BEAM DYNAMICS IN THE BUNCHING SYSTEM FOR ELETTRA

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Abstract: The 100 MeV Linac for ELETTRA will be used as preinjector for a 1.4 GeV linac and followed by a storage ring ELETTRA as a synchrotron light facility.

Pre-studies and the linac configuration have been described previously [1].

The linac will deliver electron beams according three operating modes: the single-bunch and multi-bunch modes, and a FEL mode. The present paper is concerned specially with the dynamics in the bunching system.

The accelerator includes 500 MHz and 3 GHz cavities, a 4 MeV buncher followed by two TW sections at the 2pi/3 mode. In order to produce one bunch without satellites per 500 MHz bucket, an RF subharmonic chopper, which uses a deflecting cavity is added to the injection line.

The beam behaviour, such as the radial control, the bunching process, the energy spread and emittance are analysed. The main difficulty is to provide the required characteristics for the three operating modes with a single linac.

A particular care has been taken over the initial emittance at the gun exit, and the sensitivity of the parameters values to perturbations.

TECHNICAL SPECIFICATIONS AND GENERAL LAY-OUT

It is recalled here in Table 1., the last specifications for the three operating modes. The energy spread is defined at half width of the current density measured behind an analysing magnet followed by energy slits.The emittance is measured at 1.8 σ corresponding to ~86 % of a bi-gaussian current density in the phase space X-Xp (or Y-Yp).

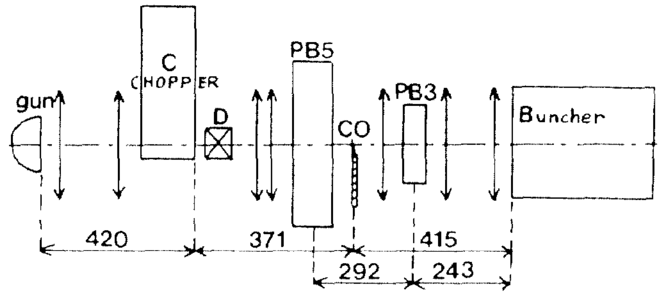

Fig 1. General lay-out of the bunching system

The schematic diagram of the bunching system is reproduced in fig. 1.

It is recalled some features of the injection line. The chopper system consists of a 500 MHz deflecting rectangular cavity [2],[3], operating in the TM110 mode, associated with bias deflecting coils and a collimator.The focusing system uses seven thin lenses designed to produce an approximate gaussian field on axis [4], and allows the radial control of the beam at each part of the injection line.The 500 MHz prebuncher cavity is a simple pill-box cavity [5]. The 4 MeV buncher is a 2pi/3 triperiodic SW structure of 465 mm length.

Some operating parameters and cavities features are mentionned in table 2.

MODE 1 Single-bunch	Warrantied	Expected
Energy	100 MeV	
Fine structure of the pulse	⩽ 3 contiguous S-band bunches	
Charge per pulse	⩾ 0.16 nC	⩾ 0.25nC
Charge ratio between filled bucket and neighbouring empty buckets	⩾ 10^3	
Emittance	< 1 π. mm.mrad	
Normalized emittance	< 200 π. mm.mrad	
Energy spread	< ± 0.5 %	
Repetition rate	10 Hz	
MODE 2 Multi-bunch		
(Same energy ,emittance,energy spread and repetition rate as for the single-bunch mode)		
Beam pulse width	10 to 300 ns	
Fine structure of the pulse	successions of 3 S-band bunches	
Current at 300 ns	> 10 mA	
Charge at 300 ns	> 3 nC	> 6 nC
MODE 3 Free Electron Laser		
Energy (variable)	30 to 75 MeV	
Beam pulse width	⩾ 10 µs	
Fine structure	3 S-band bunches in 1 bucket	
Bucket repetition rate	32 MHz max	
Charge per bucket	⩾ 0.15 nC	⩾ 0.4nC
Central bunch length (FWHM)	⩽ 10 ps	
Normalized emittance	200 π. mm.mrad	
Energy spread at 75 MeV	⩽ ± 0.5 %	⩽ ±0.3%

