IFEL PROJECT WITH HIGH ACCELERATING GRADIENT

G.A. Baranov, M.F. Vorogushin, A.A. Kuchinski, Yu.A. Svistunov, P.V. Tomashevich
FSUE "D.V. Efremov Scientific Research Institute of Electrophysical Apparatus",
St. Petersburg, Russia
A.A. Varfolomeev, S.V. Tolmachev, T.V. Yarovoi
RCL, Russian Research Center "Kurchatov Institute", Moscow, Russia

Abstract

Project of an IFEL experimental installation with powerful TW CO_2 laser is proposed by the Russian Research Center "Kurchatov Institute" and the D.V. Efremov Scientific Research Institute (NIIEFA) These institutes have experience in design and manufacturing of different devices having connection with IFEL, such as S-band electron linacs, a high-brightness pre-accelerated RF photo injector, powerful CO_2 lasers and high quality strong field undulators. It is supposed to achieve local gradients near 1 GV/m and average accelerating gradients up to 100 MV/m.

INTRODUCTION

Inverse Free Electron Laser schemes for particle accelerate were proposed as accelerators for many years. Now when SSC project is closed creation of the IFEL turns out especially important. This scheme is probability more perspective for reliable acceleration than Laser Wake Field Accelerator or Laser Beat Wave Accelerators. The Inverse Free Electron Laser is actually, a very efficient scheme for microbunching and phase-locking electrons at the optical scales. Up to now, only modest energy gain has been achieved mostly because of the limitations of the peak radiation power available. Most of worked out acceleration schemes are based on using powerful CO_2 lasers. Modern TW picosecond lasers can provide radiation intensity up to $10^{18}\div10^{19}$ W/cm^2 at the focus. This is correspond to electric field strength 60 GV/cm. Physical processes in the laser accelerators are complex enough and need further study. Although USSR in $60\div80^{-th}$ had leadership in theoretical investigations, now most of essential experimental works are producing in USA. Russia is evidently backward in this research sphere.

This project supposes IFEL developing with special undulator without plasma. Estimations showed that here one can obtain significant accelerating gradients of dense electron bunches in contrast to Plasma Beat Wave Accelerator. With help of proposed IFEL it can be obtained greater energies and significant greater electron capture into acceleration. Realization of the project means developing and manufacturing the following devices:

– CO_2-master oscillator of picosecond range;
– superatmospheric CO_2-amplifier with 100 cm^2 aperture;
– high-current photo-injector of 1 MeV electron energy;
– rf linac with working frequency 2856 MHz and output electron energy 15-20 MeV;
– non-adiabatic tapering of the undulator.

Up to now best result on laser acceleration had been achieved in the collaboration of the "Kurchatov Institute" and UCLA. Electron beam was accelerated by laser beam from 15 to 35 MV. Intensity of CO_2-laser beam was 400 GW. There is possibility to improve this result if CO_2-laser installation produces subpicosecond pulses with high intensity (up to 1 TW), good synchronization of laser and electron pulses will be provided and special optical channels will provide efficient transportation and focusing of laser beam used acceleration. It is supposed to create special laser driver to obtain strong focusing laser beams (Rayleigh range is a few cm) in single pulse mode and IFEL module which are fed by two laser beams of single driver.

PREACCELERATION SCHEME

The IFEL require an electron accelerator capable of delivering pulse train of electron bunches of high charge density. A high electron quality beam needed a high peak current (~100 A) and low transverse beam emittance (<10π mm·mrad).

A photoinjector is a laser-switched photoemissive source located in an rf accelerator cell. By placing the photoemitter in high-gradient rf cavity, the space-charge effects due high electron densities can be substantially reduced. A laser-switched electron source gives control over all aspects of the electron distribution: peak current, spatial and temporal distribution. This type of source has also a large flexibility in interpulse spacing; the interpulse spacing can range from picosecond pulse separation to a single pulse. Provisional acceleration's scheme, including photoinjector and linac, is given on fig. 1 (left part of drawing). Photoinjector can produce micropulse length of 2 picosecond and gun voltage of 1 MV. The alpha magnet is a momentum filter and is able to limit the electron energy spread to less than 0.5 %. Simultaneously it increases peak current up to 10 times. The electron source is LaB_6 cathode. Using of the laser allows to limit the emission to the correct rf phase. In this mode LaB_6 was operated just below its normal emission temperature, and laser is used to pulse cathode. It is possible to obtain electron beam with peak current 70-80 A and emittance about (4-5)π mm·mrad. Accelerating structure has working frequency 2856 MHz. The same frequency has gun cavity. Accelerating structure is combined and includes parts with standing wave and travelling wave. Main parameters of electron beam are given in table 1.

