SYSTEM FOR THE GENERATION OF AN ACCELERATING FIELD OF A 70 GEV PROTON SYNCHROTRON

By

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After the design of a high precision frequency control system of the accelerating field of a 50 - 60 Gev proton synchrotron with a compensation of the critical energy [1] it was decided to develop a variant of the accelerator with a transition through the critical energy which provides the possibility of an increase of the energy to 70 Gev. In this accelerator variant the materialization of the system for the generation of an accelerating field with a frequency control by the H-program alone, presents serious difficulties. It was decided therefore to provide the system with a double frequency control: a rough control by the H-program and an exact one by the information on the radial and phase position of the beam of accelerated particles.

This report deals with the principal singularities of the development of the programmed f-m generator, the frequency control system by the information on the position of the clusters of accelerated particles and accelerating stations.

1. Programmed f-m generator

As is shown in the block diagram of the system for the generation of the accelerating field, the programmed f-m generator contains the conventional units: A generator of the operating magnetic field intensity, an induction coil in the gap of the measuring electromagnet, electronic switch, tube integrator, modulator, fm-generator, phase manipulator, modulator of the accelerating voltage amplitude, amplifier-distributor and a system of cable connections (CKC). At the design of the control system of the frequency of the accelerating field the following requirements were set for the programmed fm-generator: range of frequency variation: 2.5 - 6.1 MHz; instability of frequency at the beginning of the acceleration cycle (before the switching in of the feedback along the beam) $\pm 5 \times 10^{-4}$ and $\pm$ 1% during the other part of the cycle; the relative magnitude of the effective parasitic modulation of a noise and background character less than 10^{-4} in the frequency band 0 - 100 KHz; transmission band along the correction channels of the frequency of signals from the accelerated particle beam 100 kHz; nominal amplitude value of the output voltage at the port of each of 53 acceleration stations 3 v $\pm$ 5% over the entire frequency range; limits of possible gradual variations of the amplitude (its decrease) in the function of the rate of the magnetic field variation up to 50%; the possibility of an amplitude increase by 1.8 times during the packeting time of the beam and a commutation of the phase of the output voltage by 120^{o} at the moment of the transition through the critical energy.

The requests setup with respect to the range of the variation and the stability of the frequency of the generator are in accordance with the margin worked out by the fm-generator whose essential elements of the principal scheme are shown in the block diagram. The generator has been designed according to a three-point induction scheme with a limitation of the amplitude by counter-switched diodes locked by the reference voltage E_0. The frequency modulation is effected by the variable inductivity $L_{\sim}$, generated in a ferrite core and by the variable capacity $C_{\sim 1}$, generated in the locked semiconducting diodes. The analogously generated variable capacity $C_{\sim 2}$ serves for a fast frequency modulation along the feedback channel by the beam. At the initial frequency the inductivity $L_{\sim}$ is essentially greater than the constant inductivity $L_{=}$. Hence, the instability and the hysteresis properties of the inductivity $L_{\sim}$ are not too pronounced at this frequency. For the materialization of the inequality $L_{\sim} \gg L_{=}$ a modulation of the frequency by the variation of the capacity $C_{\sim 1}$ has been applied, which possesses its maximum value at the initial frequency and which realizes the basic frequency variation at the start of the modulation process of the latter one. The result of these schematic resolutions is a high stability of the frequency of the designed generator: $\pm 5 \times 10^{-4}$ at all points of the modulation characteristics over several days of the generator operation. The effect of the drift of the initial potentials has been eliminated by the automatic frequency programming system with a motor-operated generating unit. The frequency programmer contains an electronic switch on semiconducting diodes, a non-linear tube integrator with a variable capacity of the feedback circuit which plays also the part of a functional transformer, and a frequency modulator - a direct current amplifier with a deep counter-coupling. The phase manipulator is designed in the shape of a two-channel quadripole with a delay line in one of the channels which commute by a diode switch. The amplitude modulator consists of a transistor high-frequency amplifier with an automatic system for the regulation of the amplification (APY), whose reference voltage is the output voltage of the induction coil. The modulator contains two amplitude manipulators. One of them serves for the switching-in of the accelerating voltage at the injection and the other one for the switching-in of the high-frequency voltage for the packeting of the beam (from the high frequency generator or from the external generator).

