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Electron cooling tests at LEAR

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Abstract

During the month of June a number of MD sessions were devoted to gaining experience with the electron cooling device installed at LEAR. The main emphasis was to check the hardware in order to determine which components needed a major upgrade. We also performed a number of tests on different possible modes of operation at lower momenta.

The LEAR electron cooler is designed to operate between 370 MeV/c and 100 MeV/c, but until now has only been used to show the cooling process at the proton injection momentum of 308.6 MeV/c and also at 138 MeV/c during the 10 MeV injection tests performed in March. It cannot be regarded as an operational apparatus in its present form as cooling can only be performed at a fixed momentum where all the necessary corrections needed to inject a beam have been previously applied.

In order to test the use of the cooler at the standard LEAR 'flat tops' during the deceleration of a proton beam to 105 MeV/c a number of major hardware changes were made for the control of the apparatus. Firstly a GFD (digital function generator) was installed for the control of the solenoid and the LEAR timing was distributed to this GFD for its synchronisation with the LEAR machine. Another function generator was used for the high voltage power supply when cooling was only required for a fixed period of time. This GFD had its own external start trigger which could be connected later to a timing decoder module. The rest of the apparatus was controlled in the normal manner via a dedicated LSI/11 and the electron cooling CAMAC loop.

1. Electron cooling at 308.6 MeV/c

Before any cooling was performed a number of measurements were made to see and to compensate the effect of the electron cooling solenoid. The electron beam is bent into the cooling section via 36° toroid magnets which have the effect of deflecting the circulating beam by an angle of approximately 10 mrad. The solenoid also causes a coupling of the horizontal and vertical betatron oscillations but this can only be corrected with additional solenoids which will be installed in LEAR in the near future.

The deflection was corrected by two horizontal dipole magnets E4DEH31 and E4DEH32 which both had to be bumped by 55 Amps. The corrected beam orbits can be seen in Figure 1. Tune shifts of -11×10^{-3} in the horizontal plane and -8×10^{-3} in the vertical were also measured and after compensation the working point was found to be $(Q_h,Q_v) = (2.310,2.733)$.

Cooling of the proton beam was observed as expected with cooling times of the order of a few seconds for 2×10^9 particles. Beam instabilities however were not seen and we managed to cool beams of 4×10^9 without any beam loss. Figure 3 shows the transverse and longitudinal Schottky scans of a cooled beam of 2.2×10^9 protons that was kept in the machine for 20 minutes without any losses. The longitudinal scan showed the usual two peak structure with a width of about 5 kHz, but transverse emittance measurements seemed to indicate that the alignment of the electron beam with the proton beam was not correct. Careful adjustment of the vertical dipole E4DEV32 showed that the cooling process depended greatly on the vertical orbit (Figure 4) but due to the lack of vertical correctors in LEAR we were unable to align the circulating beam correctly.

As in previous experiments with the electron cooling device the high voltage power supply was found to be extremely unstable. High voltage breakdowns were frequent and jumps of a few hundred volts caused beam to be lost due to excursions outside the acceptance of the machine.

