ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Milano

INFN/TC-91/06
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Servizio Documentazione
dei Laboratori Nazionali di Frascati

INFN - Istituto Nazionale di Fisica Nucleare
Sezione di Milano

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FELTRON: A POWERFUL μ-WAVE POWER SOURCE FOR HIGH GRADIENT LINEAR COLLIDERS.

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ABSTRACT

A design for a very powerful pulsed Electrostatic Accelerator (1 GW) for a high gain μ-wave FEL is discussed. The resulting radiation generator, FELTRON, is tailored to a high gradient Linac operating at 20 GHz with an accelerating gradient of 100 MV/m. The electron pulse length is 0.5 μs and the rep rate is 1 kHz. The electron beam is divided into 10 pulses and an expanded gain Free Electron Laser configuration is proposed.

1- INTRODUCTION

It is of current interest (1,2,3,4) to develop novel RF sources of EM radiation that can drive a new generation of high-gradient linear colliders for high energy physics applications. A review of proposed techniques has been presented elsewhere(1,5).

In this paper we discuss an FEL (Free Electron Laser) amplifier driven by a very powerful (1 GW) Electrostatic Accelerator (a preliminary idea has been presented in ref.6) operating at 20 GHz

with an output power of 200 MW. The electrostatic μ-wave FEL, E-FELTRON, has two blocks: an electrostatic accelerator (7) modified for very high current ($I \approx 100$ A) and pulsed operation and an FEL operating in the high gain regime with a section of tapered wiggler.
In TAB 1 we list the range of the main parameters of the High Gradient Linear Collider relevant to the μ-wave power supply. These parameters are discussed, for instance, in reference 8.

TAB1

Operating Frequency	10 - 30	GHz
μ-wave Power	80 - 300	MW
Pulse Length/m	50	ns
Rep Rate	1 - 10	kHz

Optimization of RF is of great interest. CLIC (9),at CERN, has chosen 30 GHz as accelerating frequency, while LBL/LLRL/SLAC (10) are doing tests at 11.4 GHz. Also MIT/LBL are presently working on a program to test a 35 GHz High Gradient Structure (HGS).
The RF power level needed for HGS can be derived from (11)

$$\frac{r}{Q} = \frac{E_{acc}^2}{\omega U} \qquad (1)$$

where r is the shunt impedance in MΩ/m, Q is the quality factor, E_{acc} is the gradient in MV/m, ω is the frequency and U is the stored energy per meter in J/m. The values for r, Q and U can be calculated via the computer code SUPERFISH applied to the design of the structure. We need also to know the group velocity v_g. The HGS design is such as to have typically $v_g = 0.07c$. Once the stored energy is known, the RF power is simply the ratio between the stored energy per meter and the group velocity.
The proposed E_{acc} is in the range of 80 - 200 MV/m. For a frequency around 20 GHz, this leads to power levels around 100-400 MW. In section 2 the list of HGS parameters is given.
The main objective of this paper is to show that electrostatic accelerators have a unique combination of operating characteristics which can be exploited to provide optimally the RF pulse required by the High Gradient Structure (HGS). Among these are: 1) long pulse

operation, 2) excellent voltage stability, 3) high overall efficiency through electron beam recovery 4) high peak power, 5) good rep rate and compactness.

1)LONG PULSE OPERATION. As demonstrated at UC Santa Barbara (12) electrostatic accelerators are capable of producing ampere level long electron pulses. Since a typical, one meter long, HGS requires a 50 ns RF pulse, an electrostatic accelerator is a good candidate to meet that requirement. A long pulse E-FELTRON could be designed to feed several meters of structure. A scheme for powering ten meter of HGS is discussed later. The layout of the proposal is shown in figure 1.

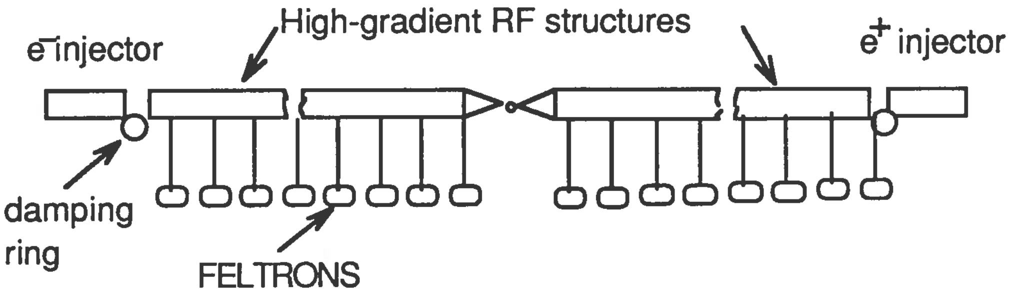


FIG.1: A schematic drawing showing the layout of the Collider with the array of FELTRON sources.

2) EXCELLENT VOLTAGE STABILITY. For low DC operation, electrostatic accelerators have demonstrated excellent voltage stability ($\Delta V/V \leq 10^{-4}$). With pulsed, ampere-level current, these machines have operated with pulse-to-pulse voltage stability better than $5 \cdot 10^{-4}$ (12). It is expected that voltage stability better than 10^{-2} can be achieved with 100 ampere-level electron pulses.

