Operational Aspects of Electron Cooling at the Low Energy Antiproton Ring (LEAR)

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Abstract

This paper describes the major modifications made to the LEAR electron cooler for its reliable and effective use in every day operations. The transverse feedback system used to counteract the coherent instabilities observed with the dense beams obtained with electron cooling will also be discussed.

I. INTRODUCTION

The electron cooling device installed on the Low Energy Antiproton Ring (LEAR) at CERN has shown that electron cooling can be used as an effective method of phase space compression of a stored ion beam. The experiments performed with a variety of particles over the past three years [1,2,3] have enabled us to modify the cooler and the LEAR environment in order to use the apparatus on the different machine 'flat tops' at momenta below 308.6 MeV/c. In the past year different operational modes were investigated so that the cooler can be used routinely during particle physics runs this year.

II. HARDWARE MODIFICATIONS

Major improvements were made on the stability of the 40 kV high voltage (HT) power supply which was the cause of longitudinal instabilities in the early days of electron cooling. Rectifier circuits were developed and have given HT stabilities of the order of 10^{-4}. To further upgrade the stability a compensator was installed which corrects any drift with respect to a reference voltage given by a ratiometer signal.

For a better understanding of the loss mechanisms in the collector a number of analogue fibre optic cables were connected to the various elements of the collector. If the current loss on one or more of these elements increases above a certain threshold a specially developed module gives a visual indication of where the losses occured. During the annual shut downs the high voltage feedthroughs and connections inside the collector were modified in order to render the ensemble more reliable. However the operation of electron cooling at 27 keV is still problematic and it is for this reason that it was decided to build a new electron beam collector.

The new electron collector is the result of a collaboration between the electron cooling team at CERN and the Centre for Applied Physics and Technology (CAPT) at Lipetsk, USSR [4,5]. The design is very simple [Fig. 1] consisting of a Faraday cup with a repeller electrode at the collector entrance. As we would like to test a number of different types of collectors on the LEAR cooler a vacuum valve has been installed at the collector entrance. Computer simulations made at CERN [Fig. 2] have shown that with an extra coil after the valve, electron trajectories are acceptable and that a magnetic mirror is created at the entrance reflecting any secondary electrons that might be created at the collector surface. Initial tests made at Lipetsk indicated that a collection efficiency of 99.995% could be obtained for an electron beam having an intensity of 3.3 Amps and an energy of 35 keV.

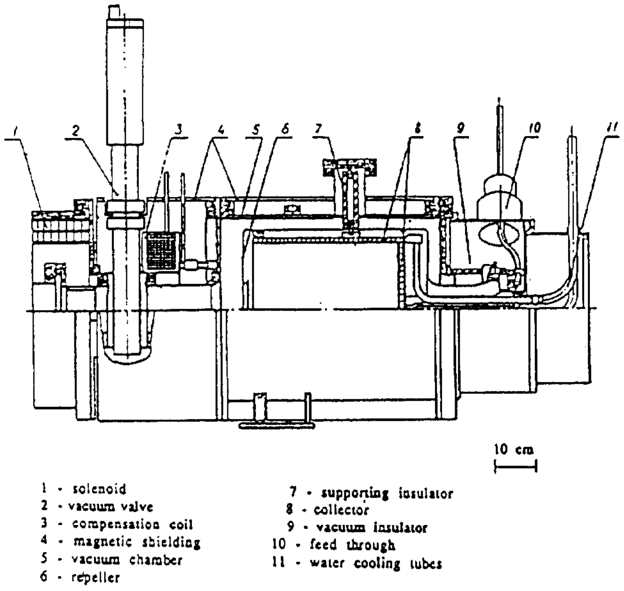

Fig. 1 : The new collector scheme

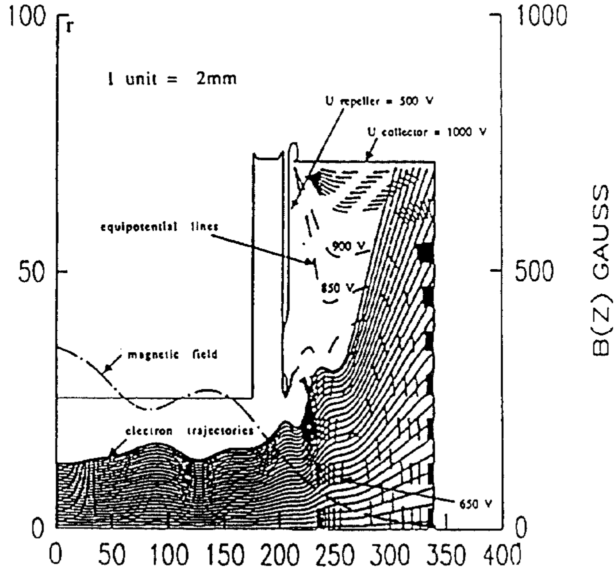

Fig. 2 : The electron trajectories with the equipotential lines and the corresponding magnetic field on axis (I coil = 1500 A)

