MACHINE STUDIES RELATED TO INTERNAL HYDROGEN PELLET TARGET AND TO ELECTRON COOLING/HEATING AT CELSIUS

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Abstract

An important project at CELSIUS during the last several years has been the installation and commissioning of the WASA detector, including the pellet target, which is now in operation. Other machine studies reported here mainly concern electron cooling and "electron heating."

1 WASA DETECTOR AND HYDROGEN PELLET TARGET

The hydrogen pellet target is designed to give an effective target thickness of up to 10^{16} atoms/cm^2. Its principle has been described before [1]. To avoid scattered pellets and hydrogen gas in the scattering chamber it is important to have the pellet beam well aligned and collimated to a diameter of around 3 mm at the point of interaction with the CELSIUS beam. The collimation is done with a 0.8 mm skimmer placed 0.7 m downstream of the pellet generator. The diagnostics to align the pellets is based on CCD cameras. The pellet beam is illuminated with lasers perpendicular to the direction of observation. The alignment is done by remotely controlled co-ordinate tables, which can translate and tilt the pellet beam.

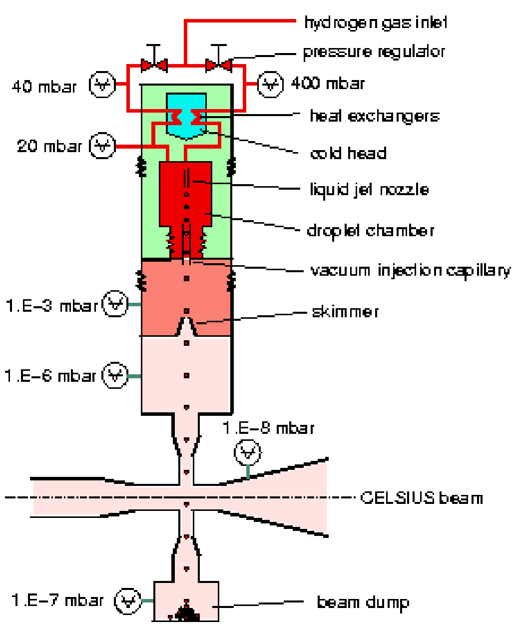

Figure 1. Schematic view of the pellet target system

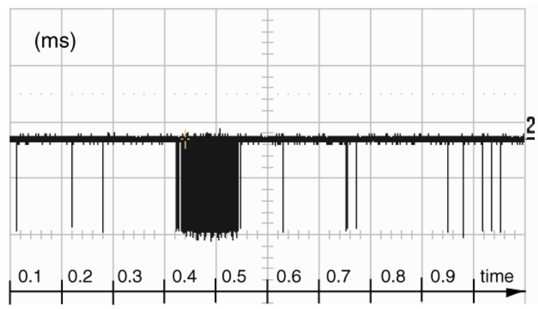

Figure 2. An oscilloscope trace showing the passage of a pellet through the CELSIUS beam. It shows pulses from single-track triggers in the forward detector.

Figure 2 shows an oscilloscope trace with very frequent forward detector signals during 100 microseconds, which in this case was the time needed for a pellet with velocity of 60 m/s to go through the CELSIUS beam.

2 DETERMINATION OF COOLING RATE FROM MEASURED BEAM WIDTH WITH INTERNAL TARGET

We usually measure the thickness of the internal targets in CELSIUS by letting the beam drift, and record how the frequency of a Schottky peak changes with time. Knowing the momentum compaction factor, we can calculate the target thickness from the Bethe-Bloch formula.

We have recorded beam profiles with our magnesium-jet beam profile monitor [3] while subjecting the beam to the internal targets and electron cooling. Knowing the target thickness we can calculate the transverse emittance growth, and therefore the equilibrium electron cooling rate. As an example, we recorded the profile of a $^{14}N^{7+}$ beam of 300 MeV/*u*, which was exposed to an argon target and cooled with an electron current of 100 mA. We measured the profile without target, and with target thicknesses of 2.8×10^{13} and 4.8×10^{13} atoms/cm^2. The measured FWHM beam widths for these cases were 1.8, 2.5, and 2.8 mm respectively, corresponding to rms. emittances of 0.055, 0.107, and 0.134 µm respectively.

