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 $\lambda = 10.6\ \mu m$.

1. 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 occured 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 $\lambda = 10.6\ \mu m$ 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, constitued 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 exixting ALIN Accelerator, a L laser with $\lambda = 10.6\ \mu m$ 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 relys on the paper [7,8]. To provide the electron beam focussing on both directions, horizontal and vertical, without destroying the rezonance 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 machinning is performed by a computerized machine for all the packs. Than they are chimically treated to avoid short circuiting and subsequently, the technique of forming and asambling 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 undulatior, each section having 108 mm length and the spatial wavelength $\lambda_u = 3.6$ mm with a gap g = 2 mm. The magnetic field on the undulator axis is $B_u = 0.25$ T. Upon these data, the deflection parameter value results $K = 93{,}4\ B_u (T)\ \lambda_u (m) = 0.1$.

Chosing the resonance energy $\gamma_r = 13.1$, an energy smaller than the injection energy, the wavelength of the spontanous radiation results $\lambda_r = (\lambda_u / 2\gamma_r)(1+K^2/2) = 10.6\ \mu m$. 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 transformes the energy modulation of the beam from the first section of

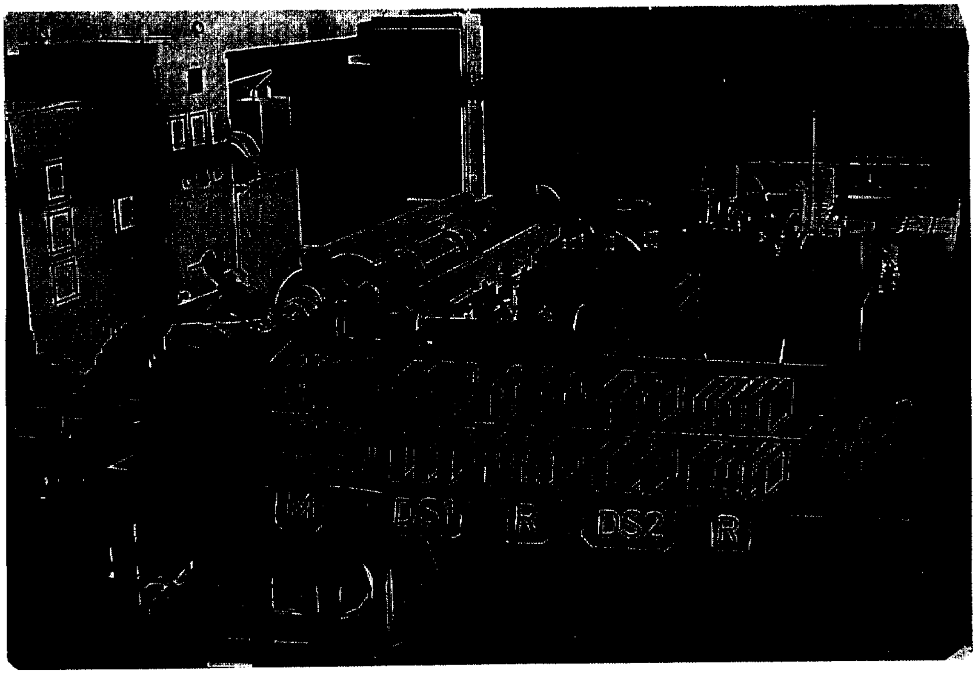

Fig. 1 Schematic Diagram of the ALIN TOK experiment

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 $\psi = (k_u + k_s)z - \omega t$ after a dispersion section length L_D, is [10] ($\Delta\psi/\Delta\gamma) = k_s\ (\Delta z/\Delta\gamma) = k_s L_D/\gamma^3$ 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_u, $(\Delta\gamma/\gamma) \sim - k_s K K_s L_u \psi/\gamma^2$.

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 achiece 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 $L_D = \lambda\gamma^2/(2\Delta\gamma/\gamma)$ 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] $\Delta z/\Delta\gamma = L^3_d(eB_d/m_0c)^2/48\gamma^3$.

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 transpott and formation system which provided the main parameters as per Table 1c.

By the Table, one may calculate the adimensional current density [13], $j = 8N_d r_0 n_0\ (\pi K(JJ)L_u)^2/\gamma^3 = 0{,}01$ where $(JJ) = J_0(\xi) - J_1(\xi) \sim 1$ adjust coupling for the linearly polarized undulator, and variable ξ is given by $\xi = (K/2)^2 / (1+K^2/2) = 0.00248$.

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 $G_1 = 0.135j\ F = 0.00135$, where $F = 1$ is the filling factor defined in [14]. The maximum energy gain for three undulator sections is $G = M^2G_1 = 0.01215$ and corespond 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	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 β_t	0.0076
Frequency ω_u	5.23 $10^{11} s^{-1}$

b. <u>Dispersion section</u>

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. <u>Electron beam</u>

Energy electron γ	13.21
Budker parameter ν	5.9 10^{-5}
Current density J	127 A. cm^2
Beam macropulse length τ	5 μs
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 ω_b	9.18 109 s^{-1}
Strength parameter ξ_0	0.00484
Betatron period λ_β	0.106 m
Rayleigh length Z_R	0.074 m
Normalized emittance ϵ_n	61 10^{-6} mrad
Self pot. energy spread $\Delta E/E_0$	66 10^{-6}

d. <u>Coherent EM radiation</u>

Wavelength λ	10.6 μm
Gain G	1.215 %
Efficiency η	0.018 %
Input radiation power P_i	100 kW
Peack stimulated power ΔP	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 elec trons in the beam.

The project component beeing modular it results that by their assambling 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 tehnical report of this study including the inhomogeneous effects as well as optimized gain and efficiences is in preparation [15].

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