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A POWER PULSE TRANSFORMER (U)  
FEB 80 O S BOGDANOV, Y P VAKHRUSHIN  
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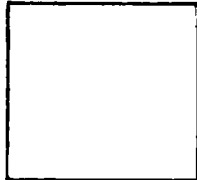


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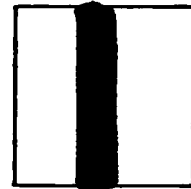
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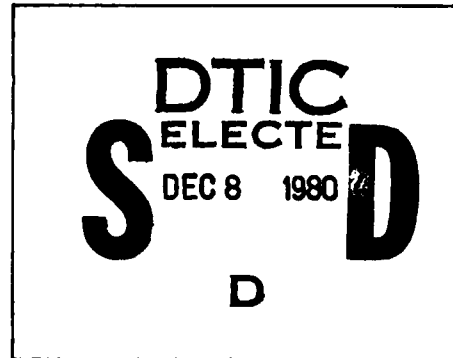
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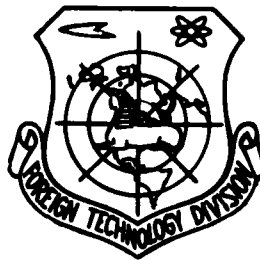
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A POWER PULSE TRANSFORMER

by

O. S. Bogdanov, Yu. P. Vakhrushin, et al.



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## EDITED TRANSLATION

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А а	<b>А а</b>	A, a	Р р	<b>Р р</b>	R, r
Б б	<b>Б б</b>	B, b	С с	<b>С с</b>	S, s
В в	<b>В в</b>	V, v	Т т	<b>Т т</b>	T, t
Г г	<b>Г г</b>	G, g	У у	<b>У у</b>	U, u
Д д	<b>Д д</b>	D, d	Ф ф	<b>Ф ф</b>	F, f
Е е	<b>Е е</b>	Ye, ye; E, e*	Х х	<b>Х х</b>	Kh, kh
Ж ж	<b>Ж ж</b>	Zh, zh	Ц ц	<b>Ц ц</b>	Ts, ts
З з	<b>З з</b>	Z, z	Ч ч	<b>Ч ч</b>	Ch, ch
И и	<b>И и</b>	I, i	Ш ш	<b>Ш ш</b>	Sh, sh
Й й	<b>Й й</b>	Y, y	Щ щ	<b>Щ щ</b>	Shch, shch
К к	<b>К к</b>	K, k	Ъ ъ	<b>Ъ ъ</b>	"
Л л	<b>Л л</b>	L, l	Ы ы	<b>Ы ы</b>	Y, y
М м	<b>М м</b>	M, m	Ь ь	<b>Ь ь</b>	'
Н н	<b>Н н</b>	N, n	Э э	<b>Э э</b>	E, e
О о	<b>О о</b>	O, o	Ю ю	<b>Ю ю</b>	Yu, yu
П п	<b>П п</b>	P, p	Я я	<b>Я я</b>	Ya, ya

\*ye initially, after vowels, and after ь, ь; e elsewhere.  
When written as ë in Russian, transliterate as yë or ë.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	sinh <sup>-1</sup>
cos	cos	ch	cosh	arc ch	cosh <sup>-1</sup>
tg	tan	th	tanh	arc th	tanh <sup>-1</sup>
ctg	cot	cth	coth	arc cth	coth <sup>-1</sup>
sec	sec	sch	sech	arc sch	sech <sup>-1</sup>
cosec	csc	csch	csch	arc csch	csch <sup>-1</sup>

Russian      English

rot      curl  
lg      log

0061

**A POWER PULSE TRANSFORMER**

O. S. Bogdanov, Yu. P. Vakhrushin, V. G. Zhitenev, N. I. Kolesov, and  
A. V. Orlov

The operating principle and design of a power pulse transformer designed for operation in the range of 50-500 ns are described. A description of the transformer prototype with parameters  $U_1 = 20$  kV,  $U_2 = 160$  kV, and  $I_2 = 700$  A is given, and results of the tests are presented which show that a transformer of this type provides good voltage pulse transfer and is characterized by reliable operation. This makes it possible to recommend it for use in the power supply of the powerful electron gun of the LIU-30/250 accelerator.

