SOME ASPECTS OF THE CAVITY RESONANT FREQUENCY CONTROL SYSTEM HEATER OPERATING POINT CHOICE

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Abstract

To adjust and to stabilize a resonant frequency of the accelerating cavities INR Linac comprises a Cavity Resonant Frequency Control System (CRFCS). The main final control element of the system is an electric heater (EH). Operating point of EH determines power consumption of the system and rf power feed in duration. Electromagnetic noise originated from thyristor regulators of the heaters and influencing linac electronics also depends on the operating point. One of the most sensitive systems is Fast Beam Interlock System (FBIS) intended for prevention of excessive activation and damage of linac components. To exclude false responses of FBIS and to decrease power consumption of CRFCS operating point of the heater has been shifted to a range of smaller power. This approach has been tested during several beam runs with the following results: no false responses of FRIB were observed; the quality of frequency stabilization during beam runs remained at the same level; relatively rare restarts of RF channels did not increase a downtime to beam time ratio; CRFCS power consumption was decreased twice. The rf power feed in duration increased insignificantly.

INTRODUCTION

The cavity resonant frequency control system (CRFCS) is intended for:

- warming up of cavity to the resonant temperature and its stabilizing before to begin rf power feed in (rf feeding) both at primary rf channel switching on and at the unauthorized switching off rf generator or system on the whole;
- providing of attenuating transient process in the system at rf power feed in (according to principle of Ljapunov - the stability "in large");
- stabilizing of cavity resonant frequency during beam run (stability "in small").

All these tasks are solved by the change of temperature of desalted water circulating in closed contour. A heat-exchanger with the regulated efficiency of heat exchange and power regulated electric heater (EH) with a corresponding measuring and regulating equipment allow to support the required thermal balance in any mode of CRFCS operation.

The circuit of EH power (current) control contains sensors measuring the regulated coordinate (cavity temperature or cavity phase off-tuning), corresponding threshold sensors, null device, PID-regulator, block of the signal transformation and fixing of EH operation point (OP) and also the thyristor regulator with the changeable angle β of thyristor switching on. Here under a concept "EH OP" the following is implied: bipolar signal of CRFCS unbalance from the PID – regulator should be transformed in unipolar ones before signal giving in the control unit RNTO-250 or ROT-250 type of thyristor regulator. Electric heater OP is point on the regulation curve, corresponding to CRFCS off-tuning $\xi = 0$.

Fronts of thyristor switching on have duration about tens of microseconds and cause appearance of noise affecting near-by located electronic equipment, and choice of angle $\beta = \pi/2$ leads to the increasing of noise amplitude to the maximally possible value. (Angle $\beta = \pi/2$ at unbalance in CRFCS $\xi = 0$ was chosen at tuning of CRFCS as providing the best condition of rf power feed in).

It should be noted the high intensity of noise: firstly, EHs are energized from the network of 220V 50Hz, that at antiparallel on of thyristors gives 100Hz frequency noise, secondly, at the present state of accelerator up to 20 channels can be involved in operation.

AFFECT OF NOISE ON FBIS AND OTHER ELECTRONIC EQUIPMENT OF LINAC

Fast beam interlock system (FBIS) is intended for prevention of the excessive activation and thermal damages of linac components. In the system there are 74 detectors of the secondary radiations located on length of linac tunnel and electronics racks behind of shield in control rooms and PS gallery. Constructively detectors are executed as plastic scintillator connected by light guides with photomultipliers. On the area of beam turn with energy of 160 MeV PM is used as a detector directly. Synchronized with linac operation electronic part of FBIS is a threshold device reacting on external signals only during the beam acceleration. FBI system produces a signal "Prohibition of FBIS" and injection of beam in linac is terminated if permissible beam losses and corresponding threshold level (~10 ÷ 20 mV) are exceeded. The reset of "Prohibition of FBIS" is performed by either an operator or automatically. During this a beam in linac is absent ~ 0.5 sec.

FBIS forms a false response "Prohibition of FBIS" and stops the acceleration of beam if attending linac work noise is coming at time gate of beam loss registration and threshold level is exceed. The losses of beam run time may reach a few percents, and on occasion - to block the work of accelerator fully.

To find the source of noise during working linac and at the regular mode and complete volume of FBIS equipment different parts of linac were independently switched on: injector, rf channels, equipment of CRFCS, pulse magnet, equipment of accelerator control system, etc. As a result the high degree of correlation between false responses of FBIS and value of EH current of CRFCS was revealed.

