ESRF Booster Synchrotron : Characteristics and achieved performances

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1. INTRODUCTION

The injection system for the ESRF 6 Gev storage ring comprises a 200 Mev linear preinjector and a full energy fast cycling booster synchrotron. The main features of the booster, a 10 hz cycling frequency and a low natural beam emittance, were chosen to ensure a fast filling rate of the storage ring.

The commissioning of the ESRF Booster synchrotron started by the end of August 91 and was completed mid December 91, when the requested beam performances in multibunch mode (5 mA accelerated up to 6 Gev in a reproducible way) had been achieved.

2. BEAM CHARACTERISTICS FROM THE LINAC

The preinjector is a commercially available 200 Mev electron linac accelerator which was commissioned in June 91. Its beam characteristics [1] which were available during the Booster commissioning are summarized in table 1. One should notice the very low transverse emittance.

Table 1 : 200 Mev electron linac Beam performances

Operating mode	e^- multi-bunch	
Peak current	10 to 25	mA
Pulse length	1 to 1.5	µs
Energy spread	±1 to ± 2	%
Measured horizontal emittance	60 π 10-9	m.rad

3. BOOSTER SYNCHROTRON DESCRIPTION

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 (in order to minimize costs for magnets and power supplies), 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 with a vanishing dispersion function in the 3 straight sections.

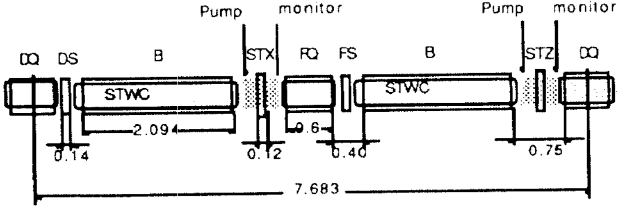

Figure 1 : Booster standard cell schematics.

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), thin wall (0.3mm) vacuum vessel (STWC), vacuum pumps and beam position monitors.

Table 2 : Parameter list for the booster synchrotron

Injection energy (Mev)	200
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 ξ_x/ξ_z	-14.9 / -12.8
Momentum compaction	9.6 10-3
Current in multibunch e- (mA)	5
Beam data at 6 Gev :	
Horizontal emittance (π m.rad)	$\varepsilon_x = 1.2 10^{-7}$
Energy spread (1 σ)	$1.1\ 10^{-3}$
Energy loss per turn (Mev)	5.22
RF voltage (q=1.4) (MV)	7.3
Damping times τ_x,τ_z,τ_s(ms)	2.3 / 2.3 / 1.14

Magnet	number	max strength		length		gap
Dipole	66	0.91	T	2.09	m	h=32 mm
Quadrup.	78	15.0	T/m	0.60	m	r=30 mm
Sextup.	54	143	T/m2	0.14	m	r=30 mm
Orbit cor.	78	1.5	mrad	0.12	m	h=70 mm

3.2 Injection, extraction

The on-axis injection is performed in one turn using a 10° pulsed septum magnet and a 5 mrad fast kicker magnet (40ns fall time). After the creation of a local beam bump by 3 slow bumpers (3 ms half sine wave), the high energy beam is extracted from the Booster in one turn using a 1 mrad fast kicker (40ns rise time) and 2 pulsed septum magnets (8 mrad and 4.6°).[2]

At extraction where no magnetic correction is possible, the closed orbit deviations are ΔX, $\Delta Z \leq 3$ mm. No further correction (as foreseen by moving the quadrupoles) has been, nor will be necessary.

4.2 Optimization of the linear focusing :

The currents and the phases of the 2 quadrupole circuits have been set in order not to be too far from the theoretical working point (Qx=11.6, Qz=9.6), to have a good injection efficiency and to minimize the loss during acceleration. At injection the machine is very sensitive to very small modifications. Figure 2 shows the decreasing of the beam current versus time for 2 slightly different quadrupole settings ($\Delta I/I=10^{-3}$). In the case where the intensity stays constant during acceleration, tune measurements show that the working point is moving parallel to the resonance line Qx+Qz=21 and is ending very close to the half integer resonance in both planes (11.3/9.8 at 5 ms to 11.48/9.55 at 50 ms).

