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LARGE DYNAMIC RANGE BEAM PROFILE MEASUREMENT IN A HIGH BACKGROUND ENVIRONMENT

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Summary

Beam profile measurements using a scanning target and loss monitor in the Fermilab Main Ring extraction channel have long proved their usefulness as a diagnostic method in analyzing extraction problems. To extend these measurements to a sensitivity greater than in the present system a different technique has been employed. A simple three element particle telescope viewing the scanning target allows a sensitive measurement of the tail on the edges of the beam profiles as well as the relative particle densities of the extracted beam and the circulating beam in the Main Ring. Both these regions are of significant interest in understanding extraction losses. The details of the profile measurement technique, some results using the telescope and possible methods of improving the measurements are discussed.

Introduction

High extraction losses are frequently the limiting factor in increasing the intensity in Fermilab's main accelerator. Artificial but firm limits, as determined by acceptable exposure rates to personnel, have been set on extraction loss monitors. Extraction efficiency therefore, plays a major role in determining the accelerator operating intensity. When the extraction efficiency is low there is considerable pressure from the physics program to understand the problem and correct it. Typically extraction problems manifest themselves in one of two ways; first the problem may be one of stability where extraction losses and loss patterns vary widely machine cycle to machine cycle or secondly they will appear as just consistantly low extraction efficiencies. These effects on machine reliability are well documented.[1]

Slow resonant extraction is accomplished by raising the operating tune of the accelerator from 19.4 toward 19.5 As the beam approaches the half integer resonance particles begin to leave the stable phase space region. The shape and turn to turn step size along the separatrix paths are controlled by extraction quadrupole and octupole strengths. Extraction from the ring is achieved when a final kick is given to the particle's trajectory by an electrostatic septa that intercepts those particles that are sufficiently advanced along the separatrix.[2] The septa consist of two 10-foot long, 0.002 in. thick planes of wires having 0.050 in. spacing, which separates the circulating beam from a high voltage cathode that supplies the final kick.[3] Fully all of the extraction loss is attributable to scattering of beam off of the wires or the cathode. A larger apparent thickness of the septa due to misalignment or being warped will contribute substantially to extraction loss. Much of this loss shows up on the extraction lambertson magnets (a two aperture magnet downstream of the electrostatic septa) which further deflects beam from the Main Ring orbit.

One of the more useful diagnostics used in working on extraction problems has been a scanning target profile monitor. The target used is a 0.001 in. wide by 0.5 cm tungsten foil whose height covers the full vertical aperture of the beam pipe. The foil carriage assembly is driven by a stepping motor with a position resolution of 2 mils per step. The target is located about 20 ft upstream of the extraction lambertson magnet. Extraction from the Main Ring is possible using either one of two sets of electrostatic septa. In the case of A0 extraction the target is 105 ft downstream of the septa while with D0 extraction the septa are on the opposite side of the ring approximately 2 miles from the target. The location of the septa are 4π/3 radians apart in phase. Normal accelerator operation uses the D0 septa for extraction. The A0 septa are relagated to a back-up role in the event of a D0 septa failure. The recent failure of a D0 septa allowed comparison studies to be made of the telescope performance under to the two extraction modes. Most particles undergoing small angle scattering from the D0 septa survive the half turn required to travel from D0 to extraction lambertson in A0. The deep inelastic scattered particles are lost in the D0 area and contribute nothing to the A0 losses or the background in which the detector must operate. Use of the A0 septa increased the background rates due to the proximity of the detector to the septa.

The original system of making target scans employs an ionization chamber loss monitor[4] just downstream of the target. The integrated loss caused by the target is then plotted as a function of target position.

There are three properties of the extracted beam that are possible to investigate using this method. These are position, profile, and step size. Of these, the present system is able to adequately measure two, position and stepsize. Neither of these measurements requires a degree of sensitivity that is affected by the background rate. However one of the regions of greatest interest in the profile measurements is the tail of the extracted beam, which has a signal rate several orders of magnitude below the peak rate. With our typically quoted extraction efficiency[5] of 98.5%, about half the particles lost are small angle scattered off the septum and survive the half turn to A0 and the extraction channel.

It is a fraction of these particles that create the tails on the outer edge of the extracted beam or end up in the valley between the extracted beam and the circulating beam. In either case this portion of the beam is lost on the extraction lambertson magnet or further downstream in the extraction channel. A careful measurement of the profile may be useful in determining the apparent thickness of the septa or detecting the presence of other obstacles in the ring that cause small angle scattering of the extracted beam and thus increase losses.

The Detector

The detector viewing the scanning target consists of 3 RCA 6655A photomultiplier tubes with 2 in. × 1 1/4 in. lucite cylinders as sources of Cherenkov light mounted on the ends. The telescope elements are located in a 6 in. × 4 ft deep hole on

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the inside wall of the main ring tunnel at an angle of 90° from the scanning target. Figure 1 shows a layout of major elements in the A0 straight section. The front tube in the telescope is approximately 12 ft from the beam and is recessed in the hole a few inches. Positioning the detector in the hole provides some shielding from the background. The background singles rates vary from 30 kHz on the front element to 2.5 kHz on the rear one using D0 extraction and at a spill rate of 5×10^{12} protons/second. Background rates here refer to target out conditions. Rates with the target in rise about 570 kHz on the front element and 210 kHz on the rear for the same D0 extraction conditions as above. The corresponding A0 extraction numbers are 150 kHz and 2.4 kHz target out with an intensity of 3.3×10^{12} protons/second. Target in rates were 450 kHz and 150 kHz front and back respectively. Table I details these values. These figures clearly indicate that counting rates scale quite reasonable with intensity and more importantly that the counting rate of the last element is reasonably independent of the background rate.

