CHAPTER 36

LINAC3-LEIR-PS LINES

36.1 OVERVIEW AND LAYOUT

The Linac3-LEIR-PS transfer lines transport the beam from Linac 3 to the LEIR injection and, after accumulation and acceleration, from the LEIR extraction to the PS. The existing transfer lines (used in the past to transfer antiprotons from the PS to LEAR and protons and ions from the linacs to LEAR) are not compatible with the LEIR requirements since :

- A part of the line (namely the ETL line) will be used both for LEIR injection and LEIR extraction, but in opposite direction (Fig. 36.1 shows the new layout and definition of acronyms). Furthermore, the beam rigidity for these two operations differs by a factor of about 4 (in case of Pb ions). Therefore, all magnets in this common line ETL (including ITE.BHN40) must be pulsed and feature laminated yokes.
- For beams extracted from LEIR and transferred to the PS, the new transfer line must cope with an increased beam rigidity of 4.8 Tm, not compatible with the available strength of some magnets of the existing lines.
- The LEIR injection and extraction systems will be completely rebuilt, requiring reconstruction of the EI and EE lines as well.

Thus, a significant part of the transfer lines connecting Linac 3, LEIR and the PS has to be reconstructed to meet the new requirements.

Most of the ITE loop can be recuperated from the previous line. As already mentioned above, only the last dipole ITE.BHN40 must be replaced by a laminated magnet. A quadrupole will be added for a better control of the matching in the last part of the transfer line towards the PS (ETP line). The ETL line has to be constructed from scratch, primarily to replace solid-core magnets by laminated ones, allowing pulsing between injection and extraction. Polarity changes of the power supplies of the bending magnets are unavoidable (except ETL.BHN20). Naively, one would assume that the ETL line quadrupoles also have to change their polarity. However, by a clever design of both the injection and the extraction optics, none of the quadrupole power supplies has to be bipolar.

The LEIR machine is be located at a level 40 cm higher than Linac 3 and the PS machine. In order to bring the beam from one level to the other, a long part of the ETL line has a slope of about 9 mrad (upwards for the beam transferred towards LEIR) produced by two vertical bending magnets.

The special injection process requires a tilted electrostatic injection septum. Thus, the beam will undergo an unavoidable vertical deflection in this injection septum. This implies a slope of the magnetic septum installed upstream from the electrostatic septum and complicates geometry of the injection EI line upstream of the injection region. Two additional vertical bending magnets will be installed to provide the correct vertical position and slope at the entrance to the two (upright magnetic and tilted electrostatic) septa.

An additional requirement for the optics design of the extraction line was to allow emittance measurements with the “3 profile monitor” method. To this end, three appropriate locations (with suitable betatron phase advances in both planes) to install Secondary Emission Monitors have been determined in the ETL line.

36.2 OPTICS

The optics presented in this section is an updated version of the one described in [1], taking small changes of the geometry into account.

The injection line considered here starts at a hand-over point located inside the shielding wall separating the Linac 3 from the PS tunnel (see Fig. 36.1). Two quadrupole triplets, belonging to the Linac3 transfer line IT and located between the hand-over point and the first bend of the ITE line, have been integrated into the modelling of the injection, in order to adjust the matching at the entrance into the loop ITE. At the end of the line at the LEIR injection, a moderate (by a factor of about 1/2) betatron mismatch w.r.t. the beam circulating in LEIR enhances the multi-turn injection efficiency. A very stringent requirement is that the dispersion of the beam arriving in the LEIR machine must vanish (note that the LEIR machine itself has a relatively large dispersion of about 10 m at the injection point). Otherwise the arriving beam would move during one linac pulse due to the momentum ramping and, thus, a finite dispersion is not compatible with the special injection process. The line has been matched to $\beta_H = 1$ m, $\beta_V = 2$ m and $D = 0$ m.

