Machine Protection Schemes for the SLC

M. C. Ross, Stanford Linear Accelerator Center, Stanford, Ca. 94309

ABSTRACT*

The beamline components of a linear collider must be protected from high power beams in a way that is both reliable and has a minimum impact on integrated luminosity. When an upstream accelerator component fault occurs, the machine protection system suppresses the appropriate beam pulses and restores them when the fault clears or is compensated for. If an unacceptable localized beam loss is detected, without an accompanying component fault that is a likely cause of the loss, the system must provide identical, lower rate (lower average power), beam pulses to be used for diagnosis. This must not be done at the expense of any upstream beam stabilization system since fault diagnosis and recovery may take some time. Since the SLC beam pulse sequence is a regenerative one, i.e. correct function on a given pulse requires that several preceding pulses have been successfully completed, beam pulse repetition rate limiting is not trivial. Smooth, rapid, recovery from this type of fault is very important and can have a significant impact on luminosity. This paper provides an overview of the beam suppression and repetition rate limiting schemes used at the SLC.

INTRODUCTION

Several next generation particle accelerators will control beams of very high effective power which are capable of causing significant damage to beamline components in a short time. While these machines share the need for a sophisticated, highly integrated machine protection system (MPS), their specific requirements differ radically. The extent to which these systems are integrated with the accelerator controls will have a great impact on their operation. Very little has been written about such systems in general.

MPS DESIGN

The MPS we address here are those that rely on measurements of a beam related parameter such as beam intensity, position or loss. Such devices are referred to as an 'errant beam detectors' (EBD).

Generally speaking, in a well designed system, damage from the beam cannot occur if all systems are functioning properly and at their design settings. The primary exception to this are beam defining devices, such as collimators, which are intended to cut the extremes of the beam but can only absorb a fraction of its total power. Neglecting these devices for the sake of argument, one could design a system which drew its input primarily from device controllers, such as power convertor or RF system controllers and control the generation of beam pulses according to the status of these systems. In this case, EBD are not required. However, under certain conditions, loss monitors indicate a problem and all device controllers indicate good status. Under these circumstances beam may be required to assist the diagnosis of the root cause of the failure. This is often the case with collimators. The beam required for diagnosis must be a low power 'copy' of the high power beam. Otherwise it will not be a useful diagnostic and the frustrating situation may result where the low power beam indicates no problem, yet the EBD will not allow generation of the high power beam. Furthermore, these trips may be caused by transient events that escape detection (or are detected too late) by the device controllers so the transition to the low power state and recovery of the high power beam must be done quickly and smoothly and must not involve the generation of any substantially different beam pulses. At SLC, low power diagnostic beams are produced by lowering the repetition rate.

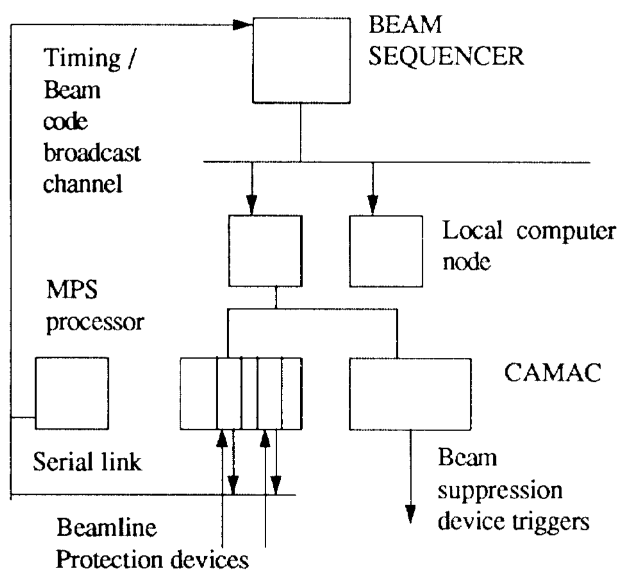

Figure 1: Block diagram of a generic MPS. At SLC, the front end errant beam detectors are usually ion chambers or temperature detectors. The beam sequencer controls the beam production through the use of broadcasted beam codes [1]. It also directly controls the beam suppression devices and controls globally synchronized data acquisition.