3) HIGH EFFICIENCY. Electrostatic accelerators can be charged efficiently in many ways, such as charging belts, pelletrons, dynamitrons, transformers etc. (13). The measured efficiency of accelerators with Cockcroft-Walton, Dynamitrons and Transformers as High Voltage Power Supplies is near 80%. The FEL efficiency can reach 40%, thus the efficiency without the beam recovery can be assumed to be around 30%. This value could be increased in accelerator configuration with electron beam recovery.

4) HIGH PEAK POWER. A reasonable electrostatic accelerator can

provide 5 MV. A current as high as 100 A is handlable with suitable accelerating tubes. An efficiency as high as 34% has been proven at the Livermore FEL experiment(14). It may be enhanced up to 40% (15), so as to have 200 MW of μ-wave radiation.

5) HIGH REP RATE. With the available high voltage power supply it is possible to operate at a rep rate greater than 1 kHz.

The Rep Rate is determined by the requirement on the beam luminosity L (16,17)

$$L = \frac{f N^2 H}{4\pi \sigma_x^2} = 10^{33} \tag{2}$$

where f is the rep rate, N the number of electrons per bunch, σ_x the rms bunch radius, H an increasing factor due to the pinch effect of electron and positrons bunches during the collision. Inserting for N and σ_x the foreseen values, a rep rate of 1 kHz is obtained.

6) COMPACTNESS. The usual value for the voltage gradient in the static machine is 2 MV/m. The 5 MV of our interest means a machine around 3m. The whole dimension of the machine is less than the ten meters assumed as a reference.

2-THE HIGH GRADIENT STRUCTURE - HGS

The accelerating section of the LINAC is a disk-loaded waveguide, operating at the 2π/3 travelling wave mode (fig.2). The parameters relevant to μ-wave power source are: the frequency ν, group velocity v_g, losses per meter P_{loss}/m and stored energy per meter W/m.

The useful frequency interval has been singled out to be 10-30 GHz (8). Since, the higher the frequency, the smaller the required energy for the same accelerating field, one wants to design at as high a frequency as possible. On the other hand, the long HGS is miniaturized at high frequency. Thirty giga-hertz seems to be the upper value compatible with the technical possibility to handle tolerances in manufacturing and alignment (9). Hence, we refer our calculations to 20 GHz. The waveguide diameter 2b and iris dimension 2a are related to the group velocity by (8)

$$\frac{b}{a} \approx 1.04 + 0.29 \ln\frac{1}{\beta_g} + 0.068 \ln^2\frac{1}{\beta_g} \tag{3}$$

They give $b/a \approx 2.3$, with $a \approx 0.2\,\lambda$ we get $v_g \approx 0.07c$.

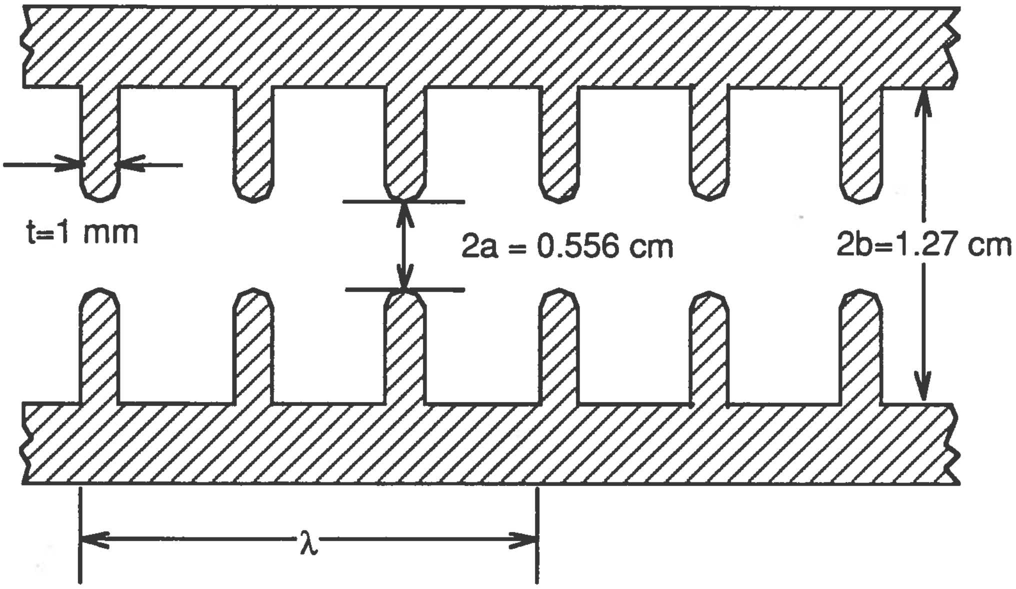


Fig.2. Schematic of High Gradient Structure at 20 GHz and group velocity ≈0.07 c.

In Tab 1 the cavity parameters for 20 and 17 GHz are listed . The parameters have been calculated with the SUPERFISH code. They agree substantially with the calculations of Palmer in ref (8). The stored energy can easily be calculated with the formula of ref.16

$$U = \frac{E_{acc}^2\ \lambda^2}{2\pi\, c\ Z}\ \frac{J}{m} \qquad (4)$$

Here the impedance Z for those structures is about 300 Ω, c is the velocity of ligth and λ the wavelength.

