# PROJECT OF SILUND-21 LINEAR INDUCTION ACCELERATOR FOR GENERATION OF CLIC DRIVING BEAM

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## Abstract

One of the possible ways to solve the problem of the driving beam for the CLIC linear collider project is application of FEL bunching technique which requires development of high-current and high repetition rate linear induction accelerators (LIA).

In the present paper we report on status of the project of SILUND-21 LIA which is under development at JINR. SILUND-21 will serve as a base of experimental facility to study microwave electronics, FEL technique and two-beam acceleration. It is assumed also to perform experiments to adopt the FEL bunching technique for generation of the CLIC driving beam. SILUND-21 will provide electron beams with the energy up to 10 MeV, peak current ~ 1 kA and pulse duration 50 – 70 ns. The present project assumes to use the equipment developed at the JINR during construction of the heavy-ion collective accelerator KUTI-20 which will allow one to realize this project rather quickly.

## Introduction

A study of the technical feasibility of building a 500 GeV to 2 TeV linear electron positron collider is underway at CERN. The CERN Linear Collider, CLIC, uses classical copper travelling wave accelerating sections operating at 30 GHz frequency with an accelerating gradient of 80 MV/m. 30 GHz RF power is generated in special low impedance transfer structures by a driving beam travelling parallel to the main beam but with a lower energy – about 3 GeV – a higher current and bunched with an 1 cm spacing [1]. The CLIC driving beam pulse is arranged in four trains spaced by 2.84 ns. Each train consists of 43 bunches spaced by 1 cm. The bunch length should be $\sigma_z \lesssim 0.1$ mm to ensure efficient energy transfer. The total charge per drive pass is 7 $\mu$C and this will be repeated at 1.7 kHz [2].

One of the possible ways to generate the CLIC drive beam is the application of a free electron laser (FEL) technique [2, 3]. In this case the driving beam is produced in an FEL amplifier constructed on the base of linear induction accelerator (LIA). One of the main problems to realize such a way of the driving beam generation is that of LIA. To achieve the required parameters, LIA should provide electron beam with the energy about of 10 MeV and peak current about of 1 – 2 kA at a high repetition rate.

The SILUND-21 linear induction accelerator will serve as a base of experimental facility to study microwave electronics, FEL technique and two-beam acceleration. It is assumed also to perform experiments to adopt the FEL bunching technique for generation of the CLIC driving beam and to study the problems of the beam bunching preservation at further acceleration of the driving beam.

Linear induction accelerator SILUND-21 is constructed using the equipment of LUEK-20 accelerator developed for experimental investigations of the collective method of acceleration [4]. It is assumed to upgrade the main pieces of the LUEK-20 equipment using the experience of construction and operation of SILUND, SILUND-II, SILUND-20 and LUEK-20 linear induction accelerators developed at JINR [4] - [8].

## Accelerator design

SILUND-21 accelerator consists of seven accelerating modules. Each module provides 1.5 MV accelerating voltage at 1 kA beam load. The general layout of the accelerating module is presented in Fig.1.

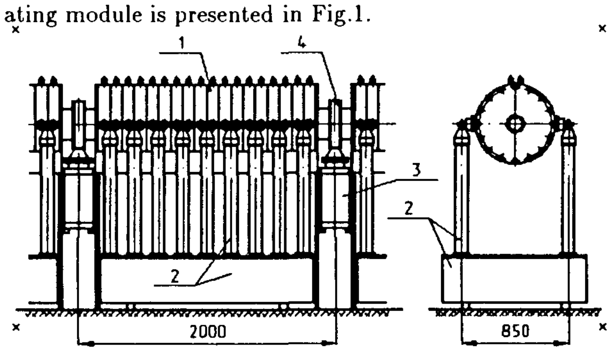


Fig. 1: Accelerating module

Induction section (1) consists of 36 permalloy cores. The core exciting windings are commutated in parallel and the input impedance of the section is equal to 0.5 Ω at nominal beam load. Pulses of accelerating voltage with 42 kV amplitude and 50 – 70 ns duration 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 nonlinear power compression schemes are used to increase the peak power.

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.

### Induction section

Design of SILUND-21 inductors is similar to that of the SILUND-20 inductors [9, 10] (see Fig.2).

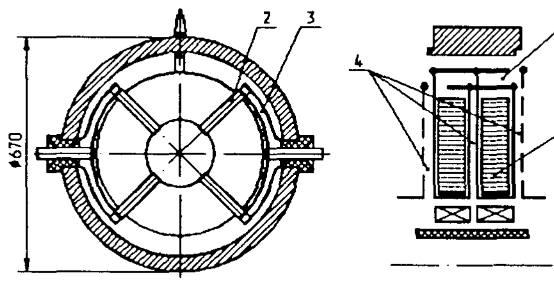


Fig. 2: Inductor scheme

Inductor consists of two permalloy cores (1) excited by four windings (2). The feed of the pulsed power to the windings is provided by strip supply lines (3). The wave impedance of each strip supply line is equal to 40 Ω. The wave impedance of strip lines (4), located between the cores, is equal to the impedance of the electron beam.

The voltage of six lines (4), commutated in a consecutive order, is fed to the accelerating gap (2) which is formed by cone diaphragm (1) (see Fig.3). The amplitude of accelerating voltage at each of six accelerating gaps of the accelerating section is equal to 250 kV.

