reproduce operational values of all system modules for one type of ions is approximately 10 kbytes.

Measuring modules shown in Fig. 1 allow to digitize useful dynamic signals of the frequency driving channel and the feedback loops. The integration constant τ is measured and corrected in each acceleration cycle, all other information is used interactively at operator's request.

Experimental results

The system and the algorithm of its tuning, as well as harmonic number change, have been tested at U-10 with protons. Relative divergence of actual frequency values from those given by Eq.(1) did not exceed 10^{-4}. We suppose this accuracy to be sufficient to accelerate in U-10 all types of ions.

When the system was used with broken feedback loops we observed exitation of coherent phase oscillations at 600 Hz - the fundamental harmonic of the magnetic field ripple. The phase oscillations have been followed by loss of some part of the beam. We hope to have no phase oscillations at ion acceleration because the resonance of the phase oscillation will be reached at essentialy higher magnetic field levels and, correspondingly, at lower relative levels of ripple. If this suggestion turns out a fauls we will insert an additional feedback channel to compensate ripple influence.

References

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