In order to find the power of the source, we have to take into account that the transfer efficiency from the source to the LINAC through the Transfer Waveguide is assessed around 75% (16). Considering both the power absorption during the filling time of the structure and the transfer losses, the E-FELTRON peak power is given by

$$\widehat{P_{RF}} = 1.25\ \frac{2\alpha}{1 - e^{-2\alpha}}\ \frac{U}{\tau} \qquad (5)$$

TAB 1

Accelerating Gradient E_{acc} (MV/m)	100	
Operating Frequency ν (GHz)	20	17
Shunt Impedance r (MΩ/m)	85	83
Group velocity v_g	0.07 c	
Filling time τ (ns/m)	50	
Q factor	5088	5600
Waveguide diameter 2b (mm)	12.72	14.8
Iris Aperture diameter 2a (mm)	5.56	6.46
Disk thickness (cm)	0.1	
Stored Energy U (J/m)	4.65	6.2
RF Attenuation coefficient α ($\omega/2v_gQ$)	0.617	0.56
Rep Rate f kHz	1	

Here, the factor 1.25 is due to transfer losses, the other factor $2\alpha/(1-e^{-2\alpha})$ is due to RF attenuation inside the structure. The peak RF power results in ≈185 MW and ≈260 MW for 20 and 17 GHz respectively. Incidentally, reducing the accelerating gradient to 90 MV/m only, reduces the 20 GHz source power to 150 MW.

The high value of the attenuation parameter demands a scheme with feeding lines at each meter.

One FELTRON ought to feed 10 meters of LINAC, in order to have a reasonable machine. This means that the μ-wave source must have ten outputs , each carrying an RF pulse of 50 ns.

3-THE HIGH VOLTAGE POWER SUPPLY

The reference parameters of the E-FELTRON in relation to the high voltage power supply are

Peak Radiation Power	$\widehat{P_{RF}} = 185$ MW
Pulse Length	$\tau = 500$ ns
Rep Rate	$f = 1$ kHz

An E-FELTRON with this pulse length will be able to feed 10 m of HGS.

Assuming a conversion efficiency η of 35%, the peak power of the electron beam results in (about)

Peak Electron Beam Power $\widehat{P_{eb}} = 530\ \mathrm{MW}$

Assuming a voltage of V = 5 MV the peak current has to be $I \approx 105$ A. The average values of current and power are respectively

Average Current $\bar{I} = \hat{I}\tau f \cong 52\ \mathrm{mA}$
Average Beam Power $\overline{P_{\hat{e}b}} = \widehat{P_{eb}}\tau f = 265\ \mathrm{kW}$

This level of power can be provided by a Crockoft-Walton, Dynamytron and Trasformer type of High Voltage Generator (HVG)(13).

An electrostatic machine of the Dynamitron type with 40 mA and 4 MV is in the catalogue of RDI Co. (USA). Therefore, it would need a simple up-grading for our accelerator. The tank is 8 m long and has a diameter of 3.5 m. It's cost is around 2 million $.

Present day technology permits a reduction of dimensions. Tubes sustaining accelerating voltages as high as 4 MV/m have been tested (18). Comparable gradients are possible also in the transverse dimension. A realistic value of 2 MV/m or nearby can be assumed(19). Usually, the difference in value of the gradient between stable fully conditioned operation and vacuum breakdown is quite small.

The size reduction must be pursued because the array of FELTRONS will be set in a tunnel, which is a very expensive space.

The Dynamitron proposed for the SIRIUS Project (20) at Dijon, Université de Bourgogne, promises to be very compact and reliable. This machine has an operation frequency of 1 MHz, instead of the 110 kHZ of the RDI machine. The high frequency allows a low capacity and so in turn a lower risk of disruptive discharges.

With the purpose of having a very powerful and compact machine, a Crockoft-Walton with a parallel of 8 oscillators (21) has been designed (see the scheme in fig.3). Each one of these generator can can provide 10 mA at 5 MV.

