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THE ENERGY STABILIZATION FOR THE SLC SCAVENGER BEAM*

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Abstract

The energy of the SLC scavenger beam which is used to produce positrons must be carefully maintained so that the beam can be transported through the collimators in the dispersive region of the extraction line which leads from the Linac to the positron target. A feedforward control loop has been developed to compensate the energy fluctuations due to the beam intensity fluctuations. The loop detects the beam intensities in the damping rings and then calculates how much energy needs to be compensated due to beam loading effects. The energy is corrected by adjusting the acceleration phases of two sets of klystrons right before the extraction. Because there is feedback loop using the same controls, their interaction needs to be carefully treated. This paper presents an overview of the feedforward algorithms.

Introduction

When operated at 120 Hz, in each beam pulse , there are three bunches in the SLC linac. These are, in order, collider positrons , collider electrons and the scavenger electrons. The last one, the scavenger electrons, is extracted at sector 19, the 2/3 point of the Linac, with energy 33 GeV to produce positrons for use later. The intensity variations of the two leading bunches and the scavenger bunch will cause an energy variation of the scavenger bunch due to the beam loading and the self-beam loading effects. A collimator, used to protect the extraction line, defines the energy acceptance to be ± 1.2 %. If, on some pulse, the scavenger beam energy is greater than 1.2 % above nominal, the collimator will scrape some of the scavenger beam and therefore reduce the intensity of the produced positrons, as shown in Fig. 1. As a consequence of that, the energy of the scavenger beam one subsequence pulse will be increased since it follows the lower intensity bunch of positrons. This energy variation will add up with the previous one and cause even more scavenger beam loss and reduce the positron beam intensity further and so on. The radiation due to the beam loss in the extraction line will trip off the whole machine by the MPS (Machine Protection System). This kind of rolling snow ball mechanism can trip off the machine within a couple beam pulses at moderate to high intensity. It is so fast that the existing extraction energy feedback loop can not prevent it. Therefore, a pulse by pulse feedforward loop has been developed to cure the problem.

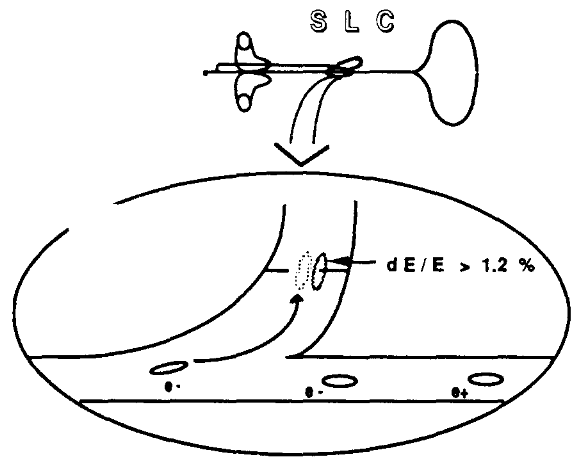

Fig. 1 The schematic drawing of the extraction line.

The Feedforward Loop

A schematic drawing of the feedforward loop is shown in Fig. 2. We pick up the three beam intensity signals in the damping rings at 5.3 msecs before they are extracted into the Linac. The intensity signals are converted into a scavenger beam energy change according to the known loss parameter k of the SLC linac structure. This is summarized in the next section. The signal for the required energy compensation is sent down the Linac to sector 17 and sector 18 which are the sectors right before the scavenger electrons extraction line. By changing the sub-booster phases of sector 17 and sector 18 in opposite direction we can accomplish the required energy compensation without changing the beam energy spread. If it takes 1 ms for the sub-booster phase to stabilize, data processing must be completed after 4.3 ms. Due to the short data processing time, the manageable algorithm and the cost of a software intensive solution, we decide to use hardware data processing techniques. The block diagram is shown on Fig. 3.

