# HIGH POWER MODULATOR FOR LINEAR INDUCTION ACCELERATOR SILUND-21

G.V. Dolbilov, A.A. Fateev
Joint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russia

Linear induction accelerator SILUND-21 is under construction at the Joint Institute for Nuclear Research (Dubna). SILUND-21 will provide electron beam with the energy up to 10 MeV, peak current $\sim 1$ kA and pulse duration 50 – 70 ns. This report presents description of nanosecond accelerating voltage scheme for the SILUND-21 accelerator. The main feature of our approach consists in the use of powerful, low-voltage generator ($V \simeq 42$ kV) and low-resistance load ($R \simeq 0.5\ \Omega$). A high power in nanosecond pulses ($W \sim 1$ GW) is achieved in nonlinear compression schemes with distributed parameters which compress electromagnetic energy in time.

## 1 INTRODUCTION

The SILUND-21 linear induction accelerator ( 10 MeV, 1 kA, 50 – 70 ns) will serve as a base of experimental facility to study microwave electronics, FEL physics and two beam acceleration [1]. SILUND-21 accelerator is constructed using the equipment of LUEK-20 accelerator developed for experimental investigations of the collective method of acceleration [2, 3]. Nevertheless, there are two principal distinctions between LUEK-20 and SILUND-21 accelerators. First, LUEK-20 accelerator has been used to accelerate compact, 4 – 6 mm long electron-ion rings, so there was no need in essentially rectangular form of the accelerating voltage. In the case of SILUND-21 we need good quality rectangular pulse of about 50 ns duration. Second, the equivalent beam current load was less then 100 A in LUEK-20 accelerator, so there were no severe requirements to the value of stray inductance of junctions. The beam load will be larger by the order of magnitude in SILUND-21, so, the main problems of upgrading the LUEK-20 equipment consist in partial reconstruction of induction sections and in design of a new modulator.

## 2 ACCELERATING MODULE

The accelerator consists of seven identical accelerating modules. Each module provides approximately 1.5 MeV accelerating voltage at 1 kA beam load. The general layout of the accelerating module is presented in Fig. 1. Induction section (1) consists of 36 permalloy cores combined in pairs. The core exciting windings of each pair are commutated in parallel. The input impedance of the section is equal to about 0.5 Ω at nominal beam load.

Vacuum pumping of the accelerator volume is provided by sputter-ion pumps (3) via channels placed in the gap (4). Electron beam diagnostic devices are also placed there.

The accelerating ceramic tube consist of 6 sections separated by cone earthing diaphragms. Cone diaphragms play also the role of screens reducing the intensity of interaction between the electron beam and dielectric waveguide and form accelerating gaps. The amplitude of accelerating voltage at each of six accelerating gaps of the accelerating section is equal to 250 kV.

Focusing of the electron beam is provided by solenoid. The solenoid winding is sectional and the number of the sections is equal to the number of permalloy cores. Design parameters of the solenoid power supply allow one to provide the guiding magnetic field with the amplitude up to 1.4 T and pulse duration about of 0.8 ms.

Pulses of accelerating voltage with the amplitude of 42 kV, duration of 50 – 70 ns and rise time of about 5 ns are formed by modulator (2) with 0.5 Ω internal resistance. TGI1-2500/50 hydrogen thyratron (2500 A, 50 kV), which is used as a commutator, does not provide commutation of the required level of the peak power, so power compression schemes are used to increase the peak power.

## 3 MODULATOR SCHEME

The modulator scheme (see Fig. 2) is based on the application of the nonlinear power compression technique and is similar to that of the SILUND-20 accelerator [4]. More than ten years of successful operation of the SILUND-20 accelerator have proved the validity of technical solutions for the modulator.

The process of pulse power compressing in microsecond range is relatively simple and could be realized without significant efforts. The main problems arise when designing power compression scheme is operating in nanosecond range with pulses of rectangular form.

Modulator scheme consists of two main parts. The first one is traditional compression scheme with lumped-elements, which includes initial pulse forming circuit (thyratron, C1, L1) and one compression cell (C2, L2).

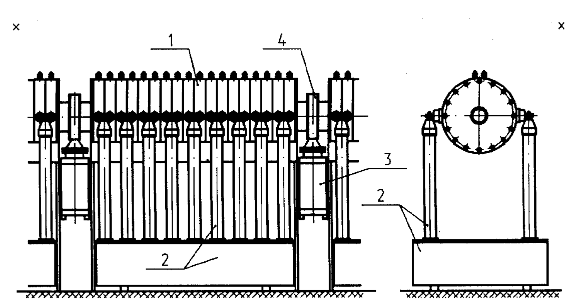


Figure 1: Accelerating module

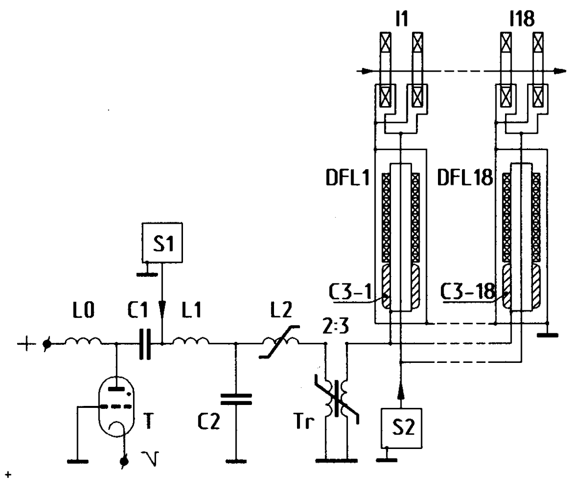


Figure 2: Modulator scheme

The second part is an output forming stage which includes forming lines and nonlinear transformer Tr.

