PS/RF/Note 97-12 (MD)
12 August 1997

EVOLUTION OF LINAC2 BEAM PERFORMANCE AND RELIABILITY OF THE LINAC EMITTANCE MEASUREMENT

M. Vretenar

1. IMPROVEMENT OF LINAC2 PERFORMANCE SINCE 1992

As linkman to the PS Performance Committee, I have been taking statistics of the Linac2 beam performance since 1993. This means going through the measurements of transverse emittances and energy spread done in principle every Monday by the SM when he starts his week, and averaging the measured values over the year (or part of it). Typical operational currents at the transformer before the PSB (TRA60) are also regularly registered in the Logs and considered in the statistics. The measurements are taken on standard users, and not on the high intensity beam that is being prepared for LHC, for which a further increase in beam intensity of about 20% is obtained by rising the source arc current.

The Linac2 average performance from 1992 to 1997 (for 1996 and 1997 the averages are done for the first and second half of the year run) is reported in Table 1 and Figure 1. We see a clear progress in both current and emittance, which can be linked to the main improvements to Linac2, introduced over the last years, i.e.:

- Shutdown 1993: replacement of the 750kV pre-accelerator with the RFQ2.
- Shutdown 1994: re-alignment of RFQ2 and source with respect to the linac.
- June 1996: introduction of the new optics in the transfer line LTB.
- May 1997: re-conditioning of the RFQ2 to a higher voltage.

In parallel, more activity was going on, in order to allow a better understanding of the linac parameter space, and practically at every start-up the linac was re-optimised to a new parameter setting.

The improvement in performance is so impressive (20% increase in current and about a factor 2 smaller transverse emittance between 1993 and 1997) that some doubts can reasonably arise on the reliability of the emittance measurement, considering that in the same period the PSB did not see any particular improvement. The increase in current on the contrary is very clear and strictly related to the higher current capability of the new RFQ injector.

This note is intended to make a survey of our data and to serve as basis for further discussion. The reliability of the Linac2 emittance measurements is also analysed, and some specific measurements done in order to get a better understanding of the emittance measurement accuracy are reported.

	Current TRA60	Emittance H	Emittance V	Comments	Source of data
	[mA]	[rms,norm,µm]	[rms,norm,µm]		
1992	140	1.5	1.4	old injector	PPD93
1993	135	1.4	1.3	RFQ2 installed	
1994	135	1.7	1.2		PPD95
1995	142	1.1	0.8	re-alignment LEBT+RFQ2	PPD96
1996/I	140	0.8	0.4		Logs
1996/II	145	0.6	0.4	new optics for LTB	Logs
1997/I	145	0.6	0.5		Logs
1997/II	160	0.6	0.5	new setting for RFQ2	Logs

