HIGH BRIGHTNESS ELECTRON LINAC WITH RF GUN AND ACCELERATING STRUCTURE ON BACKWARD WAVE

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1 INTRODUCTION

LIC (Laser Injector Complex) facility was developed and constructed in view of shaping and acceleration of high - brightness electron beams. This R&D was to be followed by beam research in the following arias:

- ultra short wave generation;
- wake-field generation in plasmas and other systems;
- relativistic electron beam focusing in plasmas;
- testing of the diagnostic equipment developed within the framework of the VLEPP program.

The electron energy at the accelerator output was to be 15 to 20 MeV which is sufficient to carry out the above programs. One of the major factors taken into account during development of the facility was limitation of the RF - power (20 - 25 MW) obtainable using the available klystron KIU-12. For creation of the multipurpose applications facility it was necessary to solve the following problems:

- the injector choice and development in order to form intense electron beams with a small emittance and a broad variation of pulse width;
- development of an accelerating section allowing to efficiently accelerate intense beams both in the steady-state regime and in the stored energy one;
- design of the accelerated beam diagnostic facility;
- design of the technological support and other control facilities.

LIC accelerator complex was commissioned during 2 years (1991 - 1992). In 1994, the facility was shut down in order to reconstruct the injector and assemble experimental devices in the area of plasma physics. The work was renewed in 1995. This paper described LIC facility, as well as results of beam performance obtained during testes held in other locations.

2 ACCELERATOR DESCRIPTION

LIC layout is given in Fig. 1. Its basic components are an RF-gun, the accelerating section, beam steering and its focusing elements, beam diagnostics, cooling water system and control elements. The RF system includes a klystron with the maximum power operation up to 25 MW, a set of waveguides, controllable phase shifter and attenuator.

2.1 The injector system

It is well known that RF-gun is a injector element, which allows to create a multipurpose accelerator facility with a high-brightness beam. It is this version that has been chosen by us while designing LIC accelerator.

Developed in 1991, the injector system comprises an RF-gun, focusing elements, beam steering elements and a laser-driver. The latter is a Nd:YAG laser, with a double-pass amplifier and a frequency-converter providing for operation at the 2-nd; 3-d and 4-th harmonics of the fundamental frequency (λ =1064 nm). The pulse energy at 7 ns duration is respectively equal to 60, 10 and 6 mJ. The driver-laser is equipped with a focusing and remote-control systems.

The RF-gun, consisting of a single cavity $E_{_{010}}$ resonator, was, basically, designed for operation in the nano-second current pulse regime within VLEPP program. In the meantime, the gun allowed operation with thermionic-emission cathodes and to perform studies at pulse duration of several microseconds. The gun resonator was equipped with channel to transport laser irradiation on to the cathode and frequency tuner. As photo-cathode, we used our tested BaNi pressed oxide [1], whose diameter was substantially lager, 14 mm.

The gun experimental studies were done at the special stand. The cathode irradiated at λ =355 nm (pulse energy in 7 ns being 5 mJ) produced current of 11 A at the gun exit. Gun testing shoved that BaNi cathode with a larger area decreases electric reliability of the cavity. Besides, a decrease in the loaded cavity quality factor was 20%. All considered particle energy at the gun exit did not exceed 0.5 MeV which did not provide for the necessary capturing of electrons in the acceleration process at the accelerating structure with β =1.

Considering this circumstance and in order to widen the scientific research performed on the accelerator, its injector part was upgraded in 1994. While designing the new injector, we had in mind the basic goal set ahead during work on the accelerator: creation of a multipurpose universal facility. While doing this, we took into account the fact that the optimum conditions of electron bunch - forming in photo - emission and thermionic RF-gun are different, and to create them into one the same cavity is a very tough proposition. On the other hand, the beam characteristics are largely known to be determined by the nature of electric field distribution along the cavity axis. For this particular reason, we decided building an RF gun with an adjustable electric field distribution along the resonance system axis to allow for selection of conditions close to optimum ones while employing different cathode types.

In 1994 we have developed and tested a new RF gun allowing to conduct beam research both in microand nanosecond pulse duration ranges. The gun resonance system comprises two E_{010} mode cavities coupled through the central aperture. The operation

- reduction of amplitudes of TEM waves which are exited by high-intensity electron beam and lead to emittance enhancement or even to shortening of pulse length (BBU instability);
- the feasibility of intense electron beam acceleration with small radial dimensions and the minimum number, or even absence, of external focusing elements.