Further researches allowed:

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- to eliminate the FBIS feed in circuits from a number of noise conductors;
- to localize CRFCSs which produce noise and false responses of FBIS: in one or another degree these are channels of main part of linac (cavities with disks and washers). Placing on the same cable shelves of EH power cables and FBIS control cables makes possible noise in ones during fast changes of EH current because of electromagnetic induction;
- to fix cross influence of CRFCS and initiation of autooscillations in the circuit of EH control (including the channels of DTL).

Many other devices and systems of accelerator are exposed to negative influence of the noise massively generated by the apparatus of CRECS: beam observation system; systems of remote-control and adjusting; systems having in the composition computers etc.

It is necessary to improve noise immunity of every specific system and at the same time it is urgent problem to reduce deeply of noise level produced CRFCS.

A few attempts to decrease the size of noise to the acceptable level (selection of points of grounding, LC - filtering etc.) were undertaken, but without success. It was therefore suggested to shift the operation point of EH from initial position (on the Fig.1 it is point on the interrupted curve P_{EH}=24 kW at regulation current of regulator I_{reg}=100 mA) to a range of smaller currents, some lowering rf power feed in duration.

INFLUENCE OF EH OPERATION POINT POSITION ON THE CRFCS FAST-ACTING

Supposition about increasing of rf power feed in time at shifting of OP from regular position (on the Fig.1 it is point on the interrupted curve P_{EH}=24 kW at regulation current of regulator I_{reg}=100 mA) in the range of smaller EH power is based on decreasing of degree of CRFCS stability "in large" and, as a result, the damping is increased at approaching to the dog leg of adjusting curve (switched off of EH).

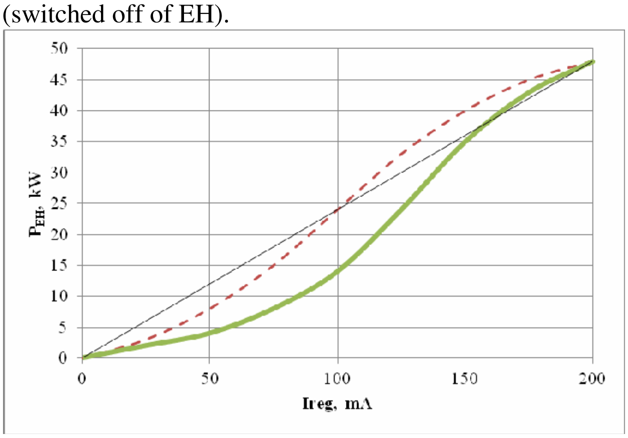

Fig.1. EH regulation curve

RF feed in, as a rule, produced for a few steps the number of that depends on the great number of factors: of value of cavity phase unbalance, admissible value of the reflected wave, condition of vacuum, pre-history of cavity and waveguides breakdowns etc. All this does correct comparison of the different settings of CRFCS concerning of operation speed very laborious without deciding practical application. Therefore an analysis on the digital model of CRFCS is more reasonable. On Fig.3 results are presented as a dependence of $Y = \theta(x)/\theta(0.5)$, where θ is duration of transitional process at a corresponding value $X=P_{op}/P_{EHmax.}$ An analysis of CRFCS behavior was realized on the model of CRFCS in MATLAB, described in details in [1] and [2]. The model of CRFCS was modified according to a Fig. 2 for the linearized regulation curve (Fig.1) at rf power feed in of P_{rf} = 20 kW in the cavity.

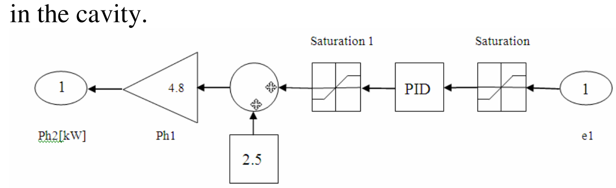

Fig..2. Model of EH regulation circuit with a possibility to change an operation point

For a situation on a Fig.2: operation point is X =0.25 if in the block of Saturation 1 upper (7.5) or lower (-2.5) limits are set; P_{EHmax} = 48 kW.