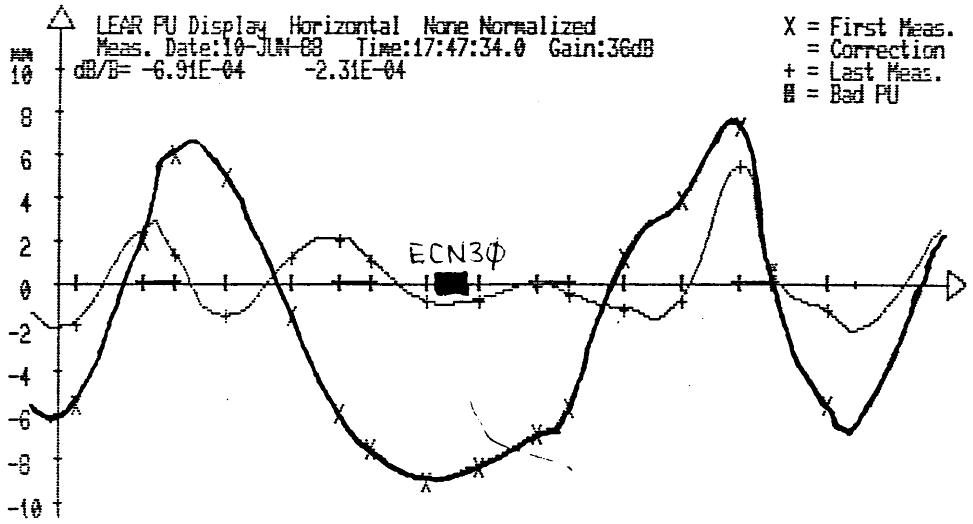
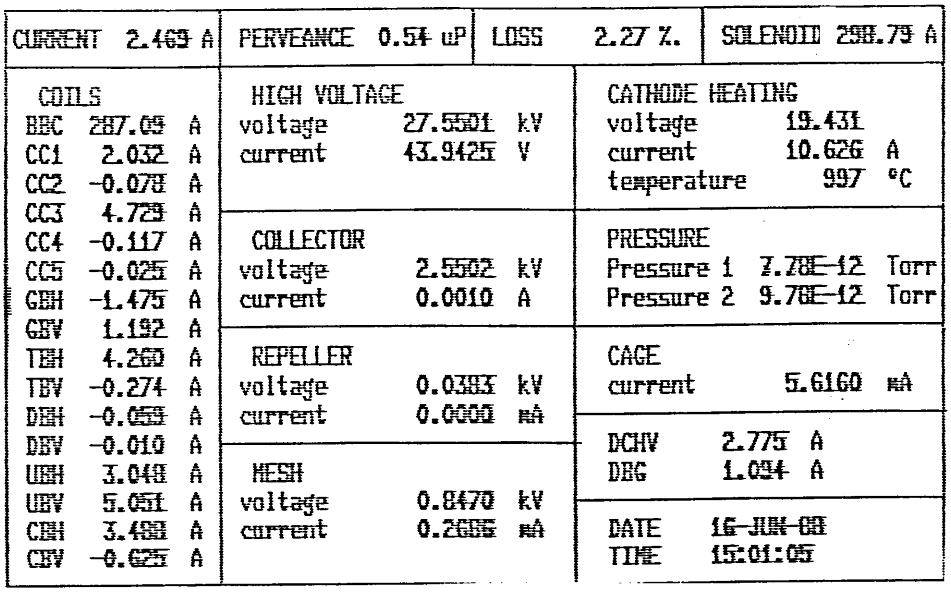


Figure 1: Horizontal orbit correction at 309 MeV/c with ECN30 solenoid on.. the thicker line shows the perturbed orbit with the solenoid at 1/6 of its nominal current.



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CURRENT  2.469 A | PERVEANCE  0.54 uP | LOSS    2.27 %. | SOLENOID 298.79 A

 COILS           | HIGH VOLTAGE                  | CATHODE HEATING
BBC  287.09  A   | voltage       27.5501  kV     | voltage         19.431
CC1    2.032 A   | current       43.9425  V      | current         10.626  A
CC2   -0.078 A   |                               | temperature       997  °C
CC3    4.729 A   |                               |
CC4   -0.117 A   | COLLECTOR                     | PRESSURE
CC5   -0.025 A   | voltage        2.5502  kV     | Pressure 1  7.78E-12  Torr
GBH   -1.475 A   | current        0.0010  A      | Pressure 2  9.78E-12  Torr
GBV    1.192 A   |                               |
TBH    4.260 A   | REPELLER                      | CAGE
TBV   -0.274 A   | voltage        0.0383  kV     | current          5.6160  mA
DBH   -0.059 A   | current        0.0000  mA     |
DBV   -0.010 A   |                               | DCHV      2.775  A
UBH    3.049 A   | MESH                          | DBG       1.094  A
UBV    5.051 A   | voltage        0.8470  kV     |
CBH    3.498 A   | current        0.2655  mA     | DATE      16-JUN-88
CBV   -0.625 A   |                               | TIME      15:01:05
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Figure 2: Electron cooler settings for 308.6 MeV/c operation.