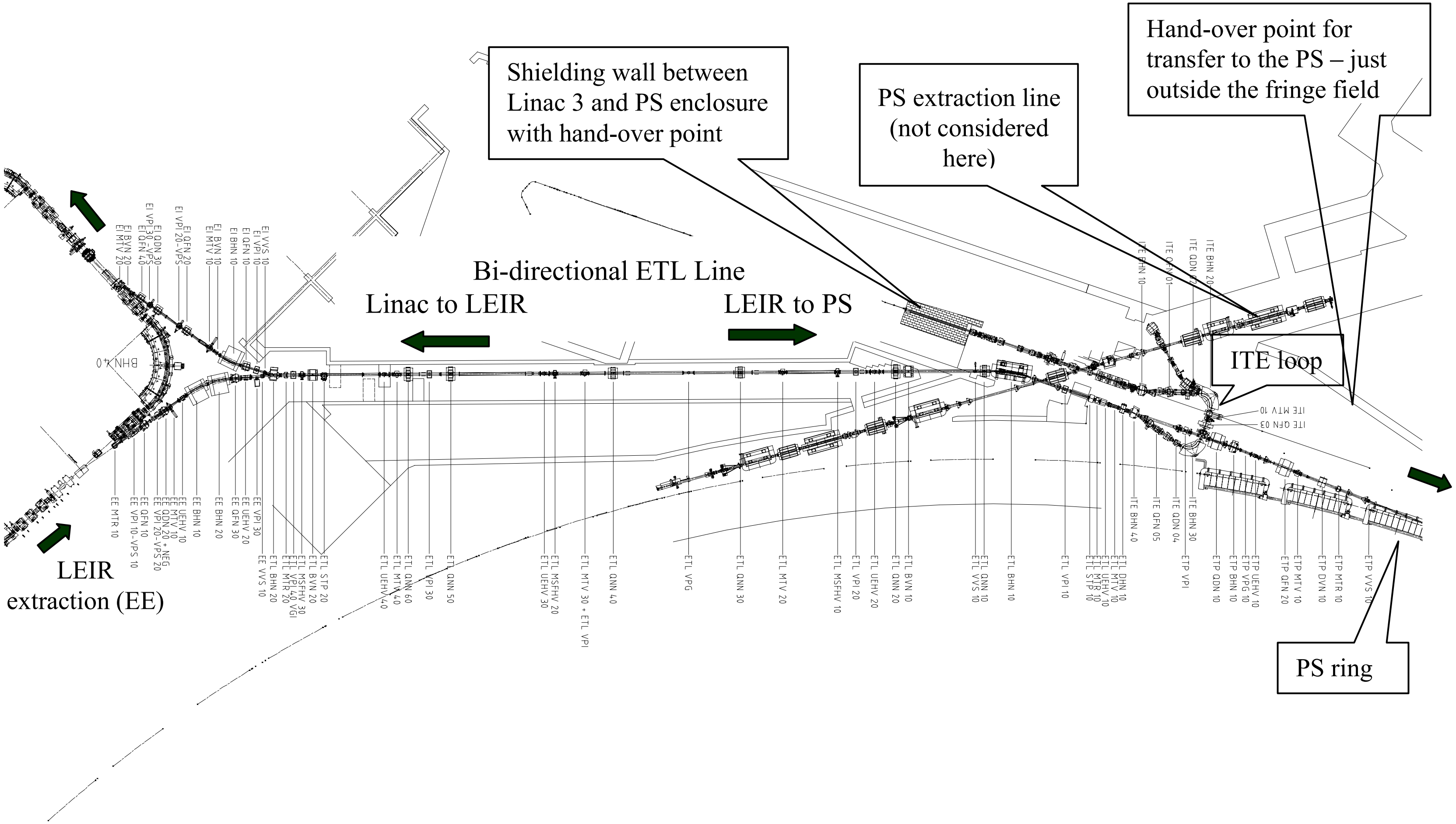

Figure 36.1: Geometry of the Linac3 , LEIR and PS accelerators and the transfer lines between them.

