K500 Operations and Development

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Introduction

During the 1998-1999 reporting period, efforts to increase the overall beam intensities were markedly successful. The intensities of several beams were increased by factors of up to six while typical total source-to-extracted-beam efficiencies went from around 2% to around 10%, with a high for one developed beam of 12.9%. Clearing out unnecessary collimation from the injection line as well as understanding and improving the extraction efficiency have been a large part of this improvement. In a separate contribution will be our upgrade plans for the ECR2 ion source, with which we hope to produce higher charge-states and intensities than those produced by ECR1.

Extraction

In the last year's progress report, we reported on some successes with increasing the extraction efficiencies for two lower cyclotron field beams, where the efficiencies improved from 25-35% to 50% for 18.6 AMeV, $^{7}Li^{2+}$ (at 33 kG) and 35 AMeV, $^{20}Ne^{7+}$ (at 36.9 kG) beams. In general the extraction efficiencies for the lower field beams, beams developed at below 38 kG cyclotron field, have been smaller (about 20-50%) than the 40-43 kG beams where occasionally up to 80% extraction efficiencies can be achieved. One obstacle for the lower field beams is the mismatching of the particle orbit with the curvature of the E1 deflector. Due to the larger field flutter at lower fields, the curvature of the particle orbit is smaller than that of E1, which is located at the end of "A" hill. The improvement in the extraction efficiencies resulted from using new trim coil solutions which follow a "flatter" sin (ϕ) curve just before the extraction; see Fig. 1 for two different trim coil solutions for 35 AMeV, $^{20}Ne^{7+}$ beam. Since then the new "flatter" sin(ϕ) solution has been applied to several beams (most of them developed below 38 kG field), from 18.7 AMeV $^{16}O^{4+}$ (at 37 kG), and 40 AMeV $^{40}Ar^{16+}$ (at 37 kG), to 60 AMeV $^{4}He^{2+}$ (34 kG) beams. The resulting extraction efficiencies ranged from about 45% to 65%, which in most cases represent some improvement from previous efforts. For one beam, 40 AMeV $^{40}Ar^{14+}$ (39 kG), the new solution resulted in better than 80% extraction efficiency and the overall transmission (from the ion source to the cyclotron extraction) of 12.7%. The "flatter" sin(ϕ) can be only applied to the lower cyclotron field beams where the larger flutter provides sufficient vertical focusing (ν_z). The new sin(ϕ) solution sacrifices some vertical focusing for radial focusing just before passing through the ν_r=1 and the ν_r=2 ν_z resonances. The new solution seems to enjoy a number of advantages over the old solution: (1) a small advantage in energy gain per turn, (2) more rapid ν_r=1 crossing, (3) a little easier extraction due to a slightly larger radius for ν_r=0.8, (4) less sensitive to the coherent oscillation produced by rapid skirting about ν_r=1 resonance (from the dip in ν_r coming close to 1 before actual crossing of the ν_r=1 resonance) [1]; the oscillation results in an increase in radial oscillation amplitude and this increase also depends on the energy gain per turn and will affect the first harmonic field bump used to extract the beam. The true reasons for the extraction improvement and hence the increase in beam intensity are not known, and in fact it would

