MITIGATION OF MAGNET HYSTERESIS EFFECTS AT LANSCE

R. McCrady, R. Keller, LANL, Los Alamos, NM 87545, USA

Abstract

We have developed a scheme to mitigate the effects of magnet hysteresis in a beamline with a complex arrangement of magnets. The complexity is due to the fact that two power supplies power eight magnets. While some of the magnets are powered by just one of the two supplies, others are excited with the currents from both supplies, with the magnetic fields from the two currents adding in some magnets and subtracting in others. The primary challenge in developing this scheme was the process of determining a reproducible current set point after heuristic optimization by operators. We have also observed the effects of hysteresis in quadrupoles and steering magnets, and have demonstrated that methods typically employed in accelerators are sufficient to mitigate the hysteresis effects in these magnets.

INTRODUCTION

The linac at the Los Alamos Neutron Science Center (LANSCE) was designed to accelerate both H^+ and H^- ions to 800MeV, with a 201.25MHz drift tube linac (DTL) bringing the beams to 100MeV and an 805MHz side coupled linac (SCL) continuing the acceleration to 800MeV. The frequency ratio of 4 between the DTL and SCL radio frequencies (RF) requires that the two beams take different flight times between the two structures in order that both beams arrive at the correct phase of the accelerating field in the SCL. To this end, the beams are split in the so-called Transition Region, with H^- taking a longer path to the SCL (see Figure 1). The H^- path length is adjustable through variation of the strengths of bending magnets BM-05 through BM-08.

The eight bending magnets are identical and each has two sets of current-carrying windings. In BM-01 through BM-04, both sets of windings are powered by power supply MP-1; we denote the excitation current as $2\times I_1$. In BM-05 and BM-08, one set of windings is powered by MP-1 and the other set is powered by MP-2, with the excitations opposing one another, i.e. the effective excitation current is I_1-I_2. In BM6 and BM7 the excitations from the two power supplies add, so the effective excitation current is I_1+I_2. The intent of this arrangement was for the MP-2 current to adjust the phase of the H^- beam relative to the SCL accelerating field without affecting any other parameter.

Recently, the Isotope Production Facility (IPF) was added to LANSCE. A 100MeV H^+ beam is directed from the transition region to the IPF beamline. Though bending magnet IPKI-01 can be operated in pulsed mode to allow simultaneous operation of IPF along with acceleration of H^+ to 800MeV, the latter beam has not been needed at all in recent times, so IPKI-01 operates in DC mode. The presence of the IPF beamline, in particular its beam position monitors (BPMs) is crucial to our process of determining a reproducible current set point for MP-1, as BPMs are not present in the linac.

Quadrupoles and steering magnets are also present in the transition region; each is powered by its own power supply, so control of the hysteresis is accomplished with simple, widely-used techniques [1].

Operators find that recovery from power-off conditions of MP-1 and MP-2 are difficult. The beam spill in the SCL is quite sensitive to the setting of MP-1 especially. Setting the current set point of MP-1 to its value before the power-off condition is usually not satisfactory.

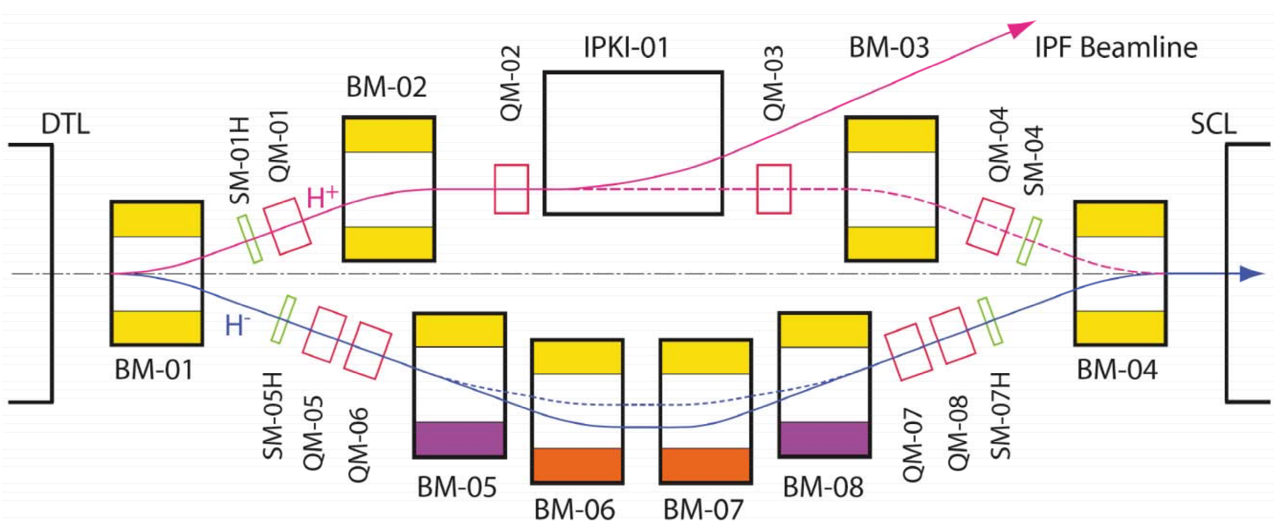

Figure 1: Transition Region of the LANSCE Linac. The bend magnets in the H^- branch are served by two power supplies, each, adding their currents for BM-06 and -07 and subtracting them from each other for BM-05 and -08.

