# MMF LINAC HIGH ENERGY PART LLRF SYSTEM STATUS

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## INTRODUCTION

Accelerated beam quality and level of beam losses are strongly affected by accelerating field phase and amplitude stability and accuracy. Due to this a constant attention was paid to the Low Level RF systems of the MMF linac. During the last 4-5 years many components of LLRF system of high -energy part of MMF linac were significantly rebuilt and reconstructed, and as a result higher accuracy and long-term stability were achieved, along with the higher reliability and more simple maintenance. Besides, the time needed to carry out a procedure of linac accelerating cavities, longitudinal tuning (setting and adjusting of nominal values of amplitudes and phases in the accelerating cavities), was reasonably decreased. Also, a preamplifier feeding the input of the klystron amplifier was modified to get more reliable operation.

## RF CHANNEL AND LLRF: STRUCTURE AND SHORTCOMINGS

The structure of the rf klystron channel of high-energy part of MMF linac along with the corresponding LLRF system are well enough described in [1]. We would like briefly remind that this structure was formed in 1990-1991 and was in operation until 1995-1996 years.

Each accelerating cavity of the high-energy part of MMF linac is fed from one multi-beam pulse klystron with a maximum output power 4.5-5 MW, maximum pulse duration and repetition rate 170 us and 100 Hz, respectively.

It requires 100-400 W of drive RF power, which is produced by a three-stage lamp (metal-ceramic triodes GS-31) preamplifier (PA). Nominal PA input power is 10-30 mW.

To control (stabilize) the amplitude of cavity accelerating field a method of klystron RF drive power modulation, under constant value of klystron gun voltage, was chosen. For making this, controlling devices of the amplitude and phase feedback systems are connected in series with klystron PA input. Both amplitude and phase feedback systems are combination of fast analog and slow analog-digital channels. Fast channels use proportional low of regulation and work within RF pulse duration. They use fast electronic attenuator and fast strip-line phaseshifter as controlling devices. Slow analog-digital channels use mechanical, driven by stepping motors, coaxial attenuator and trombone type phaseshifter. These channels are rather slow and the work-off time in a case of relatively large errors can be up to 5 – 10 minutes.

Fast electronic attenuator is built from two 3-dB strip-line hybrids and two strip-line phaseshifters (similar those used in phase feedback system). Principle of operation of such attenuator is based on an opposite-phase phase modulation of two vectors coming out from the first hybrid and their following summing on the second hybrid.

During the years of linac operation a number of shortcomings inherent to LLRF scheme described above were revealed. Main of them are following:

all stages of the lamp preamplifier are working at close to their technical limits conditions

PA anode pulse modulator is not well matched to the anode impedance of the amplification stages. It leads to the 50% reverse voltage overshoot at the rear edge of the HV pulse, thus increasing total voltage applied to the anode isolating dielectric gasket up to 4.5 kV. Due to this the isolating gasket was destroyed in a relatively short time

low work-off time of the analog-digital channels. Sometimes it can cause an additional time losses in linac operation (for example, when cavity thermal detuning is working off by phase and amplitude feedback systems)

there is no fast electronic phaseshifter with the full phase range not near 360 degrees, installed at the input of rf channel. It makes no possibility to get fast procedure of linac accelerating cavities longitudinal tuning

fast electronic attenuator has relatively large rf signal attenuation and two unstable point, due to his control low described by following expression: $Uo = U_i \left|\sin(SU_c + \Phi_0)\right|$. In one of this point the phase of output rf signal jumps at 180 degrees, in other one the sign of amplitude feedback becomes positive.

## MODERNIZATION

To improve reliability and quality, simplify maintenance and to get new possibilities of LLRF system, a set of investigating and design works were attempted during last years. Main ideas of this work can be expressed as follows.

The most unreliable and having long repair time is PA. To make his operation more stable one can decrease the number of lamp stages (make 2 instead of 3) and decrease value of anode pulse voltage. Inevitably decreasing output RF power can be compensated by increasing of input RF power. In addition, to increase lifetime of isolating dielectric gaskets, reverse voltage overshoot at the rear edge of modulator pulse should be eliminated.

To get more RF power at the PA input a new electronic attenuator with reasonably less attenuation should be designed. An existed attenuator had attenuation at the operating point ~ -(15-10) dB.

To compensate low work-off time of analog-digital channels of feedback controllers, one can propose to add an integral channel to the fast analog feedback, i. e. change proportional low of regulation to proportional-integral low. Then wide-range amplitude and phase errors can be fast compensated with high accuracy. To do so, a new electronic attenuator with smooth regulating curve needed, also.

The process of accelerating cavities longitudinal tuning takes rather long time, due to the large number of cavities. To make this process more effective, fast electronic phaseshifter with more than 360 degrees range should be designed.