The severe requirements to the modulator of SILUND-21 accelerator (low output impedance and short rise time of the output pulses) completely exclude the possibility of using lumped-element chains in the output stage. As a result, the lines with distributed parameters (both linear and nonlinear lines with ferrits) should be used in the output stage. In this case the processes of power compression and forming of rectangular shape of the pulse take place simultaneously in the output stage.

Hydrogen thyratron T operates in a pulsed mode with 3 $\mu$s pulse duration and provides commutation of 10 kA current at 30 kV voltage. Permalloy reactor L2 and saturable transformer Tr play the roles of ferromagnetic switches. The initial pulse is compressed in the traditional stage and then it charges the forming stage consisting of nonlinear double forming lines (DFL1 – DFL18) with the additional correcting capacities (C3-1 – C3-18). DFLs are charged within 1 $\mu$s time period. During this process the transformer Tr is not saturated. Each DFL consists of two coaxial lines. The external line is partially filled with ferrite rings. The rest volume of DFL is filled with rectified water. With respect to the charge current the ferrite is saturated and the efficiency of the energy transfer is about 0.9.

When the voltage amplitude in the DFL reaches its maximum, the transformer Tr is saturated and becomes to serve as a commutator forming a voltage swing with the relatively long front which then becomes shorter and forms $\sim$ 5 ns rise time of the driving pulse. Such a way to form output pulses allows one to reach a high ratio of compression and to obtain rectangular pulses of 60 ns duration from sinusoidal pulse of 1 $\mu$s duration.

The initial magnetization of the ferromagnetic materials in the nonlinear elements is adjusted by two ambipolar current sources (S1 and S2). This technique provides a high precision of the initial magnetization value.

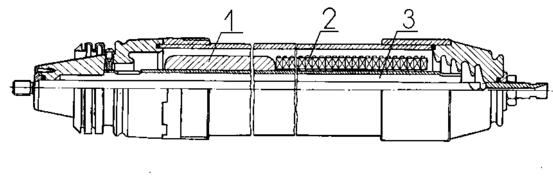


Figure 3: Nonlinear double forming line. 1-correcting capacity, 2-ferrit cores with screens, 3-internal linear line.

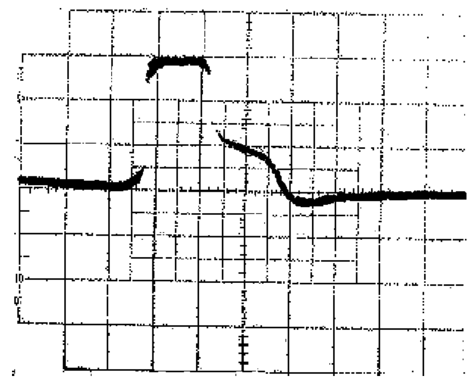

Figure 4: Oscillogram of the output pulse. Amplitude scale is 15 kV/div. Time scale is 50 ns/div.

## 4 DOUBLE FORMING LINE

Preliminary construction of the double forming line is shown in Fig. 3. All metallic parts are manufactured of stainless steel. Insulating parts are made of plastic. Ferrit cores are placed into metallic screens which increase linear capacitance and protect ferrit against electrical fields.

## 5 TEST MEASUREMENTS

The specimens of the double forming lins and water rectification systems are being manufactured and assembled in an experimental hall. This setup allows one to test the double forming lines under conditions close to operating regime.

Operating experience has been showing that the water rectification system maintains the required value of the water resistivity in the line larger than 2 M$\Omega$ cm. This value corresponds to the discharge time of 14 $\mu$s. DFL are tested with charging voltage up to 50 kV with the rise time of about 0.8 $\mu$s. The commutation time is about 200 ns. The rectangular pulses of $\sim$ 60 ns duration are formed at the equivalent load consisting of two permalloy cores and resistor. The oscillogram of the output pulse is presented in Fig. 4.

## 6 ACKNOWLEDGEMENT

The authors wish to acknowledge Dr. I. Ivanov for his constant encouragement. We also would like to express our thanks for the support from all technical groups.

## 7 REFERENCES


[1] G.V. Dolbilov et al., Nuclear Instrum. and Methods **A 375**(1996)100.

[2] G.V. Dolbilov et al., Proc. EPAC94 (London, 1994). World Scientific, 1994, Vol.1, p.748.

[3] G.V. Dolbilov et al., Proc. of the 1994 International Linac Conference (Tsukuba, Japan), Tsukuba, KEK, 1994, Vol.1, p.357.

[4] G.V. Dolbilov, A.A. Fateev, V.A. Petrov, A.I. Sidorov, Proc. of the 1994 International Linac Conference (Tsukuba, Japan), Tsukuba, KEK, 1994, Vol.1, p.360.