Adjustments of both power supplies are typically required to re-establish low beam spill, and as these magnets' currents change the beam phase, adjustment of the SCL RF phase is also typically required. These adjustments require valuable time and experienced operators. This seemed to be the beamline where mitigation of hysteresis effects would have the greatest impact and where it would gain us the buy-in of the operators, easing the way for us to apply such techniques in other beamlines. This motivated us to develop a scheme to mitigate the apparent effects of magnet hysteresis in this region.

OBSERVATION OF THE EFFECTS

Non-Ideal Behavior

Ideally one would expect the total bend produced by bending magnets BM-05 through BM-08 to be equal to that produced by BM-01 and BM-04. This is because the total excitation current for either set of magnets is identical and equal to 4 I_1, with the current from MP-2 merely moving some of the bending strength from BM-05 and BM-08 to BM-06 and BM-07 thus affecting the path length alone. However, with MP-2 involved, the excitation histories of BM-05 and BM-08 are different from that for BM-06 and BM-07, leading to differences in the magnetic fields of these magnets.

As expected under these circumstances, we have observed that changing the MP-2 current causes steering effects for the H^- beam in the SCL. Using scanning wire beam profile monitors, we have seen steering amplitudes of up to 1mm for the first 100A of MP-2 current change. And this modest amount of steering can have a strong effect on beam spill.

Sensitivity

To assess the potential importance of hysteresis effects, we studied the sensitivity of H^- beam spill in the SCL to the magnetic fields produced by MP-1. With the magnets set for low-spill conditions, we increased the MP-1 current by 0.2%, much less than the presumed width of the hysteresis curve [2]. This caused a 13% increase in beam spill, as measured by radiation detectors in the beam tunnel. This indicated that hysteresis does indeed have a significant effect, i. e. that unsatisfactory beam conditions can occur by restoring magnets to their previous current settings without regard for the path taken to get there.

MITIGATION OF THE EFFECTS

Steering and Quadrupole Magnets

We have found that control of the effects of hysteresis in steering and quadrupole magnets can be accomplished by first conditioning the magnets, describing a full hysteresis loop, and then monotonically raising the currents, thereby consistently staying on the lower branch of the hysteresis curve. This allows one to find current set points that yield reproducible effects on the beam, and in particular, low levels of beam spill. In the context of this paper, the hysteresis curve of a magnet is defined by the range limits of the employed power supplies (unipolar for bend and quadrupole magnets) which are not designed to drive a magnet into full saturation.

The process for determining a reproducible set point for a magnet, after heuristic optimization by operators, is:

1. Make note of the current set point and turn off the beam.
2. Raise the power supply current to maximum and then lower it to zero for quadrupoles or to its most negative setting for steering magnets.
3. Set the power supply to a current value about 0.1% below the one noted in step 1.
4. Turn on the beam.
5. Adjust the current set point, upward only, to optimize beam spill.

The current set point established in the final step yields reproducible effects on the beam when the magnet is carried through steps 2 through 5 above. This process is used widely with accelerators and is described here to provide contrast to the more complex procedure required for the bending magnets.

Bending Magnets

The configuration of the two power supplies serving the bending magnets makes it impossible to stay on one branch of the hysteresis curve for all of the magnets. Also, since low H^- beam spill cannot be achieved with just one of the power supplies running, optimized set points for the power supplies leading to reproducible magnet excitations cannot be determined using the H^- beam alone.

The process that we developed to determine optimized set points relies on our ability to measure the position of the H^+ beam in the IPF beamline. Since this beam is affected only by MP-1, we can find a current set point on the lower branch of the hysteresis curve that reproduces the freely optimized magnetic fields for BM-01through BM-04, by observing the beam positions along this beamline, measured by BPMs. With MP-1 set in this way, we then raise the MP-2 current set point to a value that yields low H^- beam spill.

Unfortunately, this sequence of power supply changes cannot keep magnets BM-05 and -08 on the lower branch of the hysteresis curve; this is illustrated in Figure 2.

