INCREASE OF THE RF PULSE WIDTH IN THE CAVITIES OF THE MAIN PART OF MMF LINAC

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At the MMF linac for increasing an average beam current an rf pulse width in the accelerating cavities of the main part of the linac have to be increased. Pulse widths of a preamplifier modulator and a high voltage klystron modulator limited this value. Modification of these units allowed increasing the rf pulse width at the klystron output to about 240 μs and the beam pulse duration to 200 μs. An estimation of the maximum possible rf pulse width and the results of an experimental exploration of the upgraded high voltage klystron and preamplifier modulators are presented. A possibility of the longtime stable work with a long pulse is shown.

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INTRODUCTION

At the MMF linac for providing physical experiments and solving applied tasks an average beam current have to be increased. One of the ways is a lengthening of the proton beam pulse duration in the linac. According to the project the maximum value was 100 μs. It was limited by the parameters of the injector and rf-feeding equipment of the high-energy part of the accelerator. The injector branch was upgraded in 1998 year [1]. Use of the RFQ booster cavity, decrease of high voltage at the injector and other modifications at the first part of the accelerator provided a possibility to get 200 μsec beam pulse at the input of the main part of the linac. The maximum value of rf pulse flattop in the cavities of the high-energy part was only 120 μs.

A structure and the main parameters of 991 MHz rf system are described in [2]. A pulse triode rf preamplifier and a high-power klystron with anode modulators as high-voltage supplies provide a necessary level of rf accelerating field in the cavities. Modification of the preamplifier and the klystron modulator for increasing of the pulse width was done during last several years.

1. MODIFICATION OF THE PREAMPLIFIER MODULATOR

The results of the works devoted to development of a new type modulator for the rf preamplifier were presented in [3]. Briefly repeat them.

According to the project the 3-cascade triode preamplifier with 500 W rf power at its output was droved by anode pulse modulator. A pulse-forming network (PFN) consisting of 13 LC-links was charged up to 400…600V and discharged through the primary of the pulse transformer with n=10. The maximum width of 2…3 kV output pulse was about 140 μsec. It seems that the simplest way to increase the pulse duration up to 200…220 μsec is to add some LC-links into PFN, using old other elements and units of the modulator. But researches showed impossibility to do this because of a saturation of the pulse transformer. Some curves are presented in Fig.1. One can see a nonlinear character of these dependencies. The more pulse amplitude Ua is, the earlier saturation takes place and the shorter maximum possible duration of the pulse can be reached with the same quantity of the links in PFN. For getting required output power we need Ua =2.4 kV. In this case maximum pulse width only T=155 μs can be achieved.

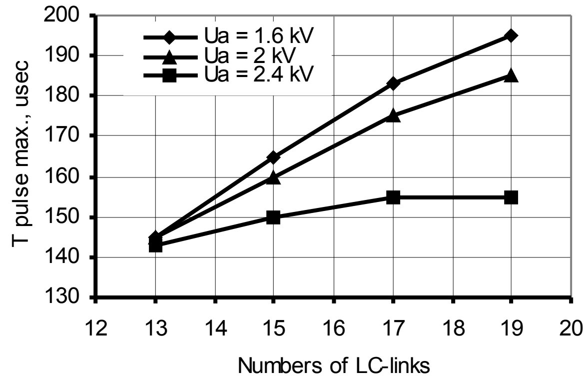

Fig.1. Maximum pulse width of the preamplifier modulator vs. numbers of PFN LC-links

This type of modulator has other disadvantages, mentioned in [3]. By these reasons another type was suggested and realized: cathode-grid modulator.

A new scheme has evident advantages. It uses 2.5 kV rectifiers with a capacitor for DC supplying anodes of the triodes. A low-voltage pulse former drives the triodes through transistor switchers. A driving voltage is 50 V. Dimensions of the new unit are sufficiently smaller. There are no high-current elements and no heating inside the modulator unit. An efficiency of the cathode modulator is twice better. A shape of the pulse is practically ideal rectangular and it is very stable. There is a possibility to adjust the pulse width from 120 μsec up to 250 μsec. The power of the high-voltage transformer and accumulator capacitor limited this value.

2. LENGTHENING OF PFN OF THE KLYSTRON MODULATOR

The high-power klystron modulator has a similar electrical schematic. 4.5 kV adjustable thyristor rectifier charges PFN, consisting of 3 parallel lines with 20 LC-links in each, through a charging choke and a diode. The parameters of the choke are like this to obtain a linear type of the charging process at any pulse repetition rate

(PRR). PFN discharges through the thyristor switcher and the primary of the pulse transformer with n=20. The main parameters of the modulator are presented below:

U out max = 80 kV;
P pulse max = 15 MW;
P average max = 280 kW;
I rectifier max = 80 A;
T pulse (flattop) = 170 µsec;
T rise = 20 µsec;
T fall = 25 µsec;
∆ U (on flattop) ≤ 1.5%
PRR = 10,50,100 Hz.