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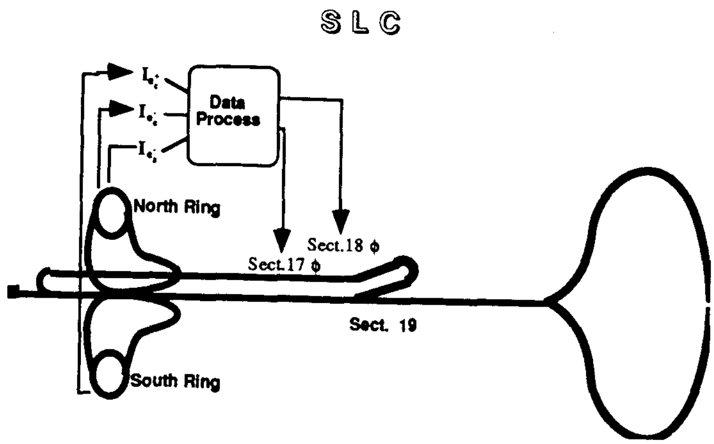

Fig. 2 The feedforward loop to stabilize the scavenger beam energy.

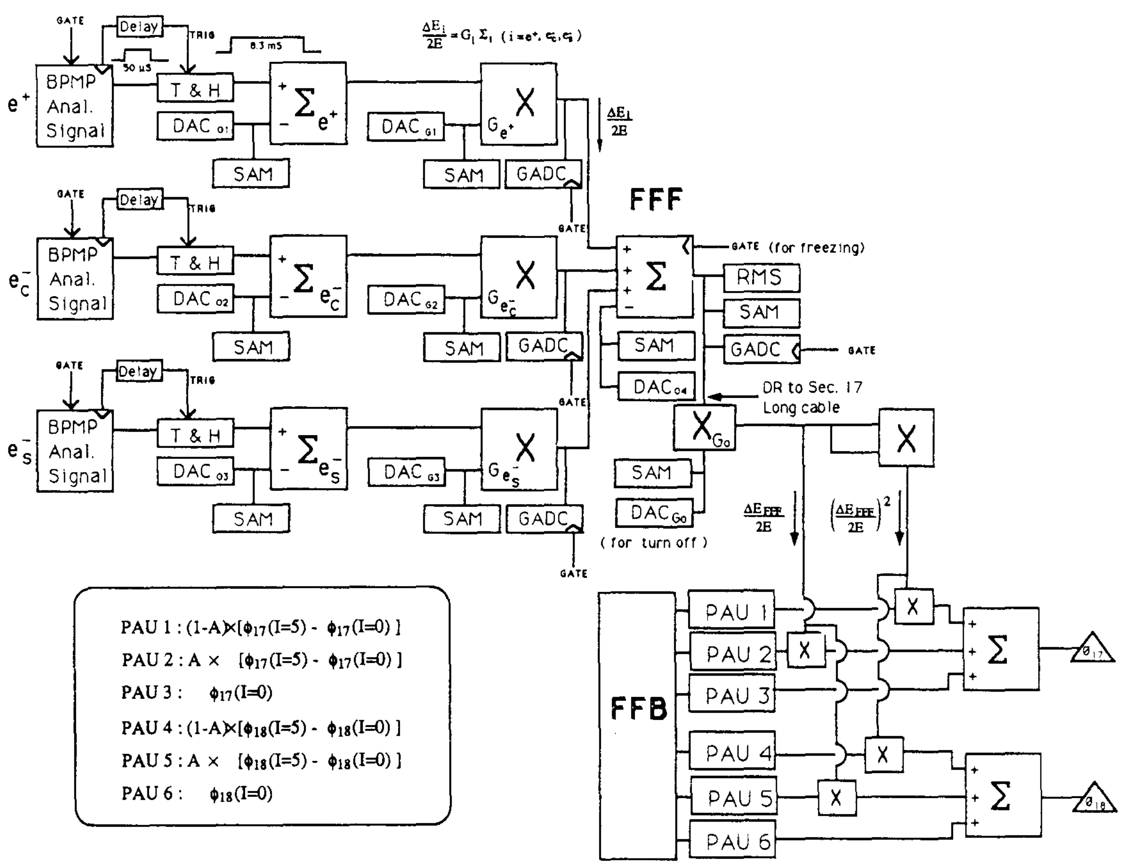

Fig. 3 The block diagram showing the overall loop stracture.