The extraction line considered here starts at the centre of the LEIR extraction section (with $\beta_H = \beta_V = 5$ m and $D = 0$ m) and ends at a hand-over point just outside the stray field of one of the PS main bending magnets. The Twiss parameters at this hand-over have been determined by tracking the PS lattice functions at the centre of the injection section through the main magnet fringe field using a transfer matrix given in reference [2].

In order to limit the number of bipolar power supplies necessary for the ETL line, the optics of the line has been designed in such a manner that the polarity of the quadrupole power supplies does not change between injection and extraction. Since the beam travels through this line in opposite directions for injection and extraction, the gradients used in a beam optics program have to change sign, i.e. a quadrupole focusing for injection becomes defocusing for extraction and vice versa.

Lattice functions along the line for transfer from Linac3 to the LEIR machine are shown in Fig. 36.2. Two triplets in the IT line (belonging to Linac3) allow matching of the beam at the entrance of the loop ITE. Inside this loop (which changes the beam direction by 180° and directs the beam towards LEIR), the lattice functions are symmetric. In order to achieve vanishing dispersion at injection, a relatively large betatron phase advance in the ETL line is necessary, giving rise to fairly large fluctuations of the betatron functions and small spot-sizes at some locations. The last triplet in the EI line has been shifted as close as possible to the injection septa, in order to facilitate focusing the beam at the injection point. The space occupied by the beam (assuming a perfect trajectory) is depicted in Fig. 36.3 for relative momentum offsets of -2 ‰ and 2 ‰[1], corresponding to the beginning and the end of the injection. The beam parameters used for the computation are transverse physical RMS emittances of $\varepsilon_H = \varepsilon_V = 2.5$ µm and an RMS relative momentum spread $\sigma_p/p = 0.2\times10^{-3}$.

Lattice functions along the extraction line are shown in Fig. 36.4. The most delicate location is around the doublet at the very beginning of the line, where the extracted beam has to be refocused. The first quadrupole EE.QFN10 has been shifted as close as possible to the extraction septum. The position of the second quadrupole EE.QDN20 is a compromise avoiding excessive gradients of both quadrupoles on the one hand and large vertical betatron functions on the other hand. Rather smooth FODO like focusing has been achieved in the ETL line. Two quadrupoles (one more than in the line previously installed at this location) are available in the ETP line and allow matching the beam to the PS while keeping the betatron functions at moderate levels. The space occupied by the beam, assuming transverse physical RMS emittances of $\varepsilon_H = \varepsilon_V = 1.75$ µm and an RMS relative momentum spread of $\sigma_p/p = 0.7\times10^{-3}$, is depicted in Fig. 36.5. Magnet parameters (e.g. strengths and currents) are given Tab. 36.1 and Tab. 36.2.

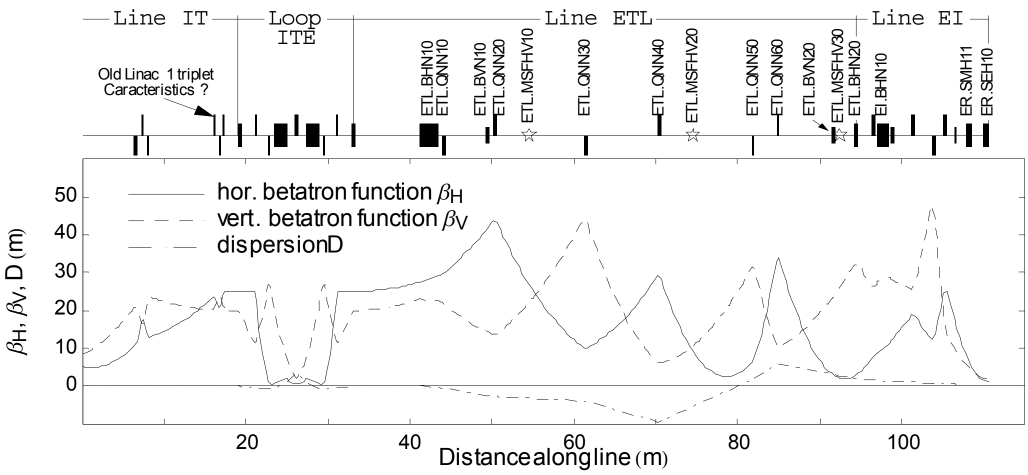

Figure 36.2 : Optics functions along the line for beam transfer from the ion Linac 3 to LEIR injection.

