PULSE MODULATORS FOR THE VEPP-5 INJECTION COMPLEX KLYSTRON POWER SUPPLY

A.V. Akimov, V.E. Akimov, P.A. Bak, I.V. Kazarezov, N.H. Kot,
A.G. Chupyra, A.M. Rezakov, V.D. Yudin
The Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia, Lavrentiev av., 11,
e-mail: I.V.Kazarezov@inp.nsk.su

In the complex VEPP-5 preinjector the klystrons are supplied by the modulators with a pulse power of 150 MW, a voltage of 47.5 kV, a primary current of 6.3 kA and a pulse duration of 3.5 μs. During the long time operation some disadvantages in the design have been revealed and proper improvements were made. The modulator design with the taking into account all the resent changes is described and test results are presented. At present, three modulators are supplying three klystrons 5045 (production of SLAC Lab., USA) and the forth modulator is tested with a dummy load in the nominal mode of operation.
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1 FEATURES OF MODULATOR DESIGN

The basic circuit of modulators used for the VEPP-5 preinjector klystrons power supply is presented in Fig. 1. Some features of the modulator operation (of the first version) were described in [1, 2]. Basic changes introduced into the circuit of the modulator with taking into account the maintenance experience of over 5 years are given below.

In a new version of the modulator circuit, instead of two thyratrons TGI1-2500/50 connected in series, one thyratron TGI1-5000/50 is used. The use of two thyratrons was complicated by the necessity of equalizing of the currents flowing through each thyratron and with the use of special synchronizing circuit for providing their simultaneous operation. The shift to the single thyratron enabled the synchronizing circuit removal, the simplification of the trigger circuit, water cooling, power systems for filament and hydrogen generator (HG) as well as the pulse forming network (PFN) circuit (see below).

At the same time, a new circuit of the thyratron filament was developed. It was designed for reducing the thermal shock of the thyratron cathode in the process of filament switching on. As is indicated in technical report for thyratron TGI1-5000/50, the guaranteed number of thermal cycles (heating of cold cathode), which thyratron can withstand is limited by 500. The use of the standby regime of the filament enables the increasing of the thyratron resource time. In this case, the thyratron filament voltage reduces down to 60% level of its nominal value. In addition, the operational resource of thyratron increases by the choice of the most optimal process of cathode heating. As the thyratron developers indicated, the nominal filament voltage should be applied to the cathode by a jump and wait after that for 8 minutes for the guaranteed heating of cathode. However, providing the smoother way of reaching the operational filament regime seems to be led to the decrease in thermal shock at the cathode and, therefore, to the increase in the thyratron lifetime. The circuit developed envisages the standby regime and provides the automated smooth process of reaching the nominal thyratron filament regime. A high power voltage stability makes also the positive effect on the thyratron lifetime.

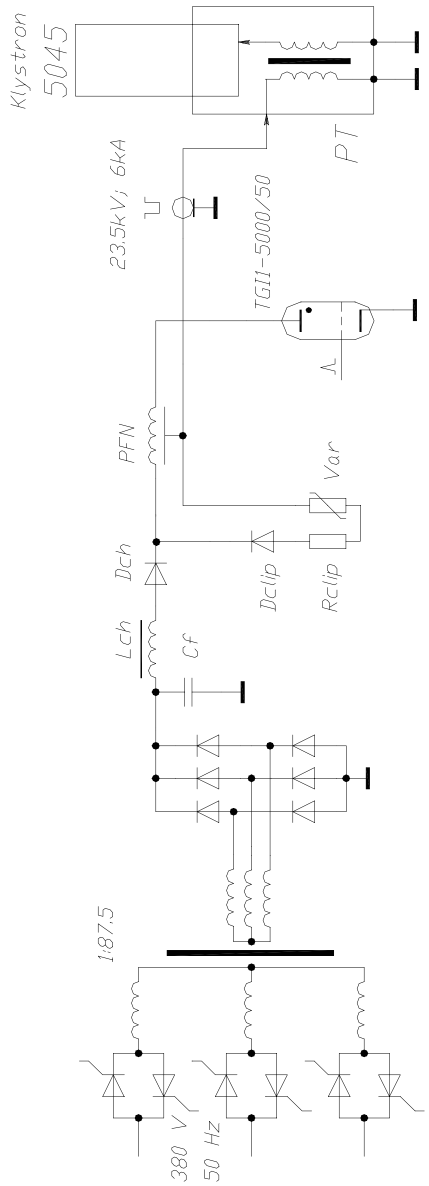

Fig.1. Schematic diagram of the pulse modulator used for klystron 5045 power supply.