[1] On leave from the Institute of Modern Physics, Chinese Academy of Sciences

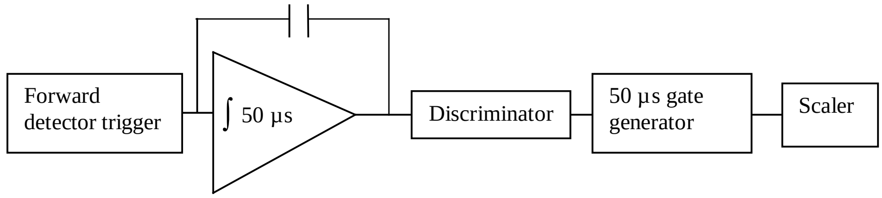

Fig. 3. To count the number of pellets which go through the CELSIUS beam, short (20 ns) logic pulses from the detector trigger is integrated with a time constant of 50 μs. This corresponds to the expected time for a pellet to pass the beam. The discriminator selects pulse clusters of a certain size (see fig. 1), and the cluster rate is counted with a scaler. The signal for a cluster is prolonged to 50 μs, to avoid double counting.

The calculated cooling time becomes about 1.8 s, which we can reproduce with "Parkhomchuk's formula" [5] only by assuming an rms. misalignment between the ion closed orbit and the magnetic field in the electron cooler of as much as 0.37 mrad. This is inconsistent with our experience that a FWHM of the beam of 1.8 mm requires "perfect" (< 0.1 mrad) alignment.

3 ACCUMULATION WITH ELECTRON COOLING

Accumulation with electron cooling is used at CELSIUS to reach useful intensities of ions that are heavier than protons, deuterons, and ^{4}He ions (so far up to ^{40}Ar). As it has also been reported from other laboratories, curves of accumulated current often show a distinct knee at some threshold intensity. It was suggested by Burov and Nagaitsev [2] that this threshold is caused by the envelope instability, and that a slight misalignment between the electron and the ion beams could increase the threshold. We tested this idea while accumulating $^{14}N^{7+}$ ions, which were stripping injected. The result was just the opposite; the threshold is always higher when the beam is narrower, see figure 4. It is our belief that the threshold is due to the non-linear properties of intra-beam scattering: When the electron cooling can no more bring the 'fresh' beam into a small enough core of the beam, then the fresh beam is lost on the stripper foil at the next injection.

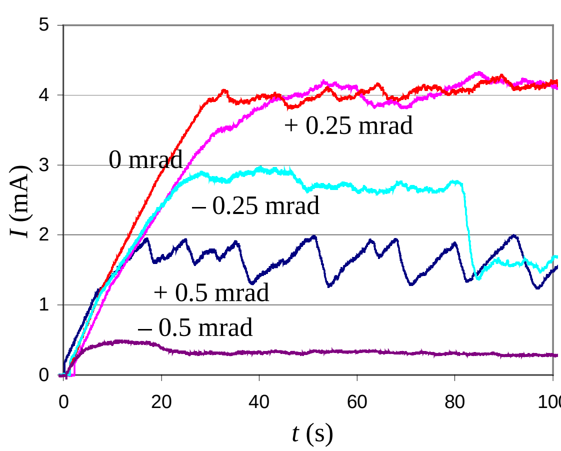

Figure 4. Accumulated ion current I as a function of time during stripping injection with cooling accumulation of 24.5 MeV/u $^{14}N^{7+}$ ions, done with different misalignment angles between the electron beam and the closed orbit.

4 DIAGNOSTIC SCRAPERS

Recently installed diagnostic scrapers in CELSIUS cut the horizontal beam size. They are inside one of the arcs, between two dipole magnets, where the dispersion goes through zero and the beta value is 12 m, compared to 10 m in the electron cooling section.

We used these scrapers to determine the effective horizontal acceptance of CELSIUS. To calibrate the position of the closed orbit, we electron-cooled a weak 48 MeV proton beam, and then used one scraper at a time to completely kill the circulating beam. This we could do with an accuracy of about ± 0.5 mm.

The horizontal acceptance was then determined by moving the scrapers towards the beam until any change in the beam lifetime could be observed. The value that was found is 50 π μm.

5 ELECTRON HEATING

We have used one of the horizontal scrapers to try to gain some more insight in the "electron heating" phenomenon [4], which we concluded already in 1994 to be due at least partly to the non-linear focusing of the beam by the electrical field from the electron beam space charge. The electron beam diameter in CELSIUS is smaller than the acceptance of the ring (the electron beam radius is 10 mm, corresponding to $I = 10$ and 15 μm in the horizontal and vertical planes respectively). We recorded the intensity vs. time with different scraper openings in the presence of electrons which had the correct energy for electron cooling as well as with "detuned" electrons (i.e. the voltage of the electron cooler's high voltage power supply was set 10 kV higher than at the correct value for cooling), and without electrons. The measurements were done without rf. Then we repeated some of the measurements with an expanded electron beam. The measurements that were repeated were with detuned electrons and without electrons. The beam was expanded by reducing the magnetic field in the drift tube to a value which was 2.7 times lower than the field at the cathode (0.0444 T compared to 0.12 T), so the electron beam