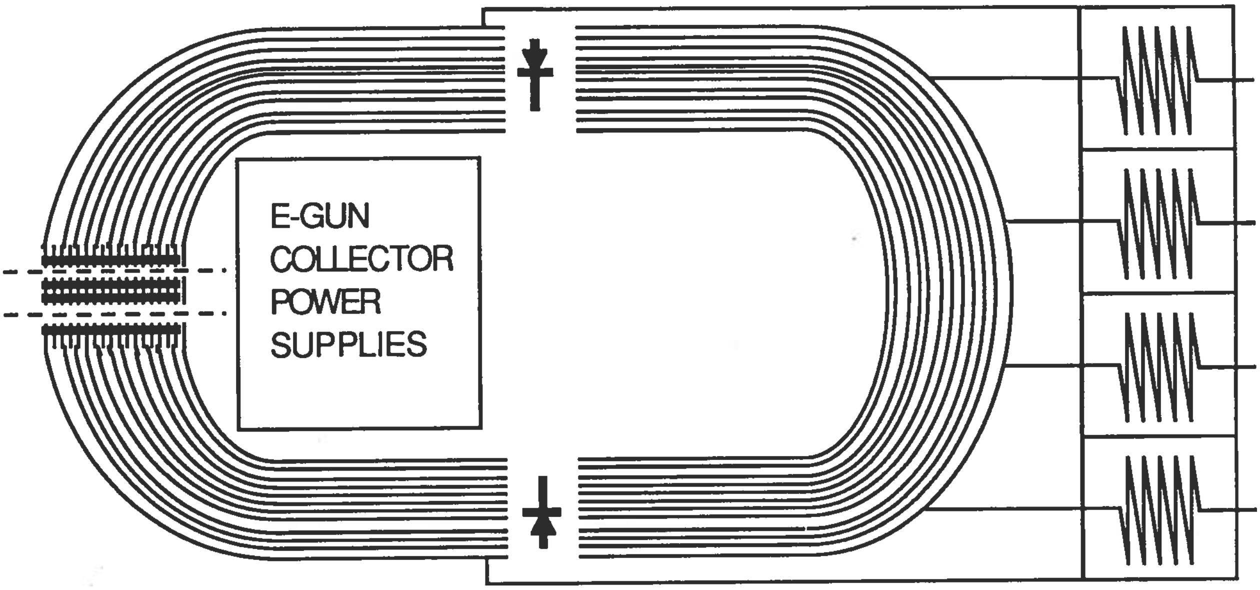


Fig. 3; Schematic of Powerful High Voltage Generator with eight driving oscillators.

This high power level means that either the rep rate or the length of the feeded HGS can be increased by a factor 2.

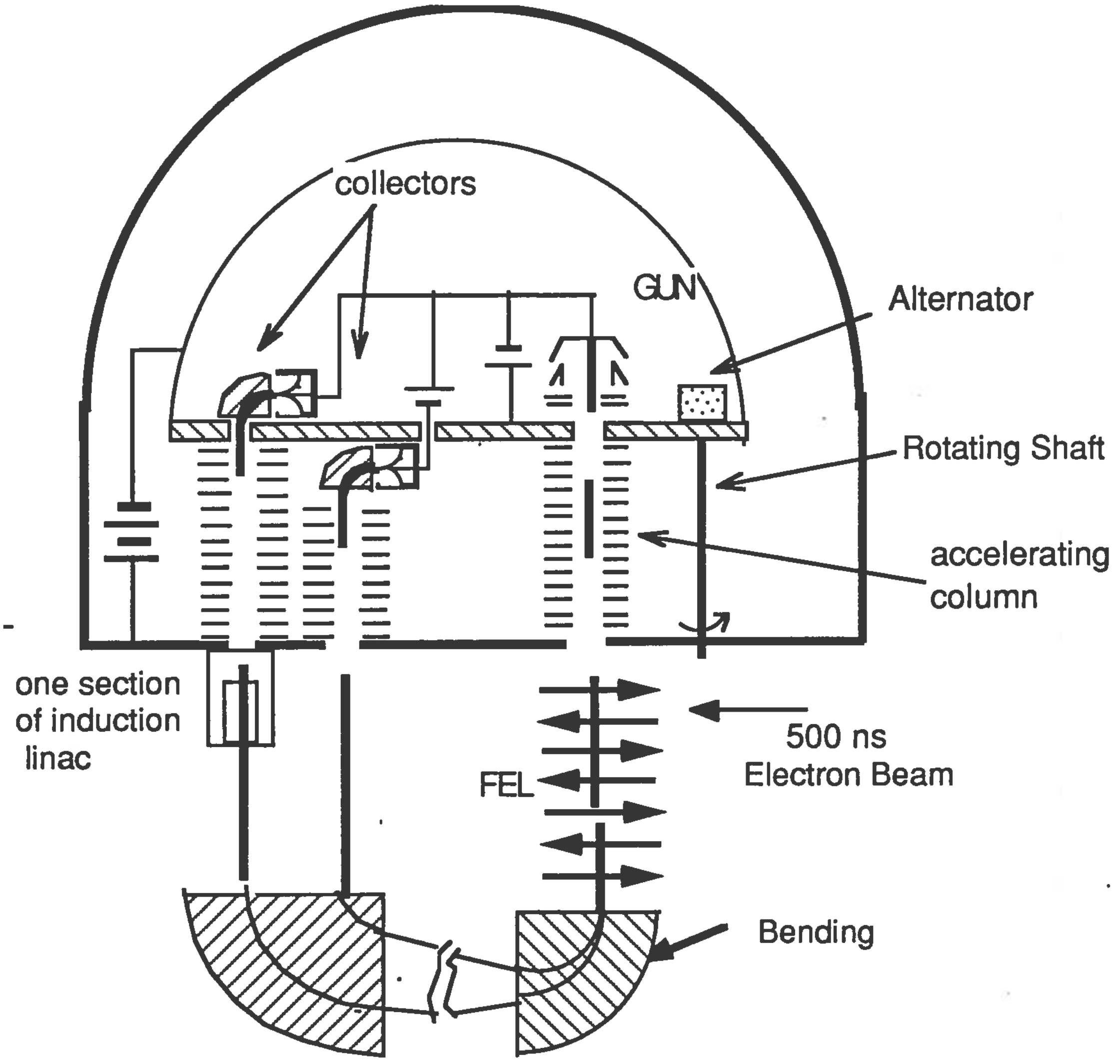
There are other two possible High Voltage Generators, the ICT of Vivirad High Voltage Co. (this is in the brochure list) and the Transformer of Novosibirsk (22), which could be used with some modifications.

The ICT is a high voltage transformer and can deliver 80 mA at 3 MV, that is a power of 240 kW. The Transformer of Novosibirsk has about the same performances of ICT.

In ref. (23) a Crockoft-Walton machine able to deliver 200 mA at 4 MV is reported.

4- E-FELTRON SCHEME

A scheme of the device is given in Fig. 4.