---

[1] This momentum range translates to a momentum ramp between about -1 ‰ and 3 ‰ in the LEIR machine.

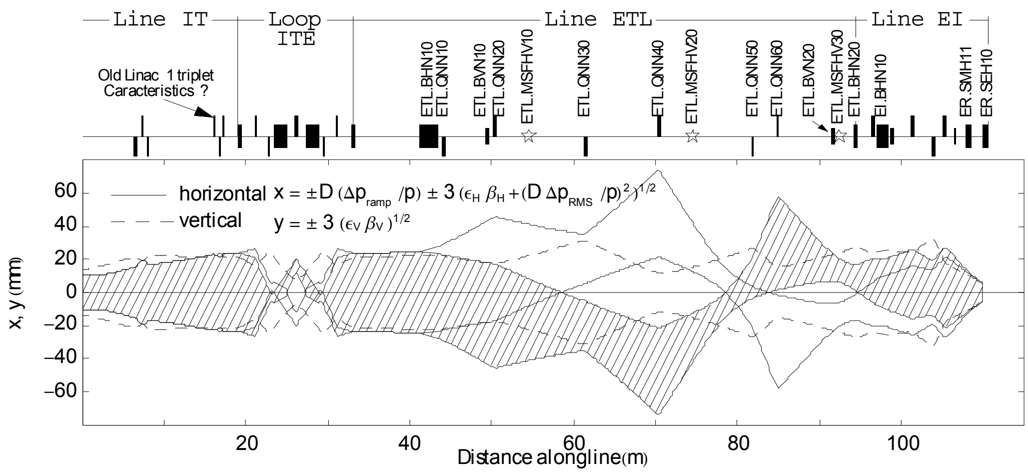

Figure 36.3 : 3 σ size of the beam transferred from ion Linac 3 to LEIR injection. The hatched area shows the horizontal beam size for a momentum offset of 2 ‰.

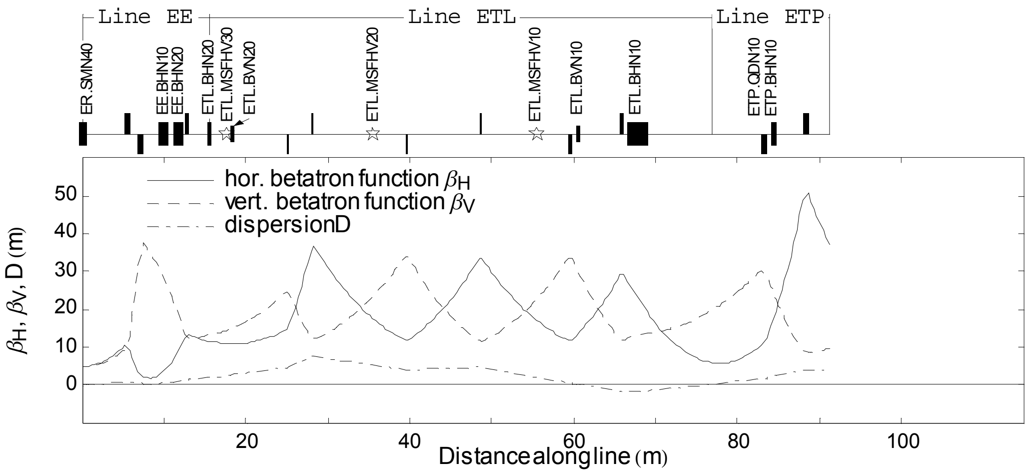

Figure 36.4 : Optics functions along the line from LEIR extraction to PS injection.

