Title
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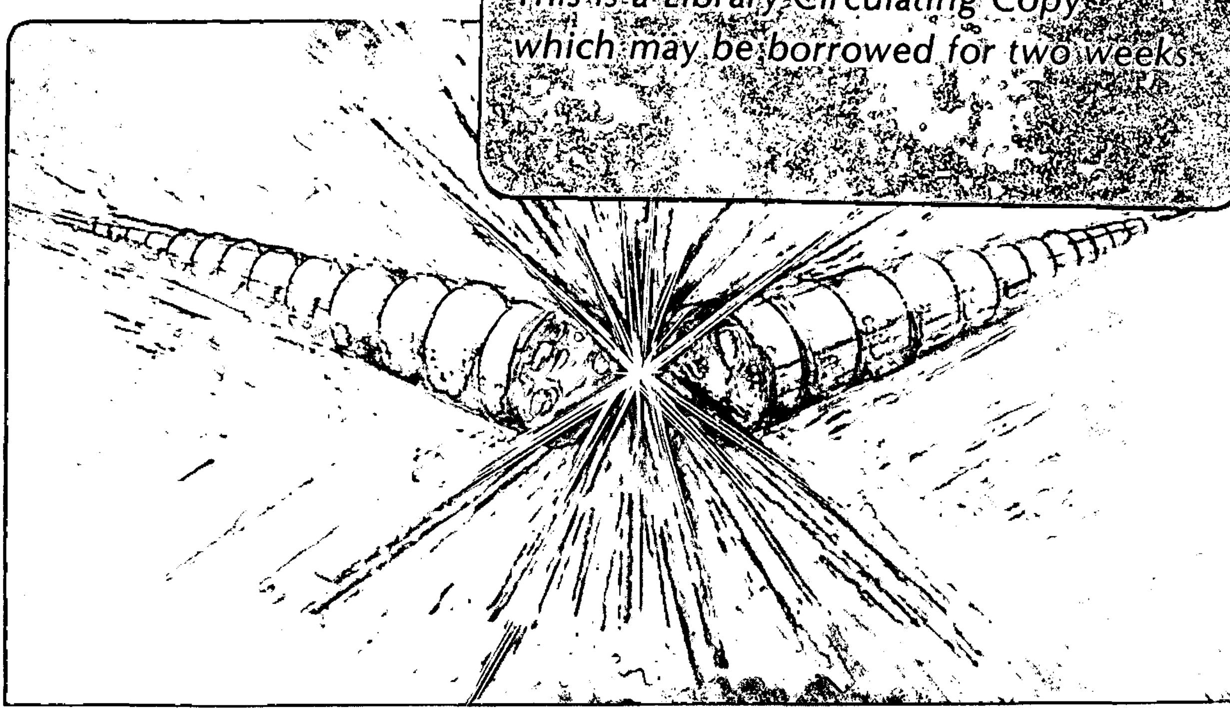

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DISCLAIMER

NEW CONTROL TECHNIQUES FOR EXTRACTION OF BEVALAC BEAMS*

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Abstract

Beams of accelerated heavy ions can now be delivered as one-second-long DC pulses with minimal fluctuations in instantaneous flux. Pulse duration can be held constant to within 1% while keeping a high non-varying extraction efficiency which minimizes pulse-to-pulse position shift in the extracted beam. In addition, differing beam intensities over several orders of magnitude can be delivered. Computer adjustment of all measurement and control devices results in linear operation over three orders of magnitude of beam intensity. Control of beam structure is accomplished by a unique combination of dual slope integrators and phase forward "predictive" circuits in the feedback loop.

Introduction

The LBL Bevalac is currently engaged in an upgrade of the beam extraction system. In the past, the beam has been delivered as a series of short bursts, each series lasting approximately half a second every 4 seconds. In some applications, we would like the Bevalac to produce a DC like spill of long constant duration pulses with all particles marching out equally spaced in single file. While this is unfortunately only a fantasy, we have demonstrated a close enough approximation for our needs.

