CLIPPER CIRCUIT OF PULSE MODULATOR USED FOR KLYSTRON-5045 POWER SUPPLY

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While the operation of modulator to the pulsed transformer of klystron-5045, current through the primary winding of the pulse transformer (PT) continues to flow even upon the end of the klystron voltage operating pulse. This is determined by an energy stored in magnetizing inductance. The prolongation of magnetizing current passing process simultaneously with the premature choking of thyratron can cause high voltage of inverse polarity at the klystron, which cause the destruction of the cathode. We have considered the possibility of shortening time of magnetizing current passage for the charge of reasonable choice of clipper circuit parameters. The behavior of clipper circuit was studied in modulators used for the VEPP-5 (BINP, Russia) preinjector klystron power supply. The optimum operation run of the circuit was selected and its design features are described.
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1 THE CLIPPER CIRCUIT OF THE MODULATOR USED FOR THE KLYSTRON 5045 POWER SUPPLY

For the protection of the klystron and the pulse forming network (PFN) against the energy released at breakdown as well as for dissipation of the energy (Wμ) stored in magnetizing inductance (Lμ) during the pulse duration the clipper circuit switched in parallel to the last capacitor of PFN (Fig. 1 [1,2]) is used. The clipper circuit consists of:

- power resistor Rclip matched with the wave resistance of PFN. In the case of breakdown the Rclip should dissipate the energy stored in PFN;
- power diode Dclip designed for the total voltage and total current of PFN discharge;
- set of varistors Var (nonlinear semi-conducting resistors with symmetric characteristics I(U)).

The use of varistors is determined by the following reasons:

- Wμ energy dissipation process proceeds faster with varistors than without them thus the faster recovery of the thyratron is stimulated;
- when the thyratron current is finished some negative voltage is applied at the thyratron, which also reduces the thyratron recovery time.

In VEPP-5 modulators there are used varistors SN-2A with classification voltage of 330 V and admissible power of 2 W (the classification voltage of the varistor is the voltage at which its current value is 1 mA) assembled in a set. A set is a parallel connection of 48 circuits, each of which consists of two varistors SN-2A connected in series. Thus, the total number of varistors in a set is 96 and an admissible power dissipated in such a set is 192 W.

The set puts the limit on the value of the inverse voltage at a klystron Ukl within the limit of 18 kV (the transformation ratio of PT is Ktr =15). Upon reaching this value (when the PFN capacity is recharged up to the voltage value a few higher than the varistor classification voltage) Iclip current begins to flow in the clipper circuit in about 40 μs after applying the operating pulse to the klystron (Fig. 2, curve a). At this moment, at the nominal operation regime of modulator (klystron voltage Ukl=350 kV) the value of Iclip is 30 A. On the basis of the computer simulation analysis, the maximum value of magnetizing current (Iμ) is 40 A. In this case, the magnetizing inductance value is Lμ ≈ 3300 μH, so the energy $W\mu = L\mu \times I\mu^2/2 = 2.65$ J. Assuming that all the energy Wμ is dissipated in varistors and taking into account that the modulator operating energy is 50 Hz, we get the mean power dissipated in varistors to be Pvar = Wμ·f ≈ 130 W. This value is less than the admissible value (actually, because of mismatching of the load and line substantially larger energy could be released in the clipper circuit, see below).

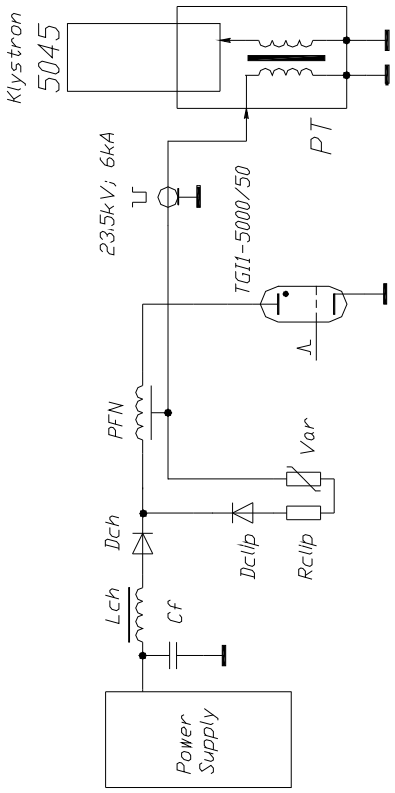

Fig. 1. Schematic diagram of pulse modulator used for klystron-5045 power supply.

