General description of the ESRF injector system

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1. Introduction

The injection system for the ESRF 6 Gev storage ring comprises a linear preinjector and a full energy fast cycling booster synchrotron.The preinjector linac system will accelerate either electrons up to 200 Mev or positrons up to 400 Mev.These particles will be injected in one turn into the booster and accelerated to the 6 Gev final output energy.For the two basic modes of operation,the multibunch and single bunch charging of the storage ring,a booster cycling frequency of 10 Hz,as well as a low natural beam emittance have been chosen to ensure a fast filling rate of the storage ring.

2. Linac preinjector

2.1 Description

The preinjector is a 200 Mev electron linac accelerator which has already been ordered. It consists of : one Pierce-type triode gun, one biperiodic $\pi/2$ standing wave buncher, and two $2\pi/3$ travelling wave sections.
Each section is powered from a pulse line modulator,equiped with a 35 MW klystron . The first modulator is also used to feed the buncher section.

2.2 Operation

The linac is operated at 10 Hz repetition frequency.It will essentially be operated in one of the three modes listed in table 1.
Mode 1 corresponds to the multi-bunch operation of the storage ring . The 1 µs pulse length will fill the whole Booster circumference.In such a mode the energy spread is mainly due to transient beam loading.
Mode 2 is the single bunch operation.The 2 ns pulse length indicated here will fill one RF bucket of the Booster at injection.
The 200 Mev linac is designed in such way as to allow a possible future positron extension : It will consist in the addition of an electron to positron converter,followed by four 100 Mev accelerating sections identical to the electron linac ones.Mode 3 of the electron linac then corresponds with single bunch positron operation.

2.3 Transfer to the synchrotron

The 20 meters beam transfer line between the preinjector and the synchrotron will match the linac beam to the optical parameters of the booster and will realize the required energy selection .

Table 1
Operation modes for the 200 Mev electron linac

Mode 1	e^- multi-bunch
Peak current	50 mA
Pulse length	1 µs
Energy spread	±1 %
Mode 2	e^- single bunch
Peak current	250 mA
Pulse length	2 ns
Energy spread	±0.5 %
Mode 3	e^- single bunch for e^+ production
Peak current	2.5 A
Pulse length	2 ns
Energy spread	±5 %
Positron peak current	12 mA
Positron energy spread	±1 %

3. Booster synchrotron

3.1 Lattice

The magnet lattice structure has been designed to obtain an equilibrium emittance of the order of $10^{-7}\pi$ m.rad at extraction. Further objectives have been : minimization of the aperture requirements for the injected linac beam, a low sensivity to magnet alignment errors and space preservation for additional lattice components.
It is based on a simple separated function FODO arrangement of magnets.At three straight sections,separated by an azimuthal angle of 120 degrees,two adjacent cells with only one bending magnet create a vanishing dispersion function in the straight regions.One of these sections is dedicated to the installation of the two RF cavities whereas the two others are well suited to accomodate the injection and extraction elements.
The location of the dispersion suppressor regions generates a threefold supersymmetry of the booster.Each superperiod is composed of 39 elementary cells and is mirror symmetric with respect to its center.A normal cell is shown in figure 1, indicating the position of focusing and defocusing quadrupoles (FQ,DQ),the H-type bending magnets (B), sextupoles (DS,FS), orbit correctors (STX,STZ),vacuum pumps and beam position monitors.

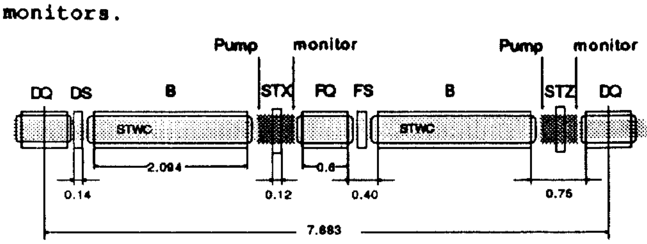


Figure 1 :Regular FODO cell of booster lattice.

3.2 Optics

The maximum of the beta functions are $\beta x = 13.4$ m and $\beta z = 13.6$ m ,whereas the dispersion function Dx varies from 80 cm down to 3 cm in the "missing magnet" region.The booster synchrotron parameters are summarised in table 2.

In order to correct the natural chromaticities $\xi x=-14.9$ and $\xi z=-12.8$, two different sextupoles families will be installed near the focusing and defocusing quadrupoles.The required correcting strengths are :

$$mL_x = 0.585\ m^{-2}\ ,\ mL_z = -0.824\ m^{-2}\quad \left(mL = \frac{L}{2B\rho}\cdot\frac{d^2B_z}{dx^2} \right)$$

Due to the time varying sextupole component induced by eddy currents in the dipole vacuum vessels,the natural chromaticities are changed at injection to $\xi x=-2.4$ and $\xi z=-26.4$ (assuming a 0.3 mm thick vacuum vessel),and the strengths required from the correcting sextupoles become $mL_x = 0.233\ m^{-2}$ and $mL_z = -1.36\ m^{-2}$.