As a result of the upgrade, the Bevalac can now deliver one-second pulses varying less than 1% while maintaining high-extraction efficiency (≈50%) pulse (15 pulses/min.) which in turn results in exceptional pulse-to-pulse spatial stability at the target. A true continuous spill held close to the mean flux has also demonstrated with only occasional excursions, which themselves are controllable. The total flux delivered can be pre-selected by controlling the injected beam before acceleration.

Beam Extraction

To explain how the stable long spill ("DC" aspect) is maintained, and the time structure ("AC" aspect) controlled, some background in the Bevalac and instrumentation is described below.

The Bevalac is a combination of two accelerators, the SuperHILAC (Heavy Ion Linear Accelerator) and the Bevatron. Ion species from hydrogen to uranium are pre-accelerated by the HILAC, and then transferred to the Bevatron for further acceleration and delivery to the end user. A set of attenuators may be plunged into the transfer line to control the quantity of beam reaching the Bevatron. The attenuators are limited to factors of 2, 3, 10, and 60, or combinations thereof. This, however, is fine enough resolution, since pulse intensity from the HILAC vary randomly by factors of 2 or 3.

The total intensity of circulating beam is measured before extraction by the BIE system (Beam Induction Electrode). The BIE system is limited by a dynamic range of approximately an order of magnitude, whereas the actual circulating beam to be measured may differ by many orders of magnitude, due to HILAC variation and attenuator settings. This can be overcome by ranging the BIE system before injection by predicting what is expected.

After acceleration, the RF system, which was used to accelerate the beam and maintain the circulating particles in a tight packet, is turned off. This allows the particles to spread out around the entire ring before extraction begins.

Once the beam has been carefully accelerated and stabilized at the maximum storage field, it must be extracted with equal care. This is accomplished using a process called resonant extraction. Resonant extraction induces horizontal betatron oscillations in the circulating beam by adjusting the synchrotron guide field for a resonant condition of two betatron oscillations per three radial turns of the beam. This condition is initiated by the mechanical insertion of a single magnet containing several independent coils. The main coil, P1, creates the resonant condition and pushes the machine's operating point toward extraction. The spiller coil, S1, controls the final betatron growth of the beam to the actual point of extraction. The field of P1 is present during tuneup to bring the Bevatron to the edge of extraction, possibly spilling a small quantity of beam by itself.

Control of current in S1 includes the use of a scintillator for feedback at F1, a location just outside the main ring. The scintillator incorporates a photomultiplier tube (PM tube) whose high voltage (HV) can be adjusted before injection for range control in a manner similar to the BIE system. An error signal is generated in the spiller chassis by summing the PM signal with a computer-generated spill rate Reference (Ref.). The error signal is then conditioned independently for the "AC" and "DC" control before being recombined to form the S1 control signal. The overall system is shown in block diagram below Fig. 1.

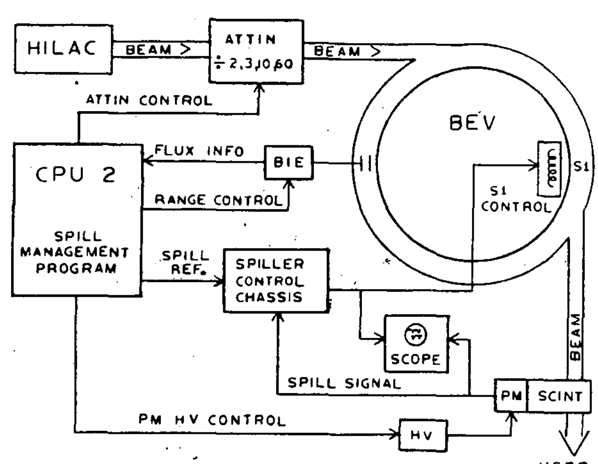

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Fig. 1 Bevalac spill control block diagram.