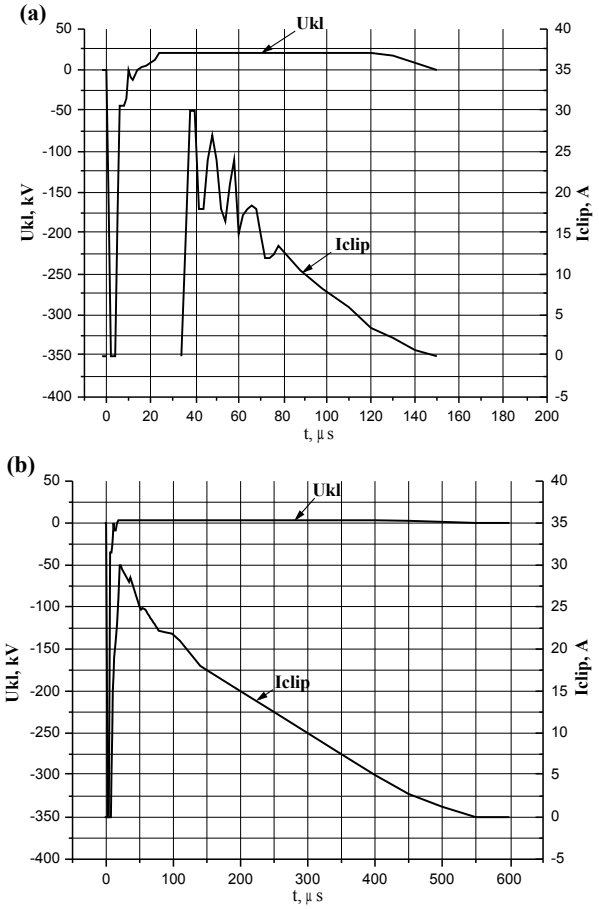

Fig. 2. Curves of klystron voltage (Ukl) and clipper current (Iclip) for clipper circuit with (a) and without (b) varistor set.

The necessity of using varistors can be justified by an analysis of Fig. 2 representing Iclip current curves with (curve-a) and without (curve-b) varistors. From the comparison of corresponding curves it is seen that the use of varistors enables on to reduce the damping process for Iclip down to 120 μs instead of 550 μs in case of the clipper circuit without varistors. Reduction of this process is caused by the necessity of providing favorable conditions for recovery of non-conducting state of the thyratron. In case of a long process of current damping, thyratron cannot restore up to the beginning of the next charge cycle of PFN that might cause short-circuit in the charging circuit of the modulator.

In addition, with an increase in the time of dissipation Wμ (t > 100 μs) for the thyratron with lowered hydrogen pressure the interruption of current Iμ can occur. The circuit is broken and energy stored in Lμ is released in PT. Because of this circumstance the undesirable burst of negative voltage applies at the klystron cathode.

Such an effect was found out in the process of a long term operation of modulators at the VEPP-5 complex. This problem can be solved in two ways: by an increase in the hydrogen generator voltage in the thyratron and by optimizing the selection of parameters of the varistor set for providing the total dissipation of energy Wμ in less than 120 μs.

