ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S12FC04

FEEDBACK SYSTEMS FOR LOCAL CONTROL OF RACE TRACK MICROTRON RF ACCELERATING SECTIONS

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Abstract.

In order to obtain an electron beam with an excellent energy resolution and stable characteristics, a tight control of the amplitude and phase of the field in all rf accelerating sections is required. The high rf power level, dissipated in the accelerating section (AS), together with temperature dependence of the AS resonance frequency caused the creation of the original control system of resonance frequency. Amplitude, phase and resonance frequency local feedback control system have been designed. All systems are computer conrtrolled analogue single loops. The control loops guarantee stable, repeatable amplitudes (10^{-3} relative error), phases (+/- 0.5^{0}) of the rf fields in AS, resonance frequency of AS (+/- 2 kHz) and have optimal bandwidth. A model of feedback loops has been developed that agrees well with measurements.

I. INTRODUCTION.

The control systems of rf power supply system of the accelerating sections of the continuous wave (CW) race-track microtron (RTM) are described in this paper. These systems operate in different parts of the frequency domain and are connected with each other by control parameters. The described systems ensure constant rf parameters of the AS, such as rf power, resonance frequency and phase difference. These systems form the bottom level of the RTM hierarchical computer control system (CCS) [1]. All analog systems are completely controlled by the top level of the CCS trough optocoupled devices. It is possible to change operating modes and reference signals for feedback control systems by an order from the top level of the CCS.

II. RF SYSTEM.

An outline of the rf power supply of the AS, which is a part of the general rf power supply system of RTM, is illustrated in Fig.1. In an operating mode, a reference rf signal of 2450 MHz (RS) passes over a microstrip rf channel to the klystron input port. The output power of the CW klystron is about 25 kW. The RS is stabilized in frequency up to 1 KHz and in power up to +/- 10^{-3}. The klystron is connected to the AS by a waveguide through the circulator, vacuum window and vacuum port. The incident and reflected waves are checked by means of the double directional coupler (DC) and diode detectors D_1 and D_2. A signal from the rf probe, located in the AS rf power input cell, passes through a 4-channel power splitter to the sensors of amplitude, phase difference, and AS resonance frequency: the detector D_3, the phase detectors PD_1 and PD_2, respectively. The voltage controlled microstrip pin-attenuator A_1 and current controlled phase shifter PS_1 are used as the controllers in the local feedback systems. It is possible to select the operating points of the respective phase detectors with the aid of phase shifters PS_2 and PS_3. Adjusting phase shifters are made as microstrip devices in the form of a meander line on the ferrite layer. They are current controlled, but it is possible to set phase shifters once by special bipolar current pulse train due to the hysteresis

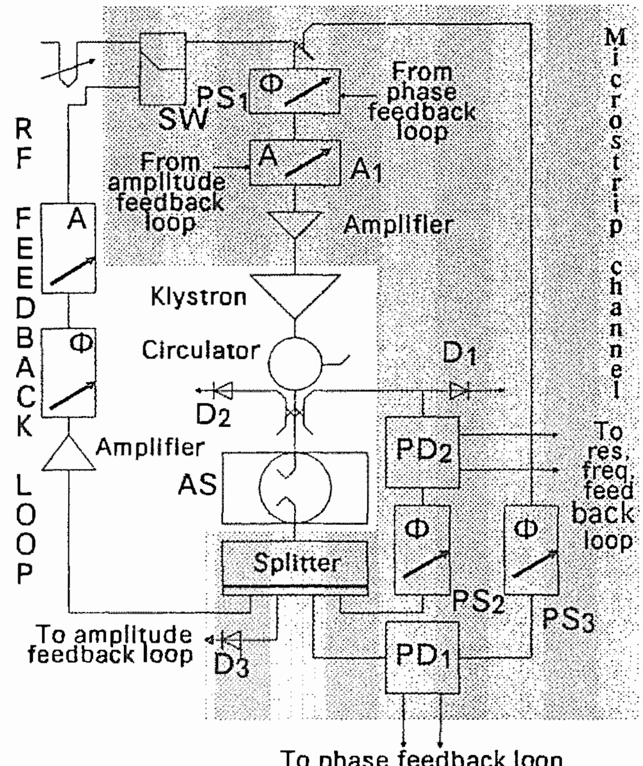

Fig.1 Outline of rf power supply of accelerating section

property of ferrite. Phase shifters are controlled by the order from the CCS with electron module. The module consists of a relay multiplexer, voltage to current converter and single channel DAC. All necessary rf parameters, such as incident, reflected waves and internal rf field, phase shifts, are measured by the CCS through optocoupled ADC. These signals are amplified and normalized by circuits of analogue feedback control systems.

Mode of power feeding.