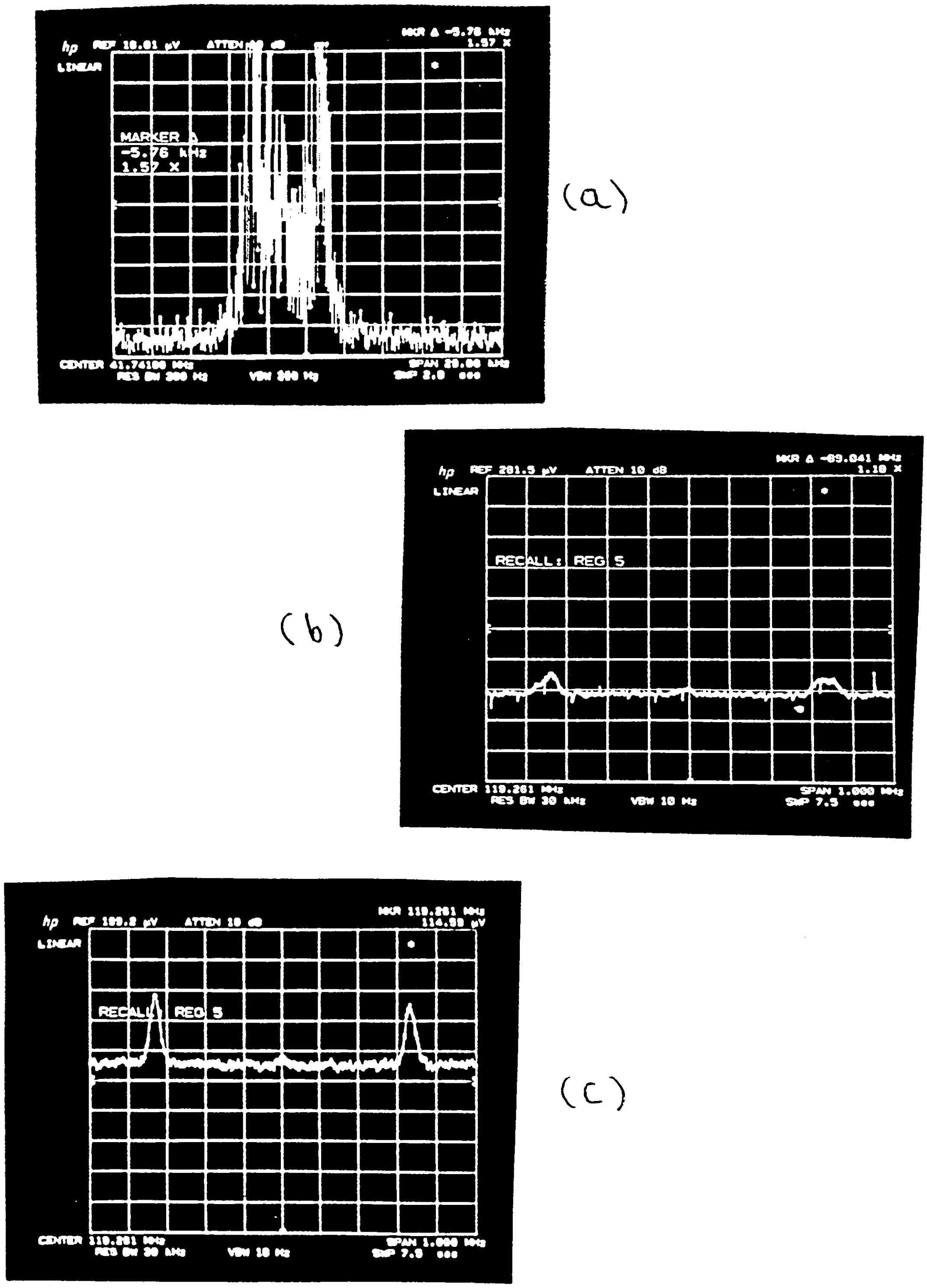


Figure 3: Schottky scans of a cooled beam of $2.2x10^9$ at 308.6 MeV/c.. (a)momentum plane (b)horizontal plane (c)vertical plane

