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The 1993 Linac II Start-up

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Abstract

During the shutdown period of December 1992 to February 1993, the 750 kV Cockroft-Walton and the Low Energy Beam Transport (LEBT) of the CERN Linac II have been replaced by a new pre-injector, a Radio Frequency Quadrupole (RFQ) and new transport lines. The installation of this ensemble, as well as its running in and performance are discussed hereafter.

Historical Background

The CERN Linac II came into operation in 1978, producing a 145 mA proton beam at 50 MeV [1]. After the succesful installation and operation of an 80 mA proton RFQ at the CERN Linac I in 1984, a feasibilty study was made for a 200 mA proton RFQ to be installed at Linac II [2]. In recent years, the need for a higher intensity beam from Linac II for the future Large Hadron Collider (LHC) programme became evident [3] and therefore it was decided to replace the existing 750 kV Cockroft-Walton and the LEBT (fig.1) by a 90 kV platform, a new LEBT, an RFQ and a Medium Energy Beam Transport line (MEBT) (fig.2).

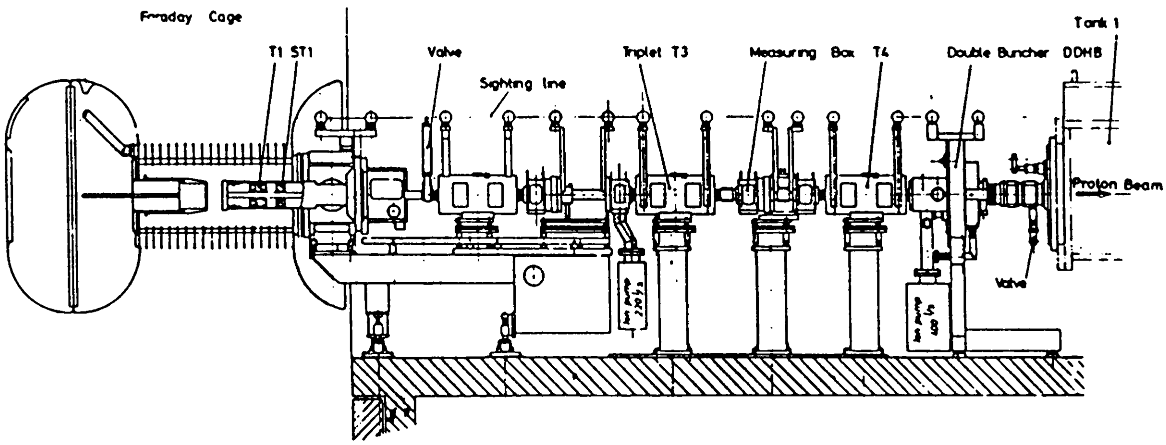

Fig.1 Preinjector and LEBT of the CERN Linac II prior to the RFQ2 installation

A test stand for this new injection scheme was installed and as from 1990 extensive equipment and beam tests have been made on two identical RFQs (RFQ2A and RFQ2B) [4]. These tests were finished by the end of 1992, when the installation of the new injector at Linac II started.

Installation

The main constraint for the installation of the RFQ was the available time: no more than about 2 and a half months (i.e. a standard yearly shut-down period). This short amount of time, if compared with the high amount of work required (mechanics, civil engineering, installation and testing of equipment and commissioning with beam), imposed a strict planning and a strong coordination between the many different groups and services involved.

Dismantling of the old LEBT took place during the last two working days of December 1992, whereas the dismantling of the old 750 kV platform was completed in January 1993 (note that the Cockroft-Walton generator as most of the equipment in the old Faraday cage could remain in place). The dismantling was done in such a way that it would still be possible to go back to the original injection scheme (e.g. in case of major damage to RFQ equipment during its transportation to the linac area) and therefore only obsolete equipment and cables were totally removed.