One of the most important parameters is a voltage ripple at the pulse flattop ∆ U. To satisfy the demands a special procedure for adjusting exists. All PFN inductances L are identical spiral coils disposed along a straight axis on three floors. There is a possibility to move each coil in transverse direction and to change the mutual inductance for neighboring coils. As a result it is able to make the amplitude ripple on the flattop after two first oscillations less than 1.5%.

To increase pulse duration up to more than 200 µsec minimum 3 additional LC-links have to be installed. All the PFN are placed in special rooms. The dimensions of these rooms are different and limited. It is possible to arrange 5 additional links, but they can be installed at the end of each PFN line in transverse direction only. In this case an inductance coupling in the local point is sufficiently different and a distortion on the pulse flattop takes place. For example, some shapes of the pulses are presented in Fig.2.

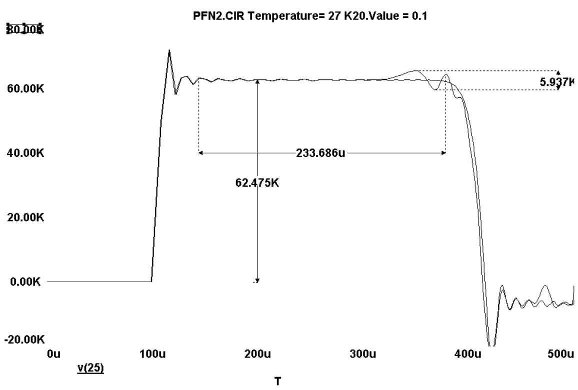

Fig.2. Shape of klystron modulator pulses (model)

This picture is a result of the transient analysis for the simplified PFN model with real parameters. One curve presents an ideal case, when all the LC links and mutual inductances are similar, and the second curve shows the case, when a jump of the coupling coefficients between 20 and 21 coils exists. To compensate this oscillation one should move other coils and vary magnetic coupling coefficients to get a desired shape of the pulse flattop.

Experimental selection of the position of each coil in 11 modulators for adjusting PFN with additional 5 LC links was done. Voltage ripple on the flattop (excepting two first oscillations at the beginning) is less than 2%. The duration of the pulse flattop is about 230 µs.

It should be mentioned that the maximum possible pulse width for high voltage pulse transformer is about 240 µsec if the secondary voltage is about maximum value. Then a saturation of the transformer iron starts.

3. TESTING OF THE MODIFIED KLYSTRON MODULATOR

The first upgraded modulator was tested when it worked to an active resistive load. A goal was to define limits for existing electrical equipment.

The following parameters were obtained during testing at PPR =50 Hz:

U load = 70 kV;
I load = 165 A;
I rectifier = 48 A;
T pulse (flattop) = 230 µsec;
P load (average) = 115 kW;
P load (pulse) = 10.5 MW.

From this table one can see that all modulator units can work well at PRR=50 Hz without exceeding the limit parameters.

In the case of PPR = 100 Hz an average power and a rectifier current will be twice as much as before and the rectifier current will exceed the maximum possible value 80 A. It is the main limit for working with 5 additional LC-links at the voltage level 70 kV. Routine working points of klystron anode voltages are 60… 65 kV. Only 3 additional LC-links can be used in this case. The maximum pulse width we can obtain at 100 Hz is about 210 µs.

4. TESTING OF THE KLYSTRON, WAVEGUIDE ELEMENTS AND ACCELERATING CAVITIES

After testing of the modulator it was necessary to check a klystron, waveguide, accelerating cavities and other elements of rf system working with a long rf pulse.

According to the klystron technical data maximum average power at its output is 100 kW and maximum rf pulse width is 800 µsec. Basing on these demands one can choose PPR and a pulse width for working point.

The following parameters were obtained when the modulator with 3 additional LC-links worked with a klystron as a load:

U klystron = 62 kV;
I klystron = 135 A;
PRR = 100 Hz;
I rectifier = 80 A;
T mod. pulse (at 0.5 level) = 215 µs;
Collector water flow, Q = 160 l/min;
T^0 coll. in = 14 grad;
T^0 coll. out = 30 grad;
P klystron beam pulse = 8.3 MW;
P klystron beam average = 180 kW.