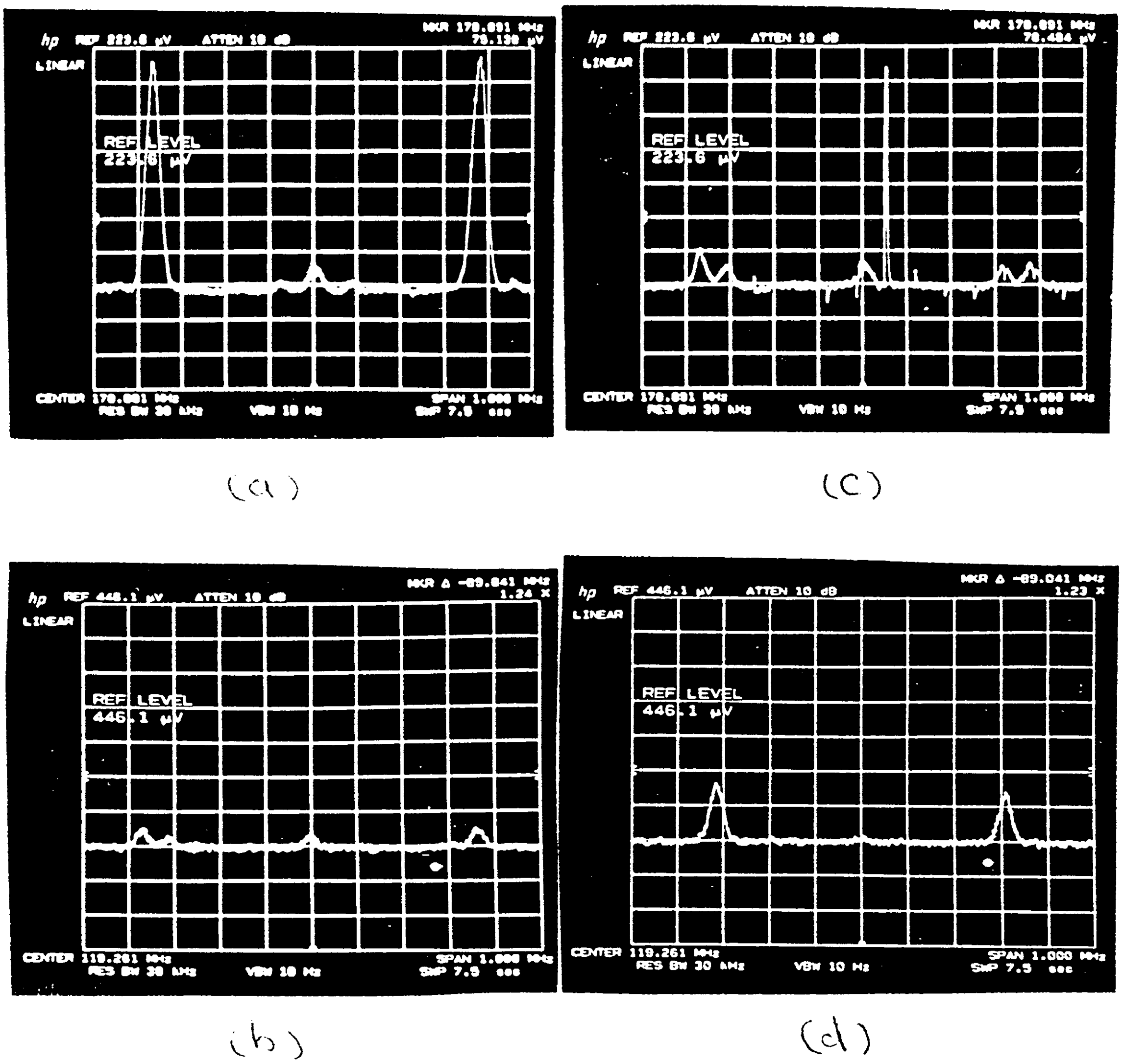


Figure 4: Dependence of transverse cooling on the vertical orbit.. (a) and (b) show the horizontal and vertical Schottky scans with E4DEV32 at −0.4 Amps and (c) and (d) with E4DEV32 at 0.2 Amps.