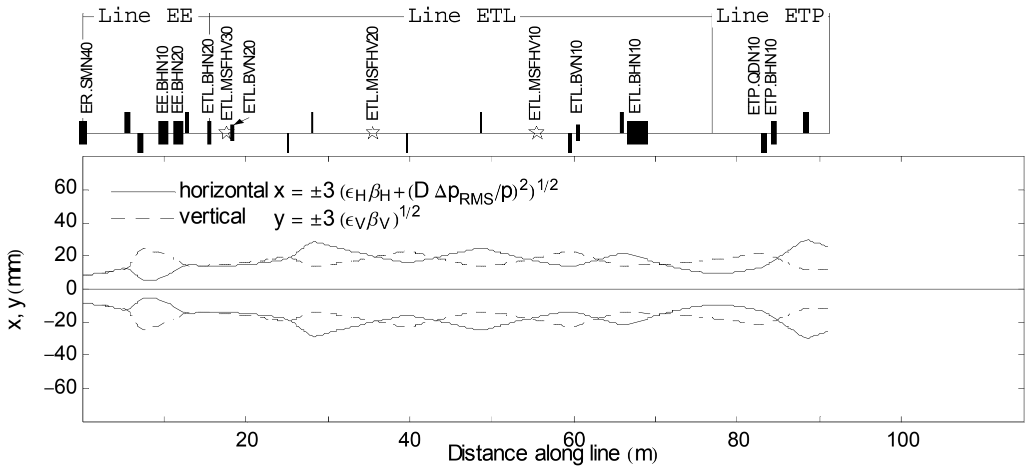

Figure 36.5 : 3 σ size of the beam transferred from LEIR extraction to PS injection.

Table 36.1 : Characteristics of the Linac 3 – LEIR – PS transfer line quadrupoles.

			Injection		Extraction			
Quadrupole	Type	L_{Mag} (m)	Strength $k \times L_{Mag}$ (m^{-1})	I (A)	Strength $k \times L_{Mag}$ (m^{-1})	I (A)	R (Ohm)	L (H)
IT.QN08/10	Linac 7	0.255	-0.2583	72.74	not used		0.068	0.00122
IT.QN09	Linac 7	0.255	0.4960	139.67	not used		0.068	0.00122
IT.QN11/13	Unknown	Unknown	0.1801	Unknown	not used			
IT.QN12	Unknown	Unknown	-0.3371	Unknown	not used			
ITE.QFN01	Linac 7	0.255	0.5098	143.58	not used		0.068	0.00122
ITE.QDN02	Linac 7	0.255	-0.5088	143.27	not used		0.068	0.00122
ITE.QFN03	Q22	0.326	1.2143	129.43	not used		0.21	0.060
ITE.QDN04	Linac 7	0.255	-0.5088	143.27	not used		0.068	0.00122
ITE.QFN05	Linac 7	0.255	0.5098	143.58	not used		0.068	0.00122
ETL.QNN10	QTN	0.385	-0.0176	1.457	0.1353	47.28	0.23	0.20
ETL.QNN20	QTN	0.385	0.0854	7.073	-0.1192	41.67	0.23	0.20
ETL.QNN30	QTS	0.385	-0.1239	10.266	0.1003	35.05	0.25	0.31
ETL.QNN40	QTS	0.385	0.1694	14.035	-0.0994	34.74	0.25	0.31
ETL.QNN50	QTS	0.385	-0.2199	18.22	0.1724	60.26	0.25	0.31
ETL.QNN60	QTN	0.385	0.3127	25.90	-0.1475	51.55	0.23	0.20
EI.QFN10	air cooled SMIT (PSB)	0.462	0.1338	4.642	not used		0.95	0.31
EI.QFN20	air cooled SMIT (PSB)	0.462	0.1837	6.373	not used		0.95	0.31
EI.QDN30	water cooled SMIT (PSB)	0.462	-0.4541	44.69	not used		0.20	0.04
EI.QFN40	water cooled SMIT (PSB)	0.462	0.4408	43.39	not used		0.20	0.04
EE.QFN10	QLC	0.499	not used		0.4495	687.1	0.09	0.00072
EE.QDN20	QLC	0.499	not used		-0.3505	535.2	0.09	0.00072
EE.QFN30	QLC	0.499	not used		0.2353	359.1	0.09	0.00072
ETP.QDN10	Q500	0.656	not used		-0.1356	37.83	0.0195	0.254
ETP.QFN20	Q500	0.656	not used		0.1673	46.68	0.0195	0.254