The high Voltage Terminal (HVT) is charged by the High Voltage Generator (HVG); the electron beam after the accelerating tube goes through the FEL section. A recovery system can be added if necessary.

An accelerating tube able to transport a current as high as 100 A is needed. In the next section it is shown that this goal is achievable. The 500 MW power of the electron beam, $P_{eb}=V*I=500$ MW, leads to a voltage of 5 MV. A machine of 100 A and 500 MV is feasible. However, the maximum achievable current is not known. The technology of very high current tubes has not been yet developed, simply because these kinds of beams were never required before.

The trade-off between the values of current and voltage pushes for voltages lower than 5 MV (for the High Voltage Power Supply and volume) and in turn for current higher than 100 A. Future tests will discover the optimized balance.

As for the recovery, we state from the beginning that the ten electron beams scheme (mentioned above) would not allow it. However, we discuss it in view of developing a scheme with a maximum of two electron beams. This could be done either dividing the RF long pulse in parts (instead of the electron beam) by plasma mirrors or other method(24) or reducing the HGS losses exploiting lower frequency and/or nitrogen cooling.

The FEL interaction with the tapered wiggler , very roughly, separates the electrons into two groups: one with a negligible energy shift and an energy dispersion assessed at around ρ (ρ is the so-called Pierce parameter, see below), that is $\delta\gamma/\gamma \approx \rho = 0.025$, and the other with the same energy dispersion but with an energy shift $\delta\gamma/\gamma \approx \eta = 40\%$. The two groups have more or less the same number of electrons. In fact, the percentage of electrons trapped inside the ponderomotive bucket is about 50%. This result comes from simulations (see for example ref. 25), but also from the Livermore experiment on high gain FEL (26).

The two spent beams must be separated by means of a dispersive magnet (fig. 4). Then the energetic beam is recovered. The power supply for it should provide a voltage as high as $V \approx \rho V_{HVT} = 100$ kV. The recovery efficiency would increase up to 50%.

Recovery of the decelerated beam does not seem worthwhile since it requires a complicated system and furthermore, the efficiency would not increase substantially. The beam energy depression is $\delta\gamma \approx 2$ MeV, therefore an induction accelerating section ought to be set (the beam must re-gain the initial 5 MeV energy to climb the decelerating tube) before re-entering the accelerator.

A simple Faraday cup with a magnetic dipole is used to collect the beam. The average power losses at the collector is roughly

$$P_{losses} \approx 50A * 100\ kV * \tau * f = 2.5\ kW$$

This is small enough for collector cooling and powering.

5-THE HIGH CURRENT ACCELERATING TUBE.

It is important to look for a high gradient tube, in order to get a reduced size machine and, in addition, to have a better vacuum. This last problem may be of some relevance with high current and high rep rate.

The high gradient section of the NEC Co. (National Electrostatic Co. USA) seems suited to our purpose. Each element, whose ref is 2 FAO 11060, has the following characteristics

- Voltage	330 kV
-Length	218 mm
-External Diameter	228 mm
-Internal Diameter	82 mm

This has an ID large enough for high current. Anyway the electrostatic focusing force is not enough to contract the space charge force. Some solenoidal focusing lenses must be added along the column (fig.5). In the simulation of ref (26), it is shown that with 5 lenses a current of 100 A can be carried by the tube. The lenses are constituted mainly of permanent magnets and a small coil permits field adjustment to the required value. The power supplies of the coils, set at the accelerating section level, consist of a small turbine which feeds a small alternator (see fig.6). In order to save power, it may be advisable to pulse the system.The magnetic lenses increase the beam emittance, but, since the beam must be used for a μ-wave FEL the required emittance ε_n is $\varepsilon_n = \gamma \lambda / 2\pi = 10^{-3}$ m rad which is very easy to get anyway. The other point to consider is the behavior of the beam through the transport optics. The simulations done with E-Gun code have shown good results.

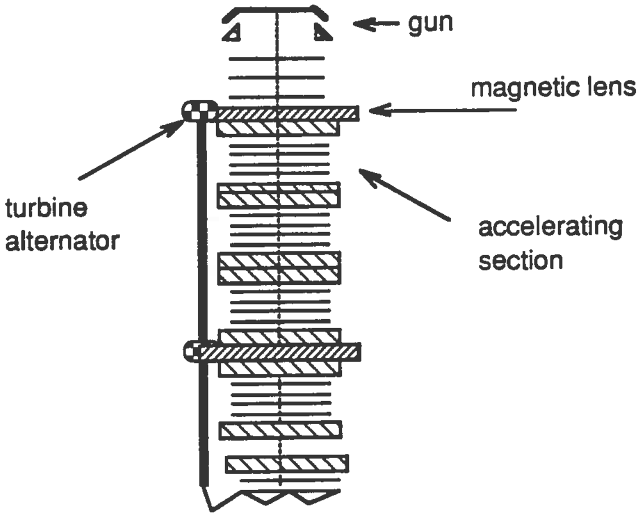


Fig. 5 Accelerating Column with magnetic lenses and relative power supplies made up of a turbine coupled to a small alternator.