The most attractive was the accelerating structure STRAM-90 (the abbreviation standing for STRucture Accelerating Modified) developed at NSC KIPT which has been designed to accelerate intense short -pulsed



mode oscillation type is - π . During designing of the RF gun the following major tasks were put forward:

- to secure a possibility of the operation mode RF electric field distribution along the resonance system axis;
- to improve, as compared to the existing single-cavity RF gun, the energy-related and radial angular performances of the beam injected into the acceleration section, in particular, increasing particle energy no less than 700 800 keV and the normalized emittance better than 30π mm·mrad.

A detailed description of the RF gun design and simulation results are given in the papers [2,3].

2.2 The accelerating structure

Having in view the multipurposeness of the facility under development, we brought out the following major criteria which were taken into account while choosing the necessary type of the accelerating structure:

- the feasibility of acceleration of beams with high charge in the stored energy mode with the suitable energy spread at moderate values of RF-power input ($P \approx 20 \text{ MW}$);

electron beams in the stored energy mode at moderate values of RF power input values ($P \approx 15 \div 20$ MW) [4]. This structure represents a disk-loaded waveguide with the period being two times higher than that in the disk-loaded waveguide with $2\pi/3$ mode. Particle acceleration in such structure is made by the first space mode of the electromagnetic wave propagating in the opposite direction to the electron beam. Beside increasing the charge value, which can be accelerated in the stored energy mode, the STRAM-type structure has the strong RF-focusing owing to the presence of a large non-synchronous space mode [5,6].

The period increase also leads to a considerable reduction in the TEM-wave generation, since the particles are synchronous with higher space modes of these oscillations.

However, employment of such a structure in the linac under development was hampered by two factors. The first one being in the fact that due to a small shunt impedance at the first space mode there was the necessity to make use of the traveling wave resonant ring in order to increase the acceleration gradient. The second one was the structure losing its advantages during transition to the single-bunch acceleration mode [7]. We have developed a new version STRAM-91, producing

acceleration at the first space mode, but having both an increased value of shunt impedance and a low level of higher mode amplitudes irradiated by particles [7]. This was achieved by making use of unusually thick disks with large values of the coupling hole.

3 EXPERIMENTAL RESULTS

Experimental studies in the operation mode of forming and acceleration of single picosecond pulses require utilization of very complicated and costly laser system. Over and above, studies on wake-field generation in plasmas in 1995 called for beams of microsecond duration. In this connection, research into accelerator characteristics during the initial stage was done at a microsecond beam current pulse. With this in mind, the gun had been outfitted with a thermionic emission cathode 5 mm in diameter [2]. The RF-tuning provided for the optimum ratio of field strength in the first and second cavities in case of the thermionic emission cathode at field strength inside the cavity of 25 to 30 MV/m. The main linac parameters are listed in Table.

	Normal	Max.or	
	Operation	Design	
RF gun beam	1.4	2.0	А
intensity			
RF gun beam	0.7	1.4	MeV
energy			
Final energy	15	20	MeV
Accel. grad.	6.5	8.7	MeV/m
$\Delta E/E(\%)$	3	< 8	FWHM
Rep. rate	16.25	6.25	Hz
Pulse length	0.31.5	2.5	μs
Beam intens.	1.0	1.3	А
1-σ norm. emit	14	< 20	π mm-
			mrad

Three gradients method was used to measure beam emittance. From three measurements it follows that in the vertical plane the integral (during the entire pulse) FWHM normalized emittance was $26 \pi \cdot \text{mm} \cdot \text{mrad}$. During emittance measurements over the temporal point corresponding to the current maximum (~1 µs after the beginning of the pulse) this value did not exceed $16 \pi \cdot \text{mm} \cdot \text{mrad}$. At a distance of 0.5 m from the accelerator exit the rms beam size was 0.8 mm. The experiments indicated a dependence of beam dimensions on the beam injection phase into the accelerating section (RF focusing with accelerating wave).

During the tests after upgrading the beam characteristics were also studded in the photo-emission operation mode. At the first stage, BaNi cathode was used as a photocathode at such a temperature that practically excluded operation in the thermionic emission mode. During cathode irradiation at the wavelength 355 nm the gun produced pulsed current 2 - 2.5 A, with the pulse width 6 - 7 ns. At the accelerator output the pulsed current value was 1.3 - 1.6 A. Beam current measurements were done relative to cathode temperature and field strength in the gun cavity.

4 CONCLUSIONS

Thus NSC KIPT has built and put into operation a universal accelerator facility for R&D purposes. Our simulations and experimental data allow to state that combination of an RF gun with the accelerating section operating at the 1-st spatial harmonic makes it possible to create injector accelerators with a high beam brightness. The subsequent research on particle dynamics in the accelerator should be continued in the direction of studies on the radial dynamics and clearing out the conditions to provide at the linac exit for intense beam production with the minimum emittance. Over above viewing to employ LIC as an FEL driver, we are planing to increase the current pulse duration to 8 - 10 μ s.

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