PS/AR/Note 96-08 (MD)
13 May 1996

Injection, Storage and Cooling Tests of $Pb^{53+,54+,\text{and }55+}$ ions in LEAR (Performed in December 1995)

S. Baird, J. Bosser, C. Carli, M. Chanel, R. Ley, R. Maccaferri, S. Maury, I. Meshkov[1], D. Möhl, G. Molinari, E. Syresin[1], G. Tranquille, F. Varenne

1. INTRODUCTION

In this machine development (MD) session, the third in the series [1,2], we further investigated the Linac III - LEAR transfer line and the transverse cooling of lead ion beams as a function of a number of parameters :

- electron beam neutralisation,
- machine lattice functions (table 1),
- and ion beam emittances.

To complement the measurements made in June 1995 we also measured the lifetime of Pb^{55+} ions subject to electron cooling and a study of the influence of the vacuum quality on the ion beam lifetime was made.

The experimental setup was the same as in previous MDs [1,2] and a particular effort was made to the measurement processing systems in order to obtain almost on-line results [3].

machine 1	
D (all sections)	3.6 m
β_h (all sections)	1.7 m
β_v (all sections)	6.5 m
machine 4	
D (SS1 and SS3), D (SS2 and SS4)	0 m , 10 m
β_h (SS1 and SS3), β_h (SS2 and SS4)	11 m , 3.5 m
β_v (SS1 and SS3), β_v (SS2 and SS4)	7 m , 7.3 m

Table 1. Lattice functions of the machines used for this MD.

2. INJECTION

The transfer line was optimised in order to improve the lead ion beam intensity injected into LEAR. Changes in the injection matching enabled us to inject regularly 10^8 charges with peaks of around 2×10^8 charges. As the circulating beam transformer is not sensitive to this

[1] Visitor from JINR Dubna

low intensity, we used the longitudinal Schottky power density to optimise the injection. The Schottky noise signal was displayed on a spectrum analyser which was connected to a PC for post processing. The integral of the Schottky noise over the band at a harmonic of the revolution frequency was calculated and was used as an indication of the injected intensity.

3. LIFETIME MEASUREMENTS

The beam lifetime was estimated by recording the ion intensity versus time as in the previous MDs [1,2]. Comparative measurements were made for the three ion charge states in order to complement the measurements made in June. The results are shown in figure 1 where the inverse of the lifetime is plotted as a function of the electron beam current. The results confirm the observations made in June, that is to say that Pb^{54+} ions are the most suitable charge state for accumulation in LEAR. The evaluation of the recombination coefficient α_r gave similar results to those obtained in previous experiments except for Pb^{54+} where α_r is a factor of two smaller than previously obtained [table 2]. The coefficient for Pb^{55+} which was measured for the first time turned out to be similar to that of Pb^{52+}.

