COOLER INTENSITY LIMITATIONS

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Electron cooling accumulation of multiple strip-injected beams allows accumulation up to currents which are limited by instabilities and space charge effects rather than injection efficiency. This note is a survey of the various current limitations encountered in the cooling ring.

In Fig. 1 the peak threshold currents (the DC beam current times the bunching factor, $BF = I_{peak}/I_{average}$) for various current limitations are plotted as a function of the bunching factor for electron-cooled 45-MeV protons. The intensity limitations are a function of the bunching factor since as it increases from 1 to about 10, the beam momentum spread typically increases by a factor 5 and the threshold currents for transverse (longitudinal) instabilities increases with the first (second) power of the beam momentum spread.

The first intensity limitation encountered by coasting beams (unity bunching factor) is that due to coherent transverse instabilities (CTI's), principally in the horizontal plane. The threshold current for CTI's as a function of beam current is depicted in Fig. 1 by the two solid lines. The lower solid line indicates the region where CTI's are first encountered; beam can, however, be stored without dampers temporarily in the region between the two lines. Cooled beams cannot be stored, without dampers, in the region above the upper line. After beam loss due to CTI's, the beam current is reduced to the neighborhood of the lower line. Since the beam momentum spread increases when the beam is bunched, and since the threshold current for these instabilities increases linearly with the beam momentum spread, larger peak currents (though lower DC currents) can be achieved with bunched beams without dampers.

We have installed a transverse damping system, with a frequency response from 0.04 to 100 MHz, for both the horizontal and vertical planes. This system allows the coasting beam current to be increased from 1 mA to 4 mA, at which point we encounter the longitudinal instabilities, shown in Fig. 1 by the dotted lines. The threshold current for this instability can probably be increased by increasing the equilibrium proton beam momentum spread; however, coasting beams are not of great interest since nearly all experiments require beams with energies above the injection energy of 45 MeV, and consequently, RF-bunched beams.

As the beam is bunched the beam momentum spread increases by a factor of 5 from about 2×10^{-5} to about 1×10^{-4} (FWHM) for bunching factors of about 10. The increased momentum spread eliminates the longitudinal instabilities, and though the CTI's are somewhat ameliorated, we still encounter them at higher peak beam currents. The CTI's can be eliminated by the use of the damping systems. With the dampers in operation a new intensity limitation is encountered at peak intensities of about 5 mA, almost independent of the BF. This limit is denoted in Fig. 1 by the dashed line and we suspect this limit is due to beam space charge effects.

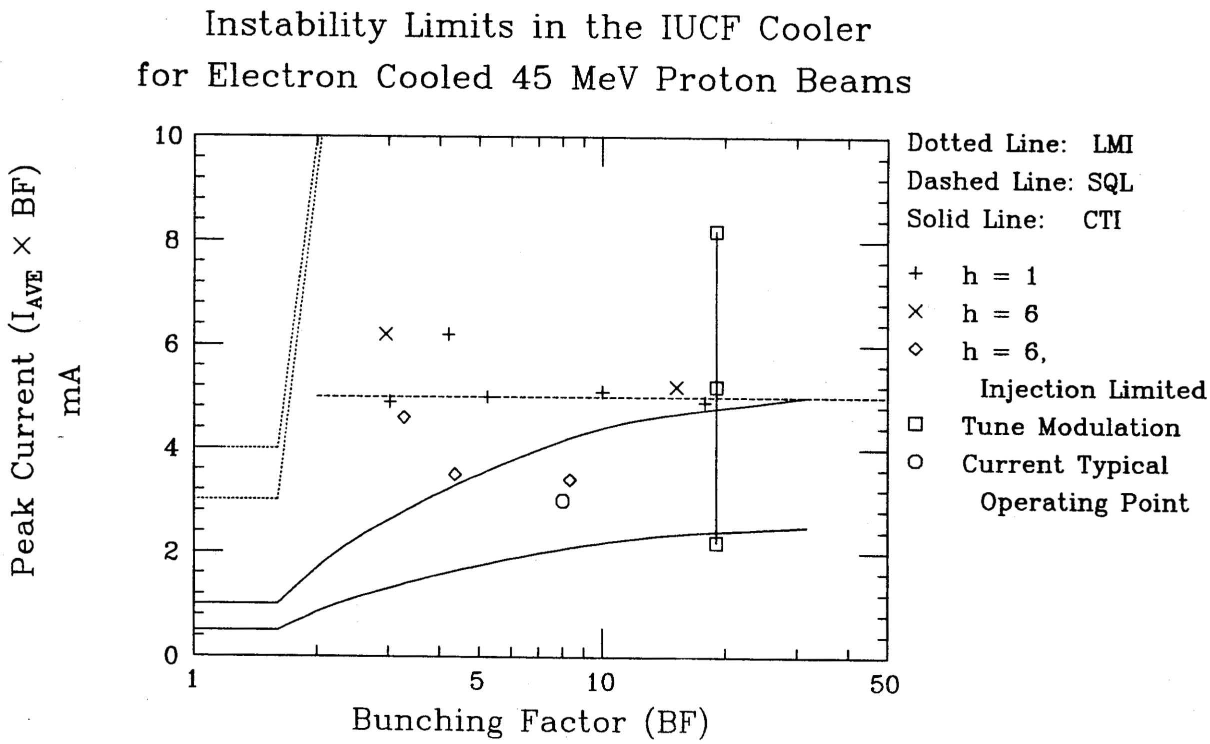

Figure 1. Instability limits in the IUCF Cooler for electron-cooled 45-MeV proton beams.

The +'s and ×'s in Fig. 1 show the maximum beam currents obtained while operating with the RF system on harmonic numbers, h, of 1 and 6 respectively. The diamonds are also data obtained while operating at $h = 6$, though in this situation the intensity was limited by a reduction in injection efficiency at higher RF voltages. The large open circle represents a typical operating point using a combination of stripping injection and electron cooling accumulation while operating in our Cool-Ramp-Cool mode. The open boxes joined by a vertical line demonstrate the effect of the encountered intensity limitations: if the dampers are deactivated the peak beam current falls from about 5 mA to 2 mA; with the dampers operating, the peak current can be increased from about 5 mA to 8 mA by increasing the quadrupole strength during the injection process.

In the upcoming year we will be improving the damper system and experimenting with methods of increasing the beam equilibrium emittance without significantly reducing the efficiency of cooling accumulation to reduce the effects of the beam space charge.