**INTRODUCTION**

The electron gun of the LIU-30/250 linear induction accelerator [1] requires a high-voltage power supply with a voltage of 300-500 kV, a load current of 250-300 A, with a pulse duration  $\tau_{0.95} = 0.5$   $\mu$ s and a sampling rate of 50  $s^{-1}$ .

One possible solution is to use the modulator of the pulsed power supply of an LIU [linear induction accelerator] [2] whose load is a pulse transformer that consists of a number of ring-shaped magnetic circuits, each of which is covered with primary windings connected in parallel; the voltage of the secondary winding is equal to the sum of the voltages of the primary windings [3, 4, 5]. We discuss the results of tests of a prototype pulse transformer which we propose to use in the LIU-30/250.

#### I. OPERATING PRINCIPLE AND DESIGN OF THE PULSE TRANSFORMER

The basic diagram of the pulse transformer is shown in Fig. 1. It consists of circular magnetic circuits 1, the number of which depends on the required voltage on the secondary winding. Each magnetic circuit is enclosed by coil 2. The coils are connected in parallel and form the primary winding of the transformer. Secondary winding 3 encompasses all the magnetic circuits; the voltage on it is determined by the equality

$$U_2 = NU_1,$$

where  $U_1$  is the voltage on the primary winding;  $N$  is the number of magnetic circuits; and  $U_2$  is the voltage on the secondary winding.

Unlike the circuits generally used [6], with such a circuit it is possible to design a transformer in which there is good transfer of the pulse shape and at the same time to easily deal with problems of insulating the secondary winding, feeding the voltage to the heater of the electron gun, and cooling the magnetic circuits.

To unify the units of the accelerator for the pulse transformer it is expedient to induction coils of the LIU-30/250 accelerating system. Figure 2 shows the design of the pulse transformer.

Cores 1 are made of strips of alloy 50MP 10  $\mu$ m thick with insulation between turns of magnesium oxide applied by catophoresis. The cores are contained in electrically-insulated frames 2 made of glass micanite. These frames insulate the cores from primary winding 3 and at the same time protect the cores against mechanical effects. The cores with frames are fastened in water-cooled housing 4 made of aluminum alloy.

The induction coils are collected into a column by means of pins 6 which form simultaneously the outer part of the secondary winding. Sealing gaskets 5 are placed between the induction coils.

Tube 8, attached at one end to flange 8 and at the other to insulator 7 passes along the axis of the column thus formed. In this

way the tube with the flange and pins forms the secondary winding. Inner cavity 10 is filled with transformer oil to assure good electrical insulation between the central tube and the induction coil bodies. No additional insulation is required between the induction coils since the buses of adjacent coils are shifted with respect to azimuth. The power supply for the gun heater is located inside the central tube, making it possible to eliminate a separating transformer. When using the transformer to power a three-electrode gun, tap 11 is taken from the central tube; the voltage on this tap is proportional to the number of enclosed induction coils.

## II. THE PROTOTYPE AND ITS TESTING

For the prototype of the pulse transformer (Fig. 3) we used eight induction coils made using an epoxy compound [2]. The basic diagram for powering the transformer and measuring its parameters is given in Fig. 4. In the modulator are used thyatron 1, type TGI-1-2500/50, and heterogeneous shaping line 2 on capacitors PKGI-50-25000. The modulator makes it possible to obtain voltages to 23 kV and to switch currents to 15,000 A. Voltage from the modulator is fed, using type PK-50-11-13 cables 3, to primary winding 4 of the transformer. In the first test mode a load was emitted by resistors 5, type TVO-60-51. The selected rating of the resistors corresponded to a beam current of 400 A. In the second mode a three-electrode gun

was connected to the transformer; currents to 700 A were taken from the gun cathode. In this case a voltage equal to  $\frac{5}{8}$  of the total voltage was fed to the grid of the gun from transformer tap 6. The gun heater was powered from transformer 7 using conductor 8 that passes inside the central tube of the transformer. The cores were demagnetized by alternating current with a voltage  $U_p = 12$  V and a current of  $\sim 160$  A using demagnetization system 9.

In the measurements we used a type DSO-1 two-beam oscillograph 10. During the tests we measured a) the voltage on the primary winding of the transformer using divider 11; b) the current across the thyatron using Rogowski loop 12; c) the voltage on the secondary winding using divider 13; and d) the beam current using system 14 and Rogowski loop 15.

The parameters of the measurement circuits were as follows:

11 - pulsed attenuator, consisting of resistors TVO-20 with a scaling ratio  $K = 56$ .