After the operators have heuristically minimized the H^- beam spill, the following process determines the current set points that yield reproducible beam quality:

1. Make note of the current set points for MP-1 and MP-2 and the H^+ beam positions in the IPF beamline and then turn off both beams.
2. Increase MP-1 to its maximum setting.
3. Increase MP-2 to its maximum setting.
4. Decrease MP-1 to zero.
5. Decrease MP-2 to zero.
6. Increase MP-1 to the value reproducing the H^+ beam positions in the IPF beamline as noted in 1.
7. Increase MP-2 to the value that results in low beam spill for the H^- beam in the SCL.

These current set points can now be used to achieve reproducible results by following steps 2 through 7 when the supplies are powered up. It should be noted that the final point 7 of the conditioning sequence as shown in Figure 2 does not necessarily end up on the upper hysteresis branch exactly. Because of the fact that point 6 is well defined on the lower hysteresis branch by the preceding sequence of steps, however, the excitation path from point 6 to point 7 is precisely determined and can therefore always be exactly reproduced.

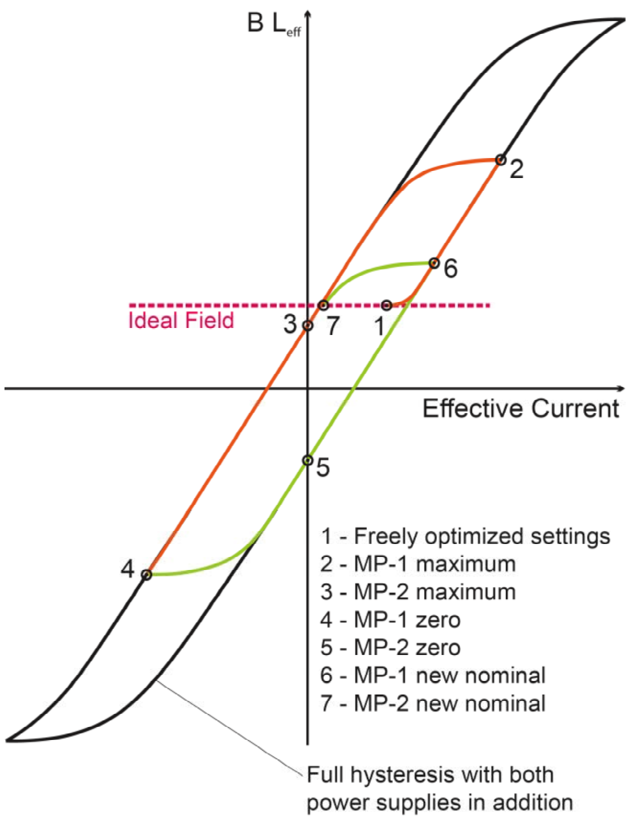

Figure 2: Excitation schematic for bend magnets BM-05 and BM-08. The curve segments connecting points 1 through 7 represent the actual magnet excitation history, with three crossings from one branch of the hysteresis curve to the other. The outer contour (which in reality would extend much farther out than shown here) represents the full hysteresis curve that would be followed if both power supplies were bi-polar and connected in addition. Also, the width of the hysteresis loop is greatly exaggerated; in reality it would be around 0.5-0.9% of the peak-to-peak extension [2].

FURTHER WORK

We have not analyzed the control loops in the magnet power supplies to determine if the system is critically damped to prevent overshoot in the current. While we have gotten satisfactory results with the present system, we intend to make measurements to see if further improvements can be made.

Presently, the control set points to the power supplies are provided by a mechanically adjusted potentiometer. We are concerned that this could introduce overshoot and backlash into the system. We are investigating upgrading to a digital to analog converter to provide this signal to eliminate such effects.

Manually cycling through the conditioning loops for the magnets is labor intensive, and could easily handled by computers. We are investigating a method of computer-controlled cycling for those parts of the cycle that don’t require human assessment of beam quality.

CONCLUSION

Magnet hysteresis has a strong effect on beam spill in the LANSCE accelerator. We have demonstrated that one can establish a conditioning and setting procedure for the two chains of bending magnets in the Transition Region that will reproduce the low-loss conditions previously found by the operators through heuristic optimization. We have also shown that simple, widely used, techniques of full-hysteresis conditioning and monotonically raising set currents can be applied to eliminate the effects of hysteresis in the steering and quadrupole magnets.

ACKNOWLEDGEMENT

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REFERENCES

[1] See, for example, R. Keller, “Tune-split effects at the ALS storage ring,” Proc. 1997 PAC, Vancouver, May 12 – 16, 1997, p. 787 – 789.

[2] A. Aldridge and J. Frank, “Effect of magnet recycling on the reproducibility of quadrupole magnetic fields,” LASL Office Memorandum, 8/21, 1973 (unpublished).