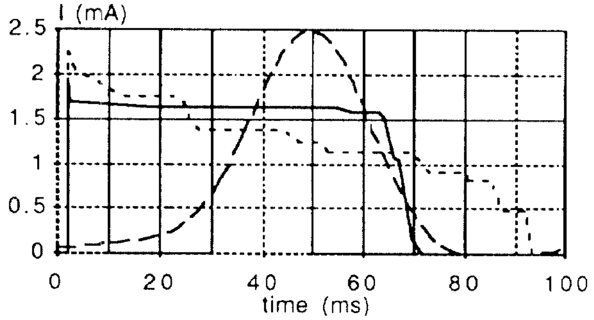

Figure 2 : Beam intensity during acceleration (2->50 ms) and deceleration for 2 different qpole settings. The RF voltage waveforme is also represented.

The injection time which determines the slope of the dipole field at injection (which could vary respectively from 0 to 5.8 ms and from 100 kG/s to 0) has been swept by varying the DC offset at injection and the optimum (i.e. the best injection efficiency) was found at 2.2 ms corresponding to dB/dt = 38 kG/s and 5% DC offset.

In these conditions there was still an important loss during the first few hundred turns (60 to 70%).Typical current values were 15 mA from the Linac, 10 mA captured at injection and 3 mA accelerated up to 6 Gev. Increasing the Linac current was not leading to a larger accelerated intensity.

The influence of the 20 hz component in the dipole field has been measured.The loss after injection can be reduced from 60 down to 40 % by damping this unwanted 2nd harmonic down to - 80db.

Due to a failure of one of the 2 Linac modulators during the course of the commissioning, injection of a 100 Mev beam has been tried and successfully realised. With 10 mA from the Linac, about 2 mA can be accelerated up to the maximum energy.

4.3 Further optimization :

To reduce the acceptance limitation of the machine at injection which, due to the large chromaticity of up to -27 in the vertical plane (taking into account the eddy current effects in the vacuum chamber) associated with the larger than expected energy dispersion in the 200 Mev beam from the Linac was leading to large tunes spread, the sextupoles have been powered with DC power supplies. The effect was not that impressive but became significant when associated to a Robinson detuning of the RF cavities thereby limiting the beam loading effect.

The best performances (9 mA accelerated up to 6 Gev with 25 mA from the Linac) were achieved with a sextupole correction associated with a slight mechanical detuning of the cavities (acting on the tuners) and a 8 khz frequency shift applied during half of the acceleration time (see figure 3). In these conditions 5.2 mA were extracted and sent into the transfer line leading to the Storage Ring, resulting in a 20% overall efficiency of the Booster.

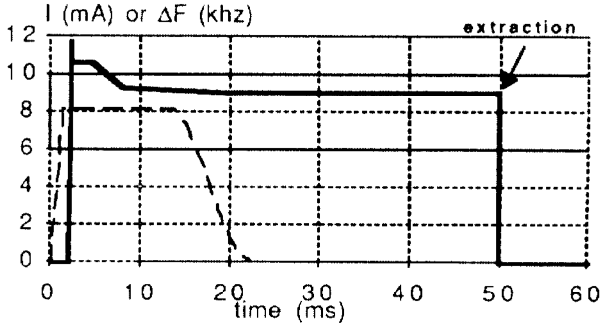

Figure 3 : Best beam intensity achieved during acceleration. The shape of the RF frequency modulation is represented.

The filling over the circumference of the machine is nearly perfect. By triggering the extraction kicker in the hole created by the fall time of the injection kicker, it is possible to get nearly a 1 μs long extracted pulse.

During the Storage Ring commissioning, the RF frequency is imposed by the bigger machine. Nevertheless, the following performances are routinely achieved :

20 mA from the Linac, 4 to 5 mA accelerated up to 6 Gev and 2 to 3 mA extracted and injected into the Storage Ring.

5. CONCLUSION

The ESRF 6 Gev injector has reached its design performance in the multibunch mode and is ready for the commissioning of the Storage Ring. Single bunch mode will be tried out during 1992.

6. REFERENCES

[1] P. Berkvens, "First beam results of the ESRF preinjector", These proceedings

[2] C. Gough and J.P. Perrine, "Injection and extraction magnets for the ESRF", These proceedings

[3] J. Jacob et al, "Commissioning and operation of one booster and two storage ring RF acceleration units at the ESRF", These proceedings

[4] K. Scheidt, "ESRF synchrotron injector beam position monitor system: concept and results", These proceedings

[5] E. Plouviez, "ESRF synchrotron injector tune monitor system: concept and results", These proceedings

[6] M. Renier, "Vacuum system of the ESRF", These proceedings

[7] W.D. Klotz, "Controlling the ESRF accelerators, status and experiences", These proceedings

3.3 R.F system

Acceleration is performed by 2 LEP type cavities, each equipped with two windows. The voltage in the cavities is pulsed at 10 hz following the law (see figure 2):

$$V(t)=V_{capt} + \alpha_1 . \frac{dE}{dt}(t) + \alpha_2 . E(t)^4 \quad ,$$

E being the e^- energy. This modulation is performed by driving the RF input power of the 1 MW klystron which feeds the 2 cavities at 352.2 Mhz. The total power varies from 300 W at capture up to 550 kW at the end of the acceleration. The peak voltage in each cavity is 3.65 MV.[3]

Detuning of the cavities has been used either by acting on the tuners or by shifting the frequency of the master source.

