A description is given of sections of a linear pulse transformer (a linear transformer driver, LTD) intended for use as a fast primary storage device in pulse generators with intermediate inductive energy storage. The results of tests of LTDs consisting of 3 and 10 series-connected sections are given. Results are described for experiments on coupling energy out of such a generator using a plasma opening switch.

INTRODUCTION

The design principles of a primary storage device taking the form of a pulse generator utilizing a linear pulse transformer have been known for a long time. The principal advantage of such a circuit compared with an Arkad'ev-Marx generator is that the housing of the capacitors in any stage is at zero potential during firing. This makes it possible to avoid the necessity of insulating the higher stages of the generator to the full output voltage and also to provide for independent triggering of the stages from an external triggering pulse. The latter factor (with simultaneous triggering of the stages) prevents a transient process occurring in the circuit which is normally accompanied by the appearance of high-voltage oscillations whose amplitude exceeds that of the output voltage pulse. This high-frequency voltage is also applied to the insulation of the stages and makes it more difficult to design the insulation of an Arkad'ev-Marx generator.

The main problem in constructing a linear pulse transformer is that of the relatively high inductance of the capacitors and spark gaps in the primary circuit of the transformer. The requirement of the efficient transfer of energy from the primary circuit to the secondary then makes it necessary to increase the inductance of the secondary circuit and the inductance of the insulating turn. The former gives a drop in the generator power as a whole and latter gives an increase in the cross section (and therefore of the weight and cost) of the iron in the transformer core. It is for this reason that up until recently the primary storage devices of pulse generators have been preferably constructed using the Arkad'ev-Marx circuit.

A description is given below of sections of an LTD (linear transformer driver) developed in the Pulse Technology Division of the Institute of High-Current Electronics of the Siberian Branch of the Russian Academy of Sciences in 1995-1997. The key elements of these sections are low-inductance capacitors made by the firm HAEFELY (75 kV, 5.65 μF, 13 nH, 45 mΩ or 90 kV, 3.95 μF, 1 nH, 13 mΩ) and low-inductance multichannel multigap spark gaps (90 kV, 750 kA, 8.5 nH) [1], developed at the Institute of High-Current Electronics for the SYRINX project (in France). These sections are intended for use as the primary storage device of a pulse generator with intermediate inductive storage and a plasma opening switch providing peaking of the power pulse when the energy is coupled out into a Z-pinch load.

1. BASIC CIRCUIT OF AN LTD STAGE

An LTD stage was developed for two parallel-connected HAEFELY capacitors. Each of the capacitors is switched into the discharge circuit by its own spark gap. Figure 1 shows the circuit of an LTD stage for the case of a short-circuited second-
Fig. 1. Electrical circuit of an LTD stage with a short-circuited secondary turn.

ary turn, where $C$ is the capacitance of the storage capacitors, $S$ represents the spark gaps, $L3$ is the inductance of the secondary turn which is made in the form of a length of vacuum coaxial line, $L4$ is the inductance of an insulating turn which provides zero potential on the capacitor housing at the moment of firing, $L1$ represents the parasitic inductance of the capacitors and spark gaps, $L2$ is the parasitic inductance of the busbars connecting the spark gaps to the vacuum coaxial line, $R$ includes the resistance of the capacitors, the spark gaps, and if necessary of an additional damping resistance ensuring the maximum permissible level of reverse voltage (50%) on the HAEFELY capacitors is not exceeded during recharging.

After the capacitors have been charged and the spark gaps have switched them to the discharge circuit of the stage, current flows in two parallel branches: $(L2 + L3)$ and $L4$. The condition $L4 > (L2 + L3)$ must be satisfied in order to reduce the losses in the insulating turn, and the efficient transfer of energy to the vacuum coaxial line requires that $(L1 + L2) < L3$.

2. LTD-02 STAGE WITH 75-kV OIL INSULATION

2.1. Design of the Stage

The construction of the LTD-02 stage with 75-kV oil insulation is shown in Fig. 2. The stage consists of two HAEFELY capacitors $C$ mounted above and below the stage housing $I$ and two multichannel multigap coaxial spark gaps (MMCS) switching the capacitors to the primary (insulated) turn of the transformer and to box-section busbars leading to the external electrode $4$ of the vacuum coaxial line. The primary turn is formed by the anode $4$ of the vacuum coaxial line and the stage housing $I$. The box-section busbars are made in the form of strip lines with a 10-mm interelectrode gap passing along three sides of the rectangular stage housing. A ferromagnetic core $3$ is used in order to increase the inductance of the insulating turn. The core is made in the form of 13 separate ferromagnetic rings, wound with an 80 $\mu$m thick ribbon, and these are insulated from each other by rings of electric-insulating cardboard. An insulator $2$ separating the vacuum and oil-filled volumes of the stage is made from polyethylene.

The stage housing is filled with transformer oil which insulates the primary turn of the transformer, the strip lines, the input terminals for the charging voltage $U_0$ and the trigger voltage $U_T$, and also the interface between the capacitors and the spark gaps. The core of the stage is magnetized with a current pulse $I$ of amplitude 1.5 kA and risetime $\sim 50 \mu$sec before firing a shot in order to avoid saturation. The magnetizing pulse is applied through a high-voltage cable to the output electrode of one of the spark gaps. A resistive potential divider is mounted on the opposite end of this cable, so enabling the voltage on the primary turn of the transformer to be recorded at the moment of firing. The triggering voltage is applied to the spark gaps when the magnetization current reaches its maximum.

A polyethylene tube $G$ serves to introduce dry air into the spark gaps before firing a shot and to exhaust it rapidly into the vacuum space immediately after firing.

The design of the LTD-02 stage makes it possible to connect such stages in series. In this case the electrical contact and vacuum sealing between the outer electrodes of the vacuum coaxial lines of the individual stages are provided by placing ring gaskets made of indium or lead, under compression using eight bolts, between neighboring stages. The inner electrode of the vacuum coaxial line (not shown in Fig. 2) is positioned along the axis of an assembly of several stages in series. The vacuum pumping system is mounted on one end of this assembly. The plasma opening switch unit and the load are mounted on the other. A break is made when mounting the inner electrode in the circuit of the secondary turn of the transformer, dis-