Design and experiment of SG–1 FEL

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INTRODUCTION

SG-1 FEL is a raman region free electron laser amplifier, with wavelength of 8-9 mm, based on induction LINAC. The SG-1 FEL contains a 3.5 MeV accelerator, electron beam transport system, tapered electro-magnetic wiggler, microwave source and computer controlled system.

The design parameters of SG-1 FEL is as follows [1]

$E = 3\text{-}3.5$ MeV, $\Delta E/E = 3\%$, $I = 450$ A,

$\epsilon_n = 0.47\pi$ CM RAD, $\tau = 60$ ns, $B_w = 3.1$ kGs

$\lambda_w = 11$ cm, $N = 36$, $\lambda_s = 8\text{-}9$ mm

$P_{in} = 10\text{-}20$ kW, $P_{OUT} = 10^7$ W (with constant wiggler) $P_{OUT} \geq 10^8$ W (with tapered wiggler)

The layout of SG-1 FEL is illustrated in Fig. 1

DESIGN OF SG-1 FEL

The induction LINAC [2] consists of a 1 MeV injector and 8 accelerating cells, Each cell can give the electron an energy increment of 300 keV. It is well know, an electron beam must have high brightness to appropriate for FEL requirement and FEL gain is strongly dependent on quality of electron beam. So the cathode of diode is finely designed to provide electron beam with small emittance and strong current. The diode has planer configuration and its emitter is made of velvet.

For improvement the stability and reliability of accelerator, the switch system of Marx generators are carefolly adjested and the total jitter time of switchs are ≤ 5 ns. So the synchronism deviation between acc. and RF source is very small. The cross section of injector is shown in Fig. 2,

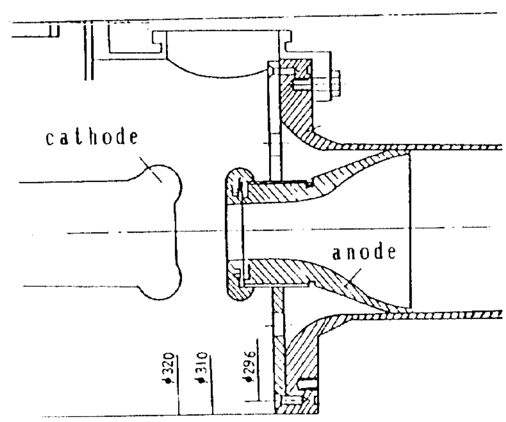
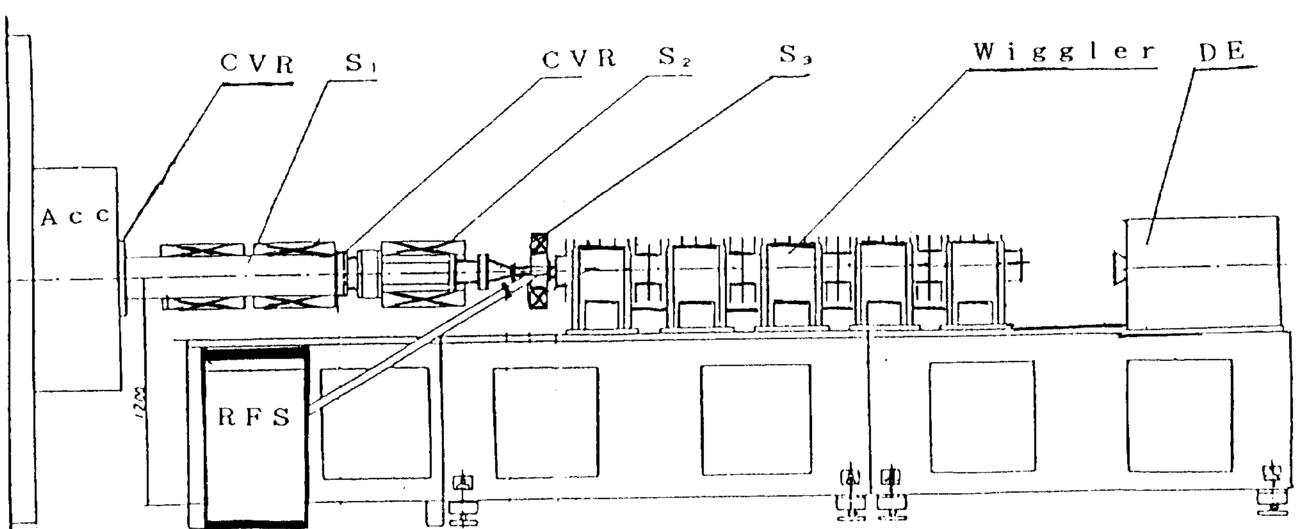


Fig. 2 The cross section of injector



S_1, S_2: Beam transport solenoid coil, RFS : Radio-Frequency Source,

S_3 : Thin focussing coil, DE : Dianostic Equipment.

