The Improved Ultra Slow Extraction Noise System at LEAR

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Abstract

The LEAR stochastic extraction system has been improved to allow extraction of large anti-proton stacks. Increased beam diffusion associated with such stacks has imposed some changes. The hardware has been modified to minimize the extraction noise bandwidth. Stochastic cooling is applied throughout the spill to counteract diffusion and improve beam lifetime. With the cooling, beam shaping loses its significance and has been abandoned. This required a review of the noise advancement algorithm. In a parallel development, the extraction control system has been migrated from a stand-alone micro computer to the LEAR control VAX cluster. This has led to an enhanced user interface and resulted in improved operation. The integrated control environment allows for feedback of measured beam quantities. Feedback of extracted beam intensity is experimentally used on a spill-to-spill basis and at present we are studying alternative methods of spill intensity control.

1. INTRODUCTION

Ultra slow extraction was first proposed in 1978 by S. van der Meer and subsequently improved by R. Cappi, W. Hardt and Ch. Steinbach [1]. It has been operational at the Low Energy Anti-proton Ring (LEAR) since 1983 [2]. In 1992 the extraction noise system has been improved to accommodate extraction of large low momentum stacks.

2. CHANGES TO THE EXTRACTION PROCEDURE

With the original system the extraction noise had a fixed bandwidth [3]. At the start of the spill a large part of the spectrum of this noise was above the extraction resonance [4]. This noise signal perturbed the beam through the closest horizontal sideband, due to undesired transverse coupling of the longitudinal kicker. This increases beam losses. In order to reduce this perturbation a noise synthesis system has been devised that cuts off the noise beyond the resonance.

Also, with the original system, the stack was 'shaped' before extraction. This was done by applying a noise to the beam with a spectrum that covered the stack. This increased diffusion and effectively changed the stack distribution from Gaussian to an even distribution. For a constant extraction flux, all that was required was a linearly advancing extraction noise. Large low momentum stacks tend to diffuse relatively fast, resulting in a bad lifetime. Shaping makes the situation worse and had to be abandoned for such stacks.

With the new method, stochastic cooling is applied to the beam during the spill. This contains beam diffusion and increases the lifetime to the order of hours. As the stack is no longer shaped the extraction noise cannot advance linearly into the stack. The noise advancement function now depends on many parameters such as beam distribution, cooling strength, extraction noise power, beam lifetime and natural diffusion. Some of these parameters are difficult to measure and may vary during normal operation [5].

As a result the noise advancement function can no longer be simply calculated and is now 'composed' manually and experiments are being made with semi-automatic correction schemes.

3. HARDWARE MODIFICATIONS

The objective of the new hardware layout is to generate a noise spectrum with a fixed upper limit and bandwidth growing downwards. This is achieved by sweeping a noise

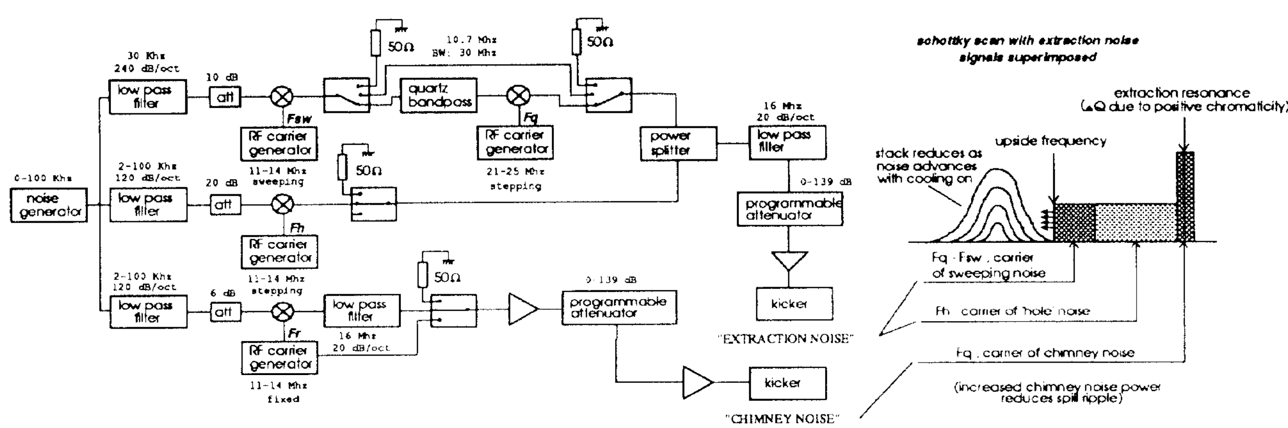

Figure 1. Layout of the noise generation hardware and signal composition

spectrum through a quartz bandpass filter. The bandwidth of the commercially available quartz filters is too small and so the bandwidth of the filtered noise is increased by adding another fixed noise spectrum that effectively bridges the hole between the sweeping noise and the resonance.

Ripple in the quadrupole current varies the tune and effectively moves the resonance to and from the stack. This results in a modulation of the extraction flux. To reduce this spill ripple, a narrow band, (relatively) high power noise signal is added around the resonance in order to increase diffusion. The spectrum of this signal resembles a chimney and is named likewise.

The start and stop frequency of this noise spectrum must be adjustable. The bandwidths of the separate components of the noise signal are programmable and each of them is shifted to the correct frequency by mixing with adjustable carriers [6]. Figure 1 shows the layout of the modified hardware and the synthesized signals.

4. CONTROL MODIFICATIONS

The control system of the extraction noise was previously based on a dedicated HPIB controller. For remote operation and to allow interaction with other processes, the noise control system is now incorporated into the LEAR control system. It is controlled from a clustered VAX with a IEEE488 port.

