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Title: **Stripper-Foil Scan Studies of the First-turn Beam Loss Mechanism in the LAMPF Proton Storage Ring (PSR)**

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Stripper-Foil Scan Studies of the First-Turn Beam Loss Mechanism in the LAMPF Proton Storage Ring (PSR)

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Abstract

First-turn beam losses in the LAMPF Proton Storage Ring were measured as a function of the left-right position of the carbon foil used to strip neutral hydrogen atoms to H^+ for proton injection into the PSR. Two foil thicknesses, 200 and 300 $\mu g/cm^2$, were tested. Results indicated that first-turn loss is caused predominately by magnetic field stripping of a small fraction of the H^0 atoms that pass through the stripper foil without being stripped to protons , and the results were not consistent with a mechanism involving protons originating from atoms in the halo of the neutral beam incident on the stripper foil.

I. INTRODUCTION

A significant fraction of beam losses in the PSR are presently due to protons being lost before completing one turn around the ring. The cause of these first-turn losses has not been understood until now. Earlier hypotheses hinged on the idea that first-turn losses constituted loss of protons in the halo of the injected beam, but measurements of the extent of beam halos did not conclusively support this idea.

In an accompanying paper [1], a new hypothesis about the cause of first-turn beam losses in the PSR is proposed. It is suggested that unstripped H^0s emerge from the foil in excited states, are subsequently field stripped to H^+s in the first bending magnet downstream of the stripper foil, and are then lost before completing the first turn around the ring because they were stripped to H^+ outside the acceptance phase space of the ring.

The present paper describes the measurements made to search for evidence that would distinguish between these two mechanisms for first-turn losses over the other.

II. BEAM INJECTION INTO THE PSR

Protons are injected into the PSR by magnetic field stripping 800-MeV H^- ions to H^0s and then stripping the H^0s to protons in a 200-$\mu g/cm^2$ carbon foil placed on the ring axis. Roughly 5% of the injected H^0s that hit the foil are not stripped to H^+s and are transported through the field of the downstream ring bender and out through a hole in the magnet yoke to a beam stop. This arrangement is illustrated schematically in Figure 1, which shows the injection section of the PSR. For each PSR pulse, protons are injected at a constant rate for typically 600 µs, and at the end of injection they are immediately extracted.

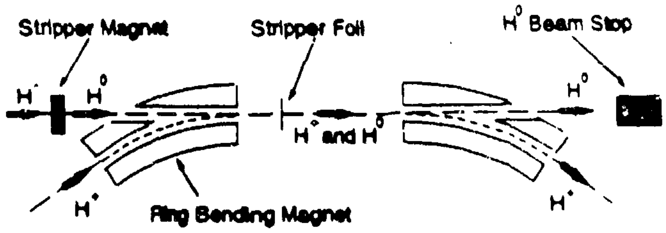

Figure 1. Beam Injection into the PSR

III. POSSIBLE ORIGINS OF FIRST-TURN LOSSES AND THEIR CONSEQUENCES

A. Beam Halos

If the halos of the injected beam are too large, protons originating from stripped H^0s in the halos will fall outside the phase space acceptance of the ring, and will be lost quickly by collisions with the walls of the ring vacuum pipe. Because, in the horizontal plane, the injected beam has a significantly larger emittance than in the vertical plane, and because there is a large mismatch between the injected beam horizontal-plane phase space ellipse and the ring lattice ellipse, protons from beam halos in the horizontal beam profile are more likely to cause first-turn losses than are halos in the vertical profile

B. Magnetic Field Stripping of Excited H^0s

A recent suggestion [1] about the cause of first-turn losses is that a small fraction of unstripped H^0s exit the stripper foil in relatively loosely bound excited states that can be field stripped to H^+s in the magnetic field of the first downstream ring bending magnet. However, since an excited H^0 has a finite lifetime in a magnetic field, it will not be immediately stripped to a proton when it enters the fringe field of the magnet, and, as a consequence, its trajectory in the magnet before being stripped will not be exactly the same as that of a proton. A significant number of the protons resulting from excited H^0 stripping will, then, find themselves outside the acceptance phase space of the ring, and will be lost by collisions with the beam pipe wall before making a full revolution around the ring.

IV. THE MEASUREMENTS

A. Methods

Our approach to gathering evidence in support of a particular first-turn loss mechanism hinged on two comparisons. The first was to look at the change in first-turn losses vs. the change in ring beam as the stripper foil was scanned horizontally across the injected H^0 beam. The relationship between the amount of ring beam and the first-turn losses was then compared with the patterns expected for each of the two mechanisms described above.