Fig. 1 Layout of SG-1 FEL

In order to decrease the loss of electronbeam, the beam transport system is designed simply and shortened. It consists of two beam-transport coils and one thin focusing coil and is easy to turning its parameters. The electron beam parameters at the input of wiggler is measured as follow:

$E= 3.3\pm 1.5$ MeV, $\Delta E/E = 3$ %, $I= 600$-700 A,

$\epsilon_n=0.43\pi$cm rad $\tau = 40$ ns, $r_e= 1$ cm

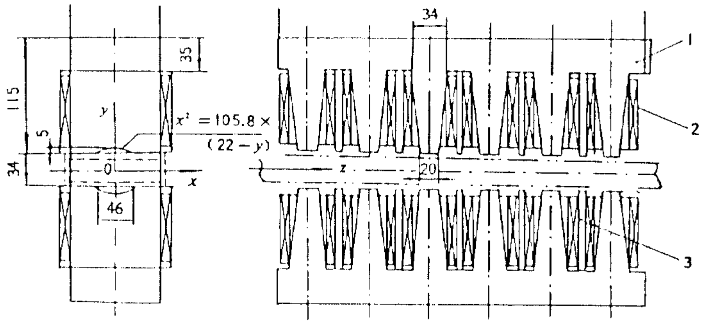
A new shield-pulse tapered electromagnet wiggler [7] with parabolic pole surface has been designed. This wiggler has some special features. It is very easy to adjust the magnetic field, it can provide horizontal focuse of electron beam and small electric power is needed. Each two periods of the wiggler magnet is energized by its own independetly controlled power supply. Thus the profile of the wiggler magnetic field along the beam axis can be tailored to almost any desired shape. The power supply is consisted by thyristors, capacitor and wiggler coils. The harf period time of the excitation current through the wiggler coils is 1ms. To ensure that the wiggler axis of the beam coincides with the mechanical axis of the wiggler, the first and second period of the wiggler is energized to ($0.3B_w$-$0.8B_w$), and the last period is energized to ($0.8B_w$-$0.3B_w$), where B_w is the peak wiggler field inside the uniform wiggler. The magnetic field of the wiggler is given by

$$\vec{B_w} = B_0 \,[\cosh k_x X \cosh k_y Y \cos k_w Z \hat{Y} + (k_x/k_y) \sinh k_x X \sinh k_y Y \cos k_w Z \hat{X} + (k_w/k_y) \cosh k_x X \sinh k_y Y \sin k_w Z \hat{Z}] \quad (1)$$

with $k_x^2 + k_y^2 = k_w^2$, k_w— wave number of wiggler.

More importantly, this field ensures that the longintudinal velocity of an electron remains constant over a betatron period. Without this property the electrons could detrap from the ponderamotive well with serious consequences for the FEL performance.

The focussing property is dependent by coefficient $\alpha = k_y/k_x$. For our case the optimum value of is (1.4-2). The shield plate is used for enchancing the field strength. It has been found that the field strength can increase by a factor of 15-20 %. The layout of the shield pulse electromagnet wiggler and its photograph are shown by Fig. 3, 4.



