THE IPNS ACCELERATOR 50 MeV AND 500 MeV TRANSPORT LINES*

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Abstract
The Intense Pulsed Neutron Source (IPNS) accelerator delivers up to 500 MeV protons to a depleted uranium target producing spallation neutrons for material science and other research. A 70-80 ns bunch strikes the target at a rate of 30 Hz with an average beam current of 15 μA. The 50 MeV and 500 MeV beam lines transport protons from the Drift Tube Linac (DTL) to the Rapid Cycling Synchrotron (RCS) and from the RCS to the Neutron Generating Source (NGS) target, respectively. Through over 15 years of operation, the accelerator has been highly reliable with the 5 billionth pulse on target recorded March 12, 1997. During this time, IPNS operators have discovered tunes for various parts of the DTL/RCS accelerator allowing for continual improvement in average current delivered to the target; however, in numerous cases this has been achieved by moving significantly away from the original design parameters. A new attempt is being made to analyze the lines and develop computer models that can be used to alleviate some of the undesirable features of the present "best tune." In the 500 MeV line, higher order elements will be included in the modeling with the goal of providing a uniform power density profile at the NGS target. This paper describes features of the present lines, and progress-to-date in analyzing and improving them.

1 INTRODUCTION

The primary components of the IPNS accelerator are a negative ion source, 750 kV DC Cockroft-Walton, 50 MeV DTL, 50 MeV transport line, 450 MeV RCS, and 500 MeV transport line. We concentrate on the two transport lines here. A plan view of the IPNS accelerator is presented in Figure 1. In the 50 MeV line, attention is centered on beam misalignments and what affect they have on RCS transmission. In the 500 MeV line, the beam profile on the target is important: if too small, the high power densities can damage to the target; if too large, protons may miss the target resulting in a reduction in neutron production and an increase in activation.

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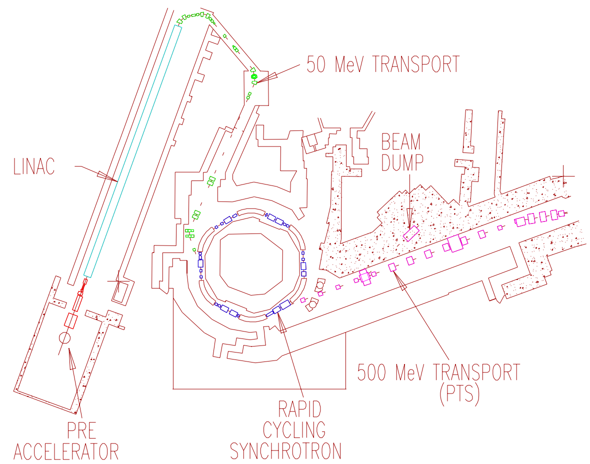

Figure 1: The IPNS Accelerator System.

2 50-MeV LINE

The 50 MeV line includes 8 sector dipoles, 16 quadrupoles, and a number of smaller vertical steering dipoles (VSM). The line is shown schematically in Figure 2. Diagnostics in the 50 MeV line include wire scanners (WS), segmented Faraday cups, toroids, scintillators, and beam position monitors (BPM). Beam positions, sizes, and profiles are analyzed with WSs at twelve locations along the 50 MeV line. BPMs provide real-time displays of beam centroid position. In addition, a segmented Faraday cup and a pair of scintillators also indicate beam size and position. Starting in 1996, a target irradiation area has been established in the 50 MeV line for the production of radio-isotopes for experiments at the Argonne Tandem Linear Accelerator System (ATLAS). The target slugs are relatively small (5 mm, diam.); therefore accurate beam positioning information is required.

A working model of the 50 MeV line was developed using the first-order-optics code, TRACE3D[1] to predict beam size and focusing. It was found that the model does a reasonable job in most sections of the 50 MeV line. For example, near the linac, it was useful in identifying the reversal of x and y axes in WS1. Nevertheless, some discrepancies remain between prediction and WS size data; in addition, WS data indicates some beam profiles are neither uniform nor Gaussian but instead are quite peaked. Beam offsets

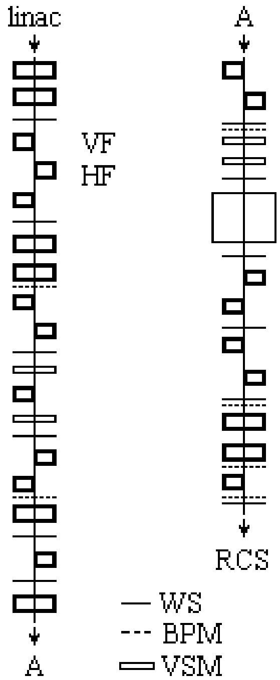

Figure 2: 50 MeV transport line elements

may be responsible for some of the observed nonlinear behavior.

Analysis of a beamline is complicated by beam misalignments. Consider the geometry in Figure 3 showing a circular beam cross section within a

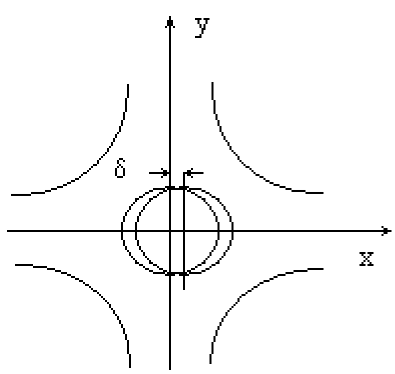

Figure 3: Beam offset geometry in a quadrupole

quadrupole magnet. The beam center is offset from the magnetic center by δ. With respect to the center of the quadrupole, the beam radius may now be expressed as,

$$r_m = \sqrt{r^2 + 2\delta\, r\, \cos\phi + \delta^2}$$

where ϕ is measured from the x-axis. The ϕ-component of field may be written as[2],

$$B_\phi = C n r^{n-1} \cos\left[n\left(\phi - \phi_r\right)\right]$$

where $C=\mu_o NI/R^n$ and $n=2$. The results of Fourier transforming both aligned and misaligned profiles are shown in Figures 4 a and b. As expected, a single