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"DC" and "AC" control of the beam centers on controlling S1, along with proper setup of instrumentation (BIE, scintillator), and the quantity of beam injected (attenuators). The "DC" aspect is managed by a computer program called "The Spill Management Program" (SMP), and controlled in real time by a dual slope integrator in the feedback loop. The "AC" aspect is controlled only in real time, using a combination of threshold, differentiator, and analog time-out circuitry in the feedback loop. the purpose of this is to predict the behavior of the spill and control it <u>before</u> it happens. Predictive control is essential because, once a particle is excited sufficiently for extraction, it may take 200-300 microseconds before it actually clears the septum to be extracted. Thus, once it has been detected that too much beam is being spilled and S1 is shut down. particles will continue pouring out for another 200-300 microseconds, usually resulting in a flux spike many times greater than the mean spill level desired. A block detail of the spiller chassis in the feedback loop is shown below (Fig. 2).

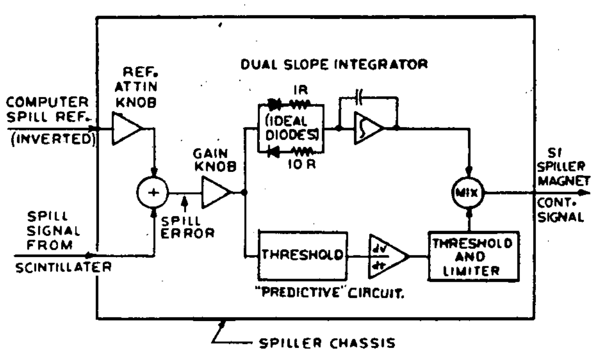

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Fig. 2 Spiller chassis block diagram.

"<u>DC</u>" <u>Control</u>: The Spill Management Program (SMP) controls the attenuators, BIE range, and PM tube HV, and sets the spill rate reference (Ref.) which is summed with the PM signal in the spiller chassis. Before each pulse a beam intensity request is made by the user via a computer link. Based on an average of previous HILAC pulses, the program calculates attenuator settings such that injection will result in twice the circulating beam requested, accounting for the 50% extraction efficiency. The BIE range and PM HV is set to correctly read the expected beam. The beam is now injected, accelerated, and read by the BIE to determine the actual circulating intenstiy, and the Ref. is set proportionally to give a constant fixed length spill, based on the available beam. A "spill rate" knob is provided on the spiller chassis, and functions as a gain control on the computer-generated Ref. The effect of this knob is to control the spill length, since the amount of circulating beam is finite. Turning the rate knob up will result in spilling all the beam sooner, shortening the spill. Proper adjustment results in spilling approximately 90% of the extractable beam before the end of the 1-second spill time is over. 10% is then left circulating to ensure against short spills due to possible errors in instrumentation and control throughout the large dynamic range of operation.

When a single circulating beam pulse is measured and found either to far exceed the desired intensity, or to be insufficient for accurate control, the spill magnets S1 and P1 are clamped by the program and no beam is extracted. If this condition continues for several pulses it will affect the running average of injected beam, causing an adjustment of the attenuators.

The job of the dual slope integrator in the spiller chassis is to generate the required control profile for S1 to produce the long spill. In general, S1 is rapidly brought up to a point where spill begins, then slowly increased as the spill progresses. At the end of the spill, control is removed form S1 and P1, causing the integrator to rise rapidly, but without any effect. See Fig. 3 below.