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The 36° toroids of the cooler cause a deformation in the closed orbit of the circulating ion beam. In the past this has been corrected using the horizontal correction dipoles in the cooler vicinity. However a second perturbation is the coupling between the horizontal and vertical betatron oscillations of the ion beam due to the 1.5m long solenoid in the cooling section. This solenoid excites the coupling resonance $Q_h+Q_v=5$ and implies a fine tuning of the machine working point. Moreover polarized beams required for the FILTEX experiment will be depolarized after a number of passages through the solenoid if it is not compensated. For these reasons two tilted solenoids have been installed, one on each side of the cooler, which have the combined effect of correcting the orbit and compensating the coupling of the betatron motions. The solenoids are connected in series with the main solenoid so that when switched on the cooler will compensate itself. Figure 3 shows the closed orbit with and without the tilted solenoids.

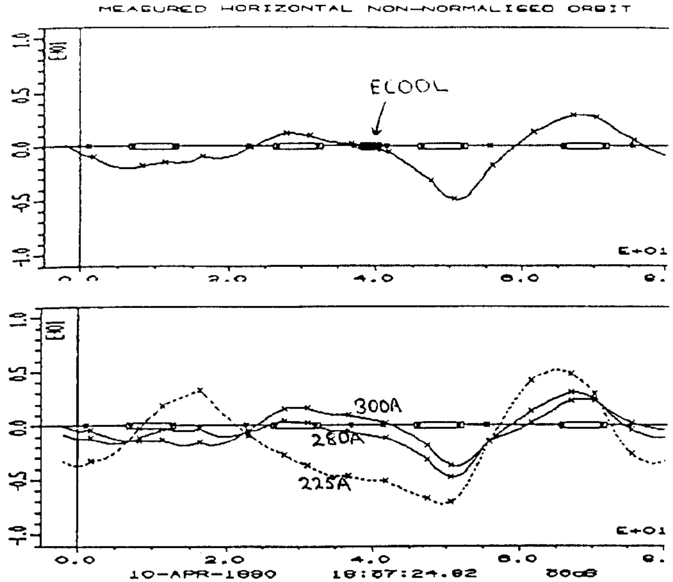

Fig. 3 : Compensation of the cooler toroid deflection with two tilted solenoids. The first trace shows the normal machine closed orbit. The second trace shows three orbits with the cooler solenoid at 100 A and the compensation solenoids at 300 A, 280 A and 225 A respectively.

III. THE TRANSVERSE FEEDBACK

During the cooling process the beam density increases and the beam can become unstable when this density reaches a given threshold. At lower intensities, a beam will resist coherent instabilities by virtue of Landau damping. Using the simple threshold criteria of refs. 6 and 7, we find that for a beam of 10^9 particles, loss of Landau damping can occur for a momentum spread $\Delta p/p$ of about 10^{-4}. The double peak structure regularly observed on longitudinal Schottky scans of an electron cooled beam [Fig. 4] is linked to the fact that the beam is near to this threshold.

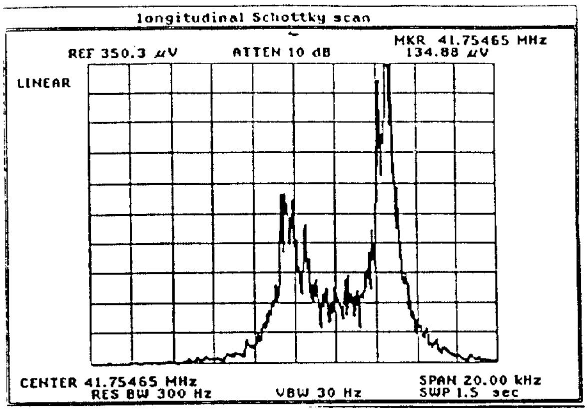

Fig. 4 : Longitudinal Schottky scan of an electron cooled beam of 2.2 10^9 protons. The two peak structure is characteristic of a beam near to the stability threshold.

