SOURCES AND CHARACTERISTICS OF ISA BEAM LOSS

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Introduction

With the large stored energy in the ISA beam, particle loss in the superconducting magnet environment must be kept to a low value and, whatever unavoidable losses do occur must be absorbed in properly designed beam scraper-absorber combinations. The magnitude of the potential problem is illustrated by the following parameters; Maximum tolerable caloric deposition into the superconducting-copper matrix[1] of the magnets 3-30 mJ/cm^3; total stored energy in the beam at 200 GeV, 20 MJ; a 200 GeV beam dump of 7×10^{14} protons in a beam cross section of 1 mm^2 into an aluminum wall would result in a maximum caloric deposition density of 40 kJ/cm^3; with Cu as the absorbing mass this could be as high as 1 MJ/cm^3 (Ref. 2). For this reason a systematic evaluation has been made of the ISA anticipated beam loss both during normal operation and due to possible component malfunctions.

A. Sources and Characteristics of Beam Loss During Normal Operation

1. Injection

A low intensity pulse (or pulses) from the AGS will be used to ensure that the injection orbit, the injection septum and kicker magnets, the injection scraper, etc., are properly established, aligned and in good operating condition.

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1. P. A. Sanger and G. T. Danby, "Radiation Effects", these Proc.
2. A. van Steenbergen, "ISA Beam Dump Absorber", these Proc.

The beam should be properly shaped longitudinally in the AGS and properly scraped transversely in the transfer line before entering the ISA. It is assumed that the beam is kicked out of the AGS only after the proper sine-wave excitation of the ISA injection septa has been sensed by sensors.

Thus, in normal operation there should be no beam loss during injection.

2. Stack Formation

a. While the beam is being accelerated to the stack, the rf voltage is reduced and the bucket size reduced to fit tightly around the beam. During this process it is likely that $\sim$ 5% of the beam will stray out of the bucket and be "left behind". However, this stray beam will likely remain inside the dump profile[3] between the injection and the stacking orbits.

b. Overstacking may have to be used to obtain a high density stack. Since stacking will be done "on top", this will cause a low density "tail" to be pushed toward the injection orbit on the low momentum side. Perhaps 50% of the total beam stack of 7×10^{14} protons is pushed into the unusable tail and has to be cleaned up after the stacking process is over, but only less than 5% total is likely to be pushed beyond the injection orbit and stray out of the dump profile on the low momentum side. With the stacking of a new pulse every 5 sec a small fraction of the 5% will stray out of the dump profile. This stray beam can be stopped on a scatterer-absorber combination with the scatterer target placed at a high x_p location just outside the dump profile on the low momentum side. This combination will be called the "low-p scraper".

c. After stacking is completed, the beam stack is moved to the horizontal center of the aperture. At this time the entire unusable

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3. A. van Steenbergen, BNL Informal Rept. ISA 75-6, July 1975.

tail containing up to 50% of the beam will be cleaned up on the "low-p scraper". This clean-up process could be arbitrarily slow and the beam loss rate can be controlled by a loss rate feedback system.

d. At the same time when the stack is centered and the low momentum tail is cleaned up the stack should be scraped vertically to give an improved vertical beam profile. Because of precise collimation in the beam transfer line, it is estimated that no more than $\sim$ 10% needs to be scraped off vertically. The scatterer target of the "vertical scraper" should be located at a high β_y location and could be retracted out of the vertical dump profile after scraping. The vertical scraping can also be done during stacking on each injected pulse while it is being accelerated into the stack. In this case a wedge shaped target would extend the loss over the duration of the stack acceleration time.

3. Adiabatic Capture and Acceleration

a. No accelerator has succeeded in adiabatic capture with more than 90% of the beam. Thus, one should expect a 10% beam loss at 30 GeV during the adiabatic rebunching. This 10% beam will stray out of the dump profile on the low momentum side and should be absorbed on the "low-p scraper". Since the adiabatic capture process can be arbitrarily slow, this 10% beam loss can be made to proceed at an arbitrarily slow rate.

b. No beam loss is expected during the acceleration from 30 GeV to 200 GeV.

4. High Energy Colliding Beam Operation

a. The beam loss due to beam-gas scattering, intrabeam scattering, and beam-beam interaction at 200 GeV are all negligibly small (otherwise the colliding beams will not be useful for physics experiments).

b. A few times during a physics run the beam may have to be scraped vertically to restore a sharp vertical beam profile. A very small part (10^{-3}- 10^{-4}) of the beam is scraped off each time. The scraping rate can be arbitrarily slow and the "vertical scraper" is used for this operation. The first scraping may be immediately after acceleration before the beams are made to collide for physics experiments.