12 - Rogowski loop made using a ferrite ring; sensitivity 0.16 V/A.

13 - pulsed attenuator, consisting of resistors TVO-10 with a scaling ratio  $K = 343$ .

14 - RC circuit; capacitors  $C_1 = C_2 = 8 \mu\text{F}$ ;  $R = 0.8 \Omega$ .

15 - Rogowski loop made using a ferrite; sensitivity 0.26 V/A.

### III. TEST RESULTS

Figure 5 shows oscillograms of voltage pulses on the primary and secondary windings of the pulse transformer. The upper oscillogram shows the voltage pulse on the induction coil (primary winding), the lower - the voltage pulse in the secondary winding of the transformer. The oscillograms were recorded with the following parameters:  $U_{\text{защитное ф.н.}} = 45 \text{ kV}$ ;  $U_{\text{инд}} = 20 \text{ kV}$ ;  $U_{\text{вт}} = 160 \text{ kV}$ . Sweep duration -  $1.2 \mu\text{s}$ . Duration of calibration marks -  $0.2 \mu\text{s}$ . The equivalent load corresponded to a beam current of 400 A. Analysis of the oscillograms showed that the durations of the flat part of the pulses of the primary and secondary windings coincide, and are  $\tau_{\text{пл.пл.}} = 540 \text{ ns}$  at level 0.95. Analysis of the leading edges of the pulses also showed good agreement  $\tau_{\text{ф}} = 200 \text{ ns}$  for both pulses.

Figure 6 gives oscillograms of the current pulses through the thyatron (upper oscillogram) and the voltage on the induction coil (primary winding). The oscillograms were recorded with the following

parameters:  $I_{TAP} = 7.16$  kA;  $U_{UH9} = 20$  kV;  $U_{3AP} = 45$  kV.

The sweep duration was  $1.2 \mu\text{s}$ ; the duration of the calibration marks was 50 ns.

Prolonged operation of the transformer showed high reliability of the oil insulation of the secondary winding. No breakdowns were noted within the transformer. It was established that filling the cavities between inductance coils with transformer oil does not worsen the shape of the voltage pulse in the primary winding of the transformer. In both cases the duration of the pulse front was 200 ns.

#### CONCLUSION

Results of prototype tests allow us to recommend the proposed transformer design as a high-voltage power supply for the LIU-30/250 electron gun. It should be noted that it is desirable to reduce the duration of the pulse front and the drop in voltage pulse, since the electrons of the gun beam, whose energy differs from nominal, are lost during acceleration and load the accelerator tube. Since the beam power is  $\sim 200$  kW, too high a loss of electrons can lead to damage to the accelerator tube. One possible way to curtail the duration of the pulse front and the drop is to introduce into the secondary circuit a

control key, e.g., an electron tube. In this case it can be expected that the duration of the pulse front and the drop will be ~30 ns.

The protoype was prepared for testing and measurements were made by V. I. Kornev and A. I. Pavlov, in addition to the authors.

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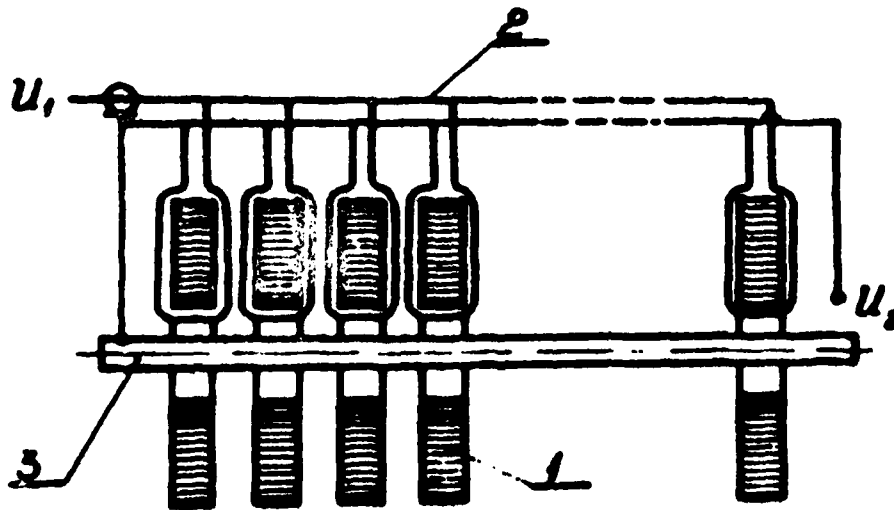


Fig. 1. Schematic of pulse transformer. 1 - circular magnetic circuits; 2 - coils of primary winding; 3 - secondary winding of the transformer.

