STATUS OF THE TEST FACILITY FOR STUDIES FEL BUNCHING TECHNIQUE FOR CLIC DRIVING BEAM

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Abstract

SILUND-21 linear induction accelerator (energy up to 10 MeV, peak current about of 1 kA, pulse duration 50 – 70 ns) is constructed at JINR in the framework of experimental program to study free electron laser physics, a problem of two-beam acceleration and microwave electronics. In this paper we present project of an experiment to adopt the FEL bunching technique for generation of the CLIC driving beam.

1 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 22 bunches spaced by 1 cm. The bunch length should be $\sigma_z \lesssim 0.6$ mm to ensure efficient energy transfer. The total charge per drive pass is 2.6 μC and this will be repeated at 2.5 kHz [2, 3].

One of the possible ways to generate the CLIC drive beam is the application of a free electron laser (FEL) technique [4, 5]. 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 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 [6, 7]. 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 [8].

2 LINEAR INDUCTION ACCELERATOR SILUND-21

The accelerator consists of seven accelerating modules (see Fig.1). Each module is 1.8 m long and provides 1.5 MeV accelerating voltage at 1 kA beam load. 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. The modulator scheme is based on the application of the nonlinear power compression technique [11]. It is charged within the time period 1 μs and produces high-voltage pulse (U = 42 kV, I = 84 kA, pulse duration 50 – 70 ns, rise time about of 5 ns).

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.

Focusing of the electron beam is provided by guiding field of solenoid. 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.

The first accelerating module is combined with the electron source. The electron gun with graphite cathode and gridded anode will be used at the low repetition rate (∼ 1 cycle per second) and a plasma electron source without anode grid – at the high repetition rate (∼ 50 cycles per second) [9, 10].

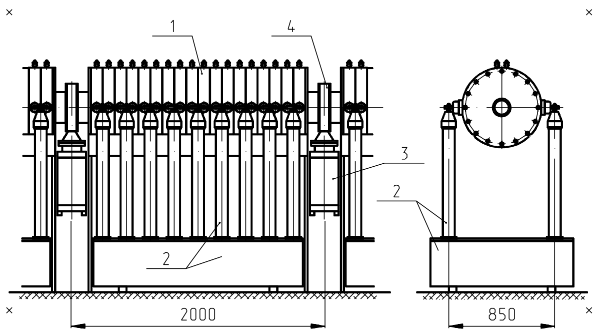

Figure 1: Accelerating module.

3 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 %. We expect to obtain the values of the normalized emittance to be equal to 0.4π cm·rad, 0.15πcm·rad and 0.1π cm·rad at 90 %, 70 % and 50 % of the nominal value of the beam current [7].

4 FEL AMPLIFIER

We assume to construct the FEL amplifier with the circular waveguide, helical undulator and axial guide magnetic field.

4.1 Magnetic system

Magnetic system of the FEL amplifier consists of the helical undulator with the period $\lambda_{\mathrm{w}} = 12$ cm placed inside the solenoid. The windings of the undulator and solenoid are powered by the pulsed supplies and provide the peak undulator field H_{w} up to 0.4 T and the axial guide magnetic field $\mid H_{\mathrm{z}} \mid$ up to 1 T. To match the beam to the constrained undulator trajectory, the undulator field is increased smoothly over the first six periods. The possibility of the undulator field tapering for the FEL efficiency increase is put in the undulator construction, too.

4.2 Microwave system

TE_{01} wave from the pulsed magnetron ($f = 35$ GHz, $P = 50$ kW) is transformed to TE_{11} linearly polarized wave and is fed to the stainless steel circular waveguide ($R = 1.45$ cm) with the tungsten mesh which is transparent for the electron beam. At nominal parameters of the FEL amplifier the radiation mode of the amplifier is close (with the accuracy better than 1 %) to the clockwise rotating TE_{11} mode of the passive waveguide.

5 CLIC TRANSFER STRUCTURE

To perform demonstration experiment on generation of RF power, CLIC transfer structure operating at a frequency 35 GHz is under construction at CERN.

6 FEL OPERATION

We assume to begin experiments with 3 MeV and 500 A electron beam. The FEL amplifier with a helical undulator and axial guide magnetic field is a somewhat complicated system with respect to the variety of the possible instabilities which could take place in this system. First, we should detune far enough from the resonances (cyclotron, anticyclotron, etc) connected with the resonance influence of the axial guide magnetic field on the transverse electron motion. As the anticyclotron resonance is not so powerful

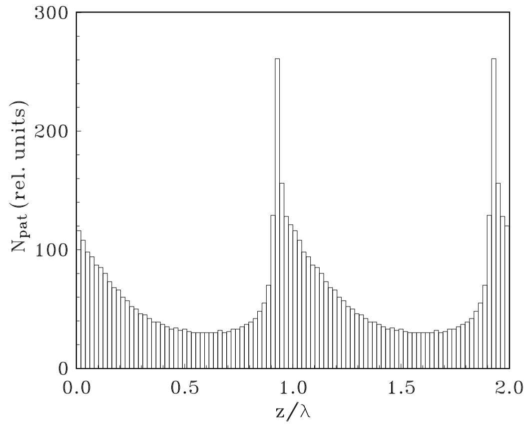

Figure 2: Histogram of the FEL bunching at saturation (regime with positive longitudinal mass parameter).