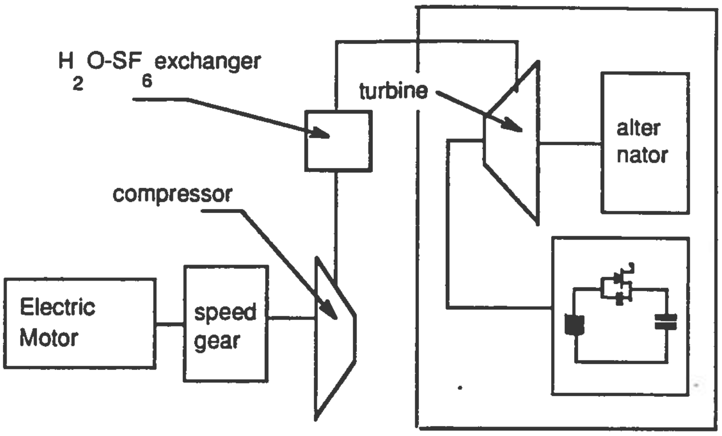


Fig.6. Principle scheme of turboalternator to provide energy to magnetic lenses coils.

6-TEN BEAMS FEL SCHEME

The 500 ns electron beam coming from the accelerator, conveyed through the FEL section of the machine, provides an RF μ-wave beam of the same time length.

The 500 ns pulse must be divided into ten, 50 ns long, pulses. This can be obtained by dividing it into ten pieces either the electron beam before entering the wiggler (fig. 7) or the long μ-wave pulse.

For the latter possibility, A. Sessler came up with the idea of plasma mirrors created by suitable lasers. This idea will be discussed in another paper. Here, we propose a technique for the former possibility. The scheme is shown in fig. 8.

The principle of electron beam division into pieces is based on the fact that it emerges from the accelerator with an energy drop. This energy modulation is transformed into spatial separation by a dispersive system. The ten beams are then conveyed into ten separated waveguides.

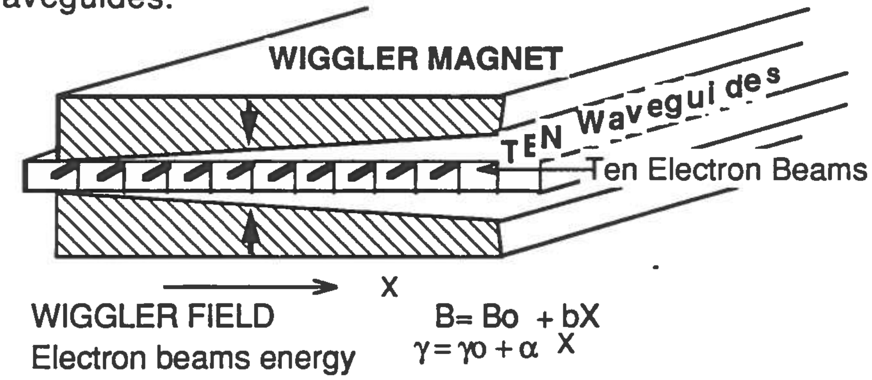


FIG. 7. Schematic of the expanded gain FEL set-up with ten electron beams and ten waveguide.

The energy drops linearly with the voltage of the terminal during discharge.

$$-\frac{dV}{dt} = \frac{I}{C} \qquad (6)$$

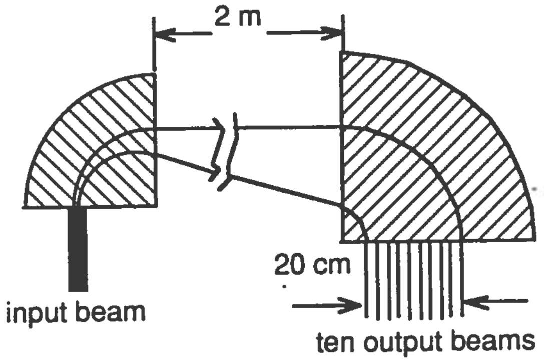


Fig.8 Schematic of Dispersive System: one input electron beam, ten output, two centimeters separate, beams.

The energy variation of the terminal during the pulse discharge results in

$$\frac{\Delta\gamma}{\gamma} = \frac{\Delta V}{V} = 2\frac{\Delta W}{W} \approx 10\% \qquad (7)$$

where W is the energy stored in the terminal. We have assumed a capacity value of the high voltage terminal of 100 pF.

An improvement of the scheme is obtained adding a sawtooth power supply at the gun (20). The linear drop is changed into a step drop, see fig. 9.

The step fashion of the voltage, and in turn of the electron beam energy, will lead to ten separate electron beams after spatial dispersion inside the dispersive system. The beams will have 1% energy shift between each other.

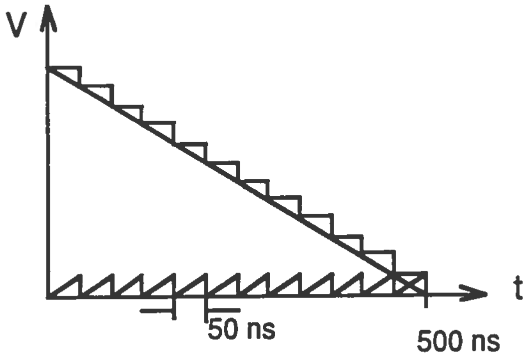


Fig. 9. Schematic of the Voltage dropping at the terminal with the sawtooth power supply at the gun.

6- THE FEL SECTION

We want to find a set of parameters which are physically and technologically self-consistent.

