PROPOSAL OF A FEL AMPLIFIER EMPLOYING THE 7 MeV IFA LINAC

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Abstract

The proposal in this paper refers to a free electron laser amplifier under transverse optical klystron regime driven by the 7 MeV linac of the Institute of Atomic Physics (IFA) in Bucharest. The undulator is made up of three identical sections and the external laser beam wavelength is \(\lambda = 10.6 \text{ \mu m}\).

I. INTRODUCTION

The research activities in Institute of Atomic Physics passed to the extension of the existing 7 MeV (ALIN) linear electron accelerator applications by its employment as a relativistic electron source for a free electron laser (FEL).

Among the problems occurred during the application one may mention: i) the modification of the accelerator operation regime for charging the micro/macro pulse duration and repetition rate; ii) transport and formation of the electron beams (current, emittance, spread energy) supplied by the accelerator to obtain parameters required by undulator; iii) the selection of FEL operation regime to get a higher gain and efficiency in the experiment by means of this accelerator.

The solutions of the above two problems are standard type solutions [1], so this paper presents solutioning only for the third problem. The solution refers to an experimental FEL facility under TOK transverse optical klystron regime for amplifying an \(\lambda = 10.6 \text{ \mu m}\) wavelength external laser radiation.

In view of the above, the paper presents some consideration which were the basis in selecting the operation regime of FEL, the constructive solution for the undulator and the design parameters resulted for the electron beam, the undulator sections, the dispersion section and the coherent electromagnetic radiation beam.

2. FEL REGIME CONSIDERATIONS

When assessing the operation regime for the ALIN TOK experiment, the idea to obtain a high gain end efficiency with the existing technologies in IFA, constituted the starting point of the project.

It is known that a relatively high gain and efficiency can be obtained by employing a tapered undulator [2], a multicomponent undulator [3], by application of longitudinal magnetic field [4], or by combining these methods [5].

Considering the low intensity of the 1 A per pulse current supplied by ALIN, we chose the operation in low gain and small signal regime in transverse optical klystron configuration [6].

Figure 1 illustrates the schematic diagram of the proposed ALIN TOK experiment. Its main components are: the existing ALIN Accelerator, a L laser with \(\lambda = 10.6 \text{ \mu m}\) wavelength and a planar undulator consisting of three identical sections marked by M and R and separated by two dispersion section (DS 1) and (DS 2).

3. CHOICE OF PARAMETERS

3.1. Undulator

The ALIN TOK project includes a uniform planar undulator consisting of three identical sections. The basic design relies on the paper [7,8]. To provide the electron beam focusing on both directions, horizontal and vertical, without destroying the resonance condition, the pole faces have the shape proposed by Scharleman [9].

As the undulator electromagnetic circuits consists of ARMCO M5X type transformer sheets, the polar faces machining is performed by a computerized machine for all the packs. Than they are chemically treated to avoid short circuiting and subsequently, the technique of forming and assembling from the magnetic poles of a cyclic induction accelerator is employed. Each undulator section is modularly structured so that, during the experiment, both the spatial wavelength and the period number of the undulator section may be modified.

The reference geometry for calculation starts from a three identical section undulator, each section having 108 mm length and the spatial wavelength \(\lambda_s = 3.6 \text{ mm}\) with a gap \(g = 2 \text{ mm}\). The magnetic field on the undulator axis is \(B_u = 0.25 \text{ T}\). Upon these data, the deflection parameter value results \(K = 93.4 \text{ B}_u \text{ (T)} \lambda_u \text{ (m)} = 0.1\).

Choosing the resonance energy \(\gamma_r = 13.1\), an energy smaller than the injection energy, the wavelength of the spontaneous radiation results \(\lambda_s = (\lambda_{inj} / 2\gamma_r) (1 + K^2/2) = 10.6 \text{ \mu m}\). Other main parameters of the undulator are listed in Table 1a.

3.2. Dispersion section

The introduction of the two dispersion section (DS 1 and DS 2) was made for two reasons. It transforms the energy modulation of the beam from the first section of
the undulator into space modulation and places the
modulation beam at the best phase position for the energy
extraction in the second and the third section of the
undulator, also called "radiator" and identified in Fig.1
by $R$.

The dispersion section design considerations in our
project are those in the papers [3,10,11].

For two electrons with energy difference $\Delta \gamma$, the
difference in the longitudinal phase change $\psi - (k_u + k_v)z - \omega t$ after a dispersion section length $L_D$, is [10] $(\Delta \psi/\Delta \gamma) = k_u (\Delta \omega/\Delta \gamma) = k_u L_D/\gamma^3$ where $\Delta z/\Delta \gamma$ is the
longitudinal dispersion of the bunching section and $\Delta \gamma/\gamma$ is
the energy spread in the beam at the end of the
undulator length $L_{\text{tot}}$. $(\Delta \gamma/\gamma) = k_u K K_u L_{\text{tot}}/\gamma^2$.