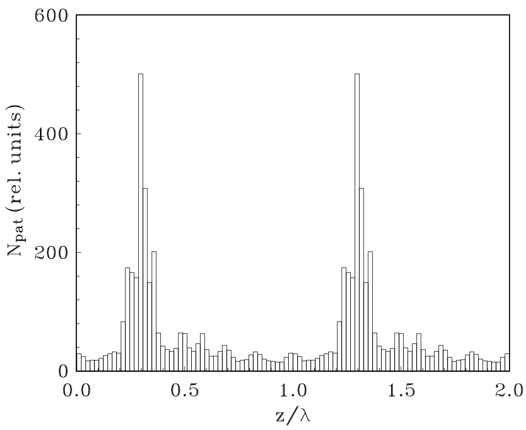

Figure 3: Histogram of the FEL bunching at saturation (regime with negative longitudinal mass parameter).

as the cyclotron one, for the first run of experiments we assume to choose the working point with the reversed axial guide magnetic field, when the direction of the cyclotron rotation is opposite to the undulator helicity.

The goal of experiments is to verify an idea to obtain CLIC driving beam using FEL technique. In Fig.2 we present histogram of electron bunching at $z = 120$ cm. During the first run of experiments we plan to measure the beam bunching in the undulator by means of the streak camera technique.

The main problem to be solved during the second run of experiments is to study the ways of preserving the beam bunching in the transition space between FEL amplifier and the CLIC transfer structure. Final step of this run is to measure RF power generated by bunched beam in the transfer structure.

When considering the further development of investigations, we should remember the final goal, namely generating of the CLIC driving beam with design parameters [2, 3]. This requires beam current of the order of 1 kA. At the current increase, the space charge forces are increasing, too.

As a result, to achieve the required bunching, the energy of the accelerator should be as large as several tens of MeV and all the facility seems to be bulky and expensive [5]. Here it is relevant to mention that the use of the FEL amplifier with helical undulator and guiding magnetic field provides a possibility to operate in the regime with negative dispersion of longitudinal velocity on the energy deviation $dv_z/d\mathcal{E} < 0$ (the regime with "negative" mass of longitudinal motion). This regime could be realized when direction of cyclotron rotation of electron in the guiding field coincides with the helicity of the undulator [12]. In this case, in the presence of strong space charge field, the "negative mass" instability influences very strong on the FEL amplifier operation at the nonlinear stage, helping the bunching of the beam and keeping the beam in the bunched state [13].

In Fig.3 we present histogram of electron bunching at $z = 85$ cm when FEL amplifier operates in a regime with "negative mass" of longitudinal motion. Comparison with Fig.2 shows that the use of the regime with the "negative mass" seems to be more preferable with respect to the FEL bunching. Simulations shows that at the increase of the beam current the bunching is increasing, too.

There could be another positive side of the FEL operation in this regime. We should remember that for the purpose of the beam bunching the FEL radiation is of no use. On the other hand, at a project parameters of the FEL buncher radiation power achieves multi-megawatt level and its handling and utilizing could be a problem. The operation with the "negative mass" reveals a possibility to overcome this problem. Here we should remember that the FEL interaction is a resonant one while "negative mass" instability has Coulomb nature and is extremely broadband [12]. So, operation of the FEL buncher could be organized as follows. At the initial stage of the undulator we organize FEL synchronism of the beam with the radiation which provides the modulation of the beam density with the wavelength of the radiation. When modulation achieves sufficient value, we detune the FEL off the synchronism, so in the rest of the undulator the beam modulation will be enhanced only due to the "negative mass" instability without amplification of radiation. As a result, a high value of the beam bunching could be achieved while the value of the radiation power will be very small with respect to the buncher operating with the FEL mechanism.

In conclusion we should emphasize that despite FEL technique provides a possibility to achieve the required value of the beam bunching, the problem of its preserving during acceleration requires a more detailed investigation.

7 PRESENT STATUS

We have seven accelerating modules today. Three of them are mounted in the site of the SILUND-21 accelerator. At the exit of the second section we obtained the electron beam with the energy of 2.5 MeV and current of 850 A. After measuring the beam parameters we plan to perform FEL amplifier experiments with the short (1.5 m) undulator to study the beam dynamics in the undulator. We also study the ways to solve the problem of the frequency and phase stability of the input radiation and the ways to preserve the beam bunching in the transition space between the FEL and transfer structure.

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