The waveguide dimension is firstly determined by the electron beam spot size and the wiggling amplitude. The radius of the electron beam inside the FEL section (given an emittance around 10^{-3} m rad and usual values for betatron wavenumbers inside the wiggler) can be estimated at around half a centimeter. The wiggling motion amplitude is about half a centimeter again. The requirement of a radiation intensity as high as possible (by FEL operation) and of electron beam separation as narrow as possible (by a dispersive system) leads to small waveguide dimensions. The waveguide effect on the FEL resonance condition pushes for oversized waveguide in order to have the right energy. We end up with $2*2\ \mathrm{cm}^2$ waveguide dimensions. In this way we match the cavity mode area with the beam spot size and the cavity height meets the wiggler technical constraints and saturation is optimized.

The effect of the wiggler appears in the FEL equations through the wiggler parameter $a_0=0.66 \cdot B_0(T) \cdot \lambda_0(cm)$ (having assumed a plane wiggler), where B_0 is the peak magnetic field and λ_0 the period. The coupling parameter a_0/γ has to be high in order to have high gain and so an exponential regime. The resonance condition with a waveguide reads

$$\lambda = \frac{\lambda_0\ (1 + a_0^2)}{\gamma^2} \left[\frac{1}{\beta_z} \frac{1}{1 \pm \beta_z \sqrt{1 - \left(\frac{\lambda_0\ (1 + a_0^2)}{2 b \gamma \beta_z} \right)^2}} \right] \tag{8}$$

with

$$\beta_z = \sqrt{1 - \frac{1 + a_0^2}{\gamma^2}}$$

We choose the lower of the two possible frequency.

Incidentally, the term $\lambda_0\ (1+a_0^2)/2b\gamma\beta_z$ inside the square root is due to the waveguide. The higher b the lower is that term and, in turn, the lower γ has to be in order to accomplish the resonance condition. If a_0 is high, the energy must be high as well from eq. (8). Thus it is wise to choose the lowest value of a_0 compatible with the requirement of the power of the electron beam (i.e. the lowest γ). The gain has a smooth dependence on a_0, because it depends on the coupling parameter a_0/γ, as it appears from the gain formula (see below).

In the high gain regime (25,28) the radiation amplification up to saturation is governed by

$$I = I_0\, e^{g z} \qquad (9)$$

were I_0 and I are the radiation intensity at the input and at the output respectively, g is the gain per unit length and holds (see also ref. 29)

$$g = \sqrt{3}\,\frac{4\pi}{\lambda_o}\,\rho \qquad (10)$$

the parameter ρ (without waveguiding effect) is

$$\rho = 0.171\ \frac{B_0^{2/3}\,\lambda_0^{4/3}}{\gamma_r}\left(\frac{I}{ab/2}\right)^{1/3} f_b^{2/3} \qquad (11)$$

We neglect for following arguments the waveguide effect on ρ. In (11) γ_r is the electron Lorentz factor (r refers to the reference particle), a and b are the two waveguide dimensions, f_b is the usual difference of Bessel functions $f_b(\xi) = J_0(\xi) - J_1(\xi)$, with $\xi = a_0^2/2(1+a_0^2)$.

In order to have high gain the parameter ρ must have a value of a few percent. Assuming as waveguide dimensions a=2 cm and b=2 cm,we need a wiggler parameter $a_0 \geq 2$. A good compromise between all the requirements leads to the following two possible lists of parameters

TABLE 4 -Wiggler and cavity Specifications

- Waveguide dimensions cm²	$a \cdot b = 2 \cdot 2$	$2 \cdot 3$
- Peak magnetic field kG	$B_0 = 2.3$	7.5
- Wavelength cm	$\lambda_0 = 15$	10
- FEL parameter	$a_0 = 2.3$	5
- Gap cm	g = 3 cm	
- Number of periods	N = 30	
- Transverse dimension	x = 25 cm	
- Hybrid type with canted poles		

The value of the ρ parameter comes out to be $\rho \approx 0.025$. The saturation power is (25,29)

$$P_{RF} \approx 1.3\ \rho\ P_{eb} \approx 15\ \mathrm{MW} \qquad (12)$$

Since the growth rate g, in nepers per unit length, from eq. (10), turns out to be $g = 3.6$, and the input programmed power is 10 kW, the saturation length z comes out to be about 2 m.