2. Electron cooling at lower momenta

For cooling at lower momenta the necessary orbit corrections were interpolated from the values used at 308.6 MeV/c and the correction dipoles were bumped accordingly on the respective flat−tops. A cycle for the solenoid was created and loaded into a GFD for synchronisation of the cooler with the LEAR machine. Once this had been done we were able to measure the beam characteristics at each flat−top and to perform the necessary corrections. Table 1 shows the applied corrections and Figure 5 the solenoid GFD cycle.

Table 2: Corrections applied at the different flat – tops

Flat – top	**momentum**	**ΔI DEH31**	**ΔI DEH32**	**ΔQ(H,V)[10^{-3}]**
1.	308.6 MeV/c	55. A	55. A	– 11., – 8
2.	609.0 MeV/c	55. A	55. A	0., 0
3.	308.6 MeV/c	55. A	55. A	0., – 7
4.	200.0 MeV/c	35. A	35. A	+ 5., 0
5.	105.0 MeV/c	18. A	18. A	0., + 7

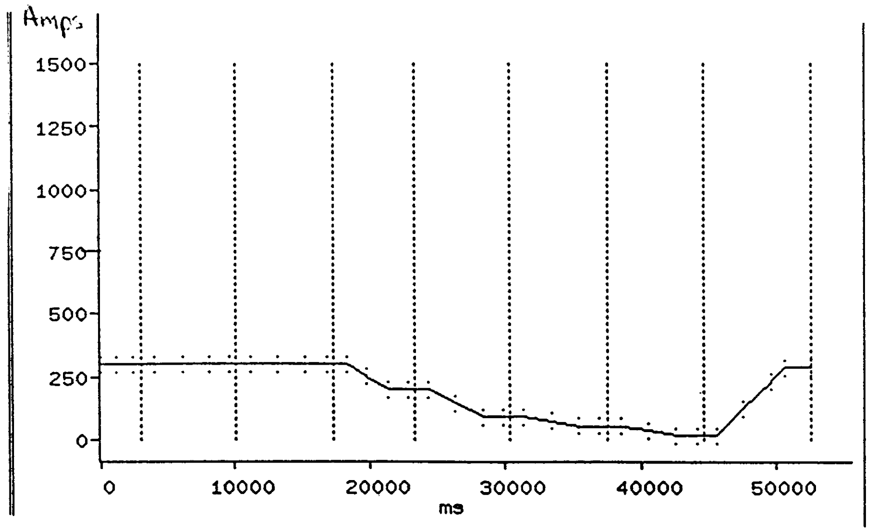


Figure 5: GFD cycle for the electron cooler solenoid

Once the proton beam had been decelerated and debunched, the cooler was ramped up to the calculated operational values of the steering and correction coils and the high voltage power supply was bumped using a second GFD. A number of tests were also performed to ramp the power supply as quickly as possible in order to avoid increasing the vacuum pressure with the unguided electron beam. It was shown that at low voltages (< 12 kV) a rise time of under 100 ms was possible and that the overshoot of power supply was only of the order of a few tens of volts, thus enabling the cooling process to act almost immediately. A first test at 27 kV seemed to indicate that the recorded loss current was much too large for us to envisage this method for effective cooling at 308.6 MeV/c.

Figure 6 and Figure 8 show the longitudinal Schottky scans of a cooled beam at 200 MeV/c and 105 MeV/c. No attempt was made to precisely measure the cooling times or the emittances of the beam but at first sight it would seem that cooling times of the order of 1 second were obtained for a few 10^8 particles. The high voltage power supply was also much more stable at these momenta and no breakdowns were recorded.