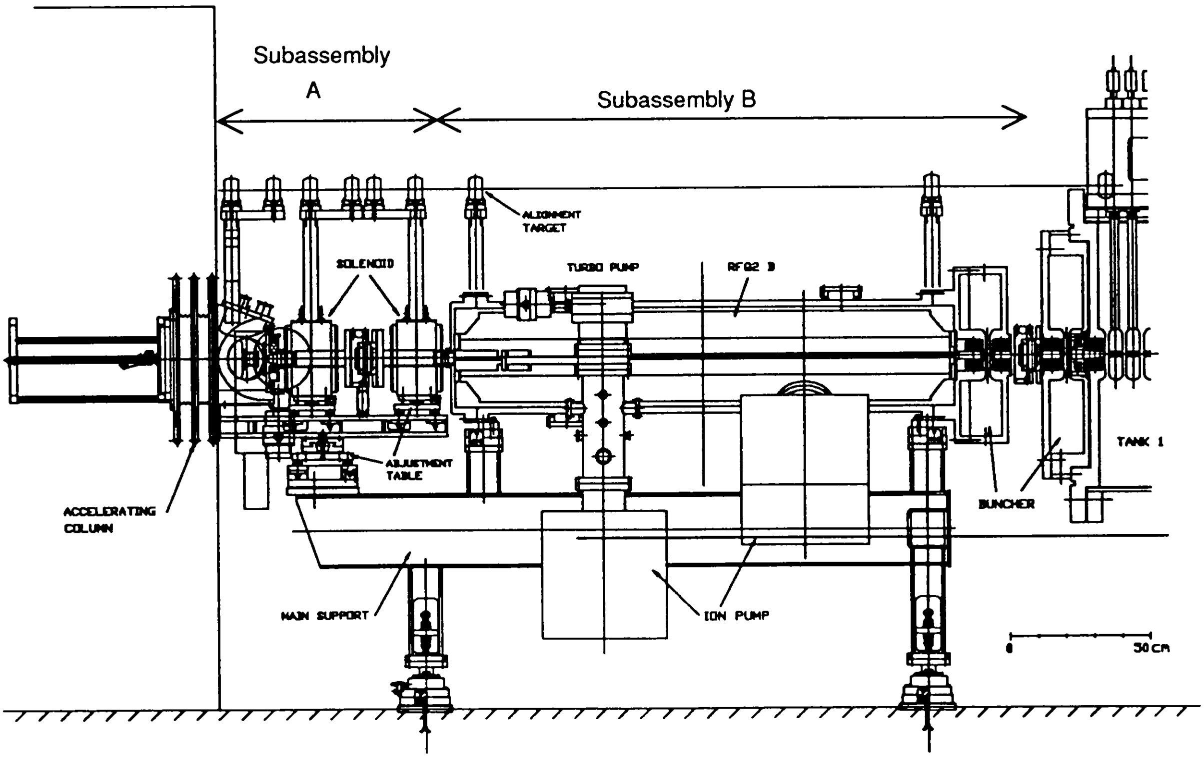

Fig.2 RFQ2 with transport lines as installed at Linac II

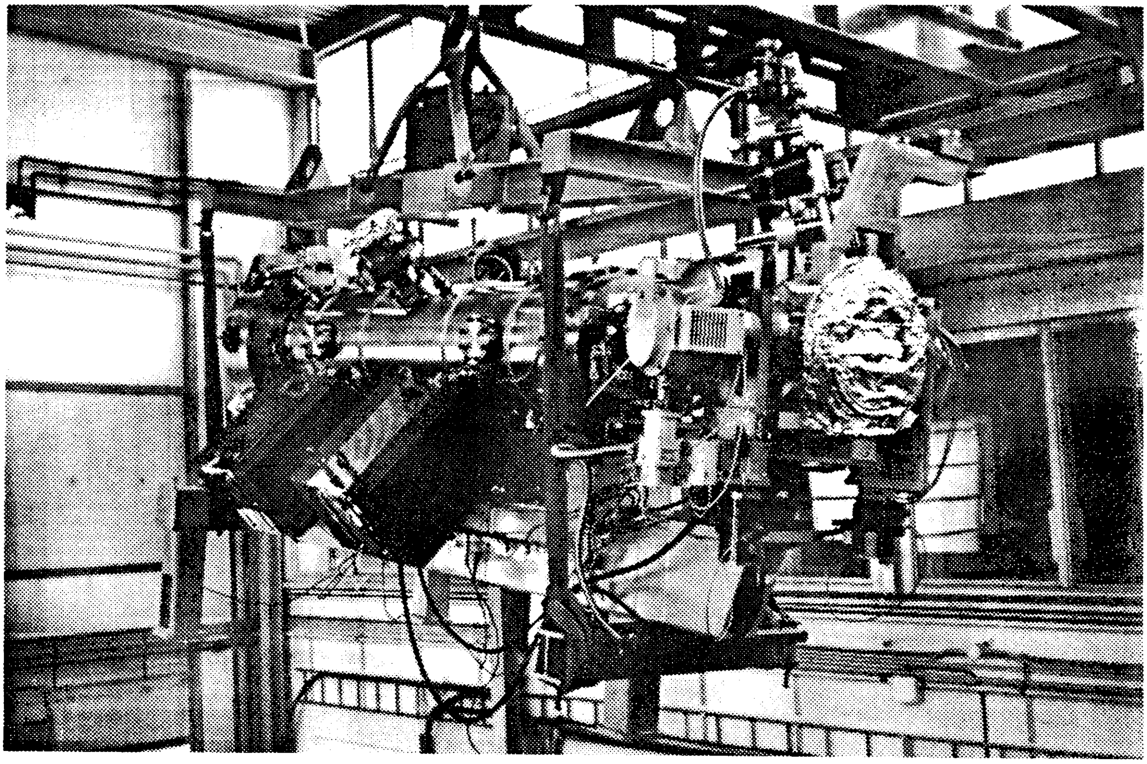

Fig.3 RFQ2 on its way to linac II

Once the old LEBT area cleared and the floor to house the RFQ support prepared, the complete RFQ line (source, LEBT, RFQ and first buncher, all mounted on a single support) was transported from the test stand in the South Hall extension to the Linac II area (fig.3), in order to maintain the alignment achieved at the test stand. To reduce the time necessary for installation, ancillary equipment such as vacuum pumps was not removed from the line. Once the RFQ complex in place, it only needed to be aligned with respect to the linac and connected to it, after which the pumping and vacuum tests could start.

The installation of the source, high voltage platform and Faraday cage was completed by mid February. Subsequently the first beam was obtained and measured using a beam transformer and a six fold Faraday cup. In the meantime, the vacuum in the RFQ became satisfactory (8.0 x 10^{-6} Torr, including the hydrogen loading from the source); RF reconditioning of the RFQ cavity, necessary after some weeks of its exposure to air, was then started, first without, then with beam.

During this period, the control system was being upgraded to a VME/Workstation based system [5]. This comprised the installation of new interfaces to RF equipment, power supplies and vacuum equipment. The source start-up was done using this new control system, and during the following weeks the commissioning of the different elements downstream the beam line went in parallel with the commissioning of the corresponding control parameters. This required a close coordination of the two activities, with daily meetings to discuss progress and problems and to define a common programme for the tests. Thanks to the good-will of all the people involved, this potential source of problems (the parallel de-bugging of two systems!) resulted in a collaboration advantageous to both sides.

