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a cura di G.C. Righini
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# CONFERENCE PROCEEDINGS

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# *Quantum Electronics and Plasma Physics 5th Italian Conference*

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Dopo l'approvazione del programma esecutivo da parte degli organi di controllo, si prevede un avvio del Progetto nel corso del 1989.

# A TUNABLE FREE ELECTRON LASER IN THE MILLIMETRIC BAND

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A free electron laser in the millimetric band is under construction.

A 700 KeV - 3A continuous electron beam is obtained from an electrostatic generator of the Cockroft-Walton type and a multi-stage collector will be used to recover the beam energy.

Aim of the experiment is to check the feasibility of a continuos FEL.

In this paper the experimental setup, with particular attention to the problem of energy recovery is described.

## Introduction

The progress in FEL technology observed in the past years has drawn the attention of a number of scientists from various branches of physics. FELs seem to be in fact a good way to obtain high power, tunable electromagnetic waves.

Millimetric FELs, able to supply powers over 10 KW, are of great interest for accelerators and plasma physics.

Such devices are essential to build high gradient ( > 200 MeV/m) accelerators in the "two-beam-accelerator" scheme (1) and are planned to be used to provide additional heating in Tokamak reactors, allowing the injection in the plasma of high power at frequencies which would not be accessible otherwise.

In particular a FEL such as the one we have designed, can be used as an injector for a superradiant high power FEL in the microwaves band (2), capable to supply the energy for a two-beam-accelerator .

The construction of a continuous FEL is of great interest in these perspectives.

To achieve a continuous FEL is necessary to use an electrostatic generator. Because of the small power this kind of generators can supply, it is of fundamental importance to recover the beam energy

( P = 2.1 MW in this experiment) and to minimize beam losses during the transport.

The latter can be fulfilled with a "fully immersed" magnetic configuration where the electron beam is immersed in a solenoidal magnetic field.

The beam that we plan to use is that of the Electron Beam Facility that is currently being assembled, at Laboratori Nazionali INFN of Legnaro, for an electron-cooling experiment(3).

## Working principles

The operating scheme of the device is shown in fig.1a. Figure 1b shows a hydrodinamic model of the system to explain the energetic balance.

The electron beam is produced by a dispenser cathode and accelerated up to 700 KeV ( pump 1 raises the fluid to a high gravitational potential).

The beam enters then the undulator, where laser effect is obtained in a cavity constituted by a waveguide with two Bragg mirrors at its ends. These are transparent to the electron beam but reflect the synchrotron radiation emitted in the undulator.

At this moment the beam loses energy emitted as laser radiation (the fluid goes through a dissipative region).

The electrons are finally decelerated by a proper decelerating column and recovered in a multistage collector. At this time a generator (pump 2) provides the energy converted into radiation and makes it possible to close the circuit.

In this way the high voltage generator (pump 1) has only to supply the energy losses due to the electrons lost during the beam transport. These losses are minimized with the full immersion configuration.

## Experimental setup

A sketch of the device is shown in fig.2. The electron beam and

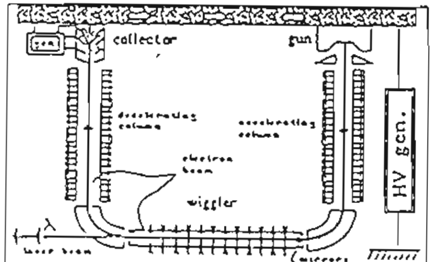

FIG. 1a - OPERATING SCHEME

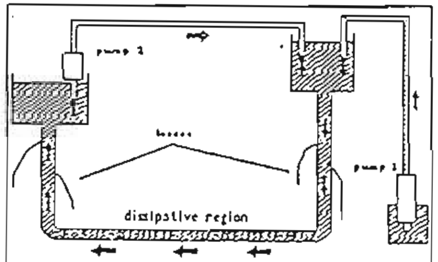

FIG. 1b - IDRODINAMIC MODEL



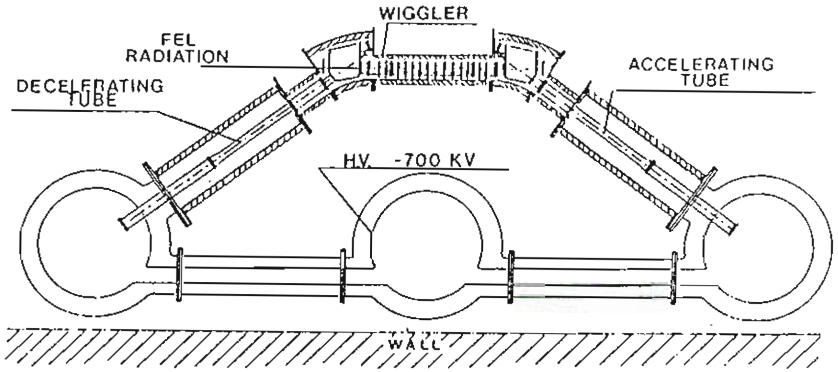

Fig. 2

the laser are its two main components.

The latter is installed in the drift region of the accelerator in place of the corresponding segment of the vacuum chamber used for the electron cooling experiment.

## High voltage system

The block-diagram of the high voltage terminal is shown in fig.3. It is made of 3 iron heads (80 cm high, 1.4 m diameter) connected by iron pipes (3 m long, 20 cm diameter).

The whole system is immersed in SF6 (3 atmospheres) for electric insulation purposes.