## FAST ELECTRONIC ATTENUATOR

As it was shown earlier, an electronic attenuator should combine both low attenuation at operating point and smooth control function and imply high stability and reliability. Large experience accumulated by authors of the paper in area of development and manufacturing of miscellaneous semiconductor stripe-line RF components made it possible to develop and produce a required quantity of such devices able to satisfy the technical requirements. It was decided to use transistor RF amplifier as a fast electronic attenuator. To control output power of such attenuator one can vary dc collector voltage of the transistor (low parasitic phase modulation is an advantage of this method). The amplifier consists of two stages built of KT919B (first stage) and KT942A (output stage) Russian industry made bipolar transistors. It uses both stripe-lines and "normal" circuit elements (resistors, inductances, and variable capacitors) as matching circuits. Only the output stage collector voltage is varied, first transistor works at constant collector voltage 27 V. Amplifier has close to linear controlling curve with input VSWR less than 1.12:1 within the whole controlling range. At nominal rf input power 0.2 W output power varies within the range of 0.2-10 W, if collector voltage changes from 3 to 30 V. At operating point output power is typically around 2 W. Nominal amplifier working frequency is 991 MHz, bandwidth +/- 5 %. The construction of amplifier allows working even in dc mode.

To control collector voltage, fast controlling amplifier also was built. It made of fast operational amplifier KP544UD2 and RF transistor KT928A and provides more then 4 MHz bandwidth at real load (measured on RF signal).

## PREAMPLIFIER

A new electronic attenuator described above can provide approximately 20 dB higher RF power at the input of PA (2-3 W instead of 10-30 mW). It gives possibility easily remove first lamp stage from the PA and get even higher output power. Furthermore, this extra RF power allows decreasing pulse HV anode voltage of the rest two stages from 3 to 1.5-2 kV. Even under this conditions, klystron input drive power well enough satisfy required values, as it was measured at large number of klystrons. One should mention that all the connecting cable and elements in the line PA-klystron were carefully checked and optimized from the point of RF losses.

To provide best performance of PA anode pulse modulator to a new load (less output voltage and current), it was subjected to a complex modernization, too. Mostly all elements of modulator scheme were changed. It concerns the value of resistors, HV transformers transformation coefficients, type of diodes, etc. As a result much higher quality of modulator output pulse were achieved, no reverse polarity overshoot observed, modulator scheme thermal conditions became much more light. Also, the working conditions for the dielectric isolating gaskets in the lamp anode circuit were considerably improved. It was very rare the gaskets in a new PA were destroyed.

## ELECTRONIC PHASESHIFTER

One of the main parameter taking into account under development of electronic phaseshifter is a value of RF power to be transmitted through the device. Study of various existing LLRF system shows that maximum transmitted RF power for the electronic phaseshifters not exceeds some mW, typically. For our case 360 degrees phaseshifter should be installed before splitting an RF signal coming from accelerator RF reference line into a phase reference signal and PA driving one. RF power in this point for linac high-energy part RF system is around 3-4 W.

After changing an old electronic attenuator to transistor regulator, two electronic phaseshifters for each RF station become available, and it was very tempting try to use them. A careful investigation and calculation of these phaseshifters were made to define a phase range, maximum transmitting power and signal attenuation, and to understand whether these parameters can be improved. The results of the investigation shows, that the phase range is depended on the transmitted rf power, and varies from 140 to 190 degrees, if transmitted power decreases from 1 to 0.42 W. Signal attenuation is independent from transmitted power and lies near –1.5 dB.

From these data follows that to get phase range more than 360 degrees one can connect two phaseshifters in series and limit rf power transmitted through the first phaseshifter at ~0.4 W. RF power at the output of second phaseshifter will be around 0.2 W. But, as it was mentioned above, we need 3-4 W at this point of RF line. The only possible decision is to introduce one more RF amplifier (similar the amplifier used as electronic attenuator) and adjust his collector voltage to get the required power.

According this idea a separate unit combined two electronic stripe-line phaseshifters, RF amplifier and some control electronics was built and installed at the linac tunnel, near the RF reference line. This phaseshifter-amplifier unit allows fast accelerating cavity RF field phase changing, in a range more than 360 degrees. No additional RF instabilities were observed.

To control this unit, a special DAC module compatible with the linac control system equipment, also was built.

## FEEDBACK CONTROLLERS

Both phase and amplitude feedback controllers have low work-off time for large phase and amplitude errors. As it was suggested above one can improve the situation by changing proportional low of regulation to proportional-integral one. For amplitude feedback system it become possible after new electronic attenuator was installed.

To realize proportional-integral law of regulation a new integrator module was built and installed both in amplitude and phase feedback controllers. Output dc signal from integrator module is added to the output signal of proportional channel of feedback controller, thus changing operating point of electronic attenuator (or phaseshifter). An integrating circuit has equivalenttime constant near 0.2-0.3 sec. Dynamic range of the integrator channel is chosen to be around 80% of full dynamic range of amplitude and phase controlling devices. It provides effective operation of fast proportional channels even at the edges of the integrator range.

To get wider dynamic range of the feedback controllers, an old mechanical amplitude and phase controlling devices were retained, also. They start working when integrator output voltage is approaching to its upper and lower limits.

## CONCLUSIONS

Several years of MMF linac operation show that modernization of high-energy part LLRF system described above have really improved quality of accelerated high intensity proton beam. Much more stable and better quality beam parameters were achieved. The exploitation of high-energy part RF system for linac technical personnel becomes much easier, due to higher reliability and wide automatic computer control of the RF system.

## REFERENCES

1. S. I. Sharamentov et all. Progress of the Moscow Meson Factory Linac RF Phase and Amplitude Control System. Proceedings of the 1992 Linac Accelerator Conference. Ottawa, Ontario, Canada, August 24-28, p. 308.