Then an input rf signal was switched on. The parameters were the following:

T rf pulse = 200 µsec;
PRR = 100 Hz;
P rf klystron out (pulse) = 3.5 MW;
P rf klystron out (average) = 70 kW.

This is a typical running regime for getting a desirable level of the accelerating field in the accelerating cavity. So it means that there is a possibility to work successfully with PRR = 100 Hz and 200 μsec rf pulse at the high-energy part of the MMF linac.

During the testing a heating of all the elements of the waveguide feeder was controlled. A temperature of regular parts of the cooper waveguide as well as temperatures of rf quartz windows, waveguide phase shifter and ferrite isolator was completely acceptable. The problem was an overheating of the steel bellow, which has no silver cover on its inner surface. To solve this problem bellows with good quality silver cover were installed in all working waveguide feeders.

We should make mention about very careful mechanical adjustment of the rotating parts of waveguide switchers to except sparking on the inner specific gaps, especially if working with a long rf pulses.

Due to lengthening of rf pulse a conditioning of all the accelerating cavities was done. Sometimes the duration of this procedure was very long. It depended on the quality of the inner cavity surface. In order to get a stable work without sparks inside the cavity, the pulse width of rf signal was increased step by step to 200 μsec during many hours.

Another problem was a choosing of the working point for a system of stabilization of the cavity resonant frequency. Power dissipated in the cavity walls increases twice when the pulse repetition rate rises to 100 Hz as compared to 50 Hz. Moreover losses in the walls are increased sufficiently when we increase the rf pulse width, and therefore an additional adjustment of the water cooling system have to be done especially at PRR=100 Hz.

5. CONCLUSION

To the moment 22 preamplifiers and 11 klystron modulators have been modified and tested at the MMF linac. During last two years the proton beam of 180-185-usec-pulse width at 50 Hz PRR was accelerated successfully up to energy 250 MeV and used for different purposes. For example, the ordinary routine for isotope program at the linac is 143…160 MeV beam with maximum peak beam current up to 15 mA and the average beam current about 110 μA.

The future plans at the linac are the following:

1. To modify the other modulators for getting a higher beam energy when working with a long pulse.
2. To increase a peak current from the injector and thereby to increase an average beam current.
3. To work at PRR = 100 Hz and thereby to increase twice an average beam current

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УВЕЛИЧЕНИЕ ДЛИТЕЛЬНОСТИ ИМПУЛЬСА ВЧ-ПОЛЯ В РЕЗОНАТОРАХ ОСНОВНОЙ ЧАСТИ ЛУ ММФ

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На линейном ускорителе ММФ для увеличения среднего тока пучка протонов потребовалось увеличить длительность импульса ВЧ-поля в резонаторах основной части ускорителя. Проведенные работы по модернизации оборудования каналов ВЧ-питания позволили увеличить длительность огибающей ВЧ-импульса на выходе усилительного клистрона до 240 мкс, что дает возможность ускорять пучок длительностью 200 мкс. В работе описаны проделанные работы, даны оценки по ограничению максимально возможных величин длительности, представлены результаты экспериментальных испытаний оборудования каналов ВЧ-питания при работе с удлиненным импульсом и показана возможность устойчивой работы мощных модуляторов, предварительных усилителей, клистронов, элементов волноводно-фидерной системы и самих ускоряющих резонаторов в эксплуатационном режиме с увеличенной длительностью импульса.

ЗБІЛЬШЕННЯ ТРИВАЛОСТІ ІМПУЛЬСУ ВЧ-ПОЛЯ В РЕЗОНАТОРАХ ОСНОВНОЇ ЧАСТИНИ ЛУ ММФ

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На лінійному прискорювачі ММФ для збільшення середнього струму пучка протонів треба було збільшити тривалість імпульсу ВЧ-поля в резонаторах основної частини прискорювача. Проведені роботи з модернізації устаткування каналів ВЧ-живлення дозволили збільшити тривалість, що обгинає ВЧ-імпульсу на виході підсилювального клістрона до 240 мкс, що дає можливість прискорювати пучок тривалістю 200 мкс. У роботі описані пророблені роботи, дані оцінки по обмеженню максимально можливих величин тривалості, представлені результати експериментальних іспитів устаткування каналів ВЧ-живлення при роботі з подовженим імпульсом і показана можливість стійкої роботи потужних модуляторів, попередніх підсилювачів, клістронів, елементів хвилевідно-фідерної системи і самих резонаторів, що прискорюють в експлуатаційному режимі зі збільшеною тривалістю імпульсу.