Figure 1 shows a block diagram of a generic MPS. The topology of the beam lines, the allowed modes of operation, the beam sequence and the limitations of pulsed devices are critical for the SLC MPS. Additionally, a globally synchronized beam diagnostic data acquisition scheme, like that used at the SLC, must be able to cleanly cope with the changes in beam rates instigated by the MPS.

Typical SLC average beam power is 150KW in a $0.05 mm^2$ area. When an electron beam of this power strikes some device the bulk of the energy is dissipated in a relatively

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large volume several radiation lengths behind the point of initial entry. However, if the beam is small enough, significant damage from a single pulse may occur near the point where the beam enters the material. At several places in the SLC, the beams are small enough so that this is a concern. The use of a thin upstream spoiler increases the beam size enough to prevent this type of damage.

To illustrate the problems posed by the above constraints, we will first briefly describe the SLC (figure 2) and some of the relevant subsystems.

SYSTEM CONSTRAINTS

Beam suppression in the upstream part of the SLC is accomplished near the gun. The nominal 120Hz SLC e+/e- bunch production scheme has the following features:

1) Three bunch co-acceleration is required in 2/3 of the main linac (1.1GeV - 30GeV) and the injector region (210 MeV to 1.1GeV). The co-acceleration results in an energy dependence of a trailing bunch on the intensity of the leading bunch(es). This dependence is caused by fundamental beam loading in the disk loaded waveguide structure.

In the SLC this leads to about 1% energy loss per 3 x 10^{10} leading particles. At nominal currents this effect is large compared to the typical beam energy spread and downstream energy acceptances and therefore must be considered. A feedforward system [2]that compensates for this in the main linac is presently being commissioned, but its role in the SLC MPS will not be considered here.

2) In the positron damping ring, the positrons must damp to about 1% of their initial emittance, about 5 damping times. Because the interpulse time is less than 3 damping times at 120Hz, the e+ must be allowed to damp more than one interpulse period. In order to achieve this, the bunches are left in the SDR for two interpulse periods. They are injected and extracted from the ring one at a time and are equally spaced around the ring circumference.

3) The SDR kicker pulses are fast enough to extract a single bunch without disturbing the remaining one. In contrast the NDR kickers use a long flat-topped pulse to inject and extract both bunches at once. Any rate limit scheme must keep the average power dissipated in the kickers and their power supply system constant. This is done using 'standby' pulses.

There is a logical boundary at the beginning of the arcs beyond which the e+ bunch can no longer affect the energy of the e- bunch that follows it. A pair of beam suppression devices, known as 'single beam dumpers', (SBD's) at this location can allow one beam or the other to continue on to the final focus. Any fault detected by EBD downstream of this location can be handled easily. If beam pulses are required to diagnose the problem the single beam dumpers may be programmed to allow a full current, low rate beam through.

RATE LIMITING

In order to provide an equivalent beam of lower power as required to diagnose an errant beam detector fault, the cycle must be broken because each rate limited pulse must produce and deliver positrons in just the same manner as the full rate pulses do. The positron storage time must therefore be made arbitrarily long. Since the kickers continue to fire, only one SDR bunch will survive. This means that the transition from full to low rate must also be a transition from 'n -> n+2' to 'n -> n+1' e+ production (and vice versa). Thus at those transitions a single e+ only (rate drop) or an e- only (rate increase) pulse is produced in the main linac. Because the e-

