VARIABLE ENERGY ELECTRON COOLING AT LEAR

J. Bosser, M. Chanel, R. Ley, G. Tranquille

CERN - PS DIVISION
CH - 1211 Geneva 23

Abstract

After a series of major upgrades to the LEAR electron cooler and its environment, the device has been successfully commissioned for low energy operations. This paper discusses the details of the application of the 'pulsed mode' of operation during the deceleration process at the standard machine flat-tops of 308.6 MeV/c and below. Results of the beam characteristics obtained with electron cooling and a comparison with stochastic cooling will also be presented.

1. INTRODUCTION

The LEAR electron cooling device is the fruit of a collaboration between CERN and KfK Karlsruhe and has been used since 1987 for cooling experiments. Antiprotons, protons, H^-, O^{6+} and O^{8+} ions have been successfully cooled and even accumulated in the LEAR machine [1,2]. During 1991 the device was upgraded in order for it to become an integral part of LEAR and to improve the beam quality for low energy antiproton operations. A detailed description of the device prior to the 1991 modifications can be found in ref. 3.

Of the numerous modifications made to the cooler, the most important are the construction of a new electron beam collector [4] and the conversion of the existing control system to a workstation based system similar to that of LEAR [5].

The design of the new collector is very simple [fig. 1] consisting of a Faraday cup and a repeller electrode at the collector entrance. A vacuum valve has been installed for the purpose of easy maintenance between the collector solenoid and the collector itself. The 'gap' in the magnetic field due to this valve is compensated by a coil placed before the collector entrance. In addition another coil has been recently installed at the end of the collector in order to spread the primary electron beam more evenly over the collector surface. Collection efficiencies of 99.95% are routinely obtained for electron beams having an intensity of 2.5 Amps and an energy of 28 keV. Moreover the vacuum pressure in the cooling section never rises above 10^{-11} Torr, even with high intensity electron beams.

For its full integration into LEAR and in view of the pulsed mode of operation (to be discussed in the next section) the LSI11 based control system was modified to a LEAR type workstation based system. All CAMAC accesses on the special fibre optic CAMAC loop are handled through a dedicated single board microprocessor acting as an intelligent controller. This controller is connected to a local area network, Ethernet, and any other computer in the same network may send requests to it [fig. 2]. New generation digital function generators (GFD) and timing event decoders have also been installed for everyday operations.

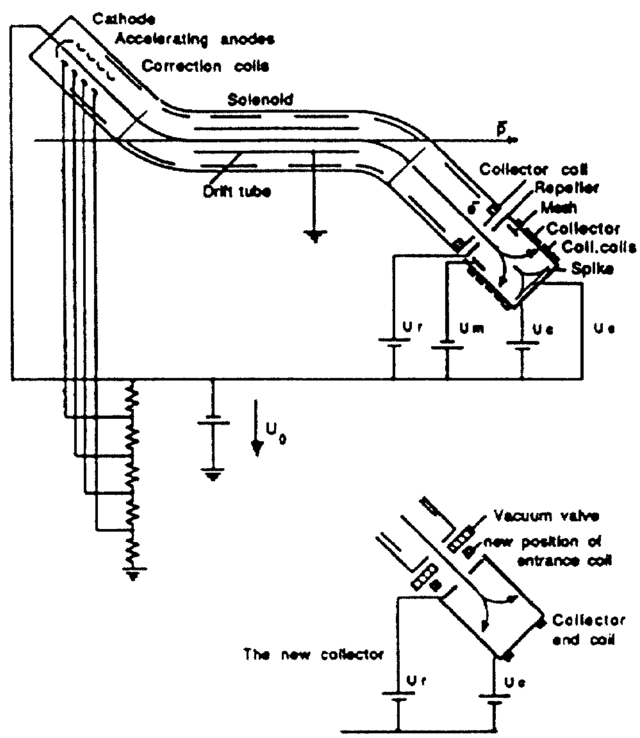

Figure 1. The old and the new collector devices

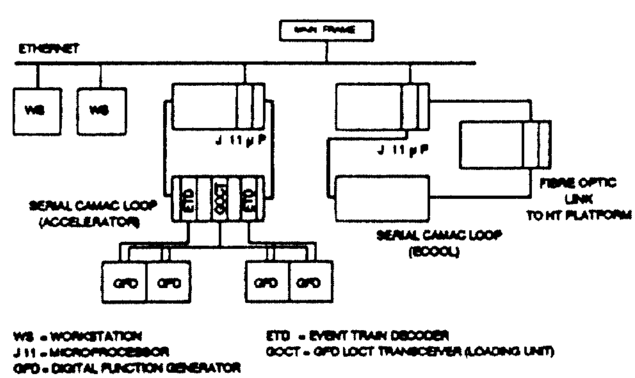

Figure 2. The new control system

2. OPERATIONAL MODES

2.1 The pulsed mode

Several modes of operation have been foreseen for use on the LEAR deceleration cycle, but it is the so-called 'pulsed mode' which has been adopted. The accelerating voltages, applied to both the cathode and the anodes, and the solenoid current are put on for 10 seconds on the 309, 200 and 105 MeV/c flat-tops of the normal LEAR cycle. At 61.2 MeV/c the electron cooler remains on during the extraction process in order to maintain a good beam lifetime. The voltages of the collector and the repeller as well as the coils at the entrance and the exit of the collector remain at fixed values throughout the cycle, whilst the correction coils are ramped, following the LEAR magnetic cycles [fig 3 and table 1]. In this way the field of the solenoid does not perturb the beam during the actual deceleration.

