IMPROVEMENTS IN ALADDIN BEND MAGNET STABILITY BY REDUCTION OF LEAKAGE CURRENTS*

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Abstract

For 800 MeV operation of the Aladdin Synchrotron Storage Ring, 730 amps of current flow through the 12 bend magnets in series. The bend magnet field coils are cooled by water which is in intimate contact with the copper coils. The elastomer hoses which deliver this water had up to 103 VDC between the coils and the electrically grounded plumbing. This configuration induced an electrolytic reaction which produced and deposited cuprous oxide on the inner walls of the hoses. The electrical resistance of the hoses was significantly reduced and leakage currents as high as 833 mA flowed to ground. This missing and changing bend magnet current resulted in significant horizontal electron orbit changes. When the deposits were large, additional deposits occurred quickly and tripped off the bend magnet power supply, resulting in lost photons for the storage ring users.

We have electrically isolated the cooling water hose manifolds and lengthened some hoses. This minimized leakage currents to ground, slowed recontamination of new hoses and reversed contamination in badly contaminated hoses. These improvements have resulted in improved storage ring orbit stability (and thereby improved photon beam stability), less electrochemistry on the copper coils, and better operations reliability.

BACKGROUND

At the SRC we have recently commissioned a reduced-emittance lattice (LF15) [1], with a significantly reduced σ_x of ~200 μm. Therefore, a reasonable target for horizontal electron beam position stability would be ~20 μm at the bend magnet source points. Attempts to achieve this beam stability demand requisite levels of both mechanical and electrical stability.

The 12 bend magnets in the Aladdin storage ring are shown in Figure 1. A closed loop system, with deionized, high resistivity (~6 Mohm cm) water, cools the copper coils which produce the magnetic fields. For each bend magnet top half or bottom half, cooling water flows from a grounded 4.5 inch diameter supply pipe through an elastomer hose, ~32 inches long and 1 inch in diameter, to a metal supply manifold. This manifold distributes the water through 9 elastomer hoses, each ~15 inches long and 0.5 inch in diameter, to 8 copper field coils and a power lead. After the water passes through the internal cooling channels in the coils, it flows to a metal return manifold through 9 similar hoses. The water continues to a grounded 4.5 inch diameter return pipe. The metal supply and return manifolds were originally grounded. The intent of this system was to provide cooling water and electrical isolation of the field coils by using the insulating elastomer hoses and high resistivity water. We observed significant leakage currents and modified this system after additional measurements and preliminary testing.

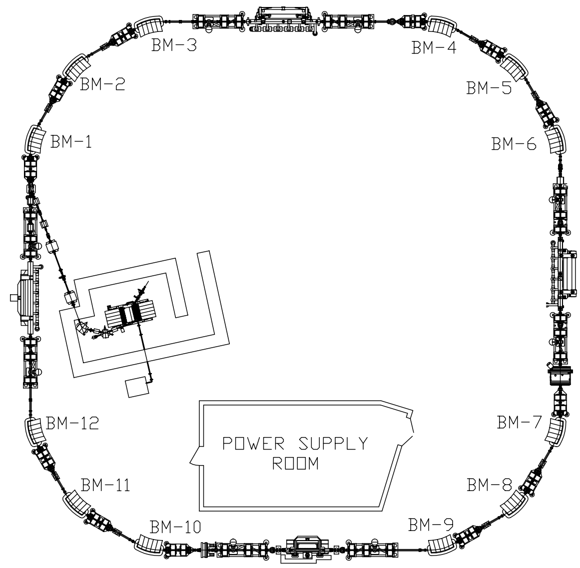

Figure 1. Aladdin storage ring with bend magnets (e.g., BM-10) and power supply room.

The Aladdin storage ring normally operates at 800 MeV and by request at 1 GeV. At the beginning of the current path, the voltage between the field coils and the grounded distribution manifolds was ~103 VDC, for 800 MeV operation (~147 VDC for 1 GeV operation). This voltage decreased proportionally around the storage ring to ~8.4 VDC at bend magnet 9. At these voltages new, clean, elastomer hoses should prevent significant leakage currents between the copper coil sets and the cooling manifolds.

The current through the 12 Aladdin bend magnets is 730 A for 800 MeV operation (1017 A for 1 GeV operation). This current begins at a Transrex power supply. The current enters the circuit at bend magnet 10, in the top set of coils, and proceeds clockwise around the ring through the series of 12 top coil sets. At the end of the top coil series (bend magnet 9) the current continues through the 12 bottom coil sets in series, in reverse order from 9 back to 10. This series circuit of top and bottom coil sets is intended to produce identical and stable currents and fields in the magnets, resulting in a stable electron beam orbit. For safe and proper power supply

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operation there is a ground fault current detector halfway around the circuit, after the top series of coils, with an established shutdown limit of 250 mA. It should be noted that this detector monitors only the net imbalance in leakage currents, with positive, top coil leakage currents being offset by negative, bottom coil leakage currents.