Running-in procedure

The running-in procedure was backed up by extensive beam dynamics simulations carried out with the programs PARMULT and PARMILA. These codes had already been used to simulate the behaviour of the beam at the RFQ test stand, giving good results [6]. The RFQ-MEBT-LINAC II complex was therefore studied with the same programs, modified in order to be able to perform an "end-to-end" simulation. The emittance and current values at the source, measured on the test stand before the installation of RFQ2B in October 1992, were used as input beam parameters for the numerical simulations. A global optimization of the parameters (four quadrupoles and two bunchers in the MEBT and 130 quadrupoles in the linac) was achieved. In parallel, a different set of values for the MEBT parameters was found, making a lower intensity operation possible without any change to the old quadrupole settings in the linac, and was used for the first beam tests.

At the end of February, a 280 mA beam was produced at the source, and the beam stopper between the RFQ and the Linac was opened. For the initial beam tests, it had been decided to adopt the following settings:

- all the Linac2 quadrupole gradients and the RF amplitude and phase values in the tanks kept at their 1992 values.
- the focusing elements in the new MEBT line (4 quadrupoles and two bunching cavities) at their theoretical values, calculated to optimize transmission with the old Linac II setting.
- the relative phases of the three cavities of the RFQ2 system (RFQ itself plus the two bunchers) at the values determined at the test stand after energy measurements.
- the phase of the RFQ (with the bunchers following it!) empirically adjusted aiming for optimum transmission through the linac.