36.3 MAGNETS

As mentioned in Sec. 36.1, a major part of the transfer lines between Linac3, LEIR and the PS have to be rebuilt in order to satisfy the requirements of the I-LHC project. To this end, a large number of the existing magnets have to be replaced. Fortunately, it has been possible to find nearly all required magnets within CERN, thus reducing cost. They have been recuperated from other accelerators and transfer lines. Before installation in the tunnel, all recuperated magnets will be carefully refurbished and upgraded if necessary. In total, around 30 magnets have to be repaired and modified until the end of 2004. The refurbishment typically includes:

- Visual inspection.
- Insulation tests, leakage tests and water flow measurements.
- Cleaning of yoke and coils.
- Repair of degraded coil clamps (usually polyurethane pads).
- Modification and upgrade of the cooling circuit: replacement of rubber hoses by stainless steel tubes and glass fibre insulators (if applicable).

- Replacement of Thermo-switches.
- Final tests (insulation resistance, leakage, water flow, interlock).

The modifications of each part of the transfer line (the magnets are compiled in Tab. 36.1 and Tab. 36.2) are described in detail below.

Table 36.2: Characteristics of the Linac 3 – LEIR – PS transfer line deflection magnets (dipoles and septa).

			Injection		Extraction			
Bending	Type	L_{Mag} (m)	α	I (A)	α	I (A)	R (Ohm)	L (H)
ITE.BHN10	Special	0.48	-16°	736.3	not used		0.012	0.006
ITE.BHN20	Special	0.80×106°	106°	928.6	not used		0.040	0.10
ITE.BHN30	Special	0.80×106°	106°	928.6	not used		0.040	0.10
ITE.BHN40	Special	0.48	-16°	736.3	not used		0.012	0.006
ETL.BHN10	VB4	2.34	-336.75mrad	-68.21	336.75mrad	289.09	0.15	0.47
ETL.BVN10	MEA43	0.558	9.56 mrad (upwards)	-8.77	9.56 mrad (upwards)	37.00	0.33	0.31
ETL.BVN20	MEA43	0.558	-9.56 mrad (downwards)	-8.77	-9.56 mrad (downwards)	37.00	0.33	0.31
ETL.BHN20	Special	0.610	17°	195.3	4.5°	217.3	0.166	0.080
EI.BHN10	MC100	1.175	330.03	160.8	not used		0.18	0.22
EI.BVN10	PSB type A water cooled	0.350	7.86 mrad	34.1	not used		0.075	0.003
EI.BVN20	PSB type A water cooled	0.350	-22.08 mrad	95.4	not used		0.075	0.003
ER.SMH11	Special	0.825	175 mrad	1055	not used		0.0115	0.000315
ER.SMH40	Special	0.850	not used		130 mrad	30400	0.00015	2.7×10^{-6}
EE.BHN10	MC100	1.175	not used		267.76 mrad	556.8	0.18	0.22
EE.BHN20	MC100	1.175	not used		267.76 mrad	556.8	0.18	0.22
ETP.BHN10	Special	0.48	not used		47.88 mrad	531	0.012	0.006

36.3.1 ITE Loop (former E0 Line)

This line will keep its present configuration and will remain unmodified apart from the last magnet ITE.BHN40. Since both the injected and the extracted beam have to pass through this bending magnet, the currently installed magnet cannot be re-used due to its massive yoke. It will be replaced by a new laminated magnet which is under construction in industry. The magnetic characteristics will be identical to the massive magnet; only a few modifications and improvements to facilitate the maintenance as well as the mounting of the coils and the vacuum chamber are planned. In fact, this laminated M16 dipole is the only magnet which could not be found at CERN and which has to be fabricated. The quadrupole of type Q22-01 in position ITE.QFN03 will be replaced by a refurbished magnet of the same type.