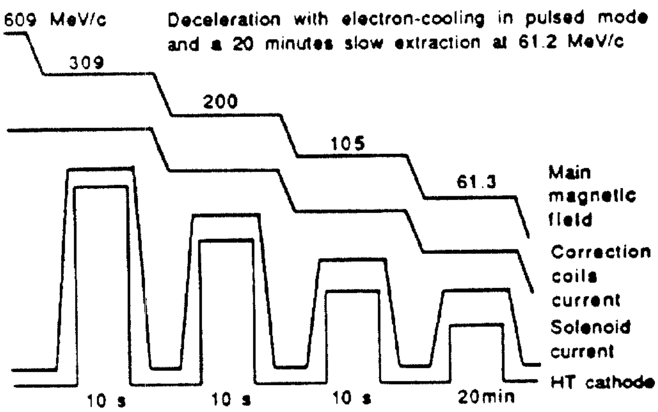

Figure 3. Typical cycle for low energy operation

Table 1: Parameter types for the pulsed mode

parameter	pulsed	fixed at all momenta	ramped with LEAR cycle
cathode heating		*	
cathode HT	*		
repeller HT		*	
collector HT		*	
correction coils			*
collector coils		*	
solenoid current	*		

It is also important to smooth the functions used for the high voltage power supply, to avoid overshoots in the applied voltage, which disturb the circulating ion beam and could damage the power supply itself. The total rise time for the high voltage is 120 msec. The smoothed function is generated by creating a series of short vectors of varying amplitudes, using the standard LEAR GFD editor. The amplitude of the high voltage (or electron beam energy)and the solenoid values for the standard LEAR antiproton and proton momenta are shown in table 2.

Table 2. Main parameters for electron cooling at LEAR

electron beam energy (keV)	solenoid field (Gauss)	electron beam current (Amps)	pbar/p momentum (MeV/c)
27.2	448	2.3	308.6
11.78	293	0.64	200.0
3.27	154	0.094	105.0
1.1	90	0.019	61.2

2.2 Parameter generation

The pulsed and ramped parameters are controlled using four 16 bit GFDs which are triggered from the LEAR cycle timing system. In addition a single CAMAC crate contains two timing event decoders and a module for loading the data into the GFDs. Two standard GFDs are used for the high voltage and the solenoid current. A maximum of eight functions can be programmed into each GFD. One function is used for each of the four 'momenta' and the correct functions are selected using timing triggers (event 'starts energy table' in fig. 4). The remaining two GFDs have been modified to output eight different functions simultaneously. In this way the various functions needed for the ramped correction coils can all be programmed on only two GFDs.

2.3 Timing

The GFDs themselves are controlled using a sequence of linked events in the LEAR timing system. A single module, containing all the relevant 'master/event starts/stops' for the pulsed and ramped elements, is inserted into the normal cycle timing for each flat-top.

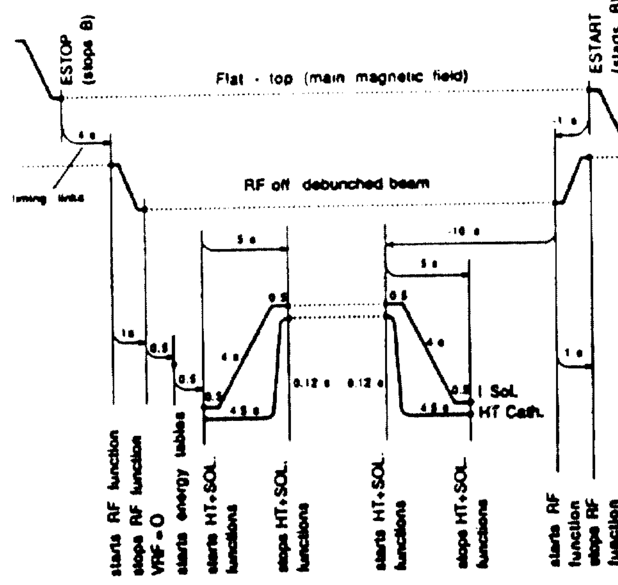

Figure 4. Timing links for electron cooling on a flat-top

3. RESULTS

The main performances obtained when using electron or stochastic cooling are shown in table 3.