These settings immediately gave a maximum current of 150 mA at the end of tank 1 and 110 mA at the end of tank 3, thus proving at the same time the efficiency of the new injector and the reliability of the simulation programs. Unfortunately, due to various hardware and software problems, it was not possible to have an emittance measurement at that moment in time.

The following step was to change the field values of all the linac quadrupoles to the calculated ones, changing the focusing law in the linac. Also the values of the MEBT parameters were set to their theoretically optimized values. After some iterations of empirical optimization of all the parameters (giving slight deviations from the theoretical values for some quadrupoles and some RF parameters), a current of 140 mA at the linac output was obtained.

The third and final step was a general debugging of the linac, through which two remaining problems were discovered and solved: an error in the reading of the source hydrogen flow, which, from the start, had caused a too low source current, and the inversion of two quadrupole connections in Tank 3, which had caused a reduced transmission there. Subsequently all the linac parameters were re-optimized, and finally a maximum intensity of 170 mA at the output of the linac was reached. At this point some of the parameters had values differing from the theoretical ones. The most important difference was found in the first buncher, set to an RF level 25% lower than foreseen by theory. Also, two quadrupoles in Tank1 and four in Tank2 differed with more than 5% from the expected field values.

In parallel, the linac-booster transfer line was being commissioned. By the 10th of March a beam of about 160 mA was obtained at beam transfomer LT.TRA60 (corresponding to the point were the beam is passed on to the booster) and its emittance analyzed in the measurement line LBE and in the so called NSPES emittance lines (both transverse and longitudinal emittances). Repeated optimizations of the parameters of the transport line to the booster , done both empirically as well as with the program TRACE, allowed to match the beam to the booster acceptance with a residual mismatch of the order of 10%. The settings optimized for standard booster operation with the corresponding measured emittances are reported in Appendix A. A comparison of the computed and measured quality of the beam for the above setting is reported in Table 1 a,b .

	alpha	beta (mm)	emittance (63%) (mm-mrad)
PARMILA	-0.67	20.26	7.69
MEAS. (18 May)	-1.5	17.8	8.3

Table 1.a: Emittance parameters for the horizontal plane at LTB.SLH10

	alpha	beta (deg /KeV)	ΔΦ (deg)	ΔW (KeV)	emittance (63%) (deg KeV)
PARMILA	2.4	0.298	19	253	2780
MEAS. (4 May)	2.0	0.6	70	250	8000

Table 1.b: Emittance parameters for the longitudinal plane at LTB.SLV20

As can be seen from Table1a,b, there is a good agreement in the transverse plane between theoretical and measured values, whereas in the longitudinal plane the measured emittance and phase spread are about a factor three bigger than foreseen.

Performance

Table 3 compares measured beam currents along the linac for the old and for the new injector. Columns A and B refer to the old injector, and in particular to a standard day of operation in December 1992 (A) and to the last of the high intensity tests of 1992 (B). Columns C and D summarize the behaviour of Linac II with the RFQ2 (production beam and a high intensity experiment in March 1993). As far as the production beam is concerned, one could obtain without problems the required intensity of about 135 mA at the booster input. For the high intensity beam, a maximum current of 165 mA could be observed at the booster, exactly the same value as obtained with the old injector. Nevertheless, the installation of the RFQ brought two advantages for high intensity operation: first of all, the beam density at the centre of the emittance seems higher with the RFQ than with the old injector (i.e. the beam seems to have a denser "core"), allowing for a 15 % higher current to be accelerated in the booster with the standard operational beam. Secondly, the smaller losses in the linac (better capture of the RFQ high intensity beam) reduce the load on the RF amplifiers, allowing safe and reliable operation (i.e. working point below saturation, even without increasing the plate voltage).