3.4 Power supplies

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

The 10 Hz variation of the fields in these magnets is created by biased sine wave currents :

$$I(t) = I_{DC} - I_{AC} \cos(20\pi t)$$

with

Magnet	I_{DC}	I_{AC}
Dipole	800 A	800 A
Focusing Quad	250 A	250 A
Defocusing Quad	250 A	250 A

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

The 10 Hz inverter is a Pulse Width Modulation (PWM) current source driven by a Gate Turn Off (GTO) thyristors bridge. With the selected pulse pattern, the production of the harmonics is rather low. All harmonics measured on the field are 75 db below the fundamental except the 2nd which, due to saturation either in the magnets or in the "white chokes", reaches 60 db in the dipoles and 70 db in the quadrupoles. Nevertheless compensation of this 2nd harmonic has already been succesfully performed (down to -80 db) on the dipole circuit by modulating the active filter of the DC converter.

The 2 quadrupole circuits are frequency and phase locked on the dipole circuit which, running on its natural resonance, is the "heart" of the 10 hz timing system. With the very acurrate zero cross detection system which has been developped (operating on signals from sensing coils installed in the gaps of the magnets), the phase stability of the 2 quadrupole circuits relative to the dipole circuit is routinely maintained within ± 3 µs. The injection and extraction processes are presently synchronized on the zero cross detection of the dipole field. Synchronisation of the injection process on a "peaking strip" detection has also been sucessfully tested and will be soon implemented definitively.

3.5 Diagnostics

The main diagnostic is the Beam Position Monitor system which measures the beam positions at the 75 locations where the BPM (consisting out of 4 button electrodes) are installed. These measurements (performed on the 352.2 Mhz signals) enable an application program to compute and draw the closed orbit errors at any time during the acceleration cycle. Each BPM block has been aligned relative to the next quadrupole. The absolute accuracy of the full system is better than 1 mm.[4]

8 fluorescent screens spread over the machine circumference can be inserted to check the progression of the beam during the first turn. The same movable fluorescent screens are used on the 2 transfer lines to center the beam all along.

The beam intensity is measured by a current transformer which has a band pass from DC to 100 khz.

The tunes are measured using a tune monitoring system which frequency analyses the beam response to an HF excitation created by 2 "shakers" (H or V).[5]

3.6 Vacuum system

The Stainless Steel vacuum chamber of the Booster is mainly composed of long thin wall vessels (0.3 mm thick) installed in the gaps of the magnets, coupled to short thick vessels where the 80 ion pumps (45l/s) are located. The UHV conditions imposed during the manufacturing process, associated with the distributed pumping are the reasons for the good static pressure ($\leq 10^{-8}$ mbar) which is achieved over 3/4 of the ring without any bake-out. Nevertheless due to the presence in the vacuum system of the laminated septum magnets, the pressure reaches 5 10^{-7} mbar in the extraction region. At the end of a full run with beam (10h), the pressure in the whole ring is in the few 10^{-7} mbar range, which can't affect the machine performances.[6]

3.7 control system

All Booster equipments are remotely controlled from a central control room. The architecture of the control system is based on a large number of VME controllers located close to the equipments and in which, devices servers are running under OS9. These VME's are linked via Ethernet to HP computers and working stations in which the application programmes (the user interface) are running under UNIX.[7]

4. PERFORMANCES ACHIEVED DURING THE COMMISSIONING PHASE

4.1 Operation in DC and closed orbit correction:

At the very beginning of the commissioning, the Booster has been operated in DC at 200 Mev. With 10 mA from the Linac, 5 mA was captured in the Booster with about 200 W RF power and after 100 ms the stored intensity was still 3 mA leading to a lifetime of a few seconds.

This was achieved without any closed orbit correction, demonstrating that the magnets are quite well aligned (this means that the magnetic measurements were efficient and that the alignment was achieved well within the tolerances).

At injection, the uncorrected closed orbit deviations are ΔX, $\Delta Z \leq 8$ mm. After correction, using the DC steerers, the machine operates with $\Delta X \leq 2$ mm, $\Delta Z \leq 4$ mm.