The second comparison was between the magnitude of first-turn losses for two different stripper foil thicknesses. If field stripping of excited H^0s is the primary cause of losses, then the losses should be less for thicker foils since the stripping efficiency is greater, leaving fewer excited H^0s to be field stripped in the bending magnet.

Both the foil-scan and the foil-thickness comparisons involved measuring two quantities, ring beam and first-turn losses. A toroidal current monitor in the ring was used to measure the ring beam current while beam losses were measured with a system of ten loss monitors spaced uniformly around the periphery of the ring tunnel.

B. Stripper Foil Scan Studies

Three different foils, 200 μg/cm² thick and 10 mm wide, 200 μg/cm² thick and 16 mm wide, and 300 μg/cm² thick and 16 mm wide, were scanned across the beam. Each foil was moved in 1-mm horizontal steps across the injected H^0 beam whose horizontal rms width at the foil was 6 mm.

At each foil position we measured both the ring beam current and the first-turn losses. The amount of beam injected into ring varied as the foil was moved to cover different amounts of the incoming H^0 beam.

If the beam-halo mechanism is the cause of first-turn losses, then the loss rate will be directly proportional to the amount of beam halo that is covered by the stripper foil. If one uses a stripper foil wide enough to completely cover the injected beam, then, as the stripper foil is moved from a position completely outside the bounds of the beam to where it starts covering the beam halo on one side, one would see a rapid rise of the loss rate. After the halo on one side is completely covered by the stripper foil, moving the foil to cover more of the injected beam would result in more ring beam, but it would not cause a significant increase in the amount of first-turn loss. As the foil is moved farther to also cover the beam halo on the other side, the loss rate would again increase until the halos on both sides are covered, at which point first-turn loss rate would be a maximum.

There is evidence, from beam steering in the horizontal plane, that the injected beam very nearly fills the accepted phase space of the ring, and that beam halos can contribute to first-turn losses if the injected beam is not steered properly on the ring axis [2]. However, there is no conclusive evidence that, when the beam is properly steered, beam halos contribute significantly to first-turn losses.

On the other hand, consider the case in which losses are caused by field stripping of excited H^0s. Since both the number of H^+s and H^0s are directly proportional to the number of H^0s incident on the foil one would expect to find that the amount of first-turn loss is linearly related to the ring beam current.

Figure 2 illustrates, for the two mechanisms described above, the expected qualitative relationship between the first-turn losses and the ring beam as the foil is moved from a position where none of the injected H^0 beam is being intercepted by the foil to a position where the foil is centered on and completely covering the beam.

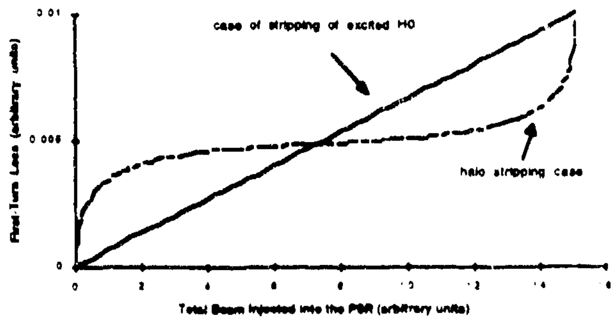

Figure 2. Expected Patterns of First-Turn Beam Loss vs. Beam Injected into the PSR for the Two Loss Mechanisms

C. Foil Thicknesses Studies

Also of interest is the difference between first-turn losses for stripper foils of different thicknesses. Thicker foils will strip more of the injected beam, leaving fewer H^0s and correspondingly fewer excited H^0s. If excited H^0s are the cause of first-turn losses, then thicker foils should result in the production of fewer excited H^0s. In this case losses will be proportional to the amount of beam injected into the ring. If, on the other hand, protons originating from the injected beam halos cause first-turn losses, the ratio of losses to ring beam will be largely independent of foil thickness. We base our comparison of first-turn losses vs. foil thickness on the data for the two 16-mm wide foils of 200 μg/cm² and 300 μg/cm² thickness.

V. RESULTS AND CONCLUSIONS

A. Stripper Foil Scan Studies

Results of the foil scan studies are summarized in Figure 3. The plots show, for each of the three foils used, the magnitude of first-turn losses vs. ring beam current as the foil is scanned across the beam. The plots trace out the first turn loss history as the foils are scanned from the far left side of the beam (negative x values), to the beam center, and finally to the far right side (positive x values).

The 10-mm-wide foil results in Figure 3a show an almost linear relationship between first-turn losses and ring beam both as the foil is moved from the far left side of the beam to the center of the beam and continuing to the right where most of the beam once again misses the foil. This result is exactly what would be expected if first-turn losses are caused by field stripping of H^0s.