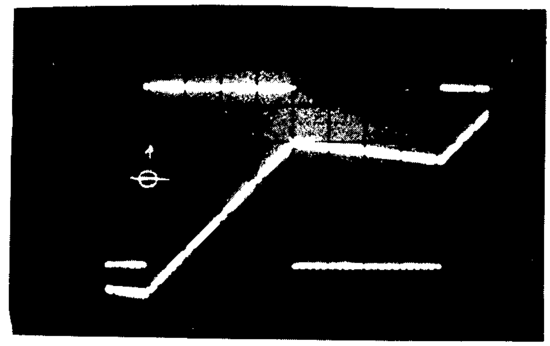

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Fig. 3 Upper trace: Inverted spill signal
Lower trace: S1 control signal

The positive and negative time constants of the integrator are designed such that it responds quickly to a positive signal, but slowly to a negative one of equal magnitude. (See Fig. 4 below). The response is quick to requests for increased spill (from the error signal), but virtually ignores the large commands to stop spill when massive spikes erupt from the machine. These spikes must be controlled by the predictive circuits, and not affect the longer-term control of S1. Some down slope integration is provided to handle the slight negative adjustments in the overall S1 control function.

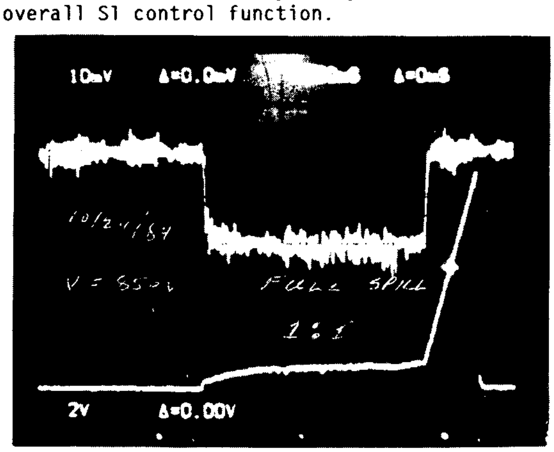

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Fig. 4 Square wave centered on zero (test input)
Sawtooth response of dual slop integrator

"<u>AC</u>" <u>Control</u>: Part of the spiller chassis controls the spill structure ("AC") by predicting the behavior of the beam, using the error signal which is the difference between the Ref. and the spill signals (spill + (-Ref.)). And since the Ref. is constant during the spill, the error signal reflects the spill. In terms of the spill itself, once it reaches a threshold, usually set near the Ref., the signal is differentiated, to asses whether the spill rate is still increasing. If it is increasing beyond some minimum rate, a negative signal is generated proportional to the rate increase, usually taking the form of a sharp negative spike. Another circuit ensures that this negative spike cannot exist more than a few hundred microseconds. Summed with the much more slowly varying signal of the dual slope integrator, it causes S1 to shut down in proportion to the anticipated spill spike. Because this powerful negative feedback occurs early, the upcoming spike can be snubbed before it gets out of hand. (See Fig. 5.)

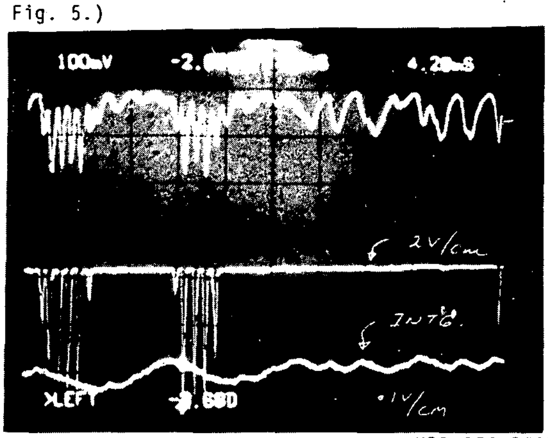

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Fig. 5 Upper trace: Inverted spill signal
Middle trace: S1 control signal (note general upslope of Integrator)
Bottom trace: Dual slop integrator response only (magnified)

Conclusion

As seen in Fig. 5, the response of the Bevatron is to attempt a few spill spikes before settling into a 5-15 microsecond stable state. During this stable time the spill wanders within a factor of 2 of the desired rate, terminating with another set of small spikes. Smoothing the spill structure ("AC") yields an approximation of a "DC" spill, and may well represent the first time the Bevatron has ever produced anything resembling a continuous beam.

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