Transverse instabilities can be observed on both Schottky noise and normal electrostatic position pick-ups. A spectrum analyzer is used to observe the variation in amplitude of an (n -q) sideband as a function of time. The instability manifests itself by an abrupt rise in the amplitude. This is followed by a cooling period of about 1 to 10 seconds in LEAR before the threshold is reached again. Usually, when instabilities occur, beam is lost until the intensity reaches 10^9 particles at 200MeV/c. At this intensity blow-up occurs without any appreciable loss in particle number.

The feedback system (or "damper") developed to counteract these coherent transverse instabilities consists of a horizontal and vertical electrostatic pick-up and a horizontal and vertical kicker placed at an odd number of quarter wavelengths of the betatron oscillation away from the pick-up. The position signal from the pick-ups is linearly amplified, delayed, and then applied to the kicker plates. The bandwidth of the system is determined by the number of modes to be corrected and the gain by the growth rate of the instability. In our case a band from 70kHz to 70MHz is desirable to cover the first 20 modes in the whole energy range at LEAR. The kick required corresponds to a beam displacement of up to 0.1mm per turn. At present only a prototype "damper" is installed, a definite version has been designed which will maintain damping during energy ramping. A closed orbit interference suppressor will be needed to reduce the strong signals observed when a bunched beam is not perfectly centred in a position pick-up.

IV. THE CONTROL SYSTEM

To be fully compatible with the LEAR environment the electron cooler control system also had to be revised. The new system uses a workstation and handles all CAMAC access through a dedicated microprocessor [8]. The CAMAC loop consists of three crates connected by fibre optic cables for data transfer to and from the high voltage platform. In addition a new crate was inserted into the LEAR loop for the installation of the new generation function generators known as GFD-GOCT [9,10] and a timing event decoder. The function generators and the timing decoder are needed in order to run the cooler in the 'pulsed mode' which will be discussed later.

The serial CAMAC access is confined to a 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. All parameters of the cooler are handled in databases which are interfaced to the control system via a limited number of subroutines. These environment routines cover the low level details of the operating system, details that the ordinary user does not wish to be confronted with when programming.

V. OPERATIONAL MODES

A number of operational modes were investigated in the past 18 months in order to determine the most effective manner in which electron cooling could be used at LEAR. With the introduction of digital function generators it has been possible to synchronize the electron cooler with the machine during deceleration and then 'switch on' the cooling process by pulsing the high voltage power supply to the desired value. However the beam loss mechanisms at the ultra low momenta of LEAR also become critical with the perturbations induced by the magnetic elements of the cooler. Therefore much machine study time was used to find acceptable working parameters (tune, chromaticity, closed orbit etc.) in order to obtain a deceleration cycle to 61.2 MeV/c with minimum losses. For operations two modes have been retained.

In the first scenario all the magnetic elements of the cooler are controlled via function generators which are synchronized with the LEAR magnetic cycle. Data relating the different electron energies needed in the cycle are down line loaded into the different GFD vector tables. An antiproton beam is injected at 609 MeV/c and is stochastically cooled for about 5 minutes. When the desired beam dimensions have been obtained, one decelerates the beam to 308.6 MeV/c, the highest momentum for which the cooler is designed to work. On this flat-top the beam is debunched and a trigger is sent from the timing event decoder to the GFD controlling the HT power supply which is ramped to the operational value in 120 msec. Cooling is kept on for typically 6 seconds and then the power supply is ramped back down to zero. The machine and the cooler are then ramped down to the next flat-top and the same cooling procedure is applied. In this way we have managed to decelerate beams to 105 MeV/c saving some 15 minutes in cooling time as compared to stochastic cooling.

The second mode is very much similar to the first with the exception that the magnetic elements as well as the HT power supply are ramped from zero to their operational values on each flat-top. In effect a current regulation system installed on the 1000 A power supply for the cooler solenoids will enable us to reduce the current to zero without any instabilites in the power supply. In this manner the beam sees the effects of the cooler magnets only during a 20 second period on each flat-top when the cooling process is active.

V. CONCLUSIONS

Electron cooling is an effective and rapid means of reducing the phase space dimensions of an ion beam at LEAR. However very high reliabilty and ease of operation are required to make its routine use profitable. Due to hardware bugs, insufficient long term stability and the need to redefine the control system, the full implementation at LEAR has been a gradual and painstaking process. Experience gained while using the cooler in a 'semi-operational' manner has enabled us to redesign the critical components. Supplemented by the active feedback system, electron cooling can now be used consistently between decelerating ramps to obtain beams of ultra low momenta with an appreciable gain in duty cycle and beam quality as compared to previous modes of operation.

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