Table 1: Linac2 Performance over the last 5 years

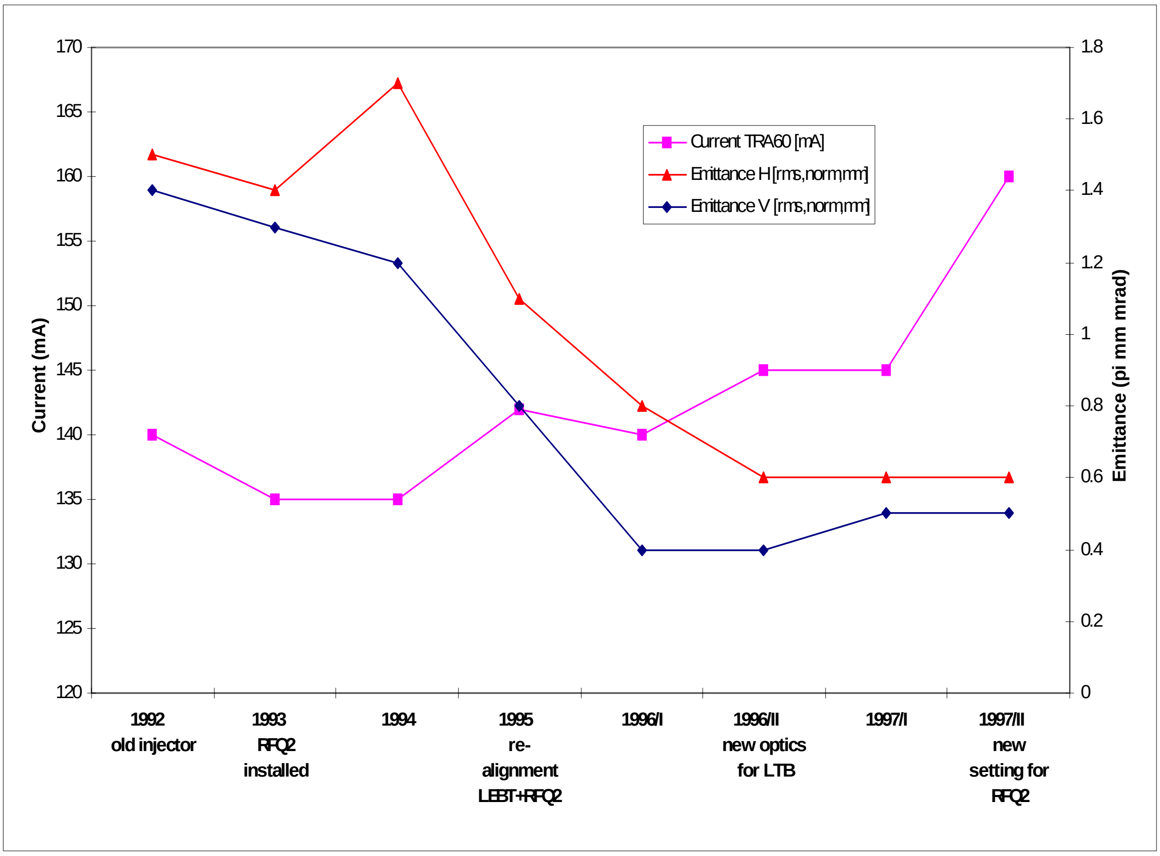
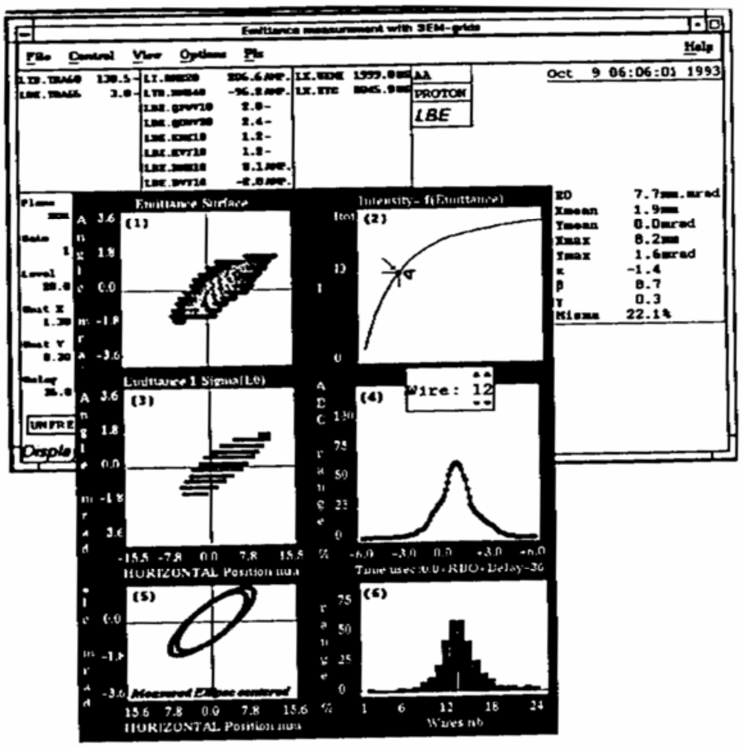


Fig.1: Measured Linac2 Performance in the period 1992-1997

The reduction of the linac emittance can be seen in Figure 2 showing two typical measurements of horizontal emittance, one done in October 1993 and the other in August 1997. The 1997 emittance is smaller by about a factor 2. The current as function of the emittance, I = f(ε), is shown in both measurement windows and indicates that the beam is more dense now than 4 years ago.

