DEVELOPMENT OF NANOSECOND PULSED GENERATORS FOR LINEAR INDUCTION ACCELERATORS AT JINR

G.V. Dolbilov, A.A. Fateev, V.A. Petrov, A.I. Sidorov,
Joint Institute for Nuclear Research, 141980 Dubna, Moscow Region, Russian Federation

Abstract

The paper presents a review of nanosecond accelerating voltage schemes for LIA developed at the JINR. The main feature of our approach consists in the use of powerful, relatively low-voltage generators ($V \sim 20-50$ kV) and low-resistance load ($R \sim 0.5\ \Omega$). 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.

Introduction

The powerful nanosecond drive pulse sources for linear induction accelerators (LIA) have been developed at JINR for more than two decades. Till the present moment this research has been performed in the frame of collective method of acceleration. Nowadays the LIA technology is developed intensively for such applications as microwave electronics, FEL physics and two-beam acceleration.

The LIA put forward the following requirements to the driving pulse generators: high pulse power, high repetition rate, high accuracy of pulse synchronization (1-5 ns), short rise and fall time of pulses.

As a rule, it is not possible to meet all these requirements using one commutator while constructing the accelerator with the energy about of 1 MeV and there rises the problem to synchronize a large number of commutators.

SILUND

A one-step modulator scheme was used in the first nanosecond LIA at JINR – SILUND [1]. It consisted of an energy storage, switch and forming stage where for the first time in the accelerating technique the nonlinear ferromagnetic lines were used.

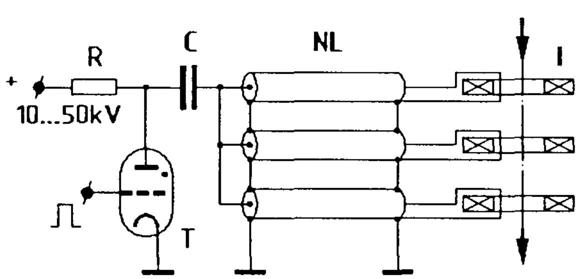

Fig. 1: Scheme of the SILUND modulator.

The modulator scheme is shown in Fig.1. The initial pulse with the rise time ~ 100 ns is formed at the discharge of the capacity C through thyratron T and is driven into the inputs of three coaxial nonlinear lines NL filled with ferrite and liquid dielectric. The shock electromagnetic wave with nanosecond rise time (~ 3 ns) is created and forms the output pulse front. The pulse fall time at the loading is formed due to the saturation of the inductor core I. The pulse power at the inductor input can exceed the power commutated by the thyratron at certain conditions but the amplification coefficient is not more than 2 [2]. The scheme is simple and reliable but possesses two significant disadvantages. First, it provides relatively low efficiency. Second, due to the limited power of the thyratrons, it uses a large number of thyrathrons and the problem of their synchronization is arisen. For instance, the modulator of the SILUND accelerator (E = 1.7 MeV, I = 700 A) uses 30 thyratrons.

SILUND-20

One of the possible ways to increase the efficiency of the generators with the thyratron commutators is the usage of the compression power scheme on the basis of the nonlinear ferromagnetic elements – magnetic pulse compression devices.

For the first time the compression schemes were used in the modulators of the SILUND-II accelerator which was the prototype of the SILUND-20 accelerator.

In the magnetic generators the initial pulse of a rather long duration is transformed into a shorter one but with the higher power. Pulse compressors are especially effective in the nanosecond duration.

One of the peculiarities of these devices which makes their usage in LIA complicated, is a considerable delay between the commutator switching and input pulse. This delay substantially depends on the charge voltage and initial magnetization of ferromagnetic. Thus, at the development and construction of such devices it is necessary to solve the problem of high repetition of the initial magnetization of the nonlinear cores from cycle to cycle and stabilization of the charge voltage with high precision.

Besides, a serious problem is to form square pulses in the nanosecond range without considerable energy losses of the pulse. These problems were solved during construction of the SILUND-20 accelerator [4].