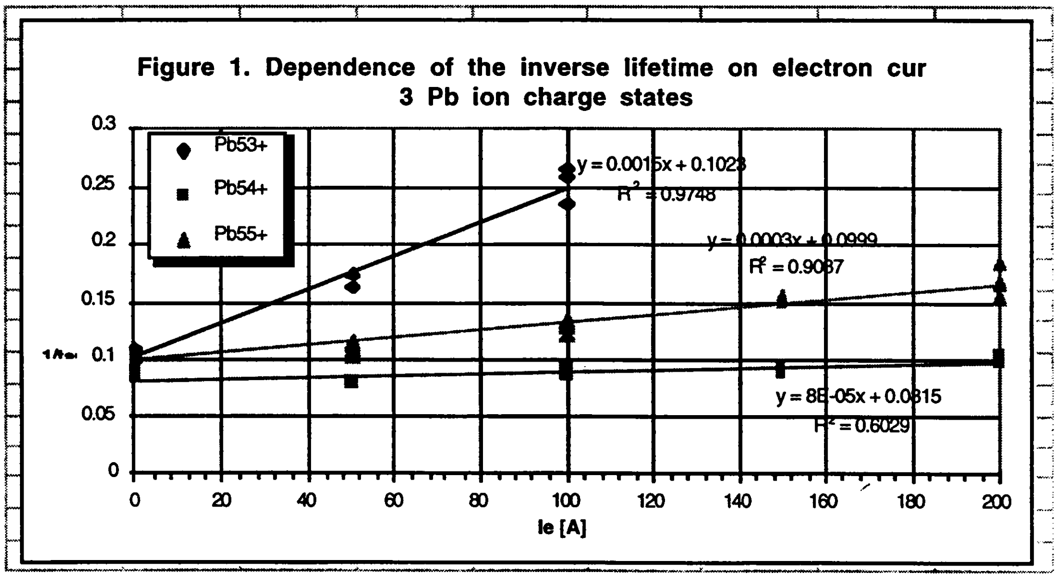


Figure 1. Dependence of the inverse lifetime on electron cur 3 Pb ion charge states

The measurements of the lifetime were made with *'machine 4'* which has large focusing functions ($\beta_h=\beta_v=10$m) in the cooling section, whereas in June the normal lattice *'machine 1'* ($\beta_h=2$m, $\beta_v=5$m) was used for the determination of the recombination coefficient. We do not know whether the factor of 2 for the recombination of Pb^{54+} is due to this difference.

	Pb52	Pb53	Pb54	Pb55
Dec 94		64		
June 95	11	60	9	
Dec 95		63	5	12

Table 2. Calculated rate coefficients for the different charge states (10^{-8} cm^3 s^{-1}).

The vacuum lifetime was found to be worse than in the two previous MDs (16 to 20 seconds in previous runs and only 10 seconds here). Table 3 shows the residual gas composition in LEAR for the December experiments. It is clear that the vacuum quality plays an important role in the beam lifetime as between the June [2] and December experiments the average pressures do not differ very much but the proportion of He and CH_4 are quite different.

sect/L[m]	*103*	*25.63*	*202*	*19.63*	*303*	*24.63*	*402*	*8.625*	
molecule	P_{abs}	<P>	P_{abs}	<P>	P_{abs}	<P>	P_{abs}	<P>	$1/\tau_{life}$
H_2	18	6.19	12	2.44	15	3.06	12	30.1	.0243
He	0.4	0.13	0.16	0.03	1.7	0.35	0.16	0.04	.0009
CH_4	6	2.06	2.6	0.53	0.7	0.14	2.6	0.65	.0277
H_2O	0.9	0.31	1.4	0.29	0	0	1.4	0.35	.0076
CO	1.1	0.38	0.1	0.02	0	0	0.1	0.03	.0048
N_2	0	0	0	0	0	0	0	0	0
O_2	0	0	0	0	0	0	0	0	0
Ar	1.6	0.55	0	0	0.11	0.02	0	0	.0072
CO_2	0.4	0.14	0.2	0.04	0	0	0.2	0.05	.0040
calculated	τ_{life}=	*13*	*secs.*					*sum=*	*.0765*

Table 3. Residual gas composition and estimation of the vacuum lifetime in LEAR during the MD. The top row gives the section name and its length. Column $\mathbf{P_{abs}}$ indicates the measured absolute pressure (in 10^{-12} Torr) and **<P>** the pressure (in 10^{-12} Torr) in a section taking into account the section length. The last column gives the calculated $1/\tau_{life}$ for each residual gas molecule.

The limiting effects of local pressure bumps on the ion beam lifetime were also demonstrated by disabling the veto on the injected beam. This means that every 1.2 seconds a new pulse is injected into the machine but is lost in the first main bending magnet as the kickers are not pulsed. The losses apparently lead to outgassing from the vacuum chamber and the circulating ion beam sees a pressure bump at this spot. As a result the measured lifetime is decreased by a factor of 2 (5 to 6 seconds lifetime). By enabling the veto only one pulse is injected from the Linac III. Then after a few minutes the lifetime increases to its original value.