36.3.2 ETL Line (former E2 Line)

As mentioned earlier, all massive magnets currently installed in this transfer line have to be replaced by magnets with laminated yokes to cope with the new requirements. The former E2.BHN02 has been taken out due to lack of strength and has been replaced by a bending magnet of type VB4. This magnet has been modified (rotated by 90˚) and completely rebuilt; all rubber hoses have been replaced by stainless steel pipes. Recuperated and upgraded quadrupoles of type QTN will be installed on positions ETL.QNN10, ETL.QNN20 and ETL.QNN60, those of type QTS at positions ETL.QNN30, ETL.QNN40 and ETL.QNN50 during the winter shut-down 2003-04. They all have been equipped with new stainless steel cooling circuits. Two magnets of type MEA43 will be installed at positions ETL.BVN10 and ETL.BVN20 to bring the beam from the Linac3 – PS level to the LEIR level and vice versa. Their maintenance and installation is planned for 2004. At the end of the ETL line, where the line splits up into the EI (injection) line to LEIR and the EE (extraction) line coming from LEIR, the bending magnet recuperated from the former position E2.BHN02 will be installed. Since the coil insulation is in a rather doubtful condition, the replacement of the coils is being considered.

36.3.3 EI and EE Lines

Magnets for both the injection and the extraction lines do not need to be laminated. Nevertheless, a reshuffling and upgrade of both EI and EE lines is required. Four massive quadrupoles of type SMIT recuperated from the former PSB injection line have been refurbished. Two air-cooled SMIT will be installed in EI.QFN10 and EI.QFN20, whereas the two water-cooled magnets of the same type will be placed at EI.QDN30 and EI.QDN40. Three massive bending dipoles of type MC100 will be placed on EI.BHN10, EE.BHN10 and EE.BHN20. All three magnets will be equipped with new stainless steel water pipes. The vertical deflection of the inclined injection septum leads to the need for two vertical bending magnets in the injection line. Water cooled "type A" dipoles, originally constructed for the PSB transfer lines, are recuperated and will be installed in positions EI.BVN10 and EI.BVN20, respectively. Three quadrupoles of type QLC currently installed in both lines will be taken out, refurbished and re-installed in the extraction line during 2004 (EE.QFN10, EE.QDN20 and EE.QFN30).

36.3.4 ETP Line

The modification of the ETP line includes the installation of two refurbished quadrupoles of type Q500 (ETP.QDN10 and ETP.QFN20) and one massive bending magnet of type M16, which has been taken from ITE.BHN40 (see above) to replace an obsolete magnet of type MNPA50 previously situated at ETP.BHN10. The MNPA25 type magnet presently installed at ETP.DVN10 will remain as corrector magnet on its current position.

36.4 POWER CONVERTERS

New and upgraded power converters are required for the Linac3 – LEIR – PS transfer lines. Their description is included in Chap. 35 (on the LEIR machine) in Tab. 35.17 and Sec. 35.8.6.

36.5 INSTRUMENTATION

The beam pulse coming from Linac 3 has a length of up to 450 μs (out of this maximum length, only a part of ~200 μs will be injected into LEIR). Its intensity will be upgraded from 25 μA at present to 50 μA at the start of LEIR. The nominal Pb^{54+} beam extracted from LEIR is composed of two bunches each one 200ns long and with a maximum intensity of 5×10^{10} charges.