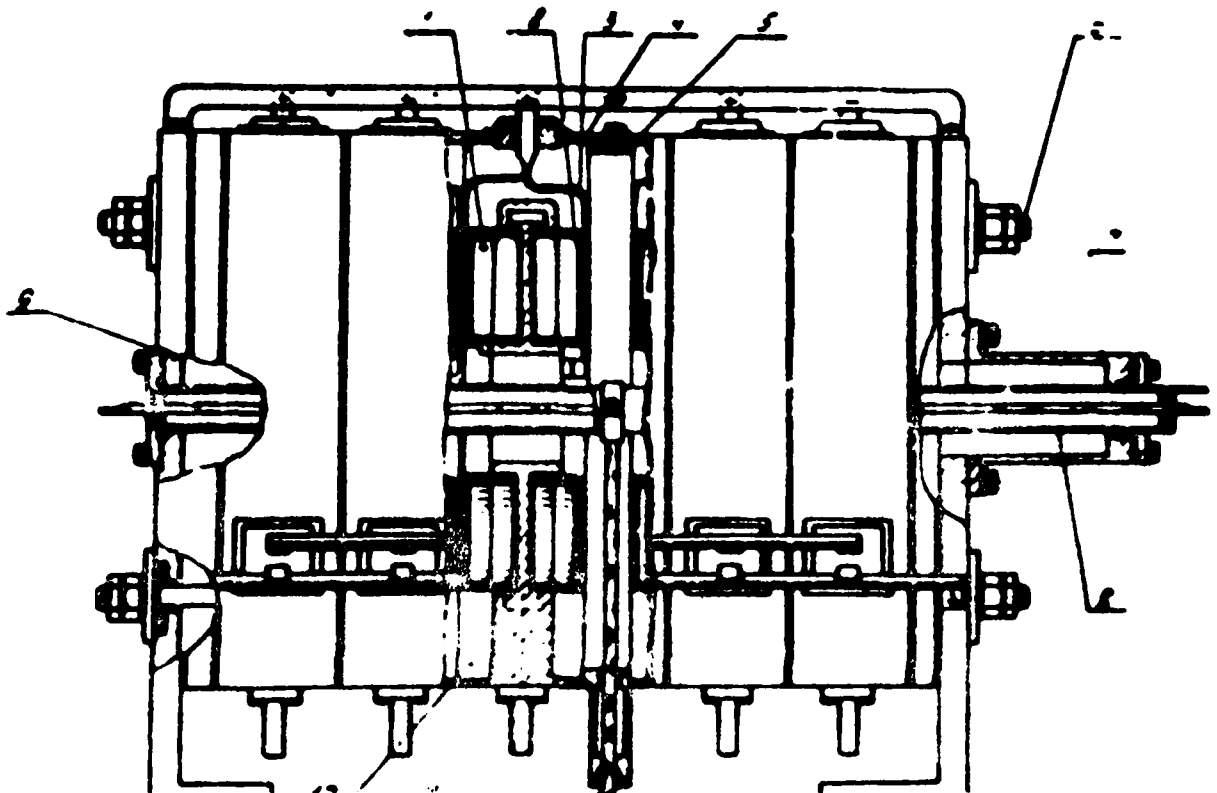


Fig. 2. Design of the pulse transformer. 1 - circular cores; 2 - electrically insulating core frames; 3 - primary winding; 4 - water-cooled housing; 5 - sealing gaskets; 6 - pins; 7 - insulator; 8 - tube; 9 - flange; 10 - volume filled with transformer oil; 11 - intermediate tap.