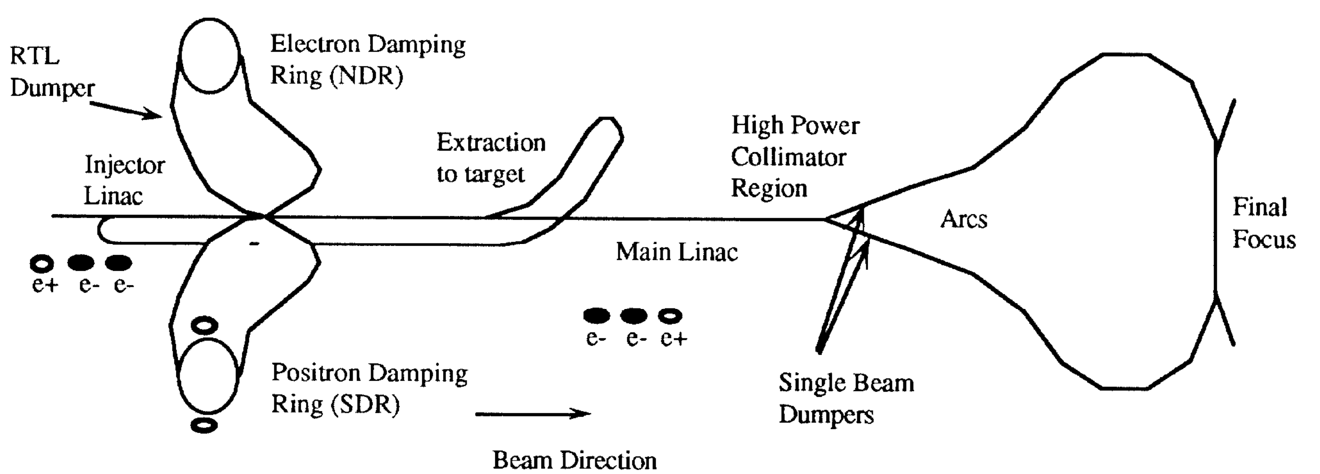

Figure 2: SLC Layout. The sequence begins when an electron bunch pair is extracted after damping 1/120s and follows a leading e+ bunch through the main linac where the trailing bunch is deflected onto the positron target. The newly created positrons are brought back to the injector and inserted behind a new electron bunch pair. The key features of this cycle from an MPS point of view are that the e+ are both delivered and generated on the same pulse and that the e+ generated on pulse *n* are destined for pulse *n*+2. The extraction line feeding the 30GeV beam to the positron target, the region surrounding the high power linac background collimators, the entrance to the arcs and the final focus are critical for MPS and most EBD trips originate in these areas.

only pulse consists of unloaded e-, some nuisance trips will result.

The behavior of the NDR is somewhat different. Since it has a long kicker pulse, no bunches will survive longer than the nominal interpulse time. These considerations result in the scheme shown in figure 3.

Since the e+ trail the e- through the injector, an additional pair of electron pulses is required in rate limited mode to provide the proper beam loading. This beam must not be allowed to continue into the main linac and is disposed of with a small dump in the ring to linac transport line. For extended rate limited periods,such as during machine development, the 'loading bunches' are turned off and an appropriate energy compensation is made.

DATA ACQUISITION

Finally, we must consider the impact of rate changes on the machine data acquisition system. Data is continuously acquired from position monitors for feedback purposes and, less often, for accelerator studies. This is accomplished by dropping the rate of the acquisition codes and assigning high priority first to operator driven acquisition and then to the feedback process. A more complex problem is the control of synchronized data acquisition across region containing the SBD's which may be rate limiting the beam. The beam sequence controls this by broadcasting data acquisition codes to the appropriate data collection processors on a user by user basis. Since it also controls the SBD's, it is able to tag the pulses which will be allowed through.