By stepping up the electron beam energy one also creates a pressure bump in the electron cooling section. This pressure bump is due to the collector inefficiency and can be increased with electron beam neutralisation. Setting the electron beam off energy eliminates the influence of recombination processes on the ion beam lifetime but the pressure bump effect and probably other effects remain. Figures 2 and 3 show the results for Pb^{54+} and Pb^{53+} in the presence of an off energy electron beam. It is clear that the presence of the electron beam perturbs the circulating ion beam irrespective of its charge state. Electron beam neutralisation further reduces the lifetime and is even more detrimental if it becomes unstable.

Figure 2. The Dependence of the Lifetime with an off Energy Electron Beam (Pb54+)

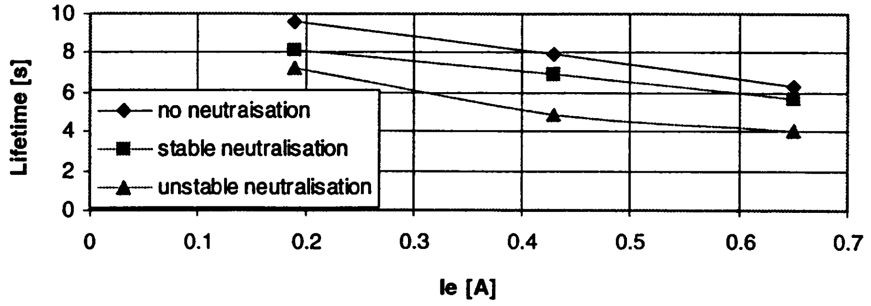
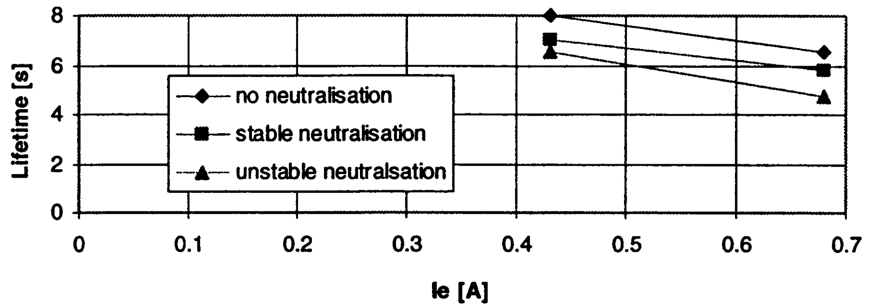


Figure 3. The dependence of the Lifetime with an off Energy Electron Beam (Pb53+)



4. TRANSVERSE COOLING DOWN TIME MEASUREMENTS FOR THE INJECTED BEAM

Transverse down cooling times were measured with the help of the transverse Schottky pick-ups by observing the evolution of the sidebands during the cooling process. A second method of estimating the cooling down time is obtained from the BIPMs, where the ionisation of the rest gas gives a direct measurement of the ion beam dimensions. An example of such a profile obtained with the BIPM is shown in Figure 4.

The cooling down time was defined as the time for the ion beam to be cooled to equilibrium i.e. until the ion beam dimensions have reached 95% of their final equilibrium value in the case of the BIPM system, or when the transverse Schottky sidebands vanish.

Experiments were made with and without neutralised electron beams of varied intensities and for the *'machine 4'* optics. Figure 5 shows the obtained results and one sees immediately that there is no appreciable gain in the cooling down time using neutralised electron beams. If one extrapolates to higher currents, cooling down times around 100ms should be obtained for electron beam intensities of about 200 mA.