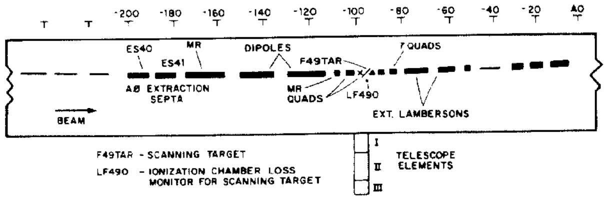

Fig. 1. Transfer hall extraction line.

No special effort has been made to accommodate higher singles rates in the tubes and in fact it was found that with the 1.4 ma tube bases being used that 700 kHz is about the practical limit for the counting rate. Above 700 kHz the tube dynode voltages start sagging and the output pulses drop below the counter discriminator levels which were set at 300 mv. This means that a full profile scan can be made only at intensities of $\leq 5\times10^{12}$ protons/second at present. This limit effectively rules out measurements on the 1 msec resonant fast spill. However scans of the beam edges can be made at very high accelerator intensities since the triple coincidence although intensity dependent is still quite low for target out conditions.

The detector output consists of a pulse for a triple coincidence in the three elements of the telescope. The coincidence was timed in using the 53 MHz RF structure of the beam. The pulse output goes to a pulse train to voltage converter and finally a log amplifier. The amplifier output is the log of the intensity normalized coincidence rate. This signal is fed to an A/D input of the computer system. A plot as in Figures 2 and 3 is generated when a scan is done. Each point corresponds to one spill.

The number of triple coincidences during a spill over the full range of the scan varies by as much as three orders of magnitude. Of particular interest is that with the target out there is only 1-2.5 accidentals per spill over the range of intensities that the detector operates. This number is independent of the extraction efficiency. The loss monitor system is not quite as good in this respect. It has target out counting rates that vary between 8-20 counts per spill over the same intensity range (1×10^{12} to 5×10^{12}/sec). These rates also vary with extraction efficiency. The above numbers

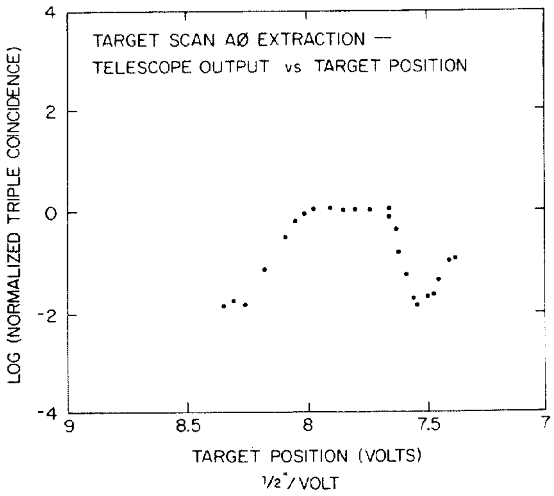

Fig. 2. Target scan A0 extraction--telescope output vs target position.

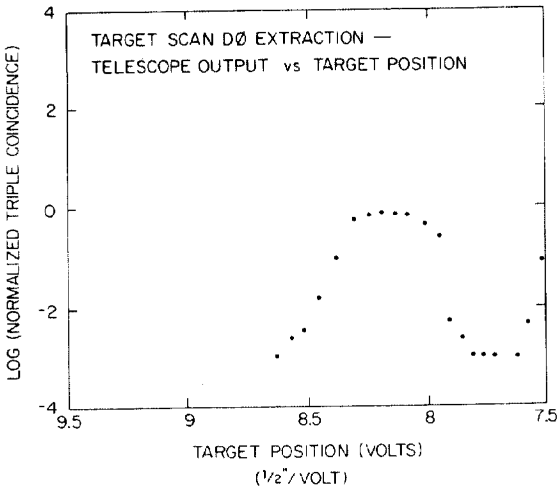

Fig. 3. Target scan D0 extraction--telescope output vs target position.

were obtained during the use of the D0 extraction system. The target in rates of the loss monitor are comparable to the telescope arrangement.

The new system has raised the sensitivity of the profile measurement at the higher intensity by nearly an order of magnitude in the region of interest. There is some hope that the noise level can be reduced and at the same time increase the useful upper range of the detector.

Improvements in the System

There are three areas where efforts are being made to improve the profile measurement system. A reduction in the singles rate of the first element of the telescope when the target is out should reduce accidentals to nearly zero. This will be accomplished by providing more shielding from spray off the upstream beam line elements. This will also provide some help in combating high count rates in the first element at intensities of 5×10^{12}/sec. Changing phototube bases to a higher current variety and providing additional current sources for the final dynodes should also extend the intensity range over which the detector can operate. It is not clear at this time whether the telescope can be made operational for the resonant fast extraction. The final improvement involves replacing the analog electronics, which have drift and noise problems at low count rate, with digital electronics.

Conclusions

It seems that this technique can be a useful diagnostic tool to be added to the present system. However, its intensity limitations have yet to be solved. Further the reliability and lifetime of the equipment in a high radiation area have not been demonstrated. Continued operational experience will be necessary to answer these questions.

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Table I. Average Counting Rates for Several Extraction Conditions.

D0 Extraction - Spill Rate = 5×10^{12} protons/second

	Total Triple Coincidence	Element I	Element II	Element III
Target Out	2.5	27 kHz	14 kHz	2.5 kHz
Target In	1400	570 kHz	540 kHz	210 kHz

A0 Extraction - Spill Rate = 3.3×10^{12} protons/second

	Total Triple Coincidences	Element I	Element II	Element III
Target Out	1.5	150 kHz	19 kHz	2.4 kHz
Target In	1000	450 kHz	400 kHz	150 kHz