The rf feedback loop is closed by the rf switch (SW) in the mode of power feeding into the AS. Constant phase shift and gain of rf feedback loop guarantees amplification

3rd Int. Conf. Accel. Large Exp. Phys. Control Syst. ICALEPCS1991, Tsukuba, Japan JACoW Publishing
ISBN: 978-3-95450-254-7 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS1991-S12FC04

of random fluctuations which causes self-excitation of the high power rf field. Frequency of self-excitation is equal to the eigenfrequency of the AS due to the high quality of the accelerating cavity (Q =10 000).

III. RESONANCE FREQUENCY FEEDBACK CONTROL SYSTEM.

The AS resonance frequency is regulated by varying the temperature of water coolant. The resonance frequency decreases due to thermoelastic deformation of the AS and heating of the coolant after the rf power supply system has been switched on :

$$\frac{dF}{dP} = -90\frac{kHz}{kW}.$$

Mode of power feeding.

The thermoregulating system (Fig.2) consists of a valve (V) and a voltage controlled thermoelectrical heater (TH) of a total power of 14 kW. The water flow is controlled by valve V and measured by flowmeter FM. The temperature of coolant is measured by two termistors T_1 and T_2, located at the input and output of the AS. The flow relay (FR) checks for the presence of coolant flow and supplies alarm blocking signal. The valve is actuated by a asynchronous motor under computer control . The CCS checks rating value of coolant flow through optocoupled ADC connected to FM.

Digital temperature feedback control system.

In order to feed and support rf power in AS, it is necessary to ensure equality between self-excitation frequency and frequency of the reference signal . The discrete-time computer control system has been designed for temperature tracking . Control system consist of cooling system of the AS, ADC sensors and DAC. It is possible to model the system in the form of "the second-order system with transport delay". Identification has been based on the measurements and computer analysis of the system's responses to a step reference signal input. Control program in the CCS station use both integral and proportional procedures for controlling. System's parameters has been chosen to minimize settling time and overshoot of a step response to a step reference input. The temperature of water is stabilized to an accuracy of 0.02°C. Settling time of a controlling parameter response to a step reference signal is about 100 s.

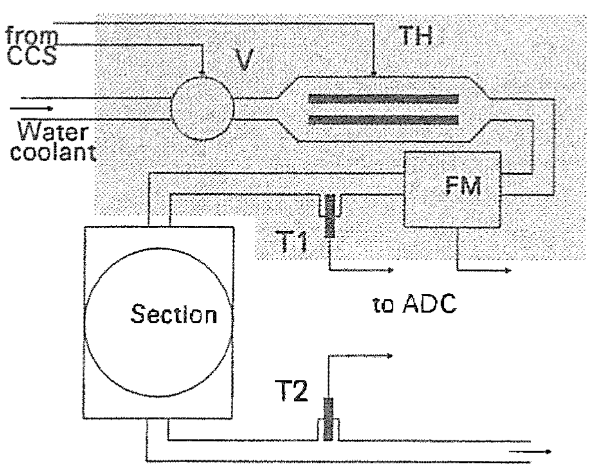

Fig.2 Outline of thermoregulating system of accelerating section.

Analogue resonance frequency feedback control loop.

The feedback loop of analogue feedback control system of resonance frequency is closing after rf power has been fed and external RS excitation has been switched on. At the same time feedback loop of digital temperature control system is opening by the order from the CCS. The error signal for the control system of resonance frequency is supplied by PD_2 (Fig.1) which compares the phases of the AS field and incident field. It is correct due to the relation between phase shift and frequency shift: $F = \frac{Fo}{2Q} tg(\Phi)$ where F -frequency shift, Fo- resonance frequency, Φ - phase difference, Q - quality of cavity. The presence of adjusting phase shifter PS_3 ensures the ability of the sensor to operate in a zero-point, quite linear, domain of static characteristic. The necessary phase shift is set up by the respective adjusting phase shifter by an order from the CCS. When two rf signals with amplitudes of As and Ar are fed to input ports of PD, two low frequency output signals are expressed as:

$$Vs^2 = As^2 + Ar^2 + 2AsArcos(\Phi)$$
$$Vr^2 = -(As^2 + Ar^2 - 2AsArcos(\Phi))$$

where Φ- is the phase difference between Ar and As. Input circuits of analogue control systems consist of operational amplifier (OA) which is summing up two input signals Vr and Vs. The resulting signal is proportional to the cosine of the phase difference.