1. Magnetic pole, 2. Coil, 3. Shield-plate.

Fig. 3 The layout of the shield-pulse electromagnet wiggler

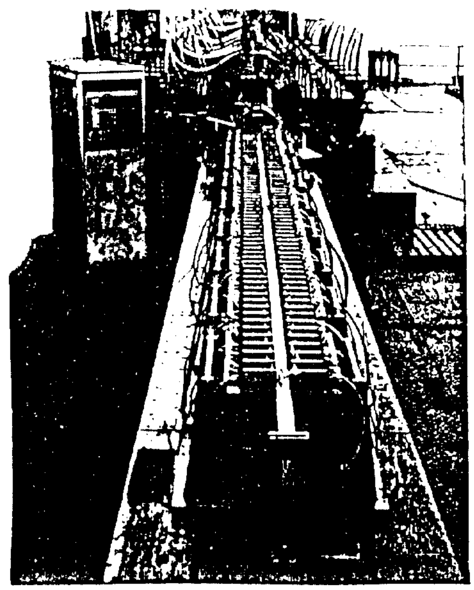


Fig. 4

NUMERICAL SIMULATION AND EXPERIMENTAL RESULTS

We have developed a 3 D numerical code (WAGFEL) incorporating standard FEL equations, modified by off axis effects in the partical dynamics and the field equations. WAGFEL can model propagation and interaction electron beam with microwave in a rectangular wavequide. In order to obtain good agreement between experimental results and numerical simulations, it is necessary to include the effect of longitudinal space-charge forces and the effect of relativistic factor of electron in the KMR equations [8]. In simulation, the wave number k_w includes the waveguide corrections for the TE_{01} mode

$$k_w^2 = w^2/c^2 - \pi^2/b^2 \quad (2)$$

where b is the waveguide width. To study the FEL dependence on wiggler length, we started with the uniform wiggler and measured the amplifier output as a function of wiggler magnetic field. The detuning curve for uniform wiggler is shown in Fig. 5

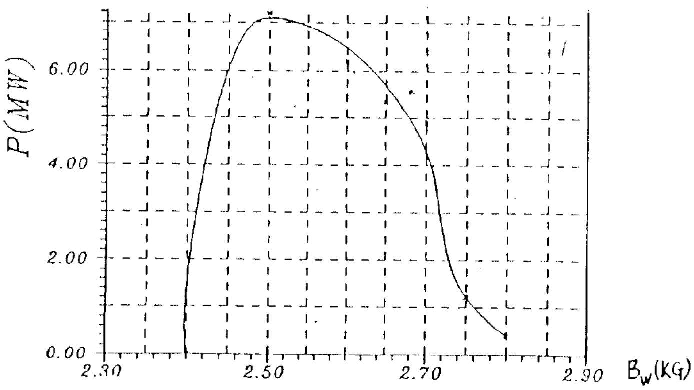


Fig. 5 Detuning curve for a uniform wiggler

Using the magnetic field corresponding to the peak at the detuning curve from experiment, we examined the FEL output power as function of wiggler length, illustrated in Fig. 6

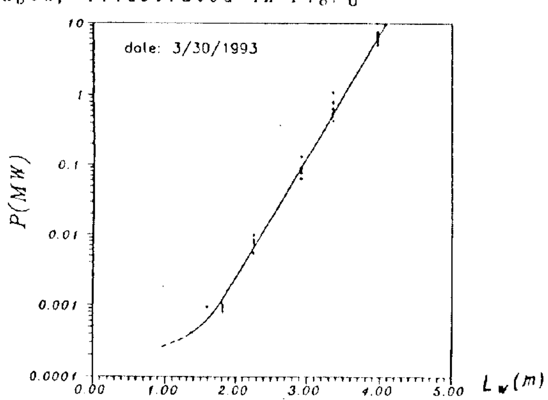


Fig. 6 Power output as a function of wiggler length

The maximum amplifier gain 20 dB/m is obtaind The output power is 10 MW, and frequence is 34 GHz at input beam E=3.1 MeV, I=600 A. But the saturation output power does not obtaind yet. At the next stege we wish to obtain saturation point and continue experiment with tapered wiggler.

SUMMARY

We have successfully designed a SG-1 FEL amplifier, that is a microwave FEL with no axial guide field and has demonstrated high gain, efficiency and output power. We also have developed a 3-D numerical code WAGFEL, which can model propagation and interaction electron beam with microwave in a rectangular waveguide In order to obtain agreement between experiment and theory we have found, it is necessary to include the effects of longitudinal space charge forces and the effect of relativistic factor of electron in the particale dynamics and field equations. The agreement between experimental results and numerical simulations is quite good. We have obtaind a detuning curve and have studied the output power of SG-1 FEL with uniform wiggler as a function of wiggler length. The maximum output power 10 MW has been achieved.

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