Table 1. Technical specifications

Subharmonic chopper : - frequency : 499.654 MHz - deflection : 2 cm after a 370 mm drift, taken into account the focusing parameters for a 700 mA beam current - material : aluminum AU-4G 2017 A - quality factor : Qo = 12000 - input power: Pd = 700-750 W Subharmonic prebuncher : - frequency : 499.654 MHz - material : stainless steel with a copper layer. - Modulation : 25-27 kV - Quality factor : Qo = 12500 - Input power : 500 W	Harmonic prebuncher : - frequency : 2997.924 MHz - material : copper - Modulation : 5-10 kV - Quality factor : Qo= 8500 - Input power : 50-150 W Buncher 4 MeV: - frequency : 2997.924 MHz - material : copper - type : 2pi/3 triperiodic SW - shunt impedance : 60 MΩ/m - quality factor : Qo = 12500 - unloaded input power : P = 600 kW

Table 2. RF structures characteristics

GUN DESIGN

In order to fulfil the emittance requirements, specially for the FEL mode, a non conventionnal gun has been designed. The gun geometry is shown in fig. 2 . The cathod is a Thomson TH306 planar 1 cm^2 cathod , with a wire grid at 100 µ from the emitting area. As it is mentionned in [6] , a way to obtain a low emittance is to have the beam trajectory almost parallel to the axis. The GUN program is used for the optimization [7]. First simulations without grid actually showed a very low emittance , nevertheless it was interesting to evaluate locally the grid influence near the cathod. To produce a 700 mA nominal beam current, a low grid potential is necessary, roughly less than several ten volts. Fig 3. shows an example of micro-beam trajectories between two wires, and it can be seen that the grid induces a divergent effect which affects the emittance.With this type of initial beam, it can be estimated an emittance less than 50π.mm.mrad at the 100 kV output gun (33π.mm.mrad normalized), and a 6 mm radius beam with a slight divergence. So we can permit a 6 factor emittance growth along the accelerator.