The scheme of the SILUND-20 modulator is presented in Fig.2. The initial pulse is compressed in the traditional

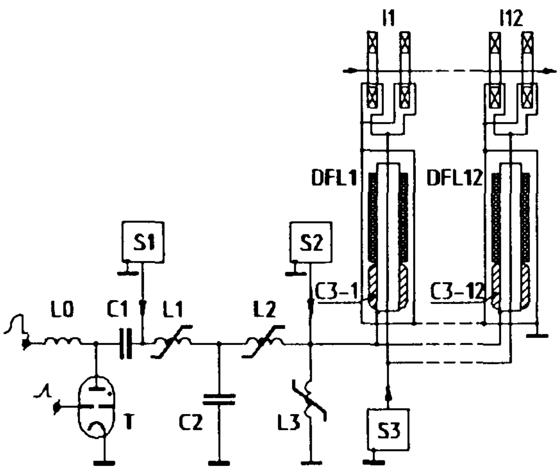

Fig. 2: Scheme the SILUND-20 modulator.

stage and then charges the forming stage consisting of nonlinear double forming lines ($DFL1 - DFL12$) with the additional correcting capacities $C3$-1 - $C3$-12. During this process the reactor $L3$ is not saturated and the passed current in it is considerably less than the charge current. DFL consists of two coaxial lines and external line is partially filled with ferrite rings. The rest volume of DFL is filled with glycerine. With respect to the charge current the ferrite is saturated and the efficiency of the energy transfer is about of 0.9.

When the voltage amplitude in the DFL reaches its maximum, the reactor $L3$ 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.

The initial magnetization of the ferromagnetic materials in the nonlinear elements is adjusted by three ambipolar current sources ($S1 - S3$). This technique provides a high precision of the initial magnetization value. Together with the high precision ($\sim$ 0.04 %) of the initial voltage supply, this dejittering technique provides the output pulse time instability not more than 1 ns.

The modulator design is presented in Fig.3 and its parameters are presented in Table 1.

TABLE 1
Modulators of the JINR accelerators

Accelerator	Years of design	P GW	U kV	ρ Ω	τ ns	f Hz	ref.
SILUND	1971-73	0.1	20	3.5	20	1	[1]
SILUND-II	1977-78	0.6	17	0.5	30	50	[3]
		1.2	17	0.25	30	50	[6]
SILUND-20	1981-82	0.6	17	0.5	30	50	[4]
SILUND-10	1979-80	2.2	40	0.7	20	1	
LUEK-20	1985-86	5	50	0.5	80	20	[5]

P - output power, U - output voltage,
ρ - output impedance, τ - pulse duration,
f - repetition rate

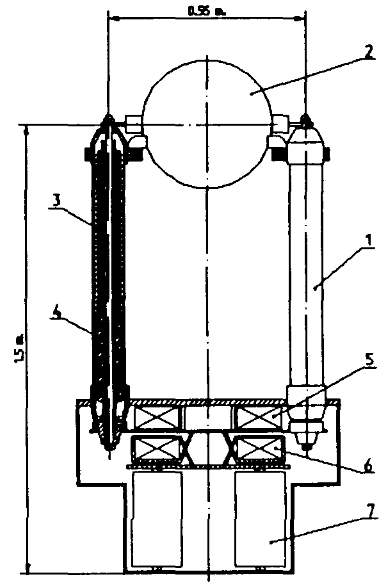

Fig. 3: The SILUND-20 modulator design. (1) - DFL, (2) - induction section, (3) - ferrite rings, (4) - correcting capacity, (5) and (6) - reactors (L_3 and L_2 in Fig.2), (7) - capacitor bank (C_2 in Fig.2).

SILUND-10

Some novel ideas on powerful nanosecond modulators have been realized during the design and construction of the SILUND-10 high current accelerator. To increase the intensity of accelerating beams and, correspondingly, the pulse power, it is necessary to increase considerably the volume of ferromagnetic material per the unit of the accelerator length. Here the stray inductances of all the elements and couplings have to be minimized.

These problems have been solved in SILUND-10 accelerator by means of the short-grounded nonlinear coaxial ferromagnetic lines as switches (see Fig.4). The lines are connected seriesly in the prior stage (L in Fig.4) and in parallel – in the forming stage.

The forming stage consists of DFL (pulse forming lines 1 and 2) switched by the short-grounded nonlinear pulse forming lines ($NPFL$1-5). If nonlinear lines are saturated, the both parts of the DFL become to be matched as in the wave resistance as in the electrical length.

The setup was manufactured as one modulator with the induction block consisting of 6 inductors. Each inductor is driven by two DFL. The total accelerating voltage U = 250 kV was obtained at the 8000 kA equivalent load. The design of the high current accelerating modulus is presented in Fig.5.