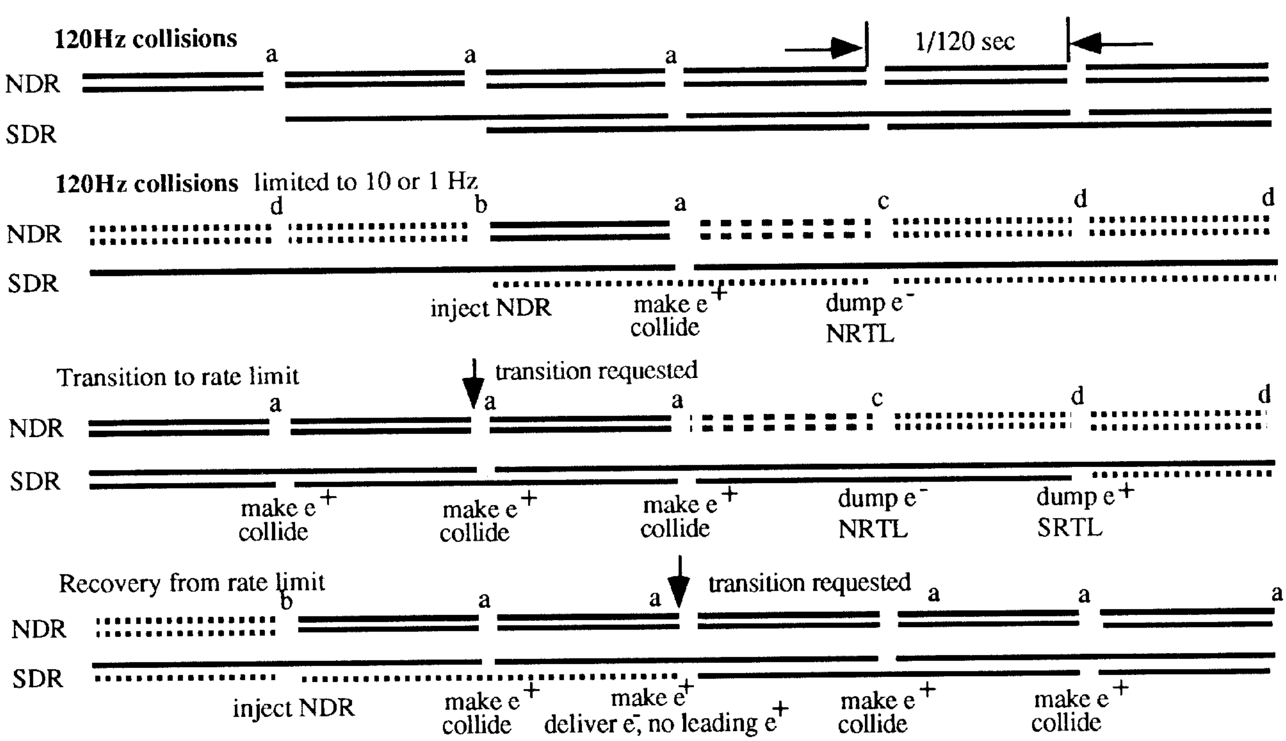

Figure 3: SLC Beam timeline diagram. This figure shows the progression of SLC bunches through the systems vs time. For each section of the figure, two sets of solid line segments are drawn indicating the bunches in each ring. The horizontal axis represents time, with an 8.33ms basic unit. Above the top group of lines, at the breaks, are the beam codes produced by the sequencer. There is a one to one correspondence between the beam code and the bunch movements that will occur on that pulse. Four levels are shown: a) full 120Hz operation, showing the bunch alternating in the SDR, b) Steady state rate limited operation, showing the production of the 'loading bunches', c) transition to low rate and d) transition to high rate. The fine dashed line indicates that beam is not present, the coarse dashed line indicates that beam was produced only for loading.

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[1] K. Thompson and N. Phinney, 'Timing System Control Software in the SLC', IEEE Trans. Nucl. Sci. NS32-5:2123, 1985.

[2] R. K. Jobe et. al., 'Energy Feed Forward System at the SLC', Proceedings of this conference.