Figure 2 shows the layout. The user interface application is used to calculate the frequency tables for the various generators using stack parameters such as bandwidth and upside frequency. These tables are converted into a list of IEEE488 commands that control the generator hardware sequentially. The IEEE488 command sequence is then fed into a real-time process that sends the commands to the hardware following both external and internal timing triggers.

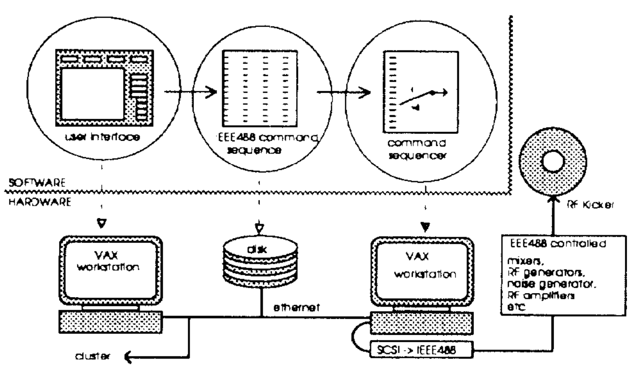

Figure 2. Extraction noise control system

5. SPILL INTENSITY CONTROL

There are now two methods of noise advancement implemented. The original method, which requires a shaped beam has not been modified. The noise advancement $\Delta f(t)$, relative to the upside frequency is:

$$\Delta f(t) = -BW_{st}\left(\frac{t + f_{sl}t^2}{T_{sp} + f_{sl}T_{sp}^{\ 2}}\right) \tag{1}$$

BW_{st} is the stack bandwidth after shaping, T_{sp} is spill duration and f_{sl} determines the proportional increase or decrease of spill intensity. The f_{sl} parameter depends on the stack diffusion and is determined experimentally.

The new parametric method suits any stack distribution and in particular the natural Gaussian distribution. The noise advancement $\Delta f(t)$, with respect to the upside frequency, is simply interpolated from a set $\{\Delta f_1,..., \Delta f_8\}$ which represents the noise advancement at predefined points in the spill.

The Δf function has some similarity to an inverted Gaussian but also depends on parameters such as stack diffusion and applied stochastic cooling power. Figure 3 shows a typical example of this function, relating it to the stack distribution and spill.

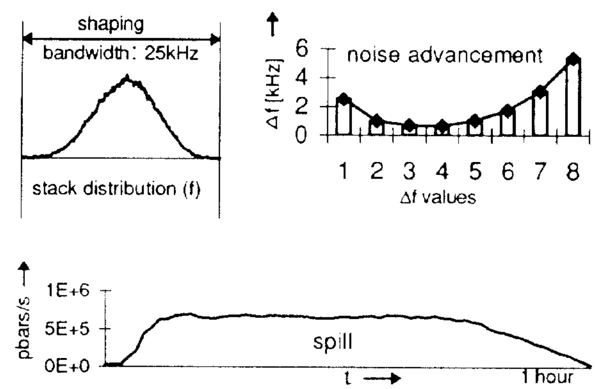

Figure 3. Stack distribution, noise advancement function and resulting spill.

The most simple method of determining the noise advancement function is through manual adjustment. The set $\{\Delta f_1,..., \Delta f_8\}$ is manually adjusted until a constant spill has been achieved. So far this is the most reliable method. However it is also a very slow method; in operational conditions it may take more than 1 day of operation to adjust the noise advancement function.

We are now trying different automation schemes in order to accelerate the adjustment process. The first method acquires a spill and compares it to the required intensity function, normally a constant. The resulting error function is used to correct the noise advancement function using a simple control algorithm. The new parameters are calculated by:

$$\Delta f_i^{new} = \Delta f_i^{old} \cdot \left(1 + K \cdot \frac{\phi_r - \phi_a(i)}{\phi_r}\right) \tag{2}$$

where $\phi_a(i)$ is the average extracted flux over the spill interval i. The gain K is actually 0.5. Using this method the spill shape converges to the required spill shape in about 4 spills. However, this method requires a clean spill shape acquisition which during the setting-up phase of extraction is often not available. By optimizing the control algorithm we intend to improve convergence to 2 spills.

At present we are testing the use of direct feedback of the extraction flux $\phi_a(i)$. This quantity is compared to the required flux ϕ_r giving the error ε_n at the time t_n of the n-th iteration:

$$\varepsilon_n = \phi_r - \phi_a(t_n) \tag{3}$$

This error function is scaled dynamically to favour small errors compared to large errors. This improves dynamic response and stability. The scaled error ε_n' is:

$$\varepsilon_n' = \varepsilon_n^{\ 3} \cdot |\varepsilon_n|^{\frac{1}{4}} \tag{4}$$

The noise advancement function, still with respect to the upside frequency is then:

$$\Delta f(t_n) = \Delta f(t_{n-1}) - P \cdot \varepsilon_n' - I \cdot \sum_{j=1}^{n} \varepsilon_j' \tag{5}$$

An example of a spill with feedback is given in figure 4.

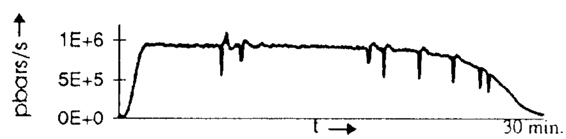

Figure 4. Spill with feedback

The spikes in the spill are caused by acquisition errors which destabilize the regulator for a short while. This method does in fact allow good spill control. The extracted flux can be modified during the spill, which was previously impossible.

6. Conclusions

The new extraction noise system has been operational since 1992. The system satisfies the requirements. We now routinely extract stacks of up to 10^{10} antiprotons at 200 MeV/c with extraction durations of 1-2 hours. The new control system encourages user interaction and allows development of spill optimization techniques.

7. Acknowledgments

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8. References

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