In the developed filament circuit, an individual power supply for HG is not envisaged. In the process of the long-term operation the hydrogen pressure in thyratron is reduced. In this connection, one has to make the correction of the HG operation voltage. A wrong choice of HG operating voltage can put substantial changes into operation of the entire modulator circuit as well as lead to the destruction of thyratron because of an increase in losses. In order to avoid critical regimes of thyratron operation, it is recommended a periodical search for the operating point of HG. Such a procedure at SLAC is called "Ranging" [3]. In the process of the long-term operation of modulators at the VEPP-5 complex, the thyratron premature deionization was found (see below), it led to the necessity of using "Ranging" for thyratrons TGI1-5000/50.

According to SLAC recommendations, "Ranging" procedure represents the search for the lower and upper limit of HG. The operating point is determined as mean of these values. The experience of "Ranging" procedure realization at thyratrons TGI-5000/50 has shown that such an approach is not optimal. For example, the upper limit characterizing by the spontaneous opening of the thyratron with the further loss of its deionizing properties and as a consequence, with an increase in the PFN charge current (Fig.2), for one of thyratrons was found out at the HG voltage level of 8.8 V (the search was performed at lowered voltage level (Upfn = 30 kV), which was determined by danger of the critical load to the thyratron and other modulator components at the thyratron loss of its deionizing properties). The lower level for the same thyratron characterizing by the occurrence of instability on the tail of the grid voltage pulse, was found out at the HG voltage level of 5.5 V. The mean value of 7.2 V is too high. HG operation at this voltage will lead to its fast exhaust and further decrease of hydrogen pressure. Therefore, as an operating point for this thyratron was chosen to be such a voltage, at which the instability at the tail of the grid voltage was not observed, of 6.7 V.

The procedure of searching the HG operating point enabled a study of influence of the HG voltage level on the delay time of thyratron switching on. With an increase in HG voltage from 5.4 V up to 7.5 V the time delay was decreased from 280 ns down to 100 ns. Further increase in voltage does not influence much on the change of time delay.

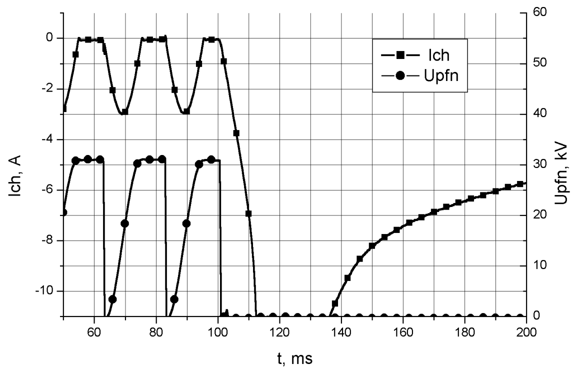

Fig. 2. Determining the HG upper limit by the increase of the PFN charge current. Ich is PFN charge current, Upfn is PFN voltage.

With the shift to the modulator operation with single thyratron, the use of one PFN became possible. Before there were used two PFN's connected in parallel and operated each to its thyratron. Both PFN's were placed into one tank filled with oil. New PFN made in air with the use of high voltage pulse capacitors of the type KMKI 50-0.04 of Sank-Petersburg production. Capacitors are made in an insulated body at a voltage of 50 kV and capacitance of 0.04 μF. The overall dimensions are 315x110x235, mass is 10.5 kg, specific energy is 10 kA, inductance of the capacitor is 80 nH, resource is 10 pulses. The operation regime is the oscillating discharge with voltage reverse up to 50%. In capacitors KMKI 50-0.004 the combined dielectric based on the polypropylene film and paper insulation is used.

The shift to the air version of PFN substantially facilitated its design, made simpler its maintenance. However, it is worth mentioning that in oil version of FL the heat removal from the line capacitors was provide what, in principle, does not eliminate the possibility of raising the modulator operating frequency. In the former version of PFN the metal tank, playing role of the tank for oil, reduced simultaneously the level of noise produced by the PFN. In the new circuit, the noise level turned out to be much higher and for its reduction we had to take additional measures.

For the protection of the klystron and PFN against energy release in the case of breakdown as well as for dissipation the energy stored in the magnetizing inductance (Lμ) during the pulse duration the clipper circuit is used. It is connected in parallel to the last capacitor of the PFN and is consisting of the diode, resistor and varistor set. (Fig. 1). The absence of varistors leads to prolongation of the magnetizing energy dissipation period up to 500 μs, which in its turn, produces a negative effect on the thyratron deionization. At the same time, with the long process of magnetizing energy dissipation (>100 μs) in the thyratron with the lowered hydrogen pressure the premature deionization can occur. It will lead to the undesirable inverse voltage applying to the klystron cathode. In order to avoid this effect one should simultaneously increase HG voltage and make an optimal choice of the varistor set parameters. It should provide the complete dissipation of the magnetizing energy in less than 120 μs.

