BEAM LOSS ISSUES FOR AN ERL UPGRADE TO APS*

CY Yao**, Louis Emery, Michael Borland, Aimin Xiao
ANL, Argonne, IL 60439, U.S.A.

Abstract

The APS is considering options to upgrade its facility in the near future. After a careful review we came to the conclusion that an energy recovering linac (ERL) upgrade is the most promising option, which offers two orders of magnitude improvement in photon beam performance and utilizes most of the existing facilities. The design goals for the ERL are 7 GeV beam energy, 100 mA maximum beam current and 0.022 nm-rad emittance. The ERL could potentially generate a continuous 2 MW beam. Beam loss at such high beam power causes many problems, including radiation hazards, heat load to the superconducting rf cavities, and damage to other beamline equipment. This report presents the issues and the research and development that are necessary to achieve successful beam loss control.

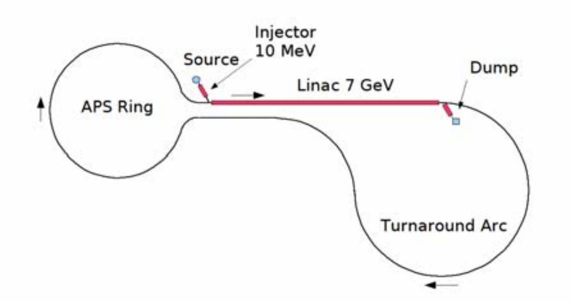

Figure 1: Layout of the APS-ERL facility.

INTRODUCTION

APS is considering upgrading its facility in the near future. The most promising option is an APS-ERL upgrade [1]. The preliminary concept calls for 7 GeV, 100 mA maximum beam current, a 7 GeV superconducting rf linac (SRF) and a 10 MeV injector. Figure 1 shows a layout of the proposed facility. Both the APS ring and the turnaround arc (TAA) accommodate user beamlines. The facility can be operated in several operation modes in order to accommodate different user needs. The main parameters of these modes and of the current APS operation mode are shown in Table 1 [2]. There are many challenges to meet the desired beam intensity and quality. Beam loss control is one of the challenges. From the rf power available, the ERL could potentially generate a continuous 2 MW beam, which presents many types of hazards, even over a short time period. We will discuss the impact of beam losses, the mechanisms of beam loss, and strategies to reduce their impact.

Table 1: Parameters of APS and APS-ERL Upgrade

	APS now	High Flux	High Coherence
Average current (mA)	100	100	25
Repetition rate (MHz)	0.27 to 352	1300	1300
Bunch charge (nC)	0.3 to 60	0.077	0.019
Emittance (nm-rad)	3.1× 0.025	0.022 ×0.02	0.006×0.006
rms momentum Spread (%)	0.1	0.02	0.02

IMPACT OF BEAM LOSSES

The first concern of a high-average-current high-energy facility is radiation hazard due to beam loss. There are two types of beam losses: continuous beam loss of normal operations and incidental beam losses in which part or all of the beam is lost.

The radiation dose produced by small but continuous beam loss accumulates over time and is the main concern for radiation safety. Under the current top-up operation condition, the APS storage ring has a lifetime of about 6 hours and an average beam loss rate of 21 pA. The average dose rate in the experiment hall is less than 0.5 mrem/hour. At this level we are able to designate the experiment hall as an “uncontrolled” area. For the APS-ERL upgrade, if we want to keep that designation for the APS and TAA areas, the continuous beam loss in these areas must be at a similar level.

Radiation produced by partial or total beam loss can have a high dose rate. But the total energy and time of exposure is limited. The total stored energy of the APS-ERL beam is in the range of 5 kJ to 10 kJ, which is in the same range as the current APS safety envelope specification of 9280 J [3]. Therefore the existing APS tunnel shielding is adequate for this type of beam loss.

Beam loss causes heat deposit in the accelerator structure. This is particularly troublesome for the SRF cavities of the linac. Heat deposit can cause local temperature rise in the SRF cavities, which in turn can cause quenching and loss of superconductivity. If this happens frequently, it is an operational reliability problem. We know that radiation can damage the permanent magnet undulators. Vacuum chamber components can also be damaged by a direct beam hit.

The cost impact of beam loss is mainly on the cryogenic system and shielding. An SRF cavity of the APS-

---

* Work supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

** Email: cyao@aps.anl.gov

ERL linac dissipates about 40 W of heat at 2˚K. The estimated total cooling capacity is 32 kW and the total AC power for the cryogenic plant is about 45 MW [4]. A heat deposit of 10 W on the linac structure would produce an estimated load of 3.5 kW and requires an additional cooling capacity of 35 MW. The estimated additional capital equipment for the cryogenic plant is $35 M.

