A FEEDBACK SYSTEM TO CONTROL THE FLUX DURING ULTRA SLOW EXTRACTION AT LEAR

S. Jacobsen, G. Molinari, H. Mulder, CERN, Geneva, Switzerland

Abstract

Prior to the introduction of extraction flux feedback, the spill intensity was controlled by a feed-forward system. Apart from the tedious adjustment procedure, this system could not react to variations in the beam conditions. In particular, density variations induced by instabilities of the stack would cause large intensity fluctuations in the extracted beam, thus reducing its usefulness for particle physics experiments. The new extraction flux feedback option has been operational since the start of the 1995 physics run. Particularly at 200 MeV/c, the improved duty cycle has significantly increased the useful amount of extracted beam with respect to a similar run in 1994. In addition the system has a greater operational flexibility allowing a rapid response to changes in user requirements. The feedback controller is implemented at software level. The system layout is described and the feedback dynamics are discussed.

1 INTRODUCTION

The ultra slow extraction system at LEAR has been improved in stages since its introduction in 1983. A status of the system in 1994 was reported to the EPAC in London [1]. The latest improvement concerns the flux control mechanism, i.e. control of the spill intensity during extraction. The feasibility of using feedback for flux control was demonstrated in 1994 [2] and control software required for its implementation on an operational basis was installed at the start-up of 1995. No hardware modifications were required.

2 LAYOUT OF THE FEEDBACK SYSTEM

The feedback system consists of a single feedback loop in parallel with a feed-forward control. The feed-forward control is an implementation of the existing flux control system. The layout is shown in figure 1.

In normal operation, the control switch is in feedback mode. The extracted flux is measured by the particle physics experiment, digitised and transferred to LEAR and compared to the required flux. The resulting error signal is fed into a control algorithm which calculates the required frequency step of the stochastic noise frequency carrier for the next time-slice of the spill.

The use of a flux measurement a long way downstream is imposed by the impossibility of non-destructively measuring the relatively low flux intensity

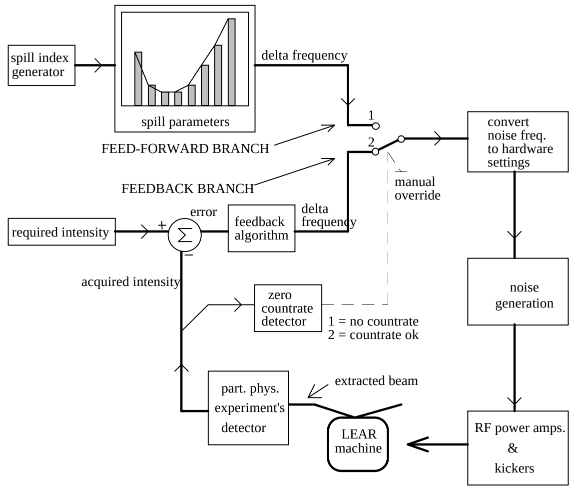

Figure: 1 Layout of the feedback control system.

nearer the machine. As a result, the flux measurement is uncertain. For example, an intervention in the experimental detector requires closure of the beam stopper between LEAR and the detector. This will interrupt the flux measurement and clearly this would upset the feedback controller. To compensate for the measurement uncertainty, a zero count rate detector is implemented that forces the controller in feed-forward mode as soon as the flux measurement is interrupted. The feed-forward system has memorised the frequency function of the previous spill and the extraction continues uninterrupted.

The experience is that this switch from feedback to feed-forward causes no discontinuities in the spill and flux measurement interruptions of as long as 10 minutes can be supported without significantly affecting the spill intensity

3 FEEDBACK DYNAMICS

The ultra slow extraction process is based on slow acceleration of particles towards a third order resonance. This acceleration is achieved through stack diffusion, induced by stochastic noise. When the natural diffusion of the stack is low with respect to the spill time - at LEAR this occurs at momenta above 500 MeV/c - and when using feed-forward only, then provided that the stochastic noise power is sufficiently high, the extracted flux depends principally on the initial stack distribution and the advancement of the stochastic noise into the stack.

When introducing feedback, the system dynamics become more complicated. The dynamics now depend on the diffusion dynamics of the stack - which are non linear - and the dynamics of the feedback system. Some simulations of this system were made but having the particle accelerator at hand, it was more practical to determine the feedback system characteristics experimentally rather than theoretically. The results are implemented in a discrete control algorithm.

The feedback algorithm is implemented as follows. The frequency advance δf_{n+1} as a function of the measured extraction flux ϕ_n is

$$\delta f_{n+1} = P \cdot \varepsilon_n^* + D \cdot \left(\varepsilon_n^* - \varepsilon_{n-1}^* \right) \qquad (1)$$

where ε_n^* is the dynamically scaled flux error:

$$\varepsilon_n^* = \varepsilon_n \cdot \left| \varepsilon_n \right|^{-\frac{1}{4}} \qquad (2)$$

and the flux error is defined as the difference between the required intensity ϕ_r and the acquired intensity ϕ_n

$$\varepsilon_n = \phi_r - \phi_n \qquad (3)$$

The parameters P and D are the proportional gain and the differential action parameters respectively. It was found that as the circulating stack decreases, the system could sustain a higher gain before oscillating. Since this improves the spill uniformity, the factor P is scaled with the stack size:

$$P = loop\ gain \cdot \sqrt{\frac{10^9}{stack\ size}} \cdot 10^{-6} \qquad (4)$$

The use of integrating action has been tried but it was found that the integration constant had to be in the order of the spill time to avoid instability. This is not very useful; the experimentally determined scaling of the flux error and the proportional action proved to be the better solution.