During all these tests the quality of the vacuum remained within acceptable limits with average pressures of 6×10^{-12} torr measured on the gun side of the cooling section and 1×10^{-11} torr recorded

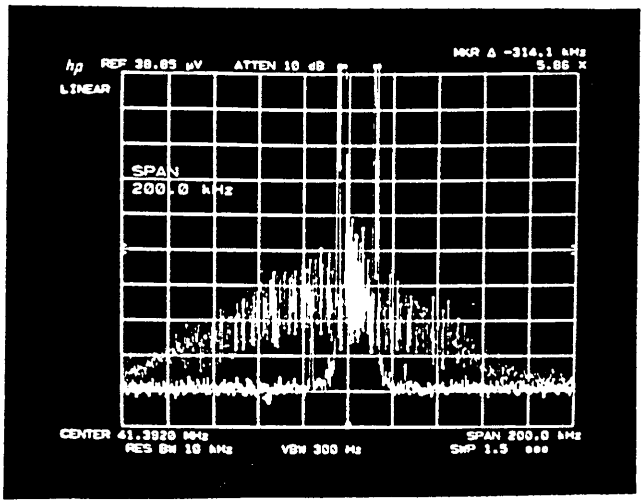
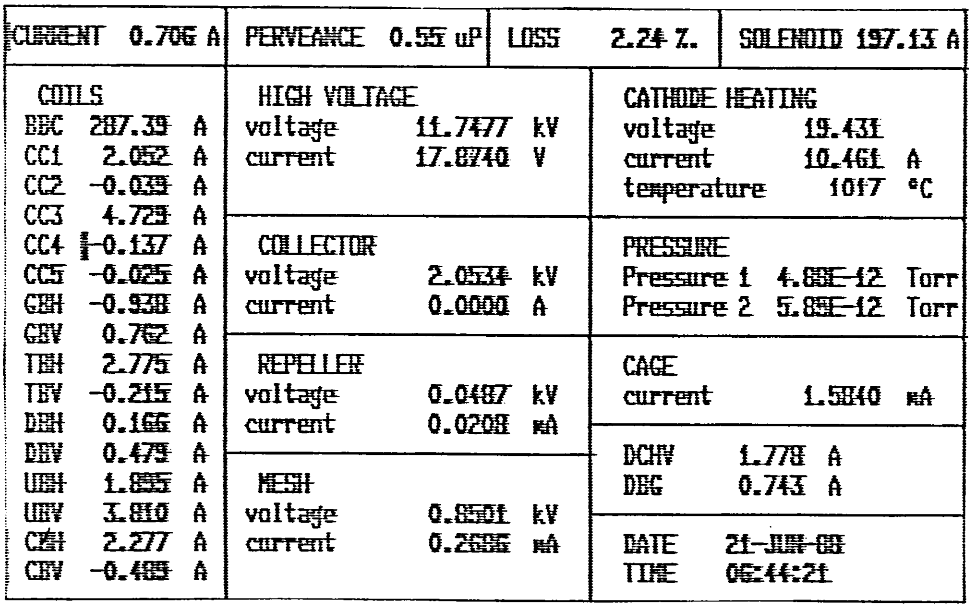


Figure 6: Electron cooling at 200 MeV/c with 1.1x10^9 protons.. the stored trace shows the beam after deceleration and the brighter trace shows the beam with electron cooling on.



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CURRENT  0.706 A | PERVEANCE  0.55 uP | LOSS    2.24 %. | SOLENOID 197.13 A

 COILS            |  HIGH VOLTAGE                  | CATHODE HEATING
 BBC  287.39  A   | voltage       11.7477  kV      | voltage        19.431
 CC1    2.052 A   | current       17.8740  V       | current        10.461  A
 CC2   -0.039 A   |                                | temperature     1017  °C
 CC3    4.723 A   |                                |
 CC4   -0.137 A   |  COLLECTOR                     | PRESSURE
 CC5   -0.025 A   | voltage        2.0534  kV      | Pressure 1  4.80E-12  Torr
 GBH   -0.938 A   | current        0.0000  A       | Pressure 2  5.89E-12  Torr
 GBV    0.762 A   |                                |
 TBH    2.775 A   |  REPELLER                      | CAGE
 TBV   -0.215 A   | voltage        0.0487  kV      | current         1.5840  mA
 DBH    0.166 A   | current        0.0208  mA      |
 DBV    0.479 A   |                                | DCHV     1.778  A
 UBH    1.855 A   |  MESH                          | DBG      0.743  A
 UBV    3.810 A   | voltage        0.8501  kV      |
 CBH    2.277 A   | current        0.2656  mA      | DATE     21-JUN-88
 CBV   -0.485 A   |                                | TIME     06:44:21
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Figure 7: Electron cooler settings for 200 MeV/c operation.