9.10.1993
ε = 7.7 π mm mrad



1.8.1997
ε = 3.7 π mm mrad

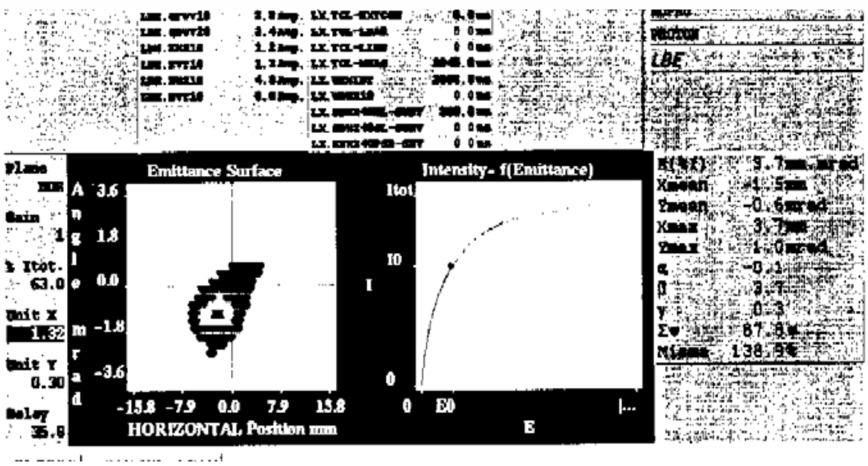


Figure 2: Typical LBE Horizontal Emittance in 1993 (top) and 1997 (bottom)

The emittance is measured in a dedicated line, LBE. The emittance value that the measurement window indicates is the area of the ellipse (unnormalised) containing 63% of the beam. The rms-normalised emittance is obtained dividing it by 2 (ratio between 63% area and rms area for a bi-Gaussian distribution) and multiplying it by the normalisation factor 0.33 ($\beta\gamma$ at 50 MeV). This gives an overall scaling factor of 0.165.

Accordingly to the more recent emittance measurements, the overall emittance growth in the linac, from the source to the entrance of the PSB, would be of the order of 50%, in good agreement with the calculations of PARMILA.

2. ERROR SOURCES IN THE LBE MESUREMENT

The LBE line is positioned at the end of the linac/booster transfer line. A pulsed magnet sends a beam pulse into the line, and then a kicker sweeps the beam in front of a slit, which defines the position. A SEMgrid placed after the slit collects the remaining particles, determining the divergence. The emittance image is recomposed by software that plots the intensity (signal on the SEMgrid wires) as function of wire number and sampled time (the kicker transforms the position into time). It then calculates the area of the ellipse containing 63% of the total current falling on the wires. Two different sets kicker/slit/SEM grid are used to measure horizontal and vertical emittance [1] [2].

The following is a list of possible error sources for this measurement :

1. The *calibration of position*, i.e. the calibration of the kicker voltage: this is the possible main source of errors. The system does not acquire the kicker current but directly the current induced by the varying magnetic field on a loop inside the kicker. The loops and their electronics are the same since many years, and there is no evidence that the loops have changed position inside the magnet. The zero crossing of the kicker field automatically triggers the measurement timing.
2. The *calibration of divergence* corresponds to the physical spacing of the wires. The SEMgrids are the same since a long time, and they cannot be rotated.
3. The *intensity of the beam in the measurement line and the form of the emittance*: if the intensity is too low, the emittance spot shrinks, and the calculation of the 63% area, if still in principle correct, is less precise. Likewise, the accuracy of the calculation is reduced if the emittance is small in position or in divergence (covers few wires or sampling times). To check these effects, a measurement was done decreasing gradually the x-scale, to obtain an emittance covering only few steps in x: the measured emittance value changed by only 5%. In the case the spot becomes too small, the wire amplifier gain is usually increased, to obtain again a reasonable spot.
4. The *gain of the amplifiers*: if too high, the beam signal can go into saturation and the emittance calculation becomes wrong. In this case a red spot appears at the centre of the emittance, usually detected by the person doing the measurement. If just one or two red points appear in the emittance, then a small error of few percent can be introduced in the emittance measurement. When the amplifiers are not in saturation, the calculation of the emittance is independent of the gain. Some time ago, the amplifier resistors were changed, and the ratio between new and old

gain has been measured by C. Dutriat (for Gain 1 in the scale) to be 1.8. However, if the amplifiers are not in saturation, this difference does not have any effect on the emittance calculation.

5. The *timing of the measurement inside the beam pulse*: if the measurement is done too early, it can take the rising part of the beam pulse, where the emittance changes due to the neutralisation of the low energy beam and to the rise time of the RF chains. Figure 3 shows a measure of horizontal emittance as function of measurement delay time, indicating that the default value of 35 μs allows measuring well inside the stable part of the beam pulse.
6. The *calculation of the emittance*: the measurement software was changed during the 1993 shutdown (new control system). The new software has been thoroughly tested, however some differences with the old one cannot be excluded. Nevertheless, no major changes were introduced after the beginning of 1993.