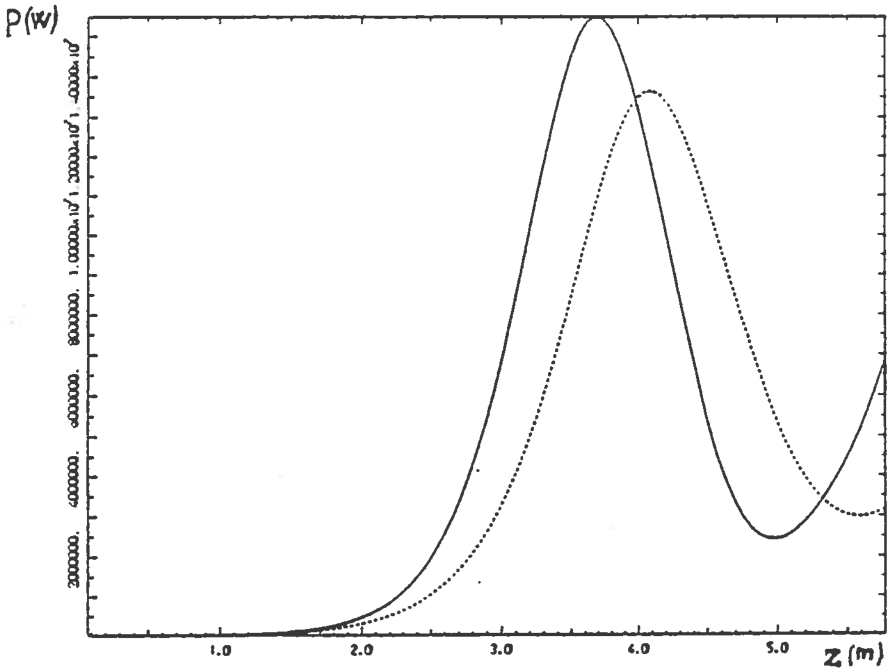


Fig. 10; FEL Computer Simulation without tapering; continuous line is for the case with $\Delta\gamma/\gamma = 10^{-3}$, dotted line refers to $\Delta\gamma/\gamma = 10^{-2}$.

The lethargy length must be added to that length. It can be estimated at around 1 meter with the assumed values of ρ and input power. These numbers are confirmed by scaling the Livermore high gain experiment (see refs. 29,30). In that experiment the value of the ρ parameter was $\rho = 0.03$, the saturation was reached within 22 periods and the power extraction was ≈4%.

In fig. 10 the results of simulation are shown.

A piece of tapered wiggler must be added in order to reach the programmed 35% efficiency.

The value of the maximum field for an hybrid configuration wiggler is given by (31)

$$B_0 = 3.33 \exp\left[-\frac{g}{\lambda_0}\left(5.47 - 1.8\,\frac{g}{\lambda_0}\right)\right] \qquad (13)$$

In our case the ratio between the gap and the period $g/\lambda_0 = 0.2$, thus the maximum field could be, actually, much higher than that programmed.
The chosen hybrid configuration permits the iron pole profile, which is very important with our high current and relatively low energy. The plane wiggler has natural focusing on the vertical plane. The horizontal focusing can be created either by shaping the poles in a parabolic fashion (32), or tilting the poles by a small angle α alternately positive and negative, making in this way the so called canted pole configuration (33).In the first case a sinusoidally modulated sextupole term is created, in the latter case a quadrupole term field is created. The canted poles are technically simpler to machine. So, since we do not have to trouble with the de-phasing between electrons and radiation wavelength introduced by the quadrupole term (we have a short wiggler and a long wavelength), the easier pole canting solution is preferable.
The pole canting determines the betatron force. Here we have also to consider the matching of the electron beam spot with that of the radiation. Having a square waveguide, the beam spot should be elliptical because the radiation pattern fills half the height.
Since the ratio between the two transverse dimensions σ_x and σ_y is equal to the square root of the betatron wavenumbers, that is

$$\frac{\sigma_x}{\sigma_y} = \sqrt{\frac{K_{\beta y}}{K_{\beta x}}} \qquad (14)$$

the ratio between the vertical and horizontal betatron wavenumbers $k_{\beta y}$ and $k_{\beta x}$ can be around 2. The canting angle is related to the betatron wavenumbers by

$$\alpha = -\frac{e}{mc^2} \frac{k_{\beta x}^2}{k_\beta^2} \frac{g B_0}{4\gamma \cosh(\pi g/\lambda_0)} \qquad (15)$$

where g is the gap height and $k_\beta^2 = k_{\beta x}^2 + k_{\beta y}^2$. With our numbers α is a couple of degrees.
A rough estimate of the spectral purity of the FEL radiation is given by the inverse of the number N_b of wavelengths contained in the

electron beam pulse, that is

$$N_b = L_b/\lambda = \tau *c/\lambda = \tau * \nu = 2000$$

$$\frac{\Delta\omega}{\omega} = \frac{1}{N_b} = 0.05\ \% \qquad (16)$$

This spectral purity is better than that one required by the high gradient linac cavity (34).

8- CONCLUSIONS

FELTRON, that is a centimeter radiation source with the required characteristics of 200 MW power, overall efficiency greater than 30%, spectral purity better than 1%, ten 50 ns RF pulses and rep rate of 1 kHz, is feasible implementing a high current electrostatic accelerator with a high gain FEL in a MOPA scheme.

The electrostatic accelerator must provide a peak current of about 100 amps at 5 Mev for 0.5 µs. The gun will have a sawtooth voltage superimposed on the usual continuous voltage. The sawtooth voltage added to the decaying voltage of the High Voltage Terminal (due to the high current during the operation) will lead to an electron beam with a step function energy drop.

A dispersion section splits the long beam into ten beams.

The FEL has the gain-expansion configuration with ten parallel channels. Each channel is an amplifier operating in the high gain regime with an input µ-wave signal of 10 kW. The total length will be less than 3 m.

The high voltage generators for the accelerator able to supply the 250 kW requested for the above performances are already available. Only some modifications, such as enhancement of the voltage by 10-20%, ought to be made.

The accelerator could also be provided with a recovery system in order to increase the overall efficiency.

The operation principle of this machine, that is the very slow DC charge of a high voltage capacitor and its discharge though short intense electron pulses, calls for electrostatic technology as we have proposed in this paper.

For completeness, the cost of the prototype can be assessed around 4 million $. thus the costs are within the established boundaries (8,35).

Acknowledgements. We acknowledge the suggestion for the sawtooth gun modulation and the turbine of M. Roche.

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