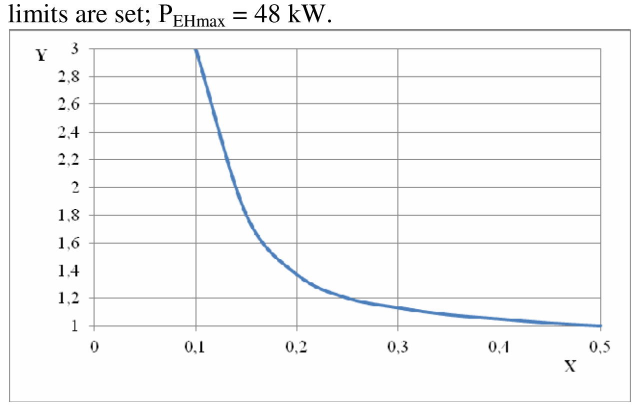

Fig.3. Relative change of transient duration

It is necessary to expect the double reduction of rf feed in duration at shifting of OP to the level with X = 0.14. It is true and at step by step rf power feed in because every next step is executed after completion of previous transition process.

CHOICE OF EH OPERATION POINT FROM THE CONDITION OF RF FEED IN DURATION

For definiteness the double reduction of rf feed in duration was accepted. From the Fig.3 X=0.14, that corresponds of P_{op} = 6.7 kW. But practically placing of OP at this level was not succeeded, because in an existent apparatus there is no possibility to set I_{reg} < 70 mA at ξ = 0. By the readjust of thyristor regulators for all channels (of three - during work of linac on an isotopic complex) single regulation characteristic was got and presented on Fig.1 as continuous curve.

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At the test of this variant during three beam runs it is not fixated false responses of the FBIS because of noise generated by the CRFCS thyristor regulators, that confirms the successful choice of EH operation point position. For channels, having advanced reliability (1 ÷ 2 unauthorized switching-off in a week), deeper shifting of operation point is possible. For the individual adjusting of every channel it is possible to recommend the choice of X coefficient from a range 0.1 ÷ 0.15. For example, channel 3 of main part of INR linac worked at X = 0.11 successfully.

INFLUENCE OF EH OPERATION POINT SHIFTING ON THE QUALITY OF CAVITY FREQUENCY CTABILIZING DURING BEAM ACCELERATION

In loaded with beam high-Q cavities having disks and washers with D~15*10³ even small variations of frequency within of frequency strip lead to the considerable changes of rf power for compensation of that with the purpose of stabilizing of cavity frequency equal power of EH is required at least. In this situation, shifting of OP from a linear area in nonlinear one (Fig.1) will lead to the lowering of CRFCS stability "in small". However, during beam run the system of cavity rf field amplitude automatic control compensates part of rf power intended for acceleration of beam. Oscillations of rf power losses do not exceed of units of percents, that allows not to take into account curvature of characteristic on Fig.1 in the viciniity of any OP, except a border one.

INFLUENCE OF EH OPERATION POINT SHIFTING ON THE ENERGY CONSUMPTION OF CRFCS DURING BEAM ACCELERATION

Full power of CRFCS energy consumption during beam acceleration is $P = 2(P_{op} + P_p) + P_{ra}$, where coefficient "2" takes into account work of refrigeration machine in a warm season; P_p = 14 kW - power of pump, providing a circulation of desalted water; $P_{ra} \approx$ 2 kW - total power of rack apparatus feed in sources. For the given example the energy consumption of the system is decreased in 1,8 time. Coefficient 2.5 (2.6 - in summer) is achieved in theory at $P_{op} \rightarrow 0$, but such regime practically could not be realized because of appearance of undamped transient during rf feed in (Fig.3).

Note. Power of EH was determined on the formula $P_{EH} = U^2$, because R_{EH} = 0.97 Ohm at the temperature T_{EH} = 16ºC. Voltage on EH was measured by digital multimeter of type DT9203. Authors understand that such method gives a considerable irregular error at $0 < \beta < \pi$. However, this fact did not prevent to make correct conclusions out of the performed researches and achieve the put aim.

SUMMARY

1. Accurate shifting of EH operation point of all working channels of main part of linac will allow to solve a compromise the problem of excluding of FBIS false responses due to the noise generated by the thiristor regulators of CRFCS at the acceptable decreasing in practice of rf feed in duration in a cavity.
2. At the same time, maximally possible an actual question of CRFCS energy-saving is solved.

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