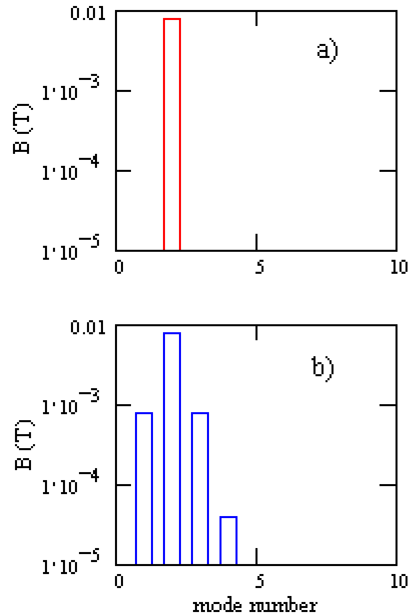

Figure 4: Modal analysis for a) an aligned beam and b) misaligned beam within a quadrupole where R=50.8 mm and δ=1mm.

quadrupole (n=2) mode is evident in the aligned case; however, dipole, quadrupole, sextupole, and octupole modes (as well as higher order components not shown) are predicted for the misaligned beam. An easily observable feature is the dipole steering effect of a quadrupole on a beam that is not on center. This can be used to check beam alignment between diagnostic locations. By varying quadrupole coil current a few percent about the operating point, BPM data from downstream indicates when steering is taking place. Higher order field components can also lead to emittance growth. In the 50 MeV line some emittance growth is tolerable[3]. $\Delta p/p$ is relatively low from the linac and should be at least 0.5 percent at injection to avoid instability in the RCS. The x and y rms beam emittance out of the linac is measured to be 1.8 π-mm-mrad. Beam emittance is monitored on the 50 MeV line using WS data at three adjacent axial locations[1], each separated by approximately 5 m of drift space. (The transfer functions of two small VSMs are ignored.) Note that this analytical technique combines dispersion with emittance.

An effort was made to reduce beam offsets in the 50 MeV line quadrupoles. Using VSMs and larger sector dipoles, the beam position was made to lie close to the center of the BPMs. (It was not possible to achieve zero BPM offset at all locations.) WS data indicates rms emittances as follows: ε_x=3.76$\pm$ 0.35 π-mm-mr and ε_y=3.28$\pm$ 0.32 π-mm-mr. These values are in reasonable agreement with TRACE3D which calculates 4.63 and

2.33 π-mm-mr for ε_x and ε_y through this region of the line. Though steering in some quadrupoles has been substantially reduced, it is still evident in others. Based on these initial results, further beam alignment studies are planned.

3 500-MeV TRANSPORT SYSTEM

The 500 MeV line carries accelerated protons approximately 45 meters from the RCS to the Neutron Generating Source (NGS) target. The line is composed of 2 dipole and 15 quadrupole magnets, not including extraction optics. The beamline is shown schematically in Figure 5. Beam size and position along the line are measured with Segmented Secondary Emission Monitors (SSEMs). A Segmented Wire Ionization Chamber (SWIC), located just in front of the target, provides similar information. Current Toroids provide transmission efficiency. TRACE3D is again used to indicate beam size and focusing along the line. While within the RCS, space charge plays a major role in longitudinal stability; however, after extraction space charge has relativley little effect on the beam. This is significant since it means that space charge can be ignored in multiparticle analysis of the 500 MeV line without loss of accuracy.

4 BEAM UNIFORMITY

By adding nonlinear magnet elements to the 500 MeV line, a more uniform beam profile may be obtained on the NGS target[4]. This modification will be significant, especially if the present RCS current limit can be increased with a proposed second-harmonic rf cavity. At the NGS target, the beam profile is observed to be circular in real space and approximately Gaussian as measured by the SWIC. We are presently developing a particle tracking model to investigate the placement of higher order elements in the 500 MeV line. Incorporating the model shown in Figure 6, the phase space distribution in x-x' space given in Figure 7 is predicted at the NGS target.

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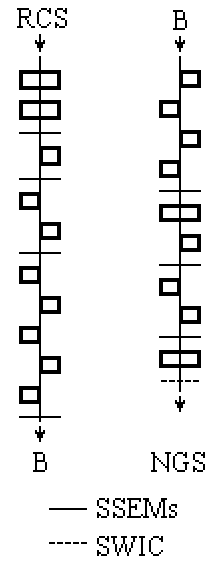

Figure 5: 500 MeV transport line elements

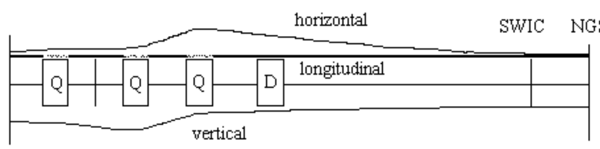

Figure 6: 500 MeV line upstream of the NGS

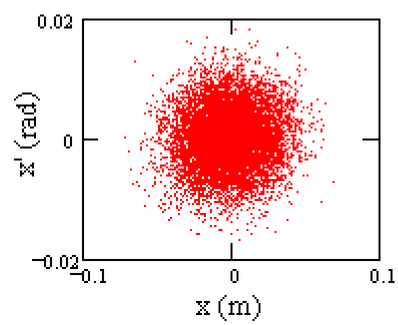

Figure 7: Modeled phase-space distribution at the NGS

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