Where

T & H : Track and Hold

SAM : Smart Analog Monitor (ADC)

GADC : Gated ADC

PAU : Pulsed Amplitude Unit (DAC)

(The detail of PAU 1 - 6 is described at the end of the paper.)

FFF : (Fast) FeedForward loop

FFB : (Fast) FeedBack loop

The Summary for the Beam Loading Estimation

For SLC Linac :

Loss parameter : k = 19 V/pC/m

Beam loading enhancement factor : B = 3.1
(for bunch length = 1 mm)

The scavenger beam energy loss due to

1) The fundamental mode wake of :

$$e_c^+ \; : \; 94.6 \, N_{e^+} \, \frac{\text{MeV}}{10^{10}}$$

$$e_c^- \; : \; 102.8 \, N_{e_c^-} \, \frac{\text{MeV}}{10^{10}}$$

$$e_s^- \; : \; 55.5 \, N_{e_s^-} \, \frac{\text{MeV}}{10^{10}}$$

2) The self beam loading of the higher order mode wake :

$$e_s^- \; : \; (B-1) \times 55.5 \, N_{e_s^-} = 116.5 \, N_{e_s^-} \, \frac{\text{MeV}}{10^{10}}$$

After the loop is finished the above theoretical results will be confirmed by checking the correlation between the beam intensities and the scavenger beam energy at the extraction line.

The Interface Between the Feedforward Loop and the Feedback Loop

As we mentioned in the introduction, there is a feedback loop to stabilize the scavenger beam energy and the extraction position and angle. The control variables of the energy feedback loop are the sub-booster phases 17 and 18. The feedforward loop, for purposes of the simplicity, could use another pair of sub-booster phases as the control variables but would take about 1 GeV of energy for the head room. Therefore, we decided to use the same sub-booster phases for control. In this way, we can also utilize the existing control software and some of the hardware by merging two loops together.

After the analysis, we discovered that because the feedback loop energy measurement is in the extraction line, downstream of the two klystron sets, and the feedforward loop intensity monitor is upstream, these two loops will not fight each other and will not diverge. In fact, if there is a consist error of the feedforward loop, it will be corrected by the feedback loop.

Several methods for merging these two loops have been studied. Due to the non-linear (cosine) wave form of the RF field, an exact mergence circuit would need three arcosine operations and one square root operation which are in principle possible in hardware but may be somewhat complicated. Under some approximations, those operations can be reduced to a single arcosine operation. According to simulations, the maximum fractional energy error due to this approximation is 0.54% which is about the half of the tolerance. A different approach is to use the final feedforward signal to do the linear interpolation of the feedback output. In this way, complicated arcosine operation is not needed, but the maximum fractional energy error is 0.64%. The method which we will use for this project is that instead of using linear interpolation , we use quadratic interpolation . In this case the maximum fractional energy error is reduced to 0.20% which is well inside the tolerance. The equation for the quadratic interpolation is :

$$\phi_{17}(I) = [1-A(\phi_{17}^0,\phi_{18}^0)] \times [\phi_{17}^{max} - \phi_{17}^0] \times [\frac{\Delta E_{FFF}(I)}{2E}]^2 + A(\phi_{17}^0,\phi_{18}^0) \times [\phi_{17}^{max} - \phi_{17}^0] \times [\frac{\Delta E_{FFF}(I)}{2E}] + \phi_{17}^0$$

where

I : The current vector = [$I_{e_c^+}$, $I_{e_c^-}$, $I_{e_s^-}$].

$\phi_{17}(I)$: The phase is applied to the sub-booster 17 for the detected currents I.

ϕ_{17}^{max} : The phase would be applied in the case of maximum currents.

ϕ_{17}^0 : The phase would be applied in the case of zero currents.

$A(\phi_{17}^0,\phi_{18}^0)$: The interpolation coefficient which dependents on ϕ_{17}^0 and ϕ_{18}^0.

$\frac{\Delta E_{FFF}(I)}{2E}$: The fractional compensation energy of the feedforward loop at I.

The formula for the sub-booster 18 is similar the above equation.