2 BEHAVIOR OF THE CLIPPER CIRCUIT AT KLYSTRON BREAKDOWN

The emergency operation run of the clipper circuit occurred at the klystron breakdown is worth of special mention. In such a regime the energy stored in PFN with maximum achievable value of 800 J (depending on the PFN-load mismatching level) will be released in the clipper circuit. The discharge of PFN through clipper will occur for the time equal to the pulse duration t ~ 4 μs, therefore, the maximum power released in the clipper circuit at the klystron breakdown can achieve 200 MW. The biggest part of the power released at the breakdown will dissipate in Rclip. In modulators of the VEPP-5 complex, the Rclip role is played by a set of 24 resistors TVO-60-27 (12 parallel circuits of two resistors connected in series). According to reference data, the ultimate power to be withstood by resistors TVO-60 in pulse is 25 MW. Therefore, for providing the operability of the resistor set of the clipper circuit in the regime of breakdown it is necessary to use no less than 8 TVO-60 resistors.

3 SELECTION OF OPERATING VOLTAGE OF VARISTOR SET

For the varistor set used at the VEPP-5 complex, the time from the applying of operating voltage at klystron to the moment of vanishing the inverse voltage is t ≈ 150 μs. For comparison, in the clipper circuit of modulators used for the klystrons 5045 power supply at the SLAC facility (USA) a set of nonlinear resistors limiting the value of Ukl_inv within the limit of 35 kV. The use of such a varistor set enables one to get the duration of the inverse voltage at the klystron t ≈ 120 μs which is 20% less than the duration of the inverse voltage formed by a varistor set used in modulators of the VEPP-5 complex. This is explained by the higher classification voltage of the set of nonlinear resistors for the SLAC version. For reducing the applying time of Ukl_inv one has to increase the varistor classification voltage. In this case, the energy dissipated in the set of varistors decrease because of energy transmitting from magnetizing inductance into PFN capacitance. In this case, the PFN capacitance is recharged up to higher voltage equal to Ukl_inv/Ktr. Then, due to the resonance discharge the PFN charge voltage increases (in the case of absence of the charge voltage stabilization circuit). Table 1 shows the calculated parameters of various operation regimes of the clipper circuit, depending on the value of the varistor classification voltage and the level of mismatching of PFN and the load ρ/Rkl (ρ is the wave resistance of PFN, Rkl is the klystron equivalent resistance).

In order to reduce the Wμ energy dissipation time, in modulators at the VEPP-5 complex, it was suggested to use the varistor set satisfying the following technical requirements (as a result of analysis of various operation runs of the clipper circuit the choice was made in favor to the varistor set with the classification voltage of

1300 V providing a rather fast dissipation of Wμ energy at quite low inverse voltage at the klystron).

Table 1

	ρ/Rkl	Varistor classification voltage		
		700 V	1300 V	1800 V
Voltage Ukl_inv		18 kV	33 kV	45 kV
Power released in a varistor set in operation regime	0.77	155 W	125 W	45 W
	0.9	210 W	200 W	140 W
Power released in resistors in operation regime	0.77	30 W	10 W	1.5 W
	0.9	115 W	65 W	35 W
Energy dissipated in a varistor set at a breakdown	0.77	80 J	105 J	130 J
	0.9	85 J	115 J	140 J
Energy dissipated in resistors at a breakdown	0.77	500 J	475 J	450 J
	0.9	580 J	550 J	525 J
Time of inverse voltage applying to the klystron	0.77	145 μs	115 μs	95 μs
	0.9	140 μs	105 μs	85 μs

Operation run (Ukl = 350 kV, Ikl = 400 A):

Magnetizing inductance current by the end of a pulse: 40 A.

Energy stored in the magnetizing inductance: 2.65 J (130 W).

Classification voltage of the varistor set: 1300 V.

Amplitude of short current pulses (t~2 μs): 200 A.

Power dissipated in varistors at operation with frequency of 50 Hz (with taking into account mismatching of PFN and load): 250 W.

Magnetizing current damping time: 120 μs.

Emergency regime - klystron breakdown:

Amplitude of current flowing through the clipper circuit: 6 kA

Current pulse duration: 3.5 μs

Voltage applied to the clipper circuit: 23.5 kV

Energy dissipated in varistors: 120 J

At present, we have an agreement with VEI (Moscow, Russia) on the production of the varistor set with the parameters mentioned above. The use of powerful varistors, which will reduce the set overall dimensions and increase its reliability was mandatory required.

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