	A	B	C	D	
Beam Transformer	low int.	high int.	low int.	high int.	Position of transformer
	.12.1992	23.11.92	29.3.93	12.3.93	
TRA02	361	412	259	300	exit of the source
TRA06	161	246	165	195	input of Tank 1
TRA07	139	185	146	173	output of Tank 1
TRA10	142	189	142	170	output of Tank 3
TRA20	139	179	144	170	transfer line
TRA30	133	164	135	165	transfer line
TRA60	— 134	165	135	165	input of booster

Table 3: Linac II currents (mA)

In spite of the satisfactory results with the high intensity tests, the transmission through the linac (87% for the high intensity case) remains much lower than predicted by the simulation programs (95%, column E in Table 4), due to the losses in Tank 1. Part of these losses might be caused by misalignement. In fact, the space charge imposed to keep the space between RFQ and linac to a minimum, there was no space left for the insertion of steering dipoles. Therefore the alignement of the RFQ beam to the optical axis of the linac has been obtained by mechanically displacing the whole injector with respect to the linac, up to a limit imposed by the connecting bellow. Moreover there are indications of a dynamics problem in the longitudinal phase plane, as seems to demonstrate the abnormal level of the buncher 1 amplitude. This might explain the losses in Tank 1 and the factor three difference between computed and measured longitudinal emittance out of the linac. Note that TR02 measures protons as well as other ions coming out of the source therefore the transmission through the RFQ and the MEBT indicated in Table 4 are much lower than the real proton transmission, that we estimate to be better that 90%.

For simplicity of operation, the same settings optimized for high intensity are used for the low intensity beam, and this explains the low transmission observed for the low intensity case.

	A	B	C	D	E	
Beam Transf.	low int.	high int.	low int.	high int.	theoret.	
	12.1992	23.11.92	29.3.93	12.3.93	with RFQ2	
TRA06/02	[0.45]	[0.60]	[0.64]	[0.65]	[0.61]	RFQ+MEBT
TRA07/06	0.86	0.75	0.88	0.89	0.95	Tank 1
TRA10/06	0.88	0.77	0.86	0.87	0.95	Linac 2
TRA60/06	0.83	0.67	0.82	0.85		Overall

Table 4: Linac II beam transmissions

Another problem that has disturbed the running-in of the booster has been a time dependent displacement (during the beam pulse) of the beam with respect to the axis, observed on the pick-ups (both horizontal and vertical) in the transfer line linac-booster. This problem has yet to be understood, but it became unimportant for the production beam once the hydrogen pressure in the source was increased to its nominal level. This seems to indicate that this "steering effect" depends on the conditions in the injection line (and in particular on the gas pressure).

As far as reliability is concerned, so far the RFQ complex has behaved satisfactory: the RF conditioning of the RFQ cavity has been smooth, and since the beginning of the run only few series of consecutive breakdowns in the RFQ have disturbed the booster operation (note that the high electric field level in the RFQ required a long and careful conditioning whilst at the test stand, and was at the origin of many concerns about the installation at the linac).

Acknowledgements

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References

[1] E.Bolthezar, H.Haseroth, W.Pirkl, G.Plass, T.Sherwood, U.Tallgren, P.Têtu, D.Warner, M.Weiss,"The New CERN 50-MeV LINAC", Proc. 1979 Linac Conference, BNL 51134, p66

[2] C.Biscari, M.Weiss, "Choice Of Parameters For The CERN High Intensity RFQ (RFQ2 Project)", Proc. 1984 Linac Conference, GSI-84-11, p106

[3] R.Cappi, R.Garoby, S.Hancock, M.Martini, N.Rasmussen, T.Risselada, J.P.Riunaud, K.Schindl, H.Schönauer, E.J.N.Wilson, "The PS Complex As Part Of The LHC Injector Chain", CERN PS/91-07 (PA)

[4] E.Tanke, M.Vretenar, M.Weiss, "Measurement Of The CERN High Intensity RFQ", Proc. 1992 EPAC Conference, p542

[5] U.Raich, C.Serre, "Second Step In The PS Rejuvenation Project, Linac 2 and Lead-Linac", PS/DL/Min 92-15

[6] A.Lombardi, E.Tanke, T.Wangler, M.Weiss, "Beam Dynamics of the CERN RFQ2; Comparison of Theory with Beam Measurements", CERN/PS 93-13 (HI)