In the first modulator version, the high voltage thyristor switch (HVS) was used. The small time of thyratron deionization (~100-120 μs) enabled one to avoid HVS and use the diode for the PFN resonant charge. This made the modulator operation simpler and reliable. The diode (or HVS) should be placed in the circuit only after the charge choke (Fig. 1) and not before it. In this case, voltage applied to the diode does not exceed 24 kV. Otherwise, because of the reverse resonant charge of the choke capacitance from the PFN capacitance the higher inverse voltage of 72 kV is applied at the diod, that can lead to its breakdown.

In the former modulator circuit a very expensive nonstandard stepping up three-phase transformer of the BINP production was used. At present it is replaced by the standard transformer TM-100/35 designed at a power of 100 kWA. Inside the transformer tank the high voltage rectifier was installed that enabled the use only one insulator instead of three one. For the charge of the reasonable placement of the transformer frame, its overall dimensions were reduced.

As a result of experiments and calculations, we decided not to use additional chokes located in phases of the power mains. There were oriented to decrease the efficient current at the modulator circuit input and to reduce the power consumed. However, in spite of the reduction of the efficient current value in phases, the excessive heating of power transformer was observed. It was explained by an increase of constant component of the phase current in the case with chokes that led to magnetizing of the transformer and to its further overheating. In addition, the computer analysis of power consumed by the modulator has shown that with the use of chokes the consumed power is reduced insignificantly. Further tests have proven these calculations and we rejected the use of chokes.

2 MODULATOR CONTROL, MONITORING AND PROTECTION SYSTEMS

For the successful maintenance of the modulator the reliable control system, protection and diagnostics is required, which combines the whole complex of systems related to the provision of the operability of the modulator. Such a system was developed and manufactured at BINP. The main functions of the modulator and klystron control and protection are carried out by the signaling and blocking system, the matching and fast protection units.

The signaling and blocking unit receives information on the blocking state controlling various parameters responsible for the safe operation of the modulator and klystron, namely, water pressure in cooling system of the main units of the modulator, the readiness of thyratron filament power supply, the position of rods, modulator doors and the high voltage turn on key. In the case of normal conditions of all the blockings the unit gives the permission for switching on the high voltage. Otherwise, the unit issues a signal on the deviation by the light diode signaling on the front panel and issues prohibition for switching on high voltage.

The main function of the fast protection unit is preventive protection of the modulator and klystron at deviations from the normal operation regime. In the case of deviation of one ore more modulator or klystron parameters it might block the thyristor regulator, turn off the thyratron trigger and call the high voltage switching off, depending on the certain deviation. Information on any deviation is displayed with the light diode indication on the front panel of the unit. The possibility of transferring this information to the control room is also envisaged.

The matching unit transforms the levels of signals applying from measuring circuits of the modulator in order to provide their acceptable values for the fast protection unit, ADC, and standard oscilloscope.

The control system enables the control of the modulator operation both in the manual regime and with computer from the control room. The control system, monitoring and protection systems are described in more detail in [4].

3 MEASUREMENT RESULTS

Fig.3 shows the curves of current and voltage of the klystron taken at the modulator operation in the nominal regime.

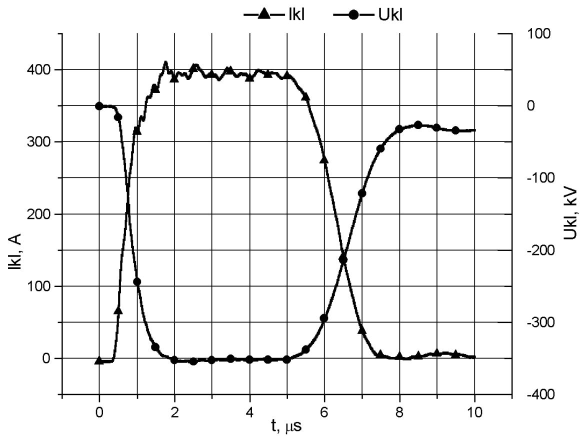

Fig. 3. The klystron 5045 current and voltage curves. Ikl - klystron current, Ukl - klystron voltage.

4 CONCLUSION

Modulators used for the VEPP-5 injection complex klystron 5045 power supply for the operation period over 5 years have shown to be the reliable and safe systems. The main advantage of modulators is its simple, well-studied and broadly used scheme of pulse forming. The main disadvantage of modulators should consider their out-dated elemental base. The use of the modern powerful semi-conducting devices and the use of improved principles of pulse forming enables a substantial improvement of many modulator parameters. At present, the new modulator circuit with the improved characteristics is under way now.

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