MECHANISMS OF BEAM LOSSES

Beam losses may come from formation of a beam halo whose particles then scrape on some aperture somewhere downstream. Another beam loss mechanism is scattering, which gives an immediate particle loss.

Many physical processes contribute to beam halo [5, 6]. Dark current of the electron gun and field emission particles generated in the injector or the linac SRF cavities can be captured and accelerated to form beam halo. Particles originally in the beam bunch can be driven away from the beam core by nonlinear forces such as space charge and nonlinear optics, and form beam halo. Impedance-driven beam instability and beam breakup in the linac can also contribute to the formation of beam halo. Although many authors have researched and developed various theories on this subject, there are no practical tools to quantitatively simulate these processes. Due to the importance of beam loss to the ERL, we need to devote substantial effort to related R&D work, which includes development of a simulation model, performing beam studies with the existing APS injector and the gun test facility, development of diagnostics tools to characterize and measure beam halo, and development of new material for the guns and SRF cavities that has low field emission.

The two main types of scattering processes are gas scattering and intrabeam scattering. The gas scattering rate depends on beam energy, vacuum pressure, and the gas component. The APS and TAA portions of the ERL have conditions similar to the current APS storage ring. We expect that gas scattering will be similar and not a concern. However, scattered particles from the low-energy beam at the end of the energy recovery linac may produce more beam loss in the TAA area. Therefore more realistic modeling and simulations are needed.

In intrabeam scattering particles in a bunch collide with each other, and some are lost due to momentum exchange of transverse and longitudinal planes. The loss rate due to intrabeam scattering is sensitive to beam energy and energy aperture of an accelerator or beam transport line. We developed an optimization method to directly minimize beam loss of the APS portion of the ERL lattice [7]. Using this method we are able to expand the energy aperture of that part to ±5%, thus reducing the beam loss dramatically. Our preliminary estimate for the intrabeam scattering beam losses is ~11 pA for the APS and TAA areas, which is below the requirement. However, our simulation only provides an overall beam loss rate. More detailed simulation is necessary to evaluate the location of the beam loss and its impact. The simulation can also provide more detailed information for collimation design.

COLLIMATION STRATEGIES

Beam collimation removes halo particles from the beam at a strategic point in a beamline to reduce the beam loss in undesirable locations downstream. Because of the space and power limitations, collimation is better suited for small and continuous beam losses. Figure 2 shows a possible collimation scheme. The first collimator is located between the injector and the linac to scrape off most of the halo particles at low energy. This collimator may be designed in such a way that it also protects the linac from getting scattered particles from the recirculating beam of the APS. The second collimator is located downstream of the linac. It prevents any outlier particles from entering the TAA area. The third collimator protects the APS portion of the beamline. Our preliminary simulation of a linac structure with shower [8] indicates that a lead collimator with a 10-cm thickness can reduce the total energy deposit on the downstream linac structure by a factor of 11. Figure 3 shows a plot of fraction of energy deposited on the linac structure for various beam energies and collimation thickness. Collimation can also be installed at a high beta location along the linac. Local shielding enhancement at the collimation points is necessary to absorb the scattered particles from collimation.

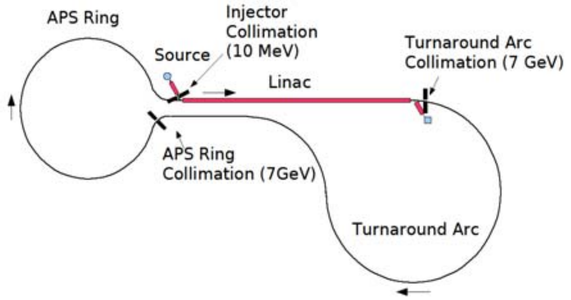

Figure 2: One possible collimation configuration.

BEAM ABORT AND SHUT-OFF SYSTEM

A fast beam abort and shut-off system is needed to provide effective radiation safety and machine protection. Our first concern is the radiation safety of the beamline area. The second concern is the SRF cavities of the linac. The third concern is radiation damage to the permanent magnet undulators and other vacuum chamber equipment.