The first head holds both the ionic pumps to mantain the vacuum and the electron beam power supply ( an electrostatic cascade Cockroft-Walton generator, driven by a 3.5 KW square wave oscillator).

It is able to supply a nominal tension of 760 KV with a current of 5 mA and with a ripple of $10^{-4}$. It is therefore possible to accelerate electrons up to 700 KV having at the same time a high quality beam.

The high voltage generator is capable to supply 3.5 KW of power, against an electron beam power of 2.1 MW. To work in a continuous mode, therefore, the loss of charge must be less than 0.17 %.

The second head holds the 40 KW power supply for the multistage collector, while the third holds an alternator (380 V three-phases, 50 HZ, 50 KW) able to supply the power necessary to the whole system.

## Electron gun

The electrons are produced by a reserve cathode heated at 1050°C.

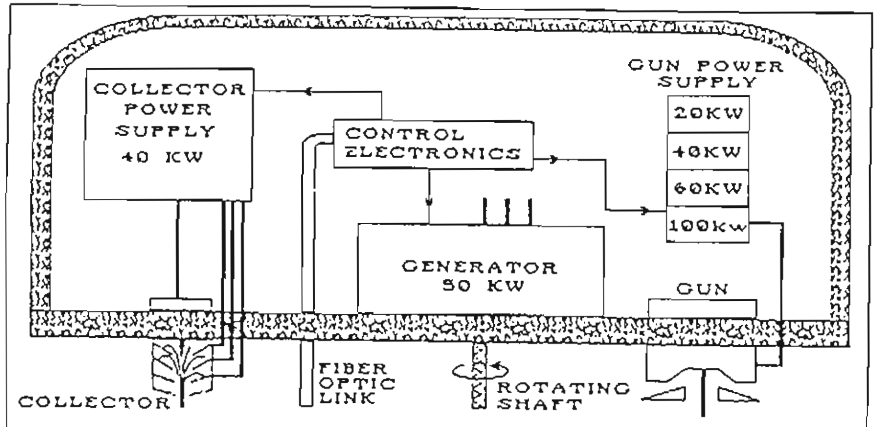


FIG. 3 - HIGH VOLTAGE HEAD

To balance space charge effects the first five electrodes are designed in a standard Pierce optics (4). The others satisfy the criteria of resonant optics ( the electrons perform an integer number of Larmor orbits while drifting along the gun).

The accelerating tube consists of a column of 37 costantan electrodes separated by ceramic rings. The total length is about 1.2 m. A special shape of the electrodes has been studied in order to protect the ceramics from ion current (4).

With this geometry we can obtain a 700 KeV - 3 A beam, 1 cm in diameter.

After coming out of the gun, the electron beam is bent, by means of a toroidal and a dipole magnetic field, and enters the undulator. An analogous magnetic configuration in used to bend the beam in the collector.

The collector

The main function of the collector is to recover as many electrons as possible and , at a lower priority, as much energy as feasible.

After the FEL interaction, the electron beam has lost about 10 KeV and its energy spread is approximately 10 KeV.

Because of this spread a simple Faraday cup is not the proper solution to recover the beam.

To be able to work in the continuous regime, a multistage collector has been investigated (5). It is made of several electrodes at the appropriate voltages in order to recover all the electrons and to minimize the energy loss.

The collection efficiency is affected by secondary emission from the anode surfaces. The geometry of the electrodes has been designed to take care of this difficulty.



In principle the collector is a spectrometer that uses electric and magnetic fields.

To obtain a charge recovery of more than 99%, the calculated energy recovery efficiency is about 60% (5). At the collector about 20 KW of power are needed, 15 of which are lost in the FEL interaction by conversion in electromagnetic waves and 5 dissipated in the collector, which will be properly cooled.

The FEL

The FEL will be assembled in the 1.5 m long drift region and will give a radiation of about 2.5 mm of minimum wavelength, to match the requirements of the ELFA project (6).

The resonant condition $\lambda = \lambda_o/2\gamma^2$ (where $\lambda_o$ is the undulator period and $\gamma$ the Lorentz factor), imposes a 30 mm period for a 700 KeV electron beam. So the maximum number of undulations we can have is 50.

This relatively low number of periods forces the gap between magnets to be as small as possible in order to obtain a reasonably high magnetic field.

On the other hand the gap is determined by the height of the waveguide, which is a rectangular cavity with internal dimensions of 60*22 $mm^2$.

The height depends ultimately on the diameter d of the electron beam (11 mm): in order to have a good superposition between beam and radiation, the height of the waveguide should be more than 2d.

The walls are assumed be 1.5 mm thick and the two surfaces facing the undulator magnets are ridged in order to withstand the vacuum pressure. The ridges are set between the magnets.

This means that the undulator configuration has a filling factor of $\epsilon$ = 0.87,from which we can obtain a magnetic field of 900 Gauss.

The output and input mirrors (the front and back-end sections of the waveguide) are Bragg reflectors. One of them with very high reflectivity, the other one with a reflectivity of at least 90%.

## Conclusions

A tunable FEL in the millimetric band is being constructed. It uses the Electron Beam Facility that is currently being assembled at Laboratori Nazionali INFN at Legnaro .

This device will be modified with the insertion of an undulator to obtain the FEL effect and of a multistage collector to recover the electron beam energy.

The collector is under construction and will be assembled and tested on the beam at the end of 1989. The whole apparatus is expected be operative in 1990.

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