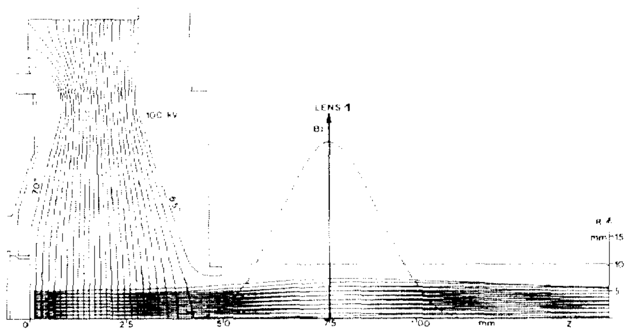

Fig 2. Gun optics

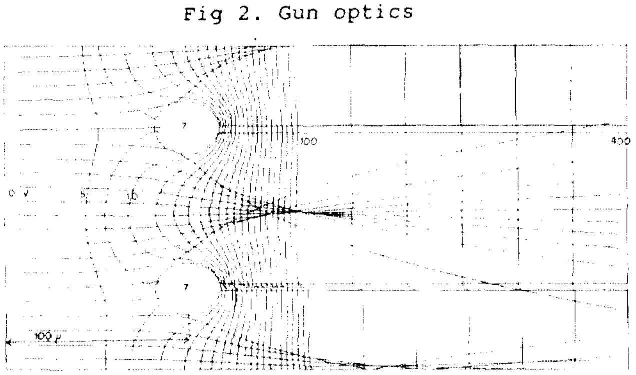

Fig 3. Grid effects on beam optics

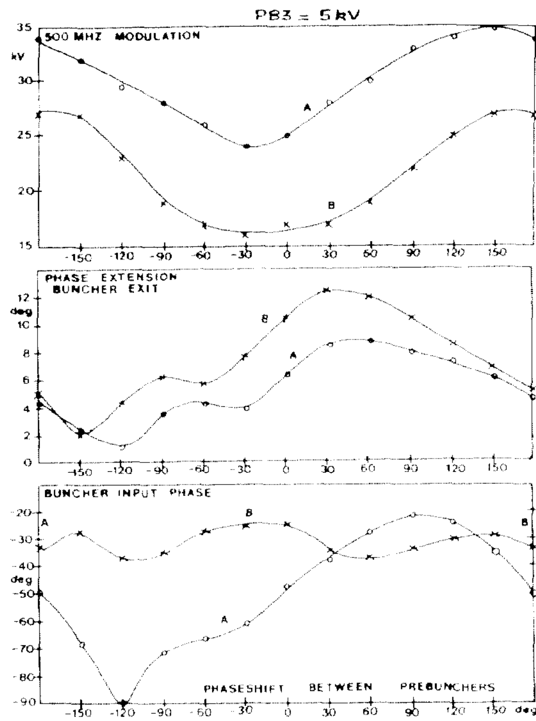

Fig 4. Parameters for a minimum bunch lenght

DYNAMICS WITHOUT SPACE CHARGE

The bunching process optimization requests to vary a lot of parameters such as, power into the cavities and so the modulation, phase-shifts between cavities, drift lengths, sensitivity to frequency perturbations, the phase window after the chopper, and so on. So the use of big particle tracking codes consummes a lot of time to find the best parameters values. The way use here to converge towards the nominal point, is to simulate first the beam dynamics without space charge with a matrix interactive code, and then with a macro-particle step-by-step code with space charge (i.e. PARDYN , CGR MeV made). This implies a feedback on the overall process. To produce roughly 0.2 nC after the buncher, the chopper phase window is estimated at 40 to 45 deg of the subharmonic frequency. The goal is to obtain the smallest bunch length at the buncher exit in order to minimize the energy spread at the end of the linac. An example of the results of the optimization process is reproduced at fig.4. Each point corresponds to a minimum phase extension at the buncher exit.

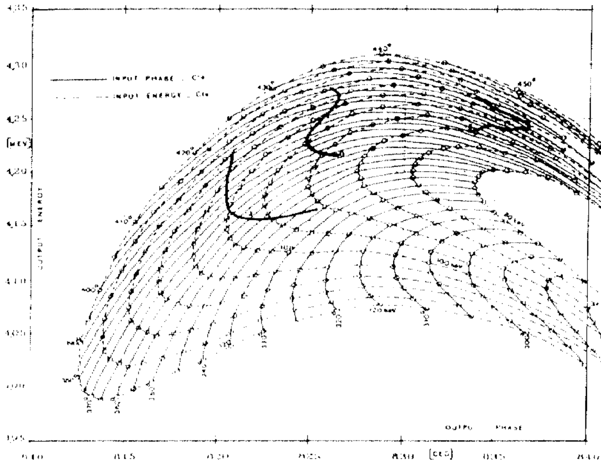

Fig 5. Phase-energy transfer diagram for the 4 MeV buncher

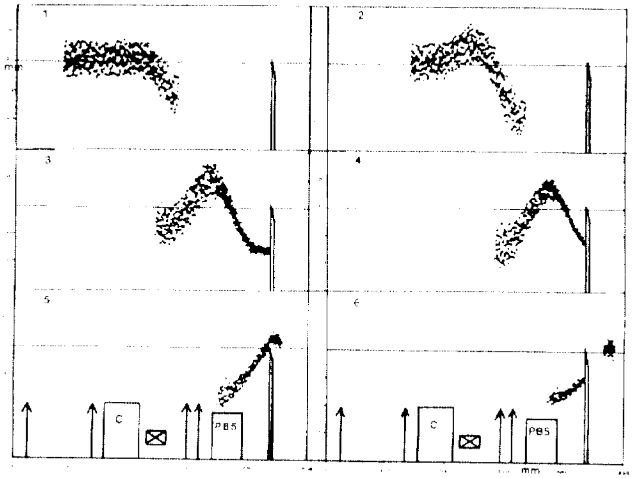

Fig 6. Beam deflection from the gun to the collimator

Two types of optima are obtained. The optimum optimorum is got for a "low" subharmonic modulation, which is less sensitive to the phaseshift perturbation. It is then expected to have a 2 deg bunch length at the end of the 4 MeV buncher. This point is reproduced at fig.5 on the phase- energy transfer diagram of the buncher. With the adequate phase-shift between cavities, it corresponds to : - 27 kV subharmonic modulation - 5 kV harmonic modulation - a bunch lenght between 2 and 6 deg taken into account a ± 0.25 °C perturbation (corresponding to a frequency detuning) - The chopper let open a 46 deg (500 MHz) phase window, and the prebuncher process allows to have 60 deg (3GHz) at the buncher input.