The amplifier-distributor possesses eight outputs, from seven of which the voltage is transmitted to seven cabinets of the cable connection system by means of approx. 800 m long cables. From each of the cabinets, which contain the corresponding resistances and the transformer the high-frequency voltages enter four accelerating stations with one phase and four stations with the opposite phase. In the amplifier-distributor the tying of the amplitude of the input voltage of the accelerating stations to the amplitude of the input voltage of the amplifier-distributor takes place. For this purpose the voltage at the end of the eighth cable (used as a standard) is detected and compared with the rectified input voltage of the amplifier-distributor. The amplified difference of the rectified voltages performs the regulation of the transfer coefficient of the amplifier distributor. Investigations showed the feasibility of a materialization of a branched system of cable connections with the application of the described amplitude regulation at a deflection of the amplitudes at the inputs of the accelerating stations of less than $\pm$ 5% and of phases less than $\pm 5^{o}$ over the total frequency range. This permits a materialization of a tying of the amplitude of the output voltages of accelerating stations to the amplitude of the output voltage of the master oscillator which carries the information on the modulation and the manipulation of the accelerating voltage.

2. Accelerating stations

For a generation of an energy increase per revolution ΔE = 166kev at a rate of the magnetic field intensity variation $\dot{H}$ = 5500 oersted/sec and $\varphi_s = 30^{o}$ an application of 53 accelerating stations with a nominal output voltage of 7 kv and capacity of 6 k-watt has been visualized. Provisions have been made also for a short-time increase of this voltage by 1.8 times during the period of the packeting of the beam (approx. 15 microsec.) and its gradual decrease by approx. two times at the end of the acceleration cycle for a preservation of a constant equilibrium phase at the drop of the rate of the magnetic field increase.

The accelerating unit consists of two resonators of a small electrical length with a common accelerating slit which are excited counter-phaseally. The resonators are filled with 44 ferrite coils of a rectangular shape. Each coil consists of six ingots (200 x 80 x 20 mm). The weight of ferrite in each accelerating unit amounts to 400 kg. Ni-Zn ferrite with an admixture of cobalt oxide is used, which weakens the effect of the decrease of the quality factor at a high magnetizing rate. Composition of the ferrite in weight %: 1.98 Fe; 0.65 Zn; 0.39 Ni; 0.0003 Co; 0.0009 V; O_4. Here the sum of harmful admixtures in the raw material (K, Na, Ca, Si, Pb) is less than 0.25 weight %. The density of the ferrite is not less than 5.1 g/cm^3. At the initial frequency the magnetic permeability of the ferrite is equal to 320 and the quality factor approx. 20 at any induction amplitude of 75 gauss.

The amplification of the high-frequency voltage from 3 v to 7 kv is materialized by a five-cascade wide-band amplifier whose output cascade is loaded with the accelerating element. The APY-system which regulates the amplification of the second cascade by the amplified difference of the rectified input and output voltages safeguards a rigid tying of the amplitudes of the latter.

The automatic tuning of the resonators to the frequency of the input signal is effected by regulating the magnetizing current of the ferrite by the output signal of the phase detector by a strong direct current transistor amplifier (direct current amplifier of the automatic phase tuning system with a maximum outlet current up to 100 amp.). For a safeguarding of the given fast-action automatic phase tuning (width of the band of the transfer of information at a frequency above 30 kHz) a programming of the magnetizing current by the frequency of the input signal and a negative feedback by the current in the direct current amplifier in the automatic phase tuning system are applied. The delay line switched into the transmission circuit of the input voltage to the phase detector equalizes (with an accuracy $\pm$ 10°) the phase shifts in both transmission channels of the high frequency voltage to the phase detector and eliminates thus a considerable detuning of the resonator.

The application of the APY and AПФ-systems results in a decrease of the internal amplitude and phase modulation of the accelerating voltage.