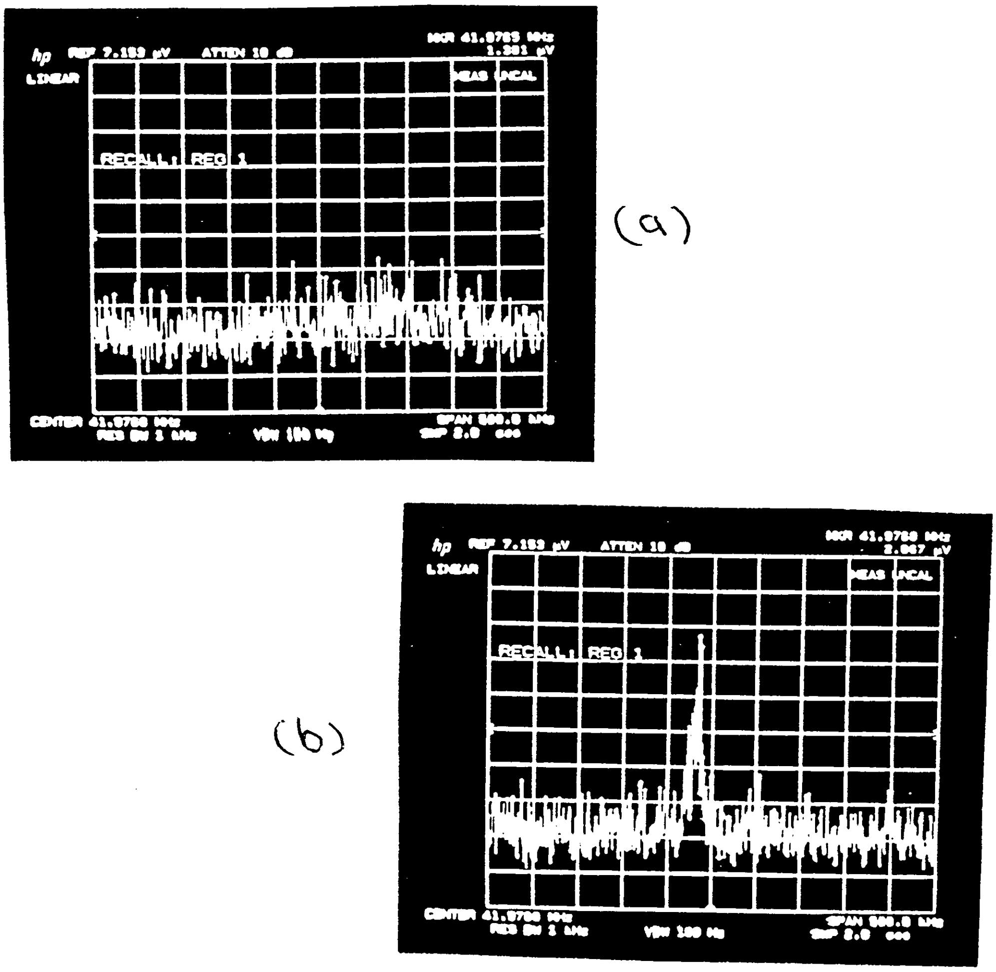

Figure 6: Electron cooling at 105 MeV/c with 8x10^8 protons.. (a) shows the beam after deceleration to 105 MeV/c and (b) shows the beam after 3 seconds of cooling.

on the collector side. Beam losses never exceeded 2.5‰ during the normal cooling procedure even at 308.6 MeV/c where the electron beam current reached 2.5 Amps.