When the phase shift introduced by the dispersion
section $\Delta \psi$ is opposite to that after the first section of the
undulator $\Delta \psi = - \psi$ it results [12] that the shape of the
gain curve for $M$ undulator sections connected through $M - 1$
dispersion sections is the same as the gain curve of the
single section and is simply scaled by factor $M^2$.

The drift length necessary to achieve electron bunching
is calculated as the length that it takes particles separated in
energy by $\Delta \gamma/\gamma$ and in space by half a radiation wavelength
to come together.

This length is $L_D = \lambda \gamma^3/(2 \Delta \gamma/\gamma)$ where $(\Delta \gamma/\gamma) = \lambda/\gamma$
$(\Delta z/\Delta \gamma)$ and the longitudinal dispersion of the bunching
section made up of three uniform magnetic field modules is
given by the formula [10] $\Delta z/\Delta \gamma = L_D^3 (eB_d/m_0c)^2/48 \gamma^3$.

The dispersion sections are also modular to provide
variation of their sizes for studying the gain and efficiency
in function of the section length. The main parameters of
the dispersion sections are specified in Table 1b.

3.3 Electron beam
The relativistic electron beam supplied by ALIN is passed
trough a transport and formation system which provided the
main parameters as per Table 1c.

By the Table, one may calculate the adimensional
current density [13], $j = 8 N_d e_0 n_0 (\pi K J T)^2/\gamma^3 = 0.01$
where $(J) = J_T (\xi) + J_T (\xi) - 1$ adjust coupling for the
linearly polarized undulator, and variable $\xi$ is given by $\xi = (KJ^2) / (1 + K^2/2) = 0.00248$.

3.4 Coherent EM radiation
The EM radiation spectrum is the result of the radiation
interference produced by the three sections of the
undulator.

The maximum gain after the first section is $G_1 = 0.135 F = 0.00135$, where $F = 1$ is the filling factor
defined in [14]. The maximum energy gain for three
undulator sections is $G = M G_1 = 0.01215$ and correspond
to a stimulated 1.2 keV/electron emission.

The gain increasing and input radiation power
decreasing are made by solutioning the basic equation for
the FEL optical klystron amplifier [15].

The main calculated parameters are specified in Table
1d.

Table 1; ALIN TOK design parameters

a. Undulator

Length $L_u$  \hspace{1cm} 0.108 m
Energy acceptance $\Delta E/E$ 0.016
Normalized field $b_u$ 146 m$^{-1}$
Vector potential $A_u$ 43 kV
Transverse velocity $\beta_t$ 0.0076
Frequency $\omega_u$ 5.23 $10^{11}$ s$^{-1}$

b. Dispersion section

Length $L_d$ 0.1 m
Dispersive magnetic field $B_d$ 0.25 T
Effective drift distance $L_D$ 0.455 m
Parameter $N_d$ 123.4
Energy spread $\Delta \gamma/\gamma$ 0.002
Longitudinal dispersion $\Delta z/\Delta \gamma$ 0.0002 m
c. Electron beam

Energy electron $\gamma$ 13.21
Budker parameter $\nu$ 5.9 $10^5$
Current density $J$ 127 A. cm$^{-2}$
Beam macropulse length $\tau$ 5 $\mu$s
Micropulse repetition rate $T_m$ 2997.5 MHz
Macropulse repetition rate $T_M$ 50 Hz
Number density $n_0$ 2.65 $10^{10}$ cm$^{-3}$
Plasma frequency $\omega_p$ 9.18 $10^9$ s$^{-1}$
Strength parameter $\xi_0$ 0.00484
Betatron period $\lambda_b$ 0.100 m
Rayleigh length $Z_R$ 0.074 m
Normalized emittance $\epsilon_n$ 01 $10^6$ mrad
Self pot. energy spread $\Delta E/E_0$ 66 $10^6$
d. Coherent EM radiation

Wavelength $\lambda$ 10.6 $\mu$m
Gain $G$ 1.215 %
Efficiency $\eta$ 0.018 %
Input radiation power $P_i$ 100 kW
Peak stimulated power $\Delta P$ 1.215 KW

4. CONCLUSIONS

The paper presented the system standard parameters for the ALIN TOK project calculated without considering the inhomogeneous effects on bunching electrons in the beam.

The project component being modular it results that by their assembling in certain configurations it's possible to optimize the gain and efficiency in function of the input radiation power and the dispersion section length.

A more detailed technical report of this study including the inhomogeneous effects as well as optimized gain and efficiencies is in preparation [15].

5. REFERENCES