DYNAMICS WITH SPACE CHARGE

The simulation with space charge shows that the preceeding optimization is in quite good agreement with the expected results. Ahead of the collimator the parameters are not changed, when behind it ,the debunching effect due to the space charge associated with the radial control, imposes a modification of parameters. The subharmonic modulation has to be decreased (i.e. 25 kV) and the 3 Ghz one is slightly increased to 10 kV. The phase-shift between cavities is such that the 3GHz prebuncher adds an extra compression to the bunch for a better acceptance in the buncher. It can be shown on fig.6 the beam deflection in front of the collimator for a 2 ns single-bunch. After the the collimator the 240 deg bunch is compressed to 80 deg at the buncher input. At the buncher exit ,one obtains a 16 deg bunch length which contains a 185 pC charge. The average energy is 4150 keV with an energy spread of 4.6 %. The radial control is obtained with a 800 gauss solenoidal field. It can be seen a divergent beam which will be controled by a lens ahead of the first accelerating waveguide.

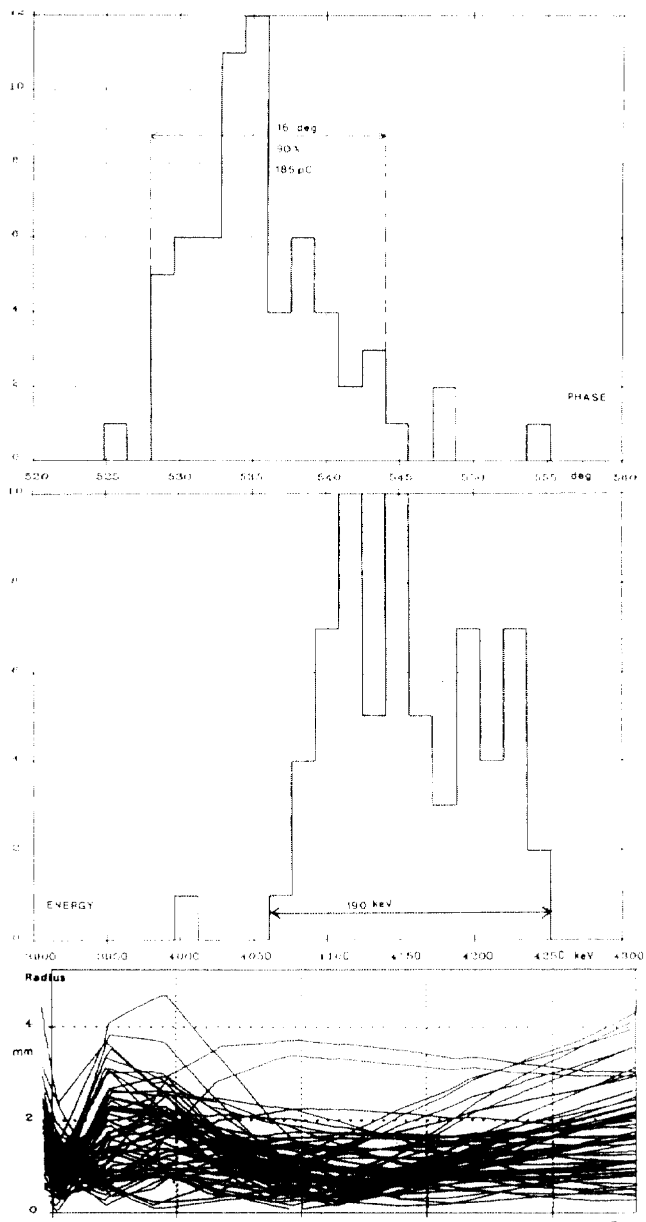

Fig 7. Buncher output characteristics and radial behaviour

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