We have used PI-compensator circuits with optimized parameters in our system . The object of controlling has been described as a second order system with a transport delay. The model transfer function of the system is:

$$Y(s) = \frac{Ko}{(T1s+1)(T2s+1)}e^{-sTd}.$$

The standard parameters of this model , correspond to real objects and are: $T1$= 11.1 s ,$T2$= 3.6 s,Ko= 0.067,Td= 5.5 s (flow of coolant - 0.4 l/s). At this point, we have used the same model and method as for digital temperature control system to optimize the analogue controller, but in continuous-time domain. The bandwidth of analogue regulator has been limited to 40Hz, because noise fluctuations with higher frequencies of controlling parameter are physically impossible. The analogue regulator consists of a sensor amplifier, a low pass filter, and PI-compensator circuits. We increased gain of open loop. The system remained stable and steady state error decreased due to a low frequency of an up edge of the system's bandwidth. The choice of optimal parameters of the model of PI-compensator circuits has been based upon

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the desired characteristics of the system: settling time and overshoot of a controlling parameter's step respose. Optimal parameters of the PI-compensator model are: gain K=10.0, integrity time Ti=8.0s, proportional coefficient Kp=1.5. The resonance frequency stability which is provided by this control system, is +/-2 kHz for all real fluctuations in the system.

IV. AMPLITUDE FEEDBACK CONTROL SYSTEM.

In order to ensure the stable rf field in AS, an amplitude control feedback system has been designed. Accuracy of field tracking must be 10^{-3} of relative error. It was difficult to anticipate all possible sources of noise in the system, so the bandwidth has been chosen up to 50 kHz. We have aspired to make the system responce in a closed loop within 10 mks, which is equal to the fill time of AS. These early conditions demanded from designers efforts both in improvement of microstrip pin-attenuators and the creation of original analog circuits with fast operational amplifiers. Furthermore, the electron circuit solves the problem of nonstop operational checking of some important parameters of different accelerator systems, such as the level of the reflected wave, low vacuum, presence of coolant in AS and the klystrons. Information about faults is transmitted to the top level of the CCS and rf inputs of klystrons are closed. Important parameters, on which the safety of the accelerator depends, are monitored twice with different sensors. One of the function of the circuit is to control rf switch, which closes the rf feedback loop. Each element in the feedback loop, from the OA to the voltage controlled attenuator, has been measured to determine ts time responses and frequency-dependent characteristics. Both proportional and integral controls have been used in the feedback control circuits. A prototype of the system has been tested assuming a mini-computer controlled testing panel. The analog model of AS, which consist of OA and RC circuits, has been used. The step responses have been measured with a CAMAC fast ADC (50ns freq. of discret). Random fluctuations of rf amplitude have been measured in real conditions of a working accelerator by using a digital spectrum analyzer. Measurements have been made in closed and open loops. The major noise sources are the high voltage supplies of the klystrons and thermoheater's thyristors with main frequencies of 50 and 150 Hz. Accuracy of the rf amplitude stabilization of about 0.1% of relative error has been achieved. The pin-attenuator is controled by current, which is supplied by an analogue board of the amplitude feedback control system. Static characteristic of the attenuator is quite linear in the operating domain. The operating point has been chosen in the region of 0.5 mA which corresponds to 4 dB of rf attenuation. Internal construction of the microstrip attenuator resulted in an rf phase shift dependence from the controlling current (Fig.3). This "bad" property caused an internal bond of the amplitude and the phase feedback control loop, which was necessary to take into consideration during the later design of feedback loops.

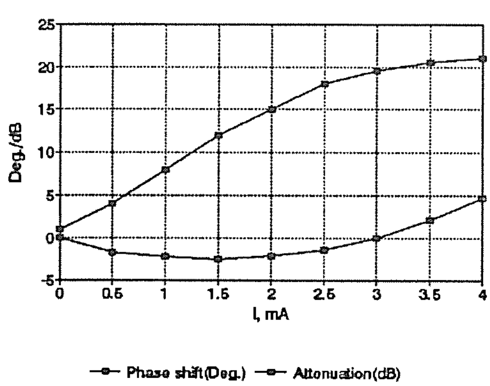

Fig3. Microstrip pin-attenuator performance characteristic.

V. PHASE FEEDBACK CONTROL LOOP.

The phase feedback control loop has been designed at the last stage of complete feedback control system of AS rf parameters designing. Phase control systems guarantee stable phase shifts for every AS, depending on AS location in the linac. PD_1 is used as sensor and PS_1 is used as a controller. An analog phase feedback control system has been created on the basis of the described above analog systems. Sensor circuits is equal to the sensor circuits of the resonance frequency feedback control loop. Regulating circuits are equal to the fast circuits of rf amplitude feedback control loop. The accuracy of the system is about 0.5^{o}.Settling time of a controlling parameter response depends on the type of phase controller. A varactor phase shifter provides a settling time of about 10 mks. A ferrite phase shifter yields 5ms, due to inductance.

VI. CONCLUSION.

The feedback control systems described above were tested , for the first time, during experiments in the capture section of RTM linac [2]. Circuits and methods of designing were improved simultaneously. Models of all systems have been calculated and simulated with the aid of original software. All the systems together with the top level of CCS have ensured stable, safe and comfortable procedure for feeding of power and experimenting with AS.

ACKNOWLEDGEMENT.

The authors would like to express their thanks to professor B.S. Ishkhanov and doctor V.I. Shvedunov who provided enormouse help for the successful designing and testing of the feedback systems.

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