3. System for the control of the frequency of the accelerating field by the information on the position of the accelerated particle beam

With respect to the operation principle this system is analogous to the system described in a different publication [1]. It is used for the stabilization of the center of gravity of the beam by the radius and the phase with given tolerances: $\Delta r \leqslant 9$ mm by the radius $(\frac{\Delta p}{p} \leqslant 2.5 \times 10^{-3})$, $\Delta\varphi_{ad.} \leqslant 0.25$ rad, for adiabatic phase translocations and $\Delta\varphi_{\omega} \leqslant 0.1$ rad for fast phase oscillations at the intensity of $5 \times 10^{8} - 10^{12}$ particles, for adiabatic deviations of the frequency of the master oscillator of $\pm$ 5%, at fast defections $\pm$ 0.1%, perturbations in the amplitude of the accelerating voltage U and the rate of the magnetic field variation H:

$$\left(\frac{\Delta U}{U}\right)_{ad} \leqslant 0.15; \quad \left(\frac{\Delta U}{U}\right)_{\omega} \leqslant 0.005;$$

$$\left(\frac{\Delta H}{H}\right)_{ad} \leqslant 0.3; \quad \left(\frac{\Delta H}{H}\right)_{\omega} \leqslant 0.05.$$

The tolerated deviations of the beam coordinates are determined by the choice of the corresponding transfer coefficients and the limitation of the intrinsic error of the correction circuit.

The low frequency voltage for the correction of the frequency is generated from signals transmitted by the accelerated particle beam upon the signal electrodes positioned in the rectilinear gap of the vacuum chamber. The signals from the electrodes enter the input block where the sum U_{Σ} and the difference U_{Δ} of these signals is formed. The total and the differential signals are amplified by the wide band amplifiers УВЧΔ (high frequency amplifier) and УВЧΣ. The total signal is proportional to the beam intensity and the differential one is proportional simultaneously to the intensity and the deflection of the beam from the normal orbit along the radius. The choice of the radius of the nominal orbit is materialized by a differential condenser C_d, positioned parallely to the signal electrodes. For a control of the operation of the input block the generation of a control signal is visualized. The block is positioned in the vicinity of the signal electrodes in the magnet compartment. The control of the block: switching in, variation of the transfer coefficient, generation of the control signal and the choice of the nominal orbit are carried out by remote control by means of a regulation and control block positioned in the electronics compartment. The input block operates with electron tubes, since it is less affected by the radiation.

The normalization of the differnetial signal and the synchronous detection are carried out in a transformation block. The signal obtained after the detection, which is proportional to the radial deflection is amplified by a direct current amplifier (УПТ). The total signal is used for the normalization of the differential one and serves as a reference signal in the synchronous detector.

For the generation of a signal proportional to the azimuthal coordinate of the gravity center of the beam, the phase of the total signal is compared with the phase of the total accelerating voltage. The latter is formed by a summation of the voltages taken from all accelerating stations. The constant phase shift between the signals is compensated with a phase shifter switched into the channel of the accelerating voltage. The limits of the compensation of the constant phase shift are 0 - 360°. The deflections of the beam phase are recorded by means of a phase detector. The generated signal is amplified by the УПТ.