Table 3. Comparison of electron and stochastic cooling

	e-cooling	stochastic cooling
deceleration time to 61.2 MeV/c	7 minutes	20 minutes
final $\Delta P/P$	0.05%	0.2%
transverse emittances	3π mm mrad	10π mm mrad
lifetime at 105 MeV/c	24 hours	6 hours
lifetime at 61.2 MeV/c	30 minutes	5 minutes

Because of electron cooling one sees that :

- the emittances in each plane are substantially reduced
- the beam lifetime is increased
- the overall duty cycle is significantly improved.

It should also be mentioned that electron cooling has been used at a constant injection energy for multi-injection (every 2.4 secs.), allowing a longitudinal stacking of ions [6].

Electron cooling has also contributed to the success of the PS 189 experiment which decelerated a proton beam from 61.2 MeV/c to 20 MeV/c (200 keV kinetic energy !) by means of an inverse RFQ. This was made possible by the fact that the lifetime and the beam characteristics were improved at 61.2 MeV/c by electron cooling.

For time-sharing operation, the ultra-slow extraction process can be stopped before the end, and by applying electron cooling for about 10 seconds the remaining particles can be re-accelerated to the correct momentum and then RF decelerated to lower momenta for other users (e.g. fast extraction at 105 MeV/c for PS 196). This process is shown in fig. 5.

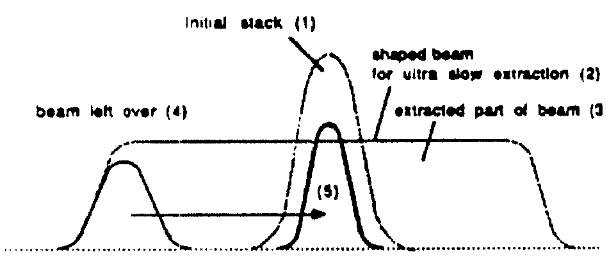

Figure 5. Principle of the time-sharing mode of operation. At the end of stochastic extraction, electron cooling sets the beam left over(4) to the right frequency for deceleration(5).

4. FUTURE

For optimal cooling and taking into account ion beam stability criteria, it has always been clear that it would be useful to be able to control the cooling forces. These forces are intimately related to the electron beam density, or if one wishes the current, and through its control, stable and dense ion beams can readily be obtained. For this reason we have initiated a collaboration with INP Novosibirsk and CAPT Lipetsk for the construction of a new variable current electron gun [7].This new gun will also simplify the pulsed mode of operation described in this paper.

5. CONCLUSIONS

Electron cooling has proved to be an invaluable tool in order to rapidly decelerate ion beams to low momenta with an appreciable gain in beam quality. All the modifications made to the cooler have resulted in a greater ease of operation and reliability of the device. The cooler is presently used for every day operations at LEAR for momenta lower than 309 MeV/c.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

[1] H. Poth, W. Schwab, B. Seligmann, M. Wortge, A. Wolf, S. Baird, M. Chanel, H. Haseroth, C.E. Hill, R. Ley, D. Manglunki, G. Tranquille and J.L. Vallet, "Results from electron cooling experiments at LEAR", Z. Phys. A332 (1989) p 277.

[2] J. Bosser, M. Chanel, R. Ley, D. Mohl, F. Ollenhauer and G. Tranquille, "Status of electron cooling experiments at LEAR", Workshop on electron cooling and new cooling techniques, Legnaro, Italy, 1990, eds. R. Calabrese and L. Tecchio (World Scientific 1991) pp 1-20

[3] H. Poth, W. Schwab, B. Seligmann, M. Wortge, A. Wolf., "The electron cooling device developed for LEAR", Proc. IVth Workshop on physics at LEAR with cooled low energy antiprotons", Villars-sur-Ollon, 1987, ed. C. Amsler, (Harwood Academic Publishers 1988) pp 121-130.

[4] J. Bosser, R. Ley, G. Tranquille, V. Bykovsky, F. Funtikov, I. Meshkov, V. Polyakov, I. Seleznev and V. Sinizky, "The new collector for the electron cooling device at LEAR", NIM A311 (1992) pp 465-471.

[5] T. Pettersson and G. Tranquille, "The new control system for the LEAR electron cooler", Workshop on electron cooling and new cooling techniques, Legnaro, Italy, 1990, eds. R. Calabrese and L. Tecchio (World Scientific 1991) p p 205-215.

[6] S. Baird, J. Bosser, M. Chanel, C. Fernandez, C.E. Hill, P. Lefevre, R.Ley, D. Manglunki, D. Mohl, G. Molinari, J.C. Perrier, T. Pettersson, P. Tetu, G. Tranquille and D.J. Williams, "Oxygen ions in LEAR", Proc. EPAC90, Nice, France. pp 580-582.

[7] J. Bosser, G. Tranquille, I. Meshkov, V. Polyakov, I. Seleznev, E. Syresin, A. Smirnov and A. Zapunjaka, "Project for a new variable current electron gun for the LEAR e-cooler", CERN/PS 92-03(AR)