Table 2
Parameter list for the booster synchrotron

Injection energy (Gev)	0.2 (e^-),0.4 (e^+)
Maximum energy (Gev)	6
Repetition rate (hz)	10
Harmonic number	352
Circumference (m)	299.6
Bending radius (m)	22
Number cells/superperiods	39 / 3
Tunes Qx/Qz	11.6 / 9.6
Max ßx/ßz/Dx (m)	13.4 / 13.6 / 0.8
Natural chromaticities $\xi x/\xi z$	-14.9 / -12.8
Momentum compaction	$9.6\ 10^{-3}$
Current in multibunch e^- (mA)	5

Final datas at 6 Gev :

Beam emittances (πm.rad)	$\varepsilon_x=1.2\ 10^{-7}$ (K=0)*
	$\varepsilon_z=1.0\ 10^{-8}$ (K=.3)
Energy spread (1 σ)	$1.1\ 10^{-3}$
Energy loss per turn (Mev)	5.22
RF voltage (q=1.4) (MV)	7.30
Damping times τ_x,τ_z,τ_s (ms)	2.3 / 2.3 / 1.14

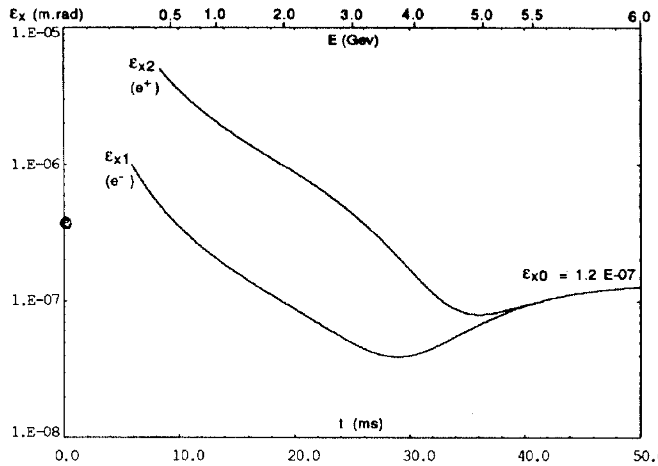
Magnet	number	strength	length	gap
Dipole	66	0.91 T	2.094 m	h=32 mm
Quadrup.	78	15.0 T/m	0.60 m	r=30 mm
Sextup.	54	143**T/m^2	0.14 m	r=30 mm
Orbit cor.	78	1.5 mrad	0.12 m	

Number of cavities	2
Number of windows/cavities	2
Nominal cavity power	235 kW
Nominal klystron power	0.8 MW

* $K = \varepsilon_z / \varepsilon_x$.

** $Gs = 1/2\ d^2B/dx^2$

The dynamic behaviour of the horizontal emittance ε_x can be described by a differential equation,which takes into account adiabatic damping and radiation excitation and damping .For both assumed electron and positron linac emittances ($\varepsilon_{x1}=10^{-6}\pi$ m.rad , $\varepsilon_{x2}=5\ 10^{-6}\pi$ m.rad) , the equilibrium emittance ($\varepsilon_x=1.2\ 10^{-7}\pi$ m.rad) is obtained at the 6 Gev extraction energy (see figure 2).



$$\frac{d\varepsilon_x}{dt} = -\varepsilon_x \left(\frac{1}{E}\cdot\frac{dE}{dt} + 2\,\alpha_x \right) + \frac{1}{2}\,\frac{\langle \mathcal{H}\, N\langle u^2\rangle\rangle}{E^2}$$

Figure 2 :transverse emittance dynamic behaviour.

3.3 Useful aperture

The physical aperture of the machine is limited by the finite size of the vacuum vessel : $a_x = 30$ mm in the focusing quadrupoles and $a_z = 14$ mm in the dipoles.With $\beta x=13.4$ m in the FQ and $\beta z=10.8$ m in the dipoles,these figures correspond to the following acceptances :
Ax = 67.2 π mm.mrad , Az = 18.1 π mm.mrad.
The useful aperture results from the intersection between the physical aperture and the "good field regions" in the magnetic elements.These good field regions ($\Delta x = 20$ mm in the dipoles and $\Delta x,z = 23$ mm in the quadrupoles) have been defined in order to get larger acceptances than the maximum foreseen emittances of the preinjector ($\varepsilon_{x,z} = 11.5\ \pi$ mm.mrad).

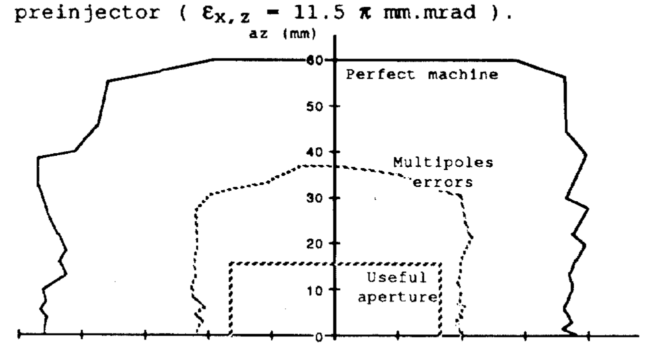


Figure 3 :Booster dynamic aperture.