LUEK-20

The modulator with a longer output pulse duration has been constructed for the LUEK-20 accelerator designed for

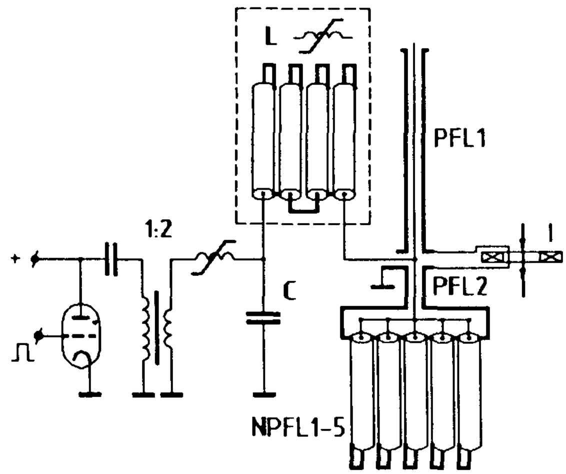

Fig. 4: Scheme of the SILUND-10 modulator.

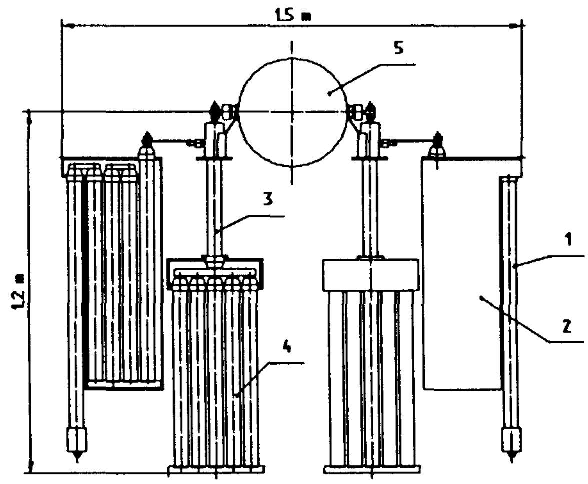

Fig. 5: The design of the SILUND-10 accelerator module, (1) - storage capacitor (C in Fig.4), (2) - block of reactors (L in Fig.4), (3) - DFL, (4) - NPFL, (5) - induction block.

the electron-ion rings acceleration [5]. The scheme of the modulator is shown in Fig.6. A hydrogen thyratron T with a grounded grid was used as a switch in the initial stage (1). It allows to increase the discharge current value by several times without substantial reduction of the resource of operation. The second stage (2) is designed as a traditional compression circuit.

The next stage consists of 6 identical blocks (3) connected in parallel. Rectified water is used as a dielectric in the intermediate charge storage SL (storage line) and in the pulse forming line PFL. The SL and PFL are fabricated as strip lines.

Each block is connected by 9 (only one is shown in Fig.6) nonlinear pulse forming lines (4) with the common section consisting of 36 permalloy inductors (5). If the nonlinear lines are saturated, their total wave resistance is equal to that of the PFL. The modulator parameters are presented in Table 1.

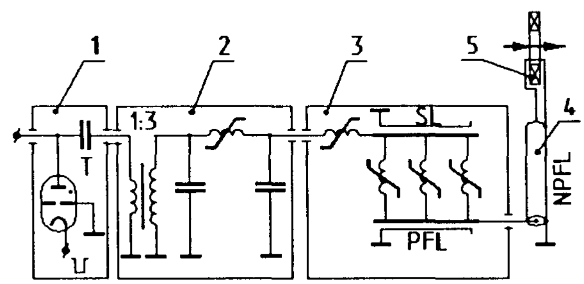

Fig. 6: Scheme the LUEK-20 modulator.

Conclusion

While constructing the nanosecond LIA at JINR, the concept of pulse forming systems has been developed. Hydrogen thyratrons with high stability of parameters in time, reliability and precision of synchronization ~ 1 ns, are used as a commutators. After that traditional compression stages are performed. Short voltage swings are produced by means of nonlinear ferrite lines. The voltage value of driving pulses is close to the initial storage voltage, usually equal to 20-50 kV. As a result, the output impedance of the modulator is comparatively low. This is achieved by a lot of final circuits connected in parallel. This concept of nanosecond modulators for LIA has proved to be fruitful and has been realized in modulators of the SILUND, SILUND-II, SILUND-20, SILUND-10 and LUEK-20 accelerators.

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