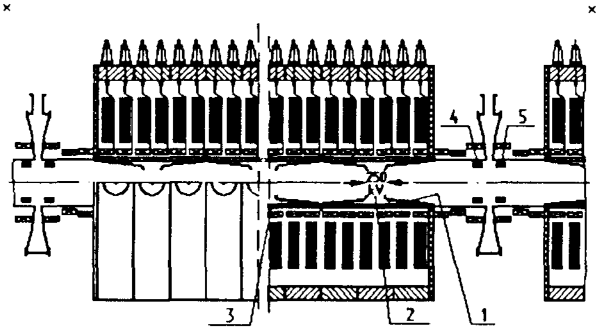


Fig. 3: Accelerating section

Focusing of the electron beam is provided by guiding field of solenoid. The solenoid winding is sectional and the number of the sections is equal to the number of permalloy cores. Parameters of the solenoid power supply, developed for accelerator LUEK-20, allow one to provide the guiding magnetic field with the amplitude up to 1.4 T and pulse duration about of 0.8 ms.

The beam diagnostics is performed by Rogowsky coil (4) and beam position monitor (5).

In conclusion of this section we should stress one problem. In our accelerator, ceramic tube (3) plays a role of the vacuum chamber. Theoretical calculations and experimental research at present accelerators have shown that intensive electron beam can excite microwave field in this dielectric waveguide. Under certain conditions, when the phase velocity of the excited waves is close to the velocity of electrons, instabilities of the electron beam may take place. With respect to this effect, cone diaphragms (1) fulfil the role of screens reducing the intensity of interaction between the electron beam and dielectric waveguide. One more problem may be connected with the accelerating gap (2) because it forms a cavity. The interaction of the electron beam with such a cavity may lead to some unwilling effects. At the design stage of the project it is assumed to study resonance properties of the accelerating gap and find out the ways to suppress the dangerous modes of oscillations.

### Injection module

The first accelerating module differs from all the other modules and is combined with the electron source. Accelerating voltage of the electron source is equal to 500 kV - 1/3 of the total accelerating voltage of the module (see Fig.4)

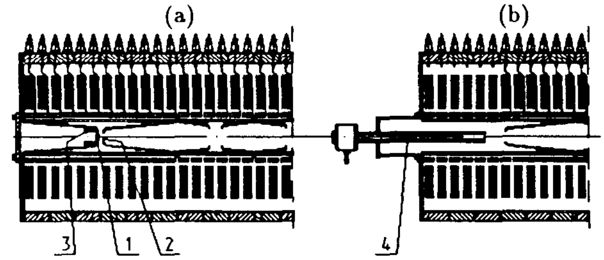


Fig. 4: Injection section

The choice of he electron source type depends on the mode of the accelerator operation. Our experience of work at the present accelerators has shown that at a low repetition rate (about of several cycles per second) it is more preferable to use the electron gun with graphite cathode (1) and gridded anode (2) [11](see Fig.4a). The value of magnetic field at the cathode is controlled by magnetic lens (3) to minimize the value of the electron beam emittance. At a high repetition rate (about of 50 cycles per second), we assume to use a plasma electron source without anode grid (see Fig.4b) [12, 13]. Ceramic tube (4) is destined to inject the plasma into the diode gap.

The both types of electron sources have demonstrated a high level of reliability and good output parameters during their operation at the accelerators SILUND, SILUND-II and SILUND-20.

### Modulator

The scheme of the modulator is close to that of the SILUND-20 accelerator [14]. More than ten years of successful operation of the latter accelerator have proved the validity of technical solutions for the modulator whose peculiar features have a high level of reliability and high quality of output characteristics. The modulator scheme is based on the application of the nonlinear power compression technique.

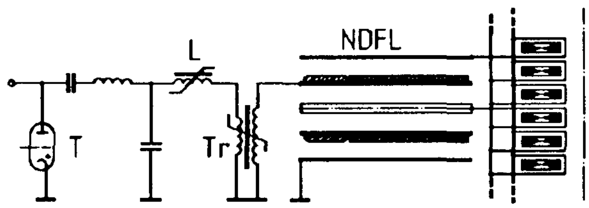


Fig. 5: Modulator scheme

Its key element is nonlinear double forming line (NDFL) which consists of 18 double forming lines evenly spaced along the accelerating module. Hydrogen thyratron T operates in a pulsed mode with 3 $\mu$s pulse duration and provides the following parameters: $U = 30$ kV and $I = 10$ kA. Permalloy reactor $L$ and transformer $Tr$ fulfil the roles of ferromagnetic switches. Transformer $Tr$ is composed of three transformers with the transfer factor equal to 2/3 which are placed along the accelerating module. NDFL is charged within the time period 1 $\mu$s and then produces high-voltage pulse ($U = 42$ kV, $I = 84$ kA, pulse duration 50 – 70 ns, rise time about of 5 ns).

## Electron beam parameters

SILUND-21 will provide the electron beam with the following parameters: energy about of 10 MeV, peak current $\sim 1$ kA and pulse duration $\sim 50 - 70$ ns. Instant energy spread of electrons in the beam will be about of a fraction of per cent and the energy spread averaged over pulse duration will be $\sim 2 - 3$ %.

As a rule, the normalized emittance of the intensive electron beam is growing during acceleration process due to the nonlinearities of focusing field and strong space charge fields. The experience of work at our linear induction accelerators has shown that the emittance growth rate is saturated at the electron beam energy about of 2 – 3 MeV. If such a tendency takes place at higher energies, at the accelerator exit we may expect to obtain the values of the normalized emittance to be equal to $0.4\pi$ cm·rad, $0.15\pi$cm·rad and $0.1\pi$ cm·rad at 90 %, 70 % and 50 % of the nominal value of the beam current.

## Present status

We have seven accelerating modules today. Three of them are mounted in the site of the SILUND-21 accelerator and we plan to obtain the beam with the project parameters ($I \sim 1$ kA, $E \sim 3 - 4.5$ MeV) at the beginning of the next year.

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