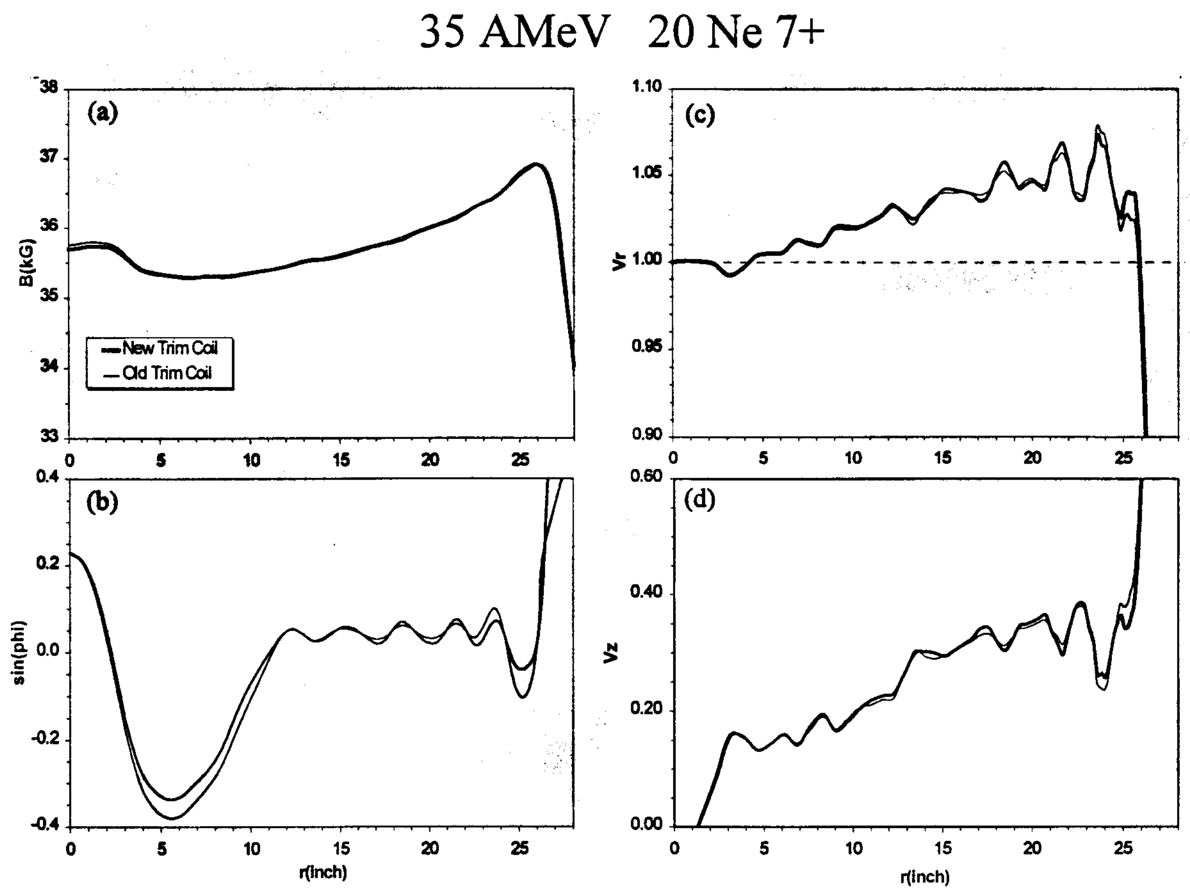

Figure 1. Results of two trim different coil solutions for 35 AMeV $^{20}Ne^{7+}$: (a) magnetic field vs. radius, (b) sin(ϕ) vs. radius, (c) ν_r vs. radius, and (d) ν_z vs. radius.

be extremely valuable to install a visual probe to observe the beam as it traverses through the decentering and the coupling resonances just before extraction.

Cyclotron Beams

In May, collimators and pulser plates were removed from the vertical section of the injection line. The collimators were directly upstream of injection-line faraday cup 04, and their original purpose was for use in determining a rough beam profile and for centering. They were positioned at a calculated focal point. However, they were never used, and they limited both pumping speed and the phase space available for tuning the injection optics. The pulser plates were occasionally used by experimenters, but they represented an even larger impediment to tuning and pumping. To provide beam pulsing capability, the A-to-B phase shifter on the rf system was modified, and a control module was designed and built to shift the A-to-B dee phase, effectively cutting off the beam. This system replaced the pulser plates, and has since been used successfully by experimenters.

Figure 2 illustrates the large intensity gain for several beams, and Table I is a list of intensities and efficiencies of some recently developed or redeveloped beams. The acceptance of the beam into the rf phase period that is correct for acceleration in first harmonic should ideally be better than 30% when the rf buncher is used. Comparing 30% to the listed injection efficiencies, there is still roughly a factor of 2 possibly to be gained with better matching. Also in an effort to obtain better pumping on the extraction channel of the K500, cryopanels cooled with liquid nitrogen have been installed in the vacant ports for magnetic channels M4 and M8. Testing is still in progress to see if this can alleviate some of the beam attenuation due to poor vacuum at this position.