5. Ejection

At the end of a physics run the beam is ejected in one revolution ($\sim$ 10 μsec) by the ejection system to be stopped on an external beam absorber. Approximately 0.1% of the beam will strike the ejection septum. The absorber to stop this beam is an integral part of the design of the ejection system.[4] So also is the external absorber which must stop the more than 99% of the beam which is ejected.

B. Sources and Characteristics of Beam Loss Due to Possible Malfunctions

1. Injection

The beam is extracted from the AGS only after the proper sine-wave excitation of the septum magnets has been noted by the sensors. However, the kicker magnet may misfire. In this case the injected beam of 2.5×10^{12} protons will stray out of the "dump profile" 90 betatron phase degrees downstream of the kicker. A 30 GeV beam absorber should be located there just outside the dump profile to stop the stray beam. This is called the "injection stopper". In addition the dump profile sensors will trigger the protective ejection sequence removing from the ISA ring the previously established stack and that part of the injected beam which did not exceed the dump profile boundary and progressed 7/8 of an orbit to the ejection insertion.[5]

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4. A. van Steenbergen,"ISA Ejection System, Components and Parameters", (to be published as an ISA Informal Rept.)

5. H. N. Brown, "ISA Injection-Ejection Trigger Logic", these Proc.

2. Stack Formation

If the stacking rf system fails, the injected beam will simply be left parked on an orbit between the injection and the stacking orbits. It is extremely unlikely that the malfunction of the stacking rf system will cause it to decelerate or to over-accelerate the beam out of the dump profile. Of course, a malfunction of the stacking rf system will inhibit further extraction of beam from the AGS.

3. Adiabatic Capture and Acceleration

The accelerating rf system should be interlocked with the beam ejection system. If the rf system fails during the acceleration cycle the beam stack should be ejected and dumped. The ejection system components will track the momentum of the beam so that the beam stack can be ejected at any time during acceleration.

4. High-Energy Colliding Beam Operation

In this regime there should be no detectable beam loss for normal operation (except for the controlled vertical beam scraping to restore the beam profile). Any beam straying out of the dump profile and above a specified minimum level is interpreted as caused by component failure. Instead of trying to scrape the stray beam on an internal absorber the entire beam stack is immediately ejected and dumped on an external absorber by the ejection system. For normal operation the beam is ejected in one revolution ($\sim 10\ \mu$sec). Approximately 0.1% of the stacked beam (7×10^{14} protons) will hit the septum and more than 99% of the beam will be ejected and stopped on the external absorber.

5. Failure of Ejection System

In case the ejection system equipment (kicker and septa) fails to operate, a back-up kicker will kick the beam on to an internal absorber. The full stacked beam of 7×10^{14} protons will be dumped on the internal absorber in one revolution. This is by far the fastest rate of beam stopping internal to the ring of all operations.

Since this is a redundant back-up operation and not expected to occur more than a few times during the useful life of the ISA, more serious consequences, in terms of local damage or even driving downstream superconducting magnets normal because of energy deposition from the nuclear cascade downstream of the absorber, is thought to be tolerable. Preliminary designs for scraper-cascade shield combinations have been worked out[6,7] however, which will prevent, even in this case, the superconducting magnet units from going normal due to cascade deposition.

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6. J. Peterson, A. van Steenbergen, L. C. Teng, "ISA Beam Scraper System", these Proc.

7. L. Blumberg, J. Ranft, A. Stevens, A. van Steenbergen, "Caloric Deposition Downstream of the ISA Beam Scrapers", these Proc.

Stray Beam		Injection	Stack Formation	Adiabatic Capture	Acceleration	Colliding-Beam Operation	Ejection
Normal Operation	# of P on Absorber	0	5×10^{14}	7×10^{13}	0	$0^{(a)}$	$< 10^{12}$ on septa 7×10^{14} on ext. absorber
	Cause		Bucket Fit Overstack V.Scraping	?	-		
Malfunction of Specific Component	# of P on Absorber	2.5×10^{12}	0	0	-	-	7×10^{14} on int. absorber
	Cause	Kicker Misfire					Ejection Component Misfire

	DUMP-LOGIC REGIME	SCRAPE-LOGIC REGIME
Ejection Triggers		Same as Dump-Logic Regime except:
	Dump Profile Triggers	
	Absorber Radiation Triggers	← Suppress
	Rf Malfunction Trigger	
	$\dot{I}$ Toroid Trigger	← Suppress
	$\int \dot{I}$ Toroid Trigger	← Suppress
	Magnet Quench	
	Sector Valve Closing (Vac Interlock)	
	Access Door Interlock	

(a) Few vertical scraping operations during a physics run (24 hrs. period).