The resulting figures are :

$A_x = 38.5\ \pi$ mm.mrad and $A_z = 18.1\ \pi$ mm.mrad which allow ,at injection, a 3mm maximum closed orbit errors together with a ± 2 % RF capture.

The magnetic tolerances have been set up so that the dynamic aperture is not too much reduced. Figure 3 shows the dynamic aperture which has been computed for the perfect machine and for a machine where the systematic multipole errors present in the dipoles and in the quadrupoles have been introduced .

3.4 Injection,extraction

The on-axis injection is performed in one turn using a 10° pulsed septum magnet and a 5 mrad fast kicker magnet.

After the creation of a local beam bump by 3 slow kickers, the high energy beam is extracted from the booster in one turn using a 1 mrad fast kicker and 2 septum magnets (8 mrad and 4.6°).

3.5 R.F system

Two LEP type cavities will be installed on the booster.These well studied cavities are the same as the ones which will be used on the storage ring.However some modifications are necessary such as the use of two windows per cavity to enhance the voltage per cavity from 2.43 MV to 3.65 MV.

3.6 Power supplies

The main power supplies will feed independantly the dipole circuit,the focusing quadrupole circuit and the defocusing quadrupole circuit.

The easiest way to produce the 10 Hz variation of the fields in these magnets is to excite them with biased sine wave currents :

$$I(t) = I_{DC} + I_{AC}\ \mathrm{SIN}(20\pi t)$$

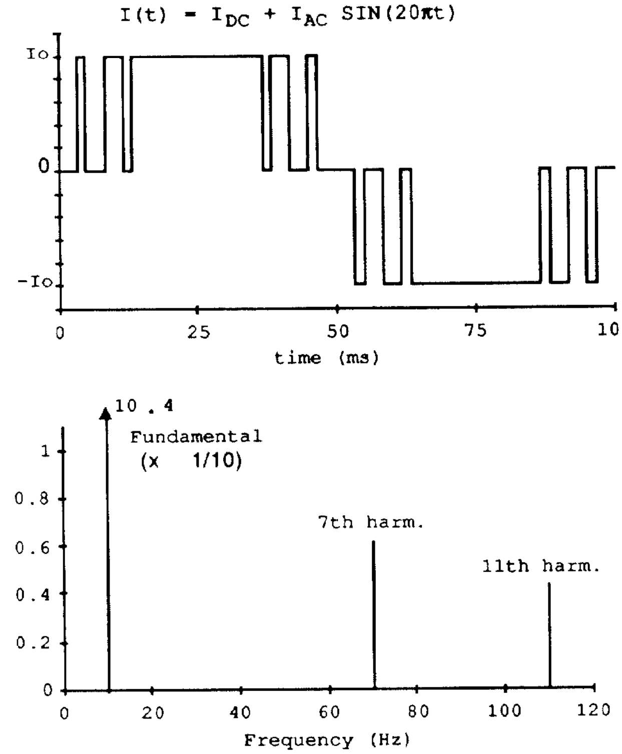


Figure 4 : 5 Pulses current pattern (upper)
Frequency response (lower)

The classical "White circuit" has been chosen to resonate the magnets because it minimizes the real and reactive power variations seen from the mains.

The 10 Hz converter is a new type one which uses a Pulse Width Modulation (PWM) current source associated with a Gate Turn Off (GTO) thyristors bridge.The main advantage of such an inverter is that it is possible to damped completely some of the most unwanted harmonics in the current flowing in the choke simply by chosing the adequate pulse pattern. Figure 4 shows the harmonic response of a five pulses pattern,as beeing choosen for the ESRF booster.

The dipole circuit will be run on its natural resonance and will be phase and amplitude wise the master of the FQ and DQ circuits.

The tracking tolerances between the dipole and quadrupoles fields have been set up in order to limit the tune change during the acceleration process to $\Delta Q \leq 0.02$ .The require figures are a phase stability of ± 3 µs and an harmonics rejection of - 74 dB from the fundamental wave form.

3.7 Vacuum vessel

The elements have been positionned in the cell in order to allow the standardization of the vacuum vessel.The half cell vacuum vessel is composed of one standard thin wall chamber (STWC),which starts at the entrance of the quadrupole,goes through the sextupole and finishes at the exit of the dipole(see figure 1).This STWC is associated with one thick wall chamber,between the dipole and the next quadrupole,where all the secondary elements (vacuum pumps,beam position monitors and orbit correctors) are to be installed and which can be easily modified from one cell to another.These two chambers are connected to earth and are isolated one from the other by the use of isolating seals in the flanges.

In order to minimize the eddy currents which will occur in the STWC, its wall thickness will be reduced down to 0.3 mm , and it will be reinforced by ribs.

4 Time schedule

The general ESRF planning requires from the injector system to be fully operationnal at the beginning of 1992.

Delivery of the linac at the ESRF site is foreseen for the end of February 1990 , and installation and commissioning will be finished by the end of July 1990.

The tender exercises for the main elements of the booster (i.e magnets,power supplies,RF cavities and transmitters,vacuum vessels) will be done before the end of this year, so that the commissioning phase could begin by the end of July 1991.