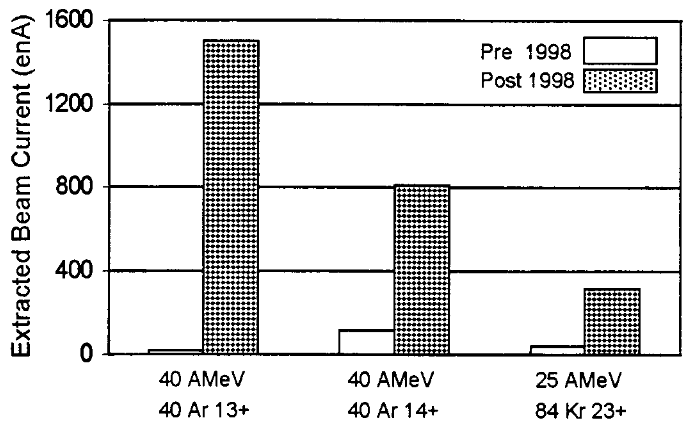

Figure 2. Recent improvements in K500 beam intensities.

Table I. Recently developed or redeveloped beams.

Ion	E/A (MeV)	I ($e\mu A$)	Injection Efficiency	Extracted Efficiency	Total Efficiency	Beam Power (watts)	Lost Power (watts)
$^{16}O^{8+}$	60	0.17	*	44%	*	20	
$^{22}Ne^{4+}$	14.6	0.71	18%	71%	12.9%	57	23
$^{23}Na^{7+}$	28	0.40	13%	40%	5.2%	37	56
$^{40}Ar^{8+}$	15	1.50	12%	50%	6.1%	112	112
$^{40}Ar^{13+}$	40	1.50	14%	88%	12.1%	185	25
$^{40}Ar^{14+}$	40	0.81	14%	90%	12.7%	93	10
$^{40}Ar^{16+}$	47	0.013	11%	36.5%	4.1%	2	
$^{84}Kr^{17+}$	15.3	1.10	23%	31.4%	7.2%	83	181
$^{84}Kr^{23+}$	25	0.31	14%	85%	11.9%	29	5
$^{84}Kr^{27+}$	40	0.001	*	84%	*	*	
$^{197}Au^{33+}$	10.5	0.175	10%	74%	7.4%	11	

Ion sources

A vacuum lock has been designed and installed on ECR1 to allow removal and installation of a high-temperature oven, a low-temperature oven or a fixture for sputtering without letting the ion source up to air (Fig. 3). The sputtering fixture has been built and tested with beams, and the low-temperature oven has been built, tested with the vacuum lock, but not tested with beams. A high-temperature oven that can be used with the vacuum lock is still under construction.

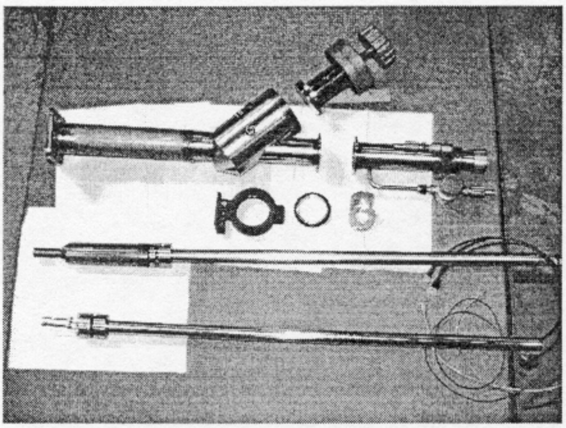

Figure 3. The disassembled vacuum lock showing the sputter fixture and low-temperature oven.

Operations

For the period of April 1, 1998 through March 31, 1999, the operational time is summarized in Table II, while Table III lists how the scheduled time was divided among the experimenters. There were no major repairs during this period.

Table II. 1998-99 Operational Time.

	Hours	% Time
Beam on target	3893.75	50.8
Tuning cyc. & optics, exp. setup	835.50	10.9
Beam development	1782.25	23.2
Scheduled maintenance	827.50	10.8
Unscheduled maintenance	229.25	3.0
Idle time	98.25	1.3
Cool-down, transfer	0.00	0.0
Total	7666.50	100.0

Table III. - Scheduled Beam Time.

	Hours	%Time
Nuclear Physics	1508.25	22.8
Nuclear Chemistry	1509.75	22.9
Atomic Physics	711.25	10.8
Outside Collaboration	619.75	9.4
Outside Users	430.75	6.5
Beam Development	1825.00	27.6
Total	6604.75	100.0

Reference

[1] M.M. Gordon and F. Marti, IEEE Trans. Nucl. Sci. **NS-32**, 2285 (1985).