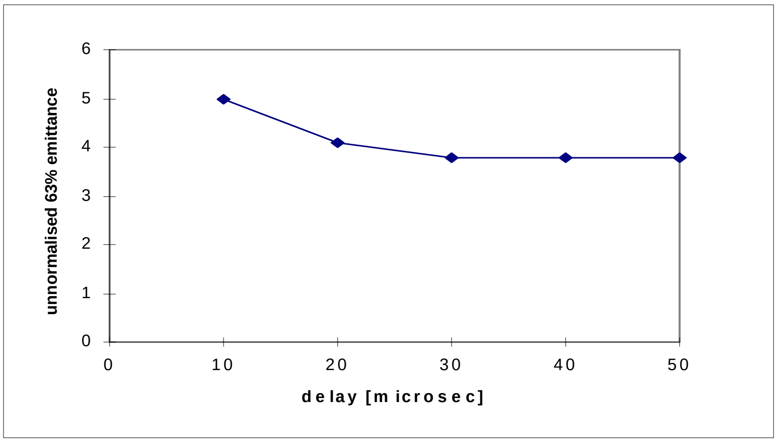


Figure 3: measured (unnormalised) horizontal emittance (LBE line) as function of measurement delay

3. COMPARISON OF LTE AND LBE MEASUREMENT

Another test of the accuracy of the LBE measurement is to compare it to the emittance measured in the LTE line, placed at the exit of the linac. This line is used sporadically, and is considered as not very reliable, but it can give an indication of the evolution of emittance over the last years.

A set of measurements is reported in Figure 4. They cover a shorter period (September 1993/August 1997) and the values reported are not averaged but relative to single measurements. The emittance values are systematically about a factor of 2 higher than what measured at the LBE lines, indicating a considerable difference in calibration between the two lines, and the values are very scattered. Nevertheless, a reduction in the measured emittance by about a factor 2 can be observed also in this line for the period 1993/94. This measurement line cannot see the effects of the new optics for the LTB transfer line, introduced in 1996.

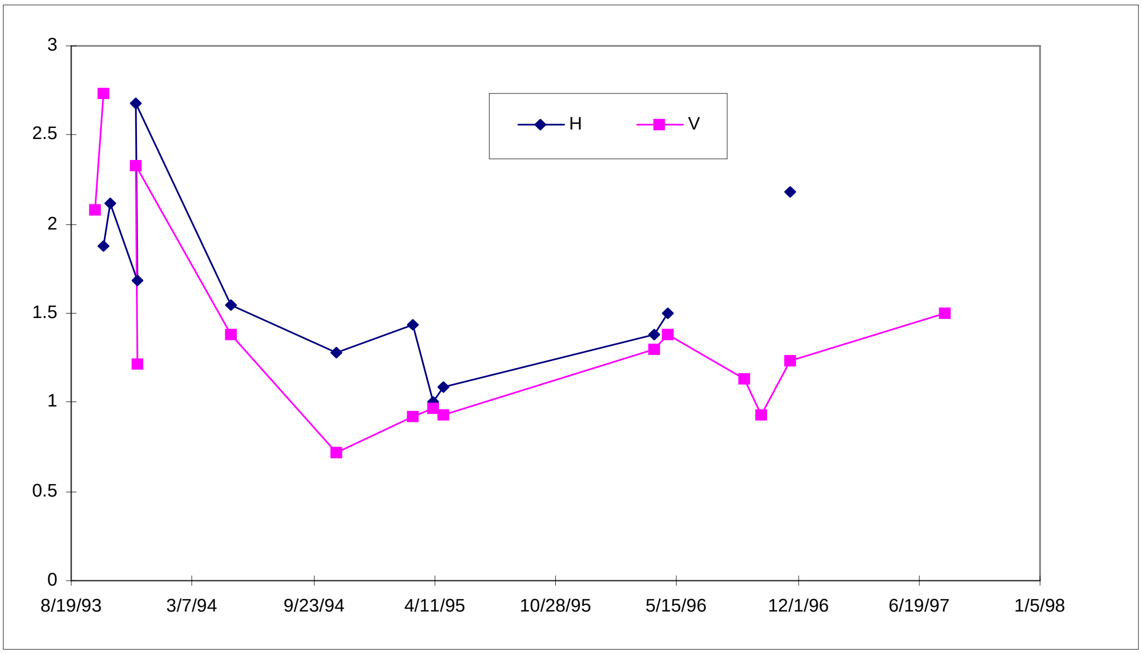


Figure 4: Emittance values measured at the LTE line, in the period 1993/97

4. REFERENCES

[1] P. Têtu, Mesure impulsion à impulsion des trois plans de phase du faisceau du linac à 50 MeV, PS/LR/Note 79-4.

[2] U. Raich, J.-M. Nonglaton, A single pulse emittance measurement.