36.5.1 Intensity Measurements

The intensity of the beam transferred from Linac3 to LEIR will be monitored using two existing transformers (ITH.MTR41 and EI.MTR10). Two existing transformers will be refurbished (EE.MTR10 and ETP.MTR10) and 3 additional transformers are available in the PS for observing the beam extracted from LEIR and transferred to the PS,. Two transformers will be installed in the common injection/ejection line and will therefore see both beams (ETL.MTR10 and ETL.MTR20). Due to the different pulse length (up to 450 μs at injection, 200 ns at ejection) different analogue treatment is needed. Three amplifier chains will be provided: one for the slow injected beam and two chains with different gains for the fast ejected pulse. Tests have been made confirming that this scheme is feasible. Each transformer will be equipped with a fast sampling ADC where the injected beam will be sampled at 10 MHz while the ejected one will use a sampling frequency of 100 MHz (yielding about 20 samples per bunch). Each of the transformers is equipped with a calibration winding generating a calibration pulse in front of each beam pulse to be measured. The digital pulse form will be available as well as the digitally integrated total charge in the bunch.

36.5.2 Trajectory Measurements

Owing to the very low intensity of the ions, no pick-up stations will be available to measure the position of the beam transferred from Linac3 to LEIR. Thus, the seven scintillating screens (see also Sec. 36.5.3) must be used to determine the trajectory as well.

For ejection trajectory measurements, seven pick-up stations (H+V), the same number as before, in the transfer line (2 EE, 4 ETL and 1 ETP) to the PS are used. The pick-ups consist of 1 Σ-electrode and 2 Δ-electrodes formed from stainless steel sheets. Four of them have to be rebuilt as they have been taken for the AD. The front-end electronics is obsolete and new head amplifiers will have to be developed. The present acquisition chain (analogue integrators followed by slow digitisation) will be replaced by a system using fast digitisation (100 MH) and digital integration as in other transfer lines of the PS complex. Details are given in Tab. 36.3.

Table 36.3: Characteristics of the seven Pick-ups in the line from LEIR to PS.

Pick-up diameter	140/172/243	mm
Electrical length (H, V) / Σ	71 / 53	mm
Capacity	200	pF
Position resolution for a bunch of 10^9 charges, 200ns	1.0	mm
Position resolution for a bunch $\geq 10^{10}$ charges, 200ns	0.1	mm
Relative precision	1	%

36.5.3 Beam Size Measurements.

A total of 9 TV stations will be installed in the Linac3 – LEIR – PS transfer lines. Each TV station will consist of a scintillating screen with its associated in/out mechanism, a TV camera and the necessary control electronics. VME based control and acquisition modules will contain everything needed to control the camera and the in/out mechanism and will also provide a frame grabber for digitization of the video image. CCD cameras will be used wherever the radiation level permits.

These 9 TV stations will be installed as follows :

- ITE loop :
  One TV station will be installed and replace a SEMGrid currently installed there.
- ETL line :
  Four TV stations will be installed in the ETL line to observe the injected and the extracted beam. In order to observe the beam extracted from LEIR, the support mechanism must allow the scintillating screen to be inserted between the last injection and the extraction and to retract it again before the next injection (in and out movement of the scintillating screen within about 1 s).
- EI line :
  Two TV stations will be installed in the EI line.
- EE line :
  One TV station will be available in the EE line.
- ETP line :
  One TV station will be installed in the ETP line.

In order to measure the emittance of the ion beam prepared in LEIR using the "3 profile method", three new secondary emission monitor stations (each one equipped with two sets of wires, allowing the horizontal and vertical profile to be measured) will be built and installed at suitable locations.

REFERENCES

[1] C. Carli, M. Chanel, J.-Y. Hémery, *Design of the LEIR Transfer Lines,* PS/AE Note 2002-218 and PIL/LEIR Note 011.

[2] G. Tranquille, Input File for Beam Optics Simulations of the Transfer of Antiprotons from the PS to LEAR.