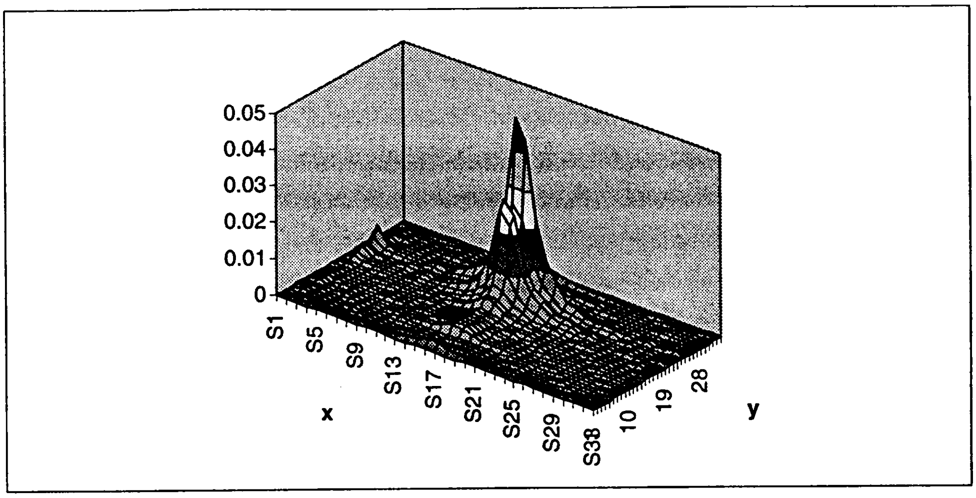
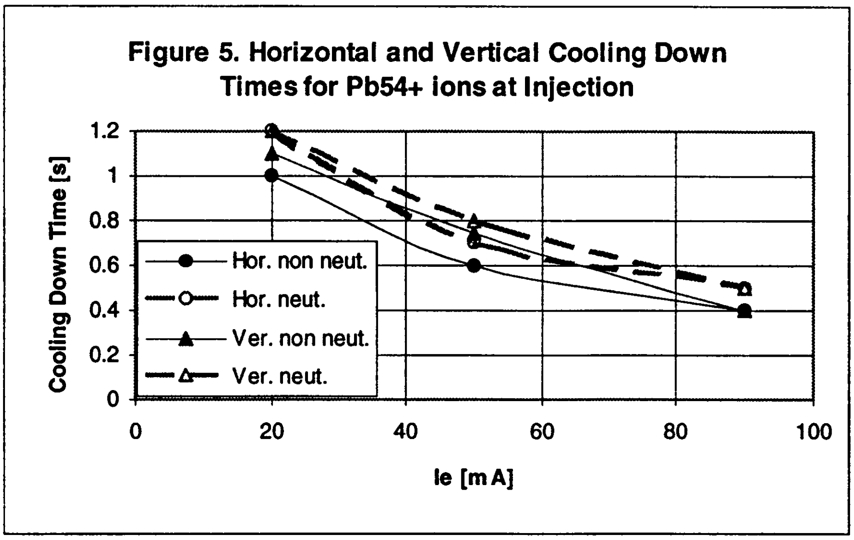


Figure 4. Horizontal (x) and vertical (y) projection of an electron cooled PB^{54+} beam 300 ms after injection. Each x-y bin represents 1mm.

5. COOLING DOWN TIMES FOR A 'KICKED BEAM'

The measurement methods described in the previous section were applied to measure the time that it takes for the electron cooler to recover a part of the circulating beam that has been given a horizontal deflection by a fast kicker. The kick duration was 750ns long, thus approximately 25% of the circulating ion beam was made to oscillate at amplitudes determined by the voltage applied to the kicker. These measurements were performed with both the normal machine and *'machine 4'* and for neutralised and non neutralised electron beams. The results are shown in figures 6 and 7 where we compare cooling with and without neutralisation and cooling with the different lattice parameters. Again it is shown that neutralised electron beams do not help to reduce the cooling down times and in some cases are even detrimental to the cooling process. We also did not observe any improvement with the *'machine 4'* optics.



6. CONCLUSIONS

It has been demonstrated that Pb^{54+} is clearly the charge state which is most favourable for the cooling and accumulation of lead ions in LEAR. The machine experiments have shown that the lifetime of the ions can be severely limited by the quality of the vacuum in any section of the ring and also by the stability of the electron beam used for cooling. The measured cooling down times are in agreement with the predicted estimations for the range of electron intensities used in these MDs.

A number of measurements need to be repeated with protons where it will be made clear if the machine lattice functions can reduce the cooling time and if neutralisation is detrimental or beneficial to the cooling process.