FIG. 3.  
Prototype of pulse transformer [ILLUSTRATION NOT REPRODUCIBLE]

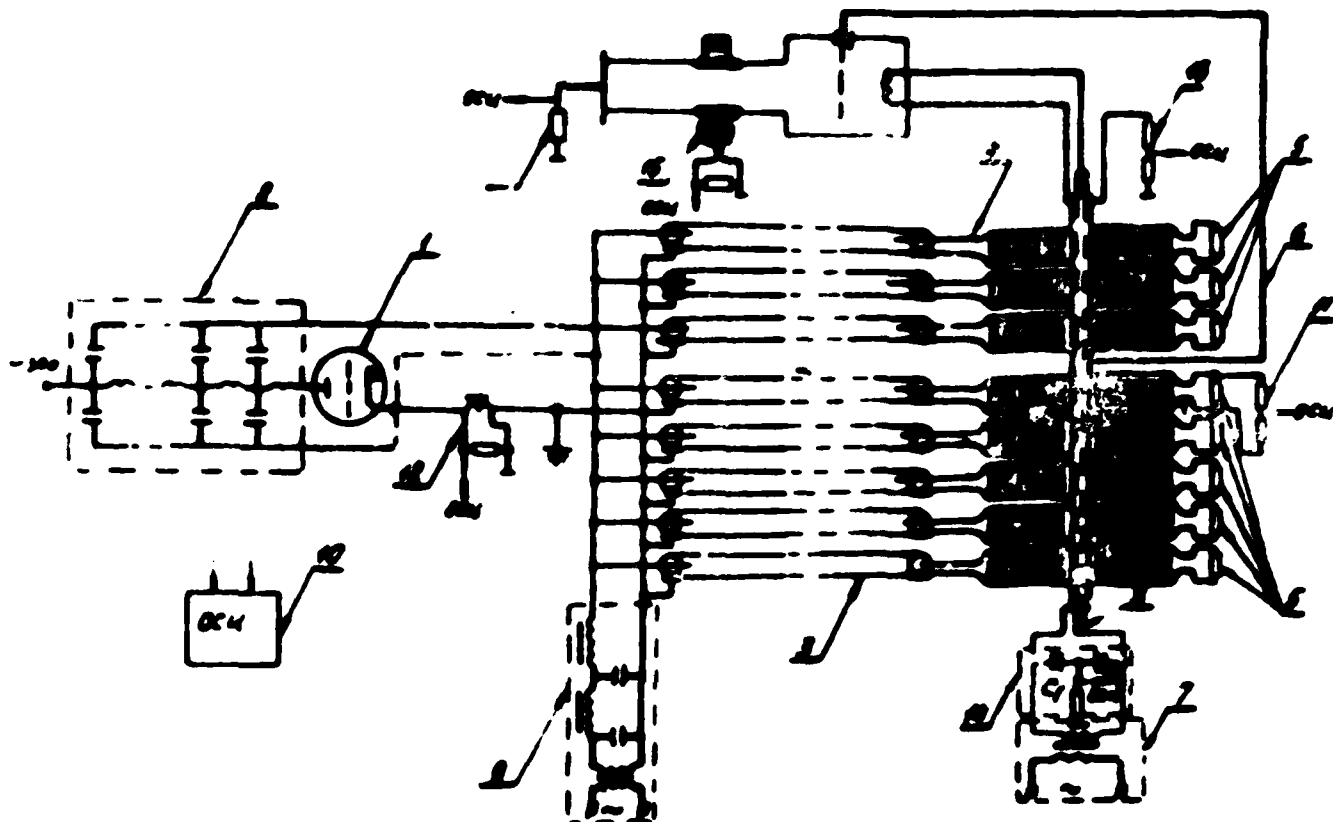


Fig. 4. Diagram of the transformer power circuitry. 1 - thyatron; 2 - heterogeneous shaping line; 3 - transmission cables; 4 - primary winding; 5 - load resistors; 6 - intermediate tap; 7 - filament transformer; 8 - conductor; 9 - demagnetization circuit; 10 - oscillograph; 11 - attenuator; 12 - Rogowski loop; 13 - attenuator; 14 - system for measuring current of secondary winding of transformer; 15 - Rogowski loop.



Fig. 5. Oscillograms of voltage pulses on primary (upper curve) and secondary windings of the pulse transformer ( $\tau_{e.05} = 0.5 \mu s$ ;  $\tau_{\phi} = 200 ns$ ;  $U_1 = 20 kV$ ;  $U_2 = 160 kV$ ). [FIGURE NOT REPRODUCIBLE]



Fig. 6. Oscillograms of current pulses through the thyatron (upper curve) and voltage on primary winding of the pulse transformer ( $U_1 = 20$  kV;  $I_{Tup} = 7$  kA). [FIGURE NOT REPRODUCIBLE]

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