Table 1.		unexpanded electron beam					expanded electron beam		
half opening (mm)	acceptance (μm)	$\tau_{cool.}$ (s) (lifetime)	$\tau_{no\ e.}$ (s) (lifetime)	$\tau_{det.}$ (s) (lifetime)	$\tau_{no\ e.}/\tau_{det.}$	$\tau_{cool.}/\tau_{no\ e.}$	$\tau_{no\ e.}$ (s) (lifetime)	$\tau_{det.}$ (s) (lifetime)	$\tau_{no\ e.}/\tau_{det.}$
2	0.32	107	59	52	1.1	1.8	45	44	1.0
4	1.26	334	94	88	1.1	3.5	117	88	1.3
6	2.8	1770	160	104	1.5	11	192	126	1.5
8	5.0	3290	239	99	2.4	14	290	147	2.0
10	7.9	4810	379	93	4.1	13	413	180	2.3
12	11	7040	602	87	6.9	12	588	189	3.1
14	15	7690	971	89	11	8	870	199	4.4
16	20	12700	1660	90	18	8	1070	200	5.4
18	26	12100	2790	93	30	4	1200	198	6.1
∞	50	9300	2860	93	31	3	1530	207	7.4

radius inside the drift tube became $10\times\sqrt{2.7}=16.4$ mm. The magnetic field in the toroids was not changed however, which means that for the expanded electron beam case, there is a part of the interaction length, maybe 10 %, in which the electron beam radius is still smaller than 16.4 mm. The electron current was 100 mA in the case of the unexpanded electron beam and 270 mA in the case of the expanded electron beam in order to get the same current density for both cases.

The intensity decayed exponentially after an initial period. We evaluate the lifetime from 30 to 90 s after the injection. The results are given in table 1, where τ_{cool} is the measured beam lifetime ($1/e$) with cooling, $\tau_{no\ e.}$ is without electrons, and $\tau_{det.}$ is with detuned electrons.

It seems clear from table 1, that the detuned electron beam does behave as a soft-edged collimator, which removes large amplitude particles from the beam. The effect becomes less obvious when those particles are removed with the physical collimator.

From the column which shows $\tau_{cool.}/\tau_{no\ e.}$ which for 50 π μm acceptance we expect to be $3.67\times\ln(\theta_{max}/\theta_{min})\approx 18$ [6], we must conclude that the useful aperture may be smaller when the electron beam is present than when it is not.

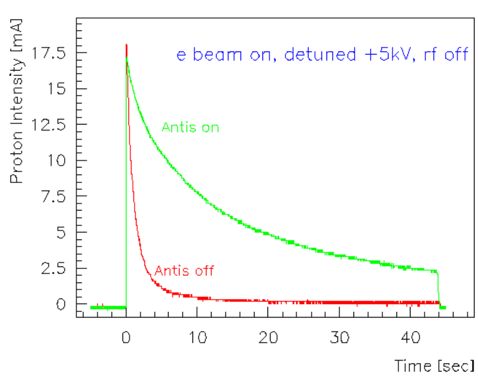

Figure 5. Plot of 48 MeV proton intensity vs. time with 100 mA electron beam current present in the electron cooler, with and without compensating for the electron cooler's magnetic field (0.1 T) with the antisolenoid.

6.1 Antisolenoid

There is a compensating solenoid ("antisolenoid") on the cooling straight section of CELSIUS. Magnetic field in the antisolenoid has made closed orbit correction more difficult in the past, before we improved our algorithms [7], and has no influence on the beam lifetime as long as the electron beam is not present. It has therefore not been routinely used. It has now been determined however, that it does have a significant beneficial effect against electron heating, see figure 5. We think that the reason is, that only half the number of resonances is excited if the planes are decoupled.

6.2 Conclusions on electron heating

Our observations are consistent with the hypothesis that electron heating in CELSIUS is partly due to the non-linear electrical field from the electron beam space charge. The hypothesis is supported by the observation that energising the antisolenoid helps to reduce it. Other effects [5] may also be important.

In addition, it should be mentioned that the electron heating effect discussed here goes as Q/A, whereas electron cooling goes as Q^2/A. Thus, it is most important for protons and may not be important for heavy ions.

7 OTHER WORK

Other work, which has recently been done at CELSIUS, includes turn-by-turn beam position measurement [8] performed with a new data acquisition system [9], and studies of intra-beam scattering [10].

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