A beam abort system consists of radiation monitors, beam loss monitors, beam position monitors, kickers, and beam dumps. The various diagnostics are used to detect

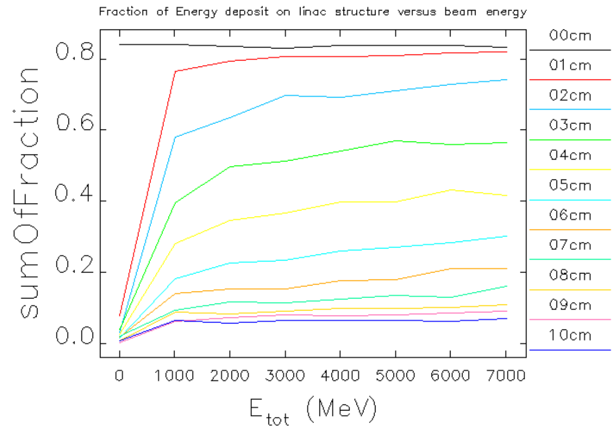

Figure 3: Fraction of energy deposit versus incident beam energy along a linac structure for various collimation thicknesses.

the onset of an unacceptable condition, such as beam loss in the APS ring or along the linac. When such a condition is detected, the abort system will act to place the accelerator and beamline in a safe state. The diagnostics must have fast reaction times and yet should be very reliable, which will require the development of low-noise, high-reliability systems. Figure 4 shows a possible configuration of an abort system using three beam dumps. The protection goals determine the location of the abort kickers and dumps. Ideally the particle source is turned off simultaneously with all three kickers firing together, and three pieces of the beam (1-km trains each with about 2-kJ energy) go to their respective dumps. It is necessary that the linac maintains the accelerating beam until the decelerating beam is dumped to avoid overpowering the SRF cavities. The linac rf power may be turned off slowly to ensure no dark current beam can be accelerated. Critical elements in the system are the system timing, the beam loss monitors, and the fast kickers. In order to achieve the desired action time, the monitor needs to detect a condition within a few μs and the kickers need to have a rise time of 100 to 200 ns.

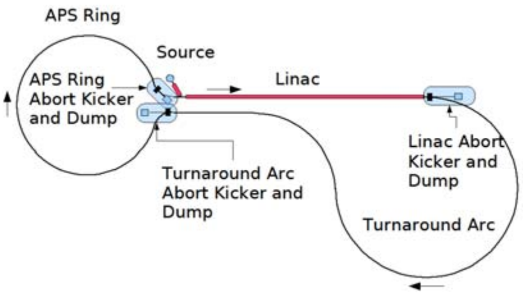

Figure 4: Configuration of a possible abort system.

SUMMARY

Controlling beam loss to an acceptable level for both radiation safety and equipment protection in an ERL facility presents a challenge. A systematic approach must be taken. At lower energy effort should be concentrated on the development of a low halo/low emittance electron gun and injector. On the high-energy linac side we must emphasize the reduction of beam envelope, maximize dynamic and energy aperture, and control beam break-up and emittance growth. Collimation techniques should be explored to remove halo particles for normal operation and protect critical elements. A fast beam abort system must be incorporated into the radiation safety and equipment protection system. Fast kickers and beam dumps can be placed strategically to reduce radiation in certain critical areas during a beam abort. Shielding requirements must be carefully re-evaluated and designed due to the significant difference in beam power between an ERL facility and the current APS.

ACKNOWLEGEMENTS

The authors would like to acknowledge Rodney Gerig and Efim Gluskin for their suggestions and discussions.

REFERENCES

[1] M. Borland, "ERL Parameter Review and Overview of Physics Issues," http://www.aps.anl.gov/News/Conferences/2006/APS_Upgrade/apsmac/Borland_ERLPhysics.pdf.

[2] G. Hoffstaetter, "Status of the Cornell ERL Project," FLS 2006 Workshop, working group2, http://adweb.desy.de/mpy/FLS2006/proceedings/HTML/SESSION.HTM.

[3] "Advanced Photon Source Safety Assessment Document," APS-3.1.2.1.0, June 1996.

[4] M. Borland et al, "Potential performance and challenges of an energy recovery linac upgrade to the APS," Proc. of SRI 2007, to be published.

[5] C. Chen, "Halo Formation in Intense Linacs," Proc. of Linac1998, p. 729-733, 1998.

[6] Y. Shimosaki, K. Takayama, "Nonlinear-resonance Analysis of Halo-Formation Excited By Beam-Core Oscillation," Proc. of EPAC 2000, Vienna, Austria, p. 1330-1332, 2000.

[7] A. Xiao et al, "Touschek Effect Calculation and its Application to Transport Line," Proc. of PAC07, to be published.

[8] L. Emery, "Beam Simulation and Radiation Dose Calculation at the Advanced Photon Source with shower, an Interface Program to the EGS4 Code System," Proc. of PAC 1995, p. 2309-2311, 1995