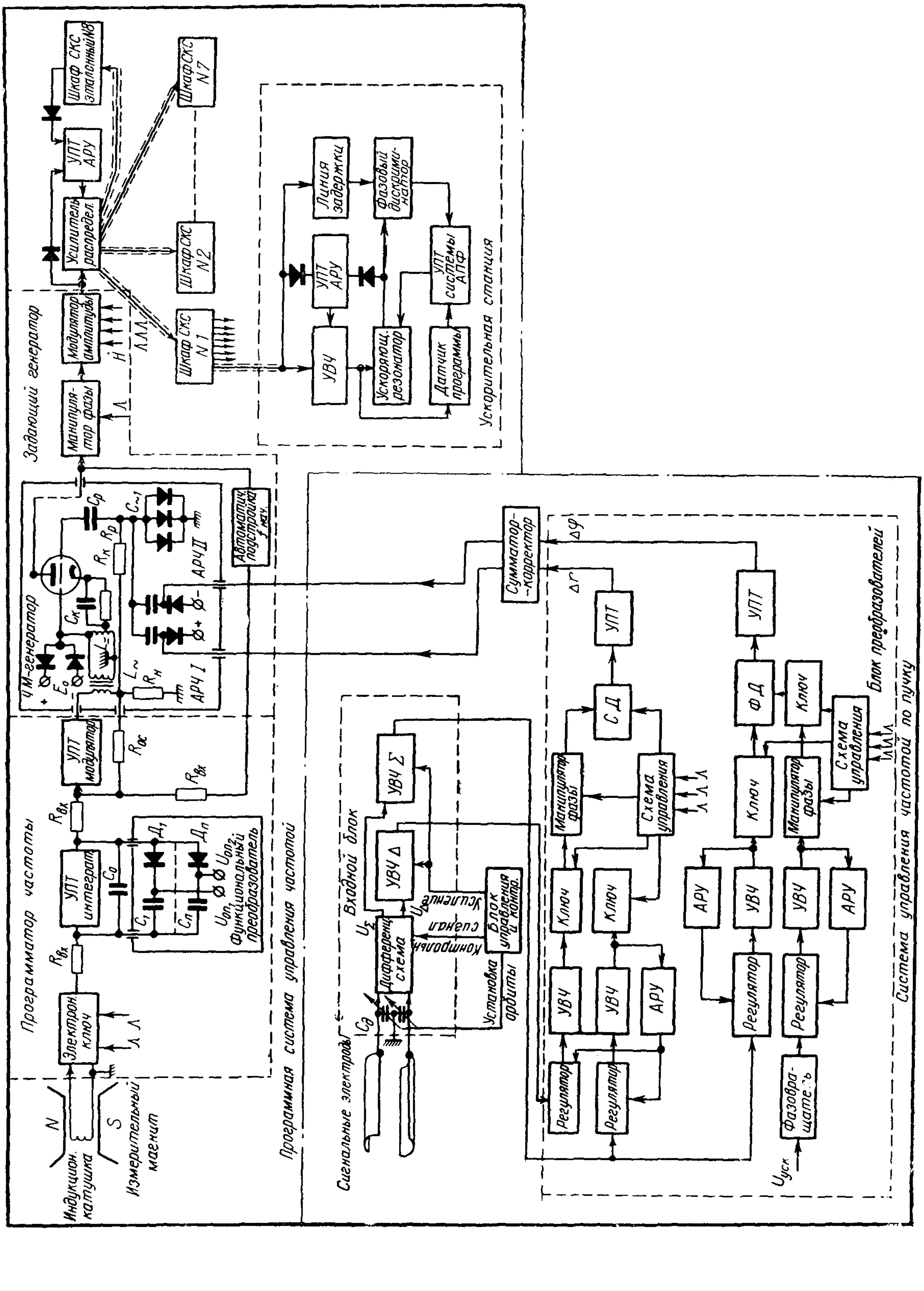
The АРУ and the normalization system safeguard the required accuracy (10%) at the intensity variation by 100 times. At a high variation of the intensity a manual control of the transfer coefficient of the input block is required. The time period of transition processes in these systems is less than 100 microsec. The transmission band of high frequency channels of the correction system is 0.1 - 12 MHz.

At the output of the high frequency part of the block in all channels there exist switches which permit a switching in of the correction system at any moment of the cycle. In contrast to the system described earlier [2] in the high frequency channels of the differential signal and of the accelerating voltage phase manipulators are used which permit a change of the phase of these signals at the moment of the transition through the critical energy by π and $\pi - 2\varphi_s$, correspondingly. The time of the change-over of the manipulators is less than 100 microsec.

For reasons of prolonging the life time, the transformer-blocks consists of transistors.

The signals proportional to the phase and radial coordinates of the beam are summed with a definite weight in the summator-corrector. It consists of two operational direct current amplifiers from whose outputs the paraphase signal is introduced into the control units of the master oscillator.

