EXPLORING THE LUMINOSITY BOUNDARIES OF THE IUCF COOLER

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In the past year, there have been two principal lines of investigation. The first of these was a study of an accumulation method for polarized beam. A description of this work will appear in the Ph.D. dissertation of X. Pei (in preparation). The second was a study of beam loss mechanisms through the dependence of cooled beam lifetime on target thickness, target species and beam energy. A description of the results is being prepared for publication.

Polarized Beam Accumulation

The easiest injection scheme for the Cooler, using electron removal from ions from the cyclotron, is not possible for the fully-stripped polarized positive hydrogen ions from the existing IUCF polarized source. The alternative method developed for polarized beams involves three processes. First a ferrite kicker is switched off after admitting one turn of beam, trapping the injected particles on a closed orbit. Second the rf cavity is programmed to debunch and decelerate the freshly injected particles, lowering their momentum by about 0.2%. Third the electron cooling acts on the decelerated particles to reduce their phase space volume and add them to a stack. The process is repeated, gradually increasing the accumulated intensity.

To avoid excitation of a large coherent betatron amplitude in the stack when the kicker fires, a second identical kicker, located half a betatron wavelength upstream is fired in synchronism to the injection kicker. To lowest order, the pair generate a localized displacement of the stack. The ring lattice designs give 4 m dispersion at the injection point, so the deceleration moves the injected beam 8 mm away from the injection septum. When the kicker fires again, this distance is sufficient that the stacked beam does not reach the septum.

Mismatch of the kickers (in timing, amplitude or phase advance) gives a small betatron amplitude to the stack. Without cooling, repetitive kicker firings would increase the emittance and limit the number of repetitions. With cooling the kicker mismatch limits the kicker firing rate. Beam losses appear if the rate is too high. Because of the imperfect vacuum of the ring, which generates a tail on the transverse distribution, a small loss occurs for each kick as the outermost fringe of the tail is moved outside the acceptance boundary. (Gas targets increase the tail generation rate and give a larger loss, so target gas should be gated off while injecting.) The optimization of the stacking injection process involves minimizing the beam heating by careful matching of the kickers, maximizing the transverse cooling rate, and then selecting the best repetition rate. If the rate is low, the filling is slow, lowering the luminosity for thick targets. If the rate is high, the loss per kick increases, limiting the maximum stored current and thus the luminosity for thin targets.

Representative values observed as of September 1990 for polarized protons injected at 185 MeV were: 0.1 μA added per cycle; loss/ kick 0.01% at 5 Hz; maximum stored current 0.3 mA. Experiment CE-08, using this setup, reported an average luminosity of about 0.5 10^{29} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

In the spring of 1991, a second rf cavity operable on first harmonic was added to the ring. This cavity allows the cooled stack to be localized in azimuth, so that shortened kicker pulses synchronized to this cavity are not seen by the accumulated beam. Preliminary (non-optimized) tests gave a loss of 0.002%/kick at 20 Hz, with the injected beam intensity reduced by a factor of 2/3 due to the shorter kicker pulse. In this mode the luminosity for thin targets should be increased about a factor 5 compared to the single rf cavity method.

Beam Loss Mechanisms

The beam lifetime observed in the presence of an internal target in the first eighteen months of Cooler operation was substantially shorter than estimates based on losses by single scattering from target nuclei. The discrepancy was largest for low Z targets. A methode of measuring transverse acceptance (by determining the amplitude of a kicker pulse which removed half the beam) was developed which showed that the operating acceptance was about A = 10π μm compared to the 20π μm limit set by aperture restrictions. An alternate tune (set of quadrupole currents giving a different beam envelope) was developed which increased the aperture limit to about 28π μm and the observed value to the range $16\pi - 20\pi$ μm. This tune increased the aperture function β at the target waist so that the ratio β/A was unchanged and so the nuclear single scattering loss cross section should not have changed. However the beam lifetime for a hydrogen target improved markedly, contributing to the higher luminosities available in 1990.

The reason for the improvement is that a target located in the "G" or "S" straight where the dispersion is 4 m is subject to an additional loss and heating mechanism arising from interaction with the electrons of the target atoms. The dispersion couples longitudinal momentum transfer into transverse emittance growth which can lead to a direct loss if the acceptance is small. The new tune switched off the direct loss although the contribution to transverse heating remained at a reduced level.

The observed loss cross section however remained higher than could be explained by single scattering events. Therefore, over the past year, as an adjunct to other experiments, loss cross section have been extracted from the relation of beam lifetime to target thickness for a range of beam energies and target species at locations of low and high dispersion in the ring. After removing the contribution of ring vacuum to the lifetime, the loss cross section normally shows a constant value for low target thickness, increasing above a threshold thickness at which transverse heating exceeds transverse cooling and increases the beam emittance. The minimum loss cross section scales approximately as $\mathrm{Z}_t^2/\mathrm{T}_p^2$ where T_p is the proton kinetic energy. There still some scatter to the data indicative of machine parameters not fully under control, but the set of measurements is sufficient to allow prediction of luminosity within a factor of two under all conditions. The loss cross section is now believed to be higher than the single scattering prediction due to the effects of multiple scattering (within one cooling time the beam makes many passes through the target).