Figure 6. Cooling Down Times for a Horizontally Kicked Beam

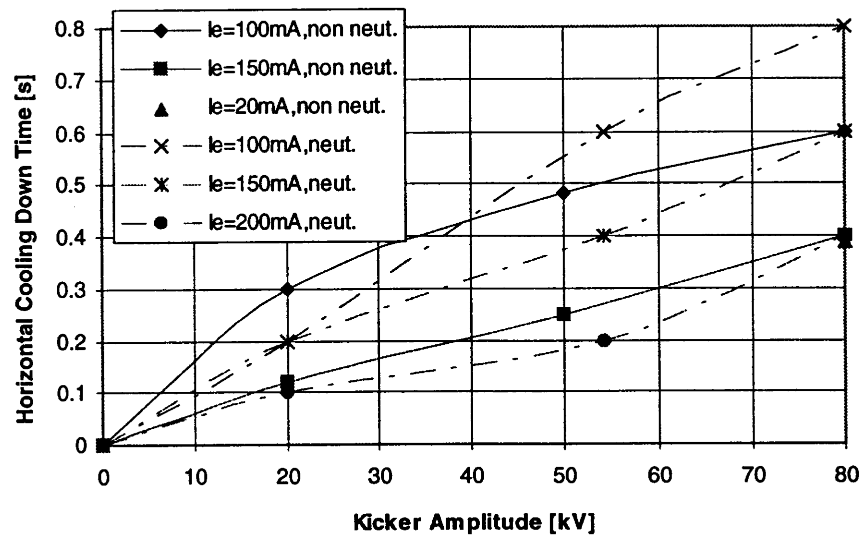
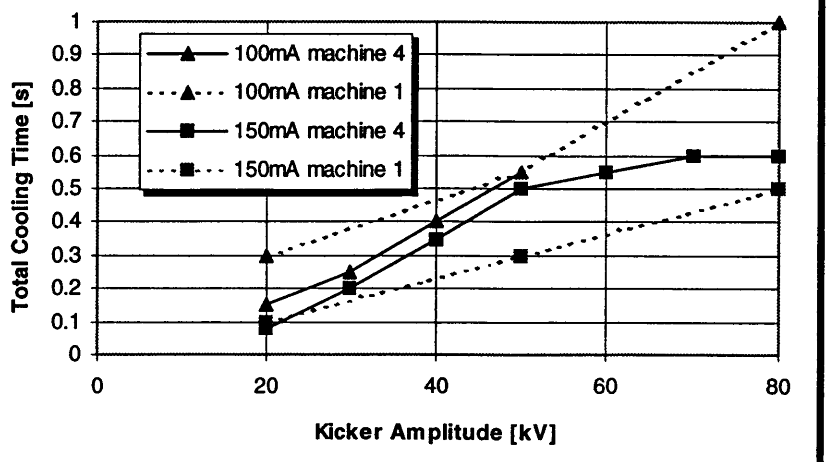


Figure 7. Cooling Times Without Neutralisation. A Comparison Between Machines 1 and 4.



7. REFERENCES

[1] S. Baird, J. Bosser, M. Chanel, J. Duran, R. Giannini, P. Lefèvre, R. Ley, R. Maccaferri, S. Maury, I. Meshkov, D. Möhl, G. Molinari, F. Motsch, H. Mulder, U. Oeftiger, J.C. Perrier, E. Roux, G. Tranquille, F. Varenne, *First Electron Cooling Tests With* Pb^{53+} *Ions (Performed in December 1994).* PS/ AR/ Note 95-06(MD).

[2] S. Baird, J. Bosser, C. Carli, M. Chanel, P. Lefèvre, R. Ley, R. Maccaferri, S. Maury, I. Meshkov, D. Möhl, G. Molinari, F. Motsch, G. Tranquille, F. Varenne, *Beam Lifetime Measurements for* PB^{52+}, Pb^{53+} *and* Pb^{54+} *Ions Subject to Electron Cooling in LEAR (Performed in June 1995).* PS/ AR/ Note 95-12 and Physics Letters B 361,p. 184, 1995.

[3] G. Tranquille and A. Findlay, *A PC Based Control and Data Acquisition System.* PS/ OP/ Note 95-35