LEAKAGE CURRENT PROBLEMS

In 1997, 98 and 99 there were a minimum of 5 unplanned and uncontrolled bend magnet power supply shutdowns per year. These were due to excessive ground fault currents from electrical leakages in the cooling water hose system. The fault correction involved determining which magnet's hoses were "bad" and replacing all the hoses for that magnet. These shutdowns interrupted machine operation and the experimental programs which depend on the photons generated by the electron beam. The fast shutdown of these large currents also placed additional magnetic and mechanical stress on the magnet cores, possibly leading to observed lamination separations.

After careful analysis of the interactions among the cooling water hoses, the copper field coils and the applied bend magnet voltages, we determined that an electrolytic reaction was removing copper from inside the coils. This reaction created copper oxides and deposited them on the inside of the insulating elastomer hoses. Sufficient internal coatings eventually built up allowing the hoses to become significant leakage paths. The worst observed leakage of 833 mA from the top manifolds of bend magnet 11 tripped the ground fault detector during 1 GeV operation. This leakage occurred across a 135 VDC drop.

The leakage currents were also found to seriously affect the position of the electron beam in each bend magnet. Obviously, any current leaking to ground from hoses decreased magnetic fields in that magnet and in each sequential bend magnet in the ring. Furthermore, changing leakage currents result in changing electron beam positions. During 800 MeV operation, increases in leakage currents of 38 mA were observed in one magnet over 5 hours. During 1 GeV operation, increases of 225 mA were observed over 8 hours. Since any change in leakage changes the electron orbits, the source position and the trajectory angle of the photon beam would also change.

Figure 2 shows a plot of the ground fault detector current (lower continuous trace) and the horizontal beam position in bend magnet 10 (upper disconnected points) as a function of time. This data covers 2 months of normal storage ring operation with the global feedback system [2] providing real time position corrections. It is clear that the ground fault detector current was changing and in some cases changing very quickly on the left half of the plot. The horizontal photon beam position moved by more than 160 µm, which is clearly beyond our position stability target of 20 µm. The main contribution to these leakage currents was bend magnet 11 with an individual leakage current larger than 800 mA.

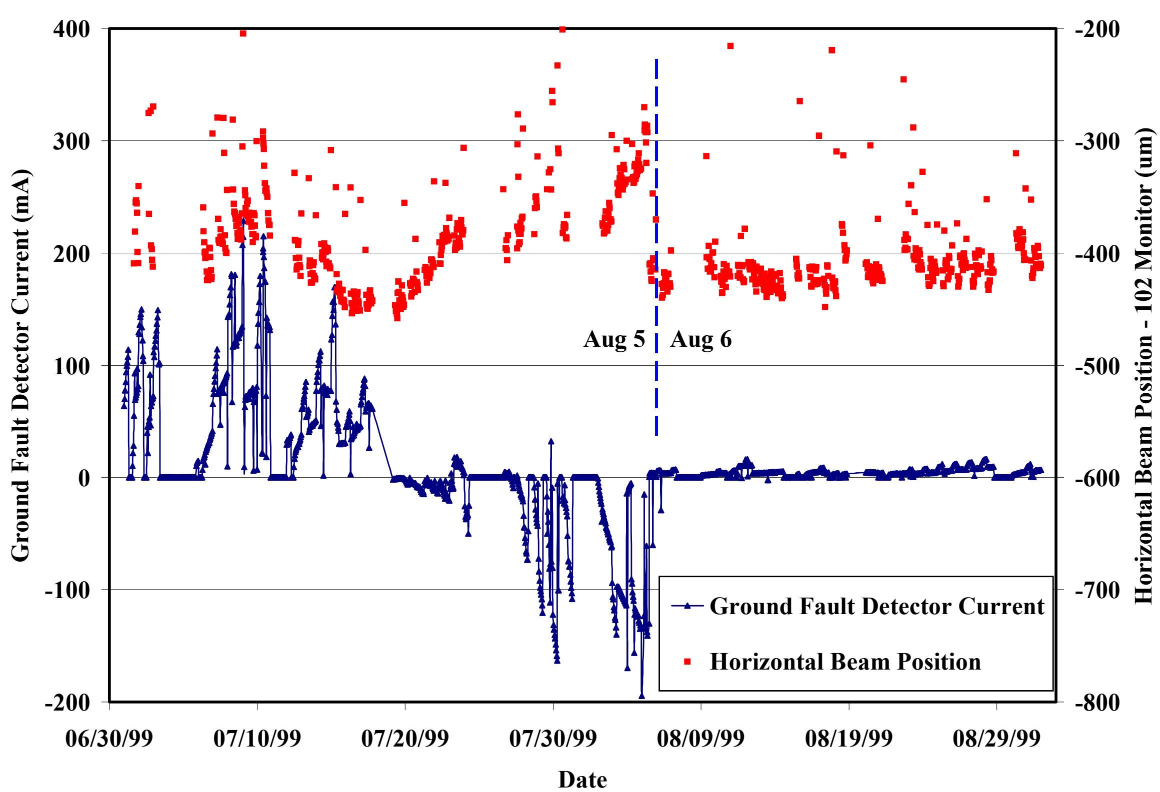

Figure 2. Ground fault detector current and horizontal beam position at monitor 102 during Aladdin ring operation.