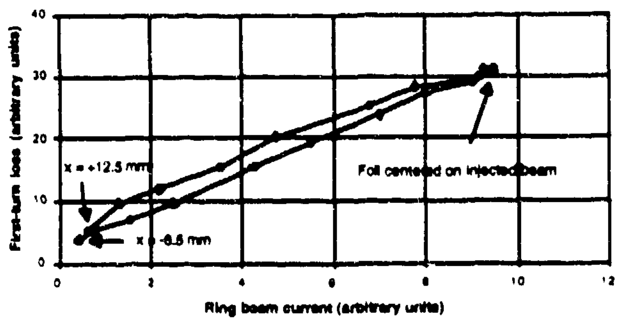

Figure 3a. First-turn loss vs. Ring Beam for 200 μg/cm², 10-mm-wide Carbon Stripper Foil

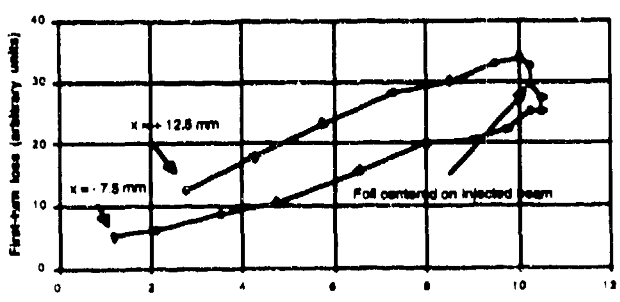

Figure 3b. First-turn loss vs. Ring Beam for 200 μg/cm², 16-mm-wide Carbon Stripper Foil

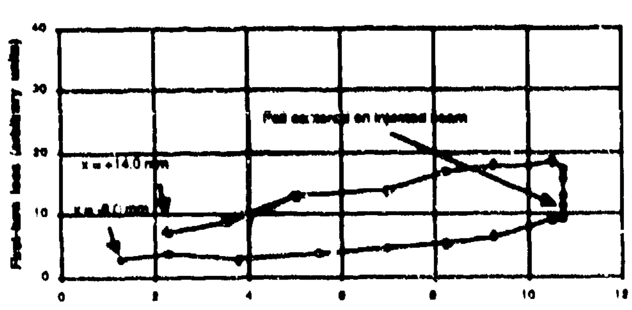

Figure 3c. First-turn loss vs. Ring Beam for 300 μg/cm², 16-mm-wide Carbon Stripper Foil

Results sh wn in Figure 3b and 3c for the 16-mm-wide foils also show a generally linear relationship between beam loss and ring beam as the foil is scanned toward and away from the injected beam center. However, in these two wide-foil cases there is a range of foil positions near beam center for which most of the injected beam is covered resulting in an essentially constant ring beam current for several adjacent foil positions. An unexpected feature of the results for these two wider foils is that first-turn losses change significantly over the range of positions for which the foil is roughly centered on the beam. We believe that this asymmetry in the pattern of the first-turn vs. beam current relationship is probably due to some combination of an asymmetry in the phase space acceptance of the ring and/or a spill-location sensitivity of the loss monitors, although we have not yet made detailed studies or calculations to verify this idea.

B. Foil Thicknesses Studies

Figures 3b and 3c indicate that, for the same amount of ring beam current, first-turn losses with the 300 μg/cm² foil are about 45% of the losses with the 200 μg/cm² foil. Assuming that field stripping of excited H^0s is the cause of first-turn losses, and estimating the fraction of the injected H^0s that survive unstripped after passing through a foil, we predicted that losses with the 300 μg/cm² foil would be roughly 30% of the losses with the 200 μg/cm² one. This prediction is significantly lower than was observed. However, there is considerable uncertainty about the effect of foil thickness on in the energy level distribution of excited H^0 states. The number of H^0s that are field stripped is sensitive to this distribution so the observed discrepancy between measurement and prediction is not surprising. If protons from the halos of the injected beam were the cause of first-turn losses, the losses would be the same fraction of the injected beam independent of foil thickness.

Therefore, we conclude that the results of the foil thickness studies are consistent with the hypothesis that field stripping of excited H^0s is the cause of first-turn losses.

VI. REFERENCES

[1] R. Hutson and R. Macek, "First-Turn Losses in the LAMPF Proton Storage Ring (PSR)", these proceedings

[2] R. Macek, *et al* , "Analysis of beam losses at PSR", *Conference record of the 1988 EPAC Conference*, Vol. 2, pp. 1252-1254.