Tests of the simulator of the correction mechanism showed that the intrinsic errors of the measurement of the radial shifting of the beam do not exceed 1 mm and the errors of the measurement of the phase



Программатор частоты
Задающий генератор
ЧМ-генератор
Электрон. ключ
УПТ интегратор
УПТ модулятор
Функциональный преобразователь
Манипулятор фазы
Модулятор амплитуды
Усилитель распредел.
УПТ АРУ
Шкаф СКС эталонный N8
Шкаф СКС N 1
Шкаф СКС N2
Шкаф СКС N7
Автоматич. подстройка f нач.
АРЧ I
АРЧ II
УВЧ
Ускоряющ. резонатор
Датчик программы
Линия задержки
Фазовый дискриминатор
УПТ системы АПФ
Ускорительная станция
Индукцион. катушка
Измерительный магнит
Программная система управления частотой
Сигнальные электроды
Входной блок
Дифференц. схема
УВЧ Δ
УВЧ Σ
Блок управления и контр.
Установка орбиты
Сумматор-корректор
Регулятор
УВЧ
АРУ
Ключ
Манипулятор фазы
Схема управления
С Д
УПТ
Ф Д
Фазовращатель
Блок преобразователей
Система управления частотой по пучку

Block diagram of the system for the generation of the accelerating field: **УПТ** - direct current amplifier; **УВЧ** - high frequency amplifier; **АРУ** - automatic amplification control; **СКС** - system of cable connections; **АПФ** - automatic phase tuning; **СД** - synchronous detector; **ФД** - phase detector.

Индукцион.катушка - Induction coil
Измерительный магнит - Measuring magnet
Программная система управления частотой - Programming system for frequency control
Программатор частоты - Frequency programmer
Злектрон. ключ - Electronic switch
УПТ интеграт. - Integrator
УПТ модулятор - Modulator
функциональный преобразователь - Functional converter
УМ-генератор - fm-generator
Автоматич.подстройка $f_{нач}$ - Automatic tuning, $f_{init.}$
Задающий генератор - Master oscillator
Манипулятор фазы - Phase manipulator
Модулятор амплитуды - Amplitude modulator
Усилитель распредел. - Amplifier-distributor
Шкаф СКС **эталонный** N8 - СКС-cabinet, standard N8
Шкаф СКС, N1, N2, N7 - СКС-cabinet N1, N2, N7
Сигнальные электроды - Signal electrodes
Входной блок - Input block
Дифференц. схема - Differential circuit
Установка орбиты - Orbit adjustment
Контрольн. сигнал - Control signal
Усиление - Amplification
Блок управления и контр. - Regulating and control block
Сумматор-корректор - Summator-corrector
Линия задержки - Delay line
фазовый дискриминатор - Phase discriminator
Ускорающ. резонатор - Accelerating resonator
Датчик программы - Program pickup
УПТ системы АПФ - **УПТ** of the **АПФ**-system
Ускорительная станция - Accelerating station
Регулятор - Regulator
Ключ - Switch
Манипулятор фазы - Phase manipulator
Схема управления - Regulating circuit
$И_{уск}$ → **Фазовращатель** - $U_{accel.}$ → phase rotator
Регулятор - Regulator
Ключ - Switch
Манипулятор фазы - Phase manipulator
Ключ - Switch
Схема управления - Regulating circuit
Блок преобразователей - Converter block
Система управления частотой по пучку - System for the frequency regulation by the beam

shifting of the beam are not higher than 0.2 and 0.05 rad for the adiabatic and fast components, respectively.

Literature cited

1. Mints A. L. et al., In: Proceedings of the International Conference on High Energy Accelerators and Instrumentation (CERN, 1959), p. 477.
2. Ivanov Yu. S. and Kuz'min A. A., "Pribory i tekhnika eksperimenta", Nr. 4, 106 (1962).

Discussion

M. Plotkin

What are the sizes of ferrite rings? How is the cavity tuned?

S. M. Rubchinskii

The resonator length is 1 m. The resonators are tuned automatically by the phase detector signals. The maximum current is 100 ampere.