The leakage currents from a particular bend magnet were found to be directly proportional to the applied voltage, for a constant level of internal contamination. It was also found that magnets (10, 11 and 12) with higher voltage drops across the cooling hoses developed contamination more quickly and developed higher leakage currents. Since the voltage drops during 1 GeV operation were 43% higher, significantly higher rates of contamination occurred during those operating conditions.

MINIMIZING LEAKAGE CURRENTS

An electrolytic reaction can be minimized by reducing the voltage across the electrodes. This was done in this situation by ungrounding the supply and return water manifolds for each half of each bend magnet. This was accomplished by inserting 6 concentric pieces of PVC pipe around each manifold in the appropriate places to electrically isolate the manifold from ground. When this was done the manifolds floated to a voltage based on the cumulative resistance of the 9 small hoses relative to the high resistance of the larger, 32 inch long hose. This is basically a voltage divider circuit. In bend magnets 10 and 11 respectively the voltage drops at 800 MeV, from the field coils to the manifolds, have been reduced from 103 VDC to 6 VDC and from 96 VDC to 5 VDC. Furthermore, the added high, series resistance of the 32 inch long elastomer hose reduced all leakage currents by more than a factor of 100.

Since the isolated manifolds floated up in voltage (142 VDC is worst case, at bend magnet 10, at 1 GeV), it was necessary to shield personnel from manifold contact. This was done with bent plexiglass shields and insulating pipe foam. A test point wire was also attached to each manifold to allow monitoring of leakage currents and hose contamination.

RESULTS

Between July and November of 1999, the cooling manifolds on the bend magnets with the worst leakage currents were electrically isolated to test the new system. The remaining manifolds were electrically isolated in November of 2001. Immediately after isolating manifolds with badly contaminated hoses and high leakage currents, hoses “cleaned up” due to the reduced voltage drop. When the top supply manifold on bend magnet 11 was isolated, that leakage current decreased from 612 mA to 25 mA over 4 days. Test measurements over the last 3 years with manifolds temporarily regrounded show individual leakage currents remain below 40 mA, even during 1 GeV operation. (The added series resistance of the longer hose further reduces actual leakage to less than 0.4 mA.)

On August 5, 1999 the extremely high leakage currents at bend magnet 11 tripped the ground fault detector and shut down the ring. At midnight between August 5 and 6, the cooling manifolds on bend magnet 11 were electrically isolated in an attempt to correct this problem without changing the contaminated hoses. This point in time is marked in Figure 2 by the vertical dashed line. It is clear that the ground fault detector current was significantly reduced and the horizontal beam position became much more stable after manifolds were isolated. Since August 6, 1999 there have been no bend magnet power supply shutdowns due to ground faults. The smaller changes in beam position after August 6 are due to leakage currents from the remaining 10 bend magnets with grounded manifolds.

Recently, known leakages at bend magnet 12 and at bend magnet 1 were separately imposed on a stable LF15 electron orbit by temporarily grounding the cooling manifolds. Changes were monitored by our recently updated optical beam position monitoring system. With the global feedback system off, a leakage current of 100 mA caused a 45 μm beam position shift. The manifold isolation system reduces leakages and their effects by a factor of over 100. The resulting beam position shifts, from the present level of current leakage, is less than 0.4 μm. This is well within the position stability target of 20 μm. Changes were also monitored with the global feedback system on. Beam shifts were further reduced by a factor of 6 with global feedback.

CONCLUSION

Gains realized by isolating bend magnet cooling manifolds:

- Direct monitoring of leakage currents and hose contamination is possible.
- Voltage drops and leakage currents between the magnet coils and the cooling manifolds are significantly reduced.
- Bend magnet coils receive proper current resulting in correct electron beam orbits.
- Electron orbit stability is improved providing more stable photon beams.
- Electrolytic damage to the copper magnet coils is reduced along with hose contamination.
- Storage ring reliability is improved.

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REFERENCES

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[2] K.J. Kleman, "High Precision Real Time Beam Position Measurement System", Proc. of the 1989 P A C, Chicago, IL, pp. 1465-1467.