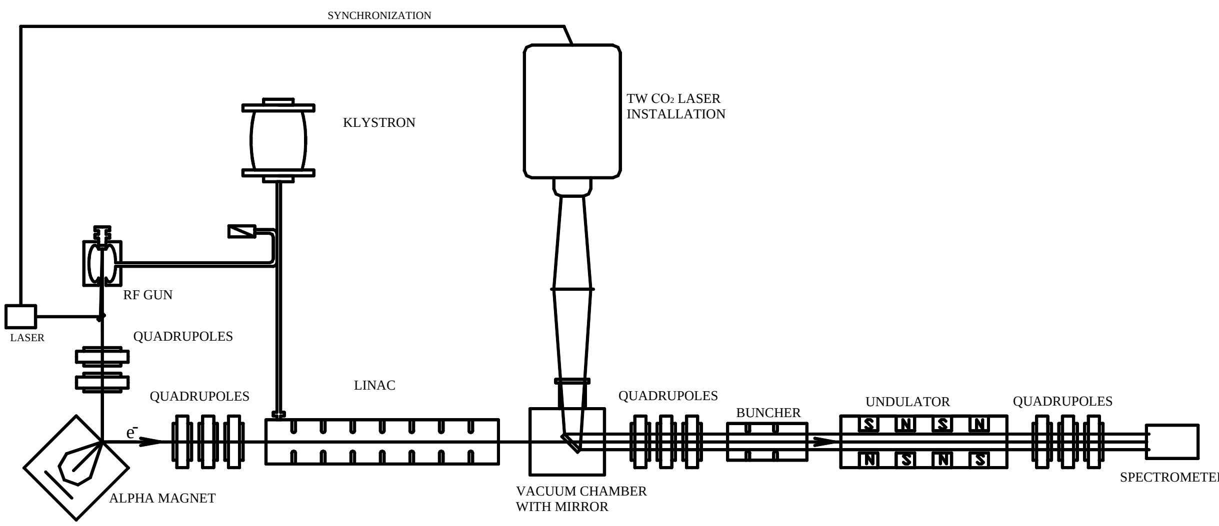

Figure 1: Schematic layout of the IFEL facility

Table 1: Main characteristics of preliminary rf acceleraton

Input beam energy, MV	1
Output beam energy, MV	15
Output bunch length, ps	> 2
Emittanc, mm·mrad	5
Electron bunch charge, nC	0.1

LASER ACCLERATOR SCHEME

Principle scheme of designed IFEL is given on fig.1. Powerful TW laser worked out in the Efremov Institute [1] must provide required electromagnetic field for accelerating of 15 MV electrons after additional bunching. At the last time in several scientific centers master oscillators of picosecond diapason with wave length near 10 μm had created (in partly at BNL in USA and Moscow State University). Because contemporary forming and compression systems of 10 μm range subnanosecond laser pulses have limitation of output generator energy about 10^{-5} J, it is appeared problem of pulsed amplification up to 10^5-10^6 times. Effective solving of this task may be prove with help large-aperture superatmospheric amplifiers only. Here main problem is to provide stable volumetric discharge of laser pumping in high pressure and big interelectrode gaps. Experimental researches fulfilled in the Efremov Institute indicate th required amplification may be obtained under following conditions:

– working mode with tightened front of voltage;
– preionization of a gas mixture (in our case CO_2:N_2:He) by soft Roentgen rays;
– using of intermediate small-inductive storage unit precisely matched with load.

At present working out of modern CO_2-amplifier is completed in the Efremov Institute. Main parameters of amplifier and IFEL's laser system are given in table 2 and table 3.

Table 2: Main parameters of amplifier

Working volume, cm^3	(5-10)x10x10
Interelectrode distance, cm^3	5-10
Pressure of gas mixture, atm	5-10
Quantity of molecular gases, %	≥ 15
Specific energy contribution, J/1·atm	≥ 100
Coefficient of small signal amplification, cm^{-1}	≥ 0.02

Table 3: Main parameters of IFEL's laser system

Laser power, TW	0.8-1
Wave length, μm	10.6
Laser waist size, μm	350
Raleigh range, cm	>3.6

Undulator of designed IFEL may be fulfilled as alog of undulator which was built by Coherent iation Laboratory of Kurchatov Institute for IFEL experiment at the Neptun Laboratory. Undulator initial period was 1.5 cm and period at exit 5 cm. It corresponds to electron output energy 55 MeV. Another option is possible when electrons are accelerated preliminary up to 20-25 MeV in rf linac. Then necessity of creation a new undulator is appeared. As accelerating structure in this case may be used the modified structure of LUER-20M linac.

CONCLUSION

Scientific Production Division of Linac and Cyclotrones and Laser Technologies Division of the Efremov Institute have significant experience on designing, manufacturing and exploitation of linacs, their injection systems, powerful lasers of different types. Specialists of RRC Kurchatov Institute have the same experience on designing, manufacturing and exploitation undulators and deep knowledge in IFEL research area. Now it is possible taking into account results of UCLA experiment to optimize laser beam parameters and obtain higher gain of electron energy than in other projects. It is clear that serious difficulties will appear during solving of synchronization problem of laser beams and electron bunches and diagnostic system creation.

REFERENCES

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[2]. A.A. Varfolomeev et al., An undulator with non-adiabatic tapering for the IFEL project. NIM, in Physics Res. A483(2002), 377-382.