Some typical parameter values are shown in table 1.

Momentum	200 MeV/c
stack size	$5\ 10^9$ particles
diffusion constant due to extraction noise	$2\ 10^{-7}\ s^{-1}$
required intensity	$800\ k\bar{p}\ /\ s$
loop gain	1200
differential action	P / 3
controller update interval	10 s

Table 1: Operating parameter values

4 SOFTWARE IMPLEMENTATION

The feedback control system is entirely constructed at software level. The measured flux is digitised, processed and the extraction control hardware is driven through an IEEE488 interface [3].

The system is implemented as a set of interacting real-time processes (figure 2). The real-time task interacts with the physical world through the LEAR physical parameter subsystem for acquisition of spill rate, stack size and other process parameters and actuates the extraction hardware through an IEEE488 driver. It reports status messages to the LEAR database which can be accessed by external processes. It uses the VMS system resources for time ticks and stamps.

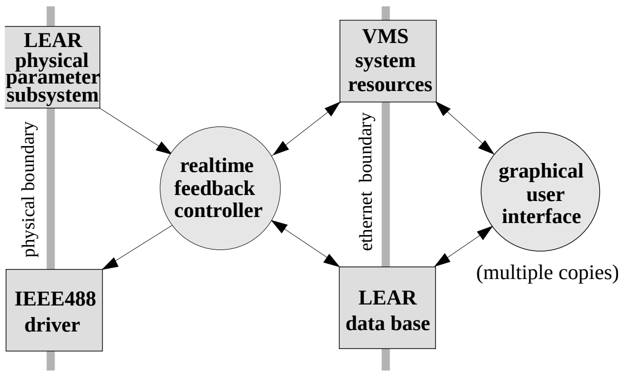

Figure 2: Overview of the real-time task interaction

The existing ultra slow extraction user interface was re-coded to include the feedback option. Functionality of the previous system was retained. Figure 3 shows this interface in feedback mode.

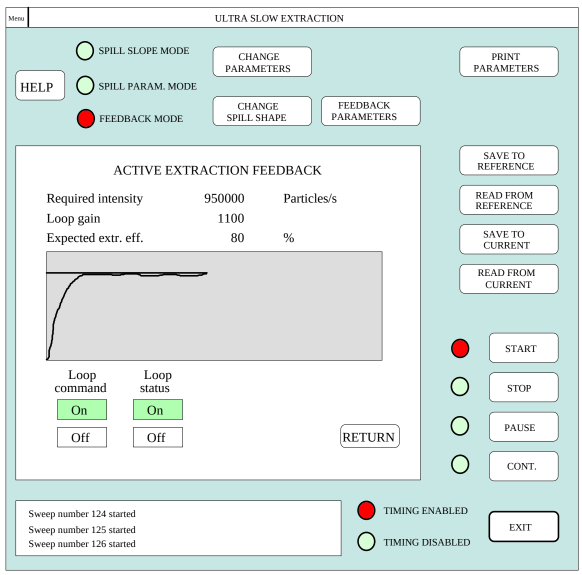

Figure 3: Graphical user interface

5 OPERATIONAL RESULTS

The system was put into operation in April 1995 an has remained so since. Figure 4 shows a spill measure during normal operation at 200MeV/c.The required flu was 800 $k\bar{p}/s$. The start of the spill gives an indicatic of the response time of the system. The require intensity may be changed during the spill with response time of typically a few minutes.

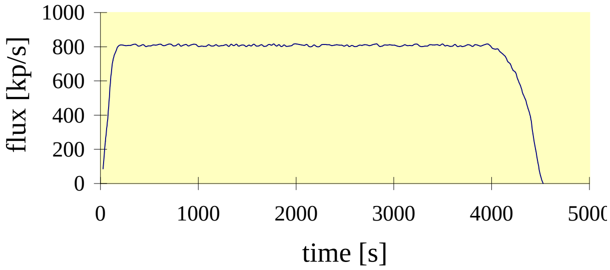

Figure 4: Spill with extraction feedback

The average spill quality has improved as shown in tab 2. Here we compare the end of run statistics for the 1994 run - using the old extraction system - and the 1995 run, with the extraction feedback system for one of our main users: CP Violation (PS195).

This experiment requested a beam rate of 800 $k\bar{p}/s$ to 1 $M\bar{p}/s$. The table shows that the long term average beam rate has been much closer to match this requirement than was the case in 1994.

***CP Violation* run statistics**	1994 run (34 days)	1995 run (41 days)
average beam rate	540 $k\bar{p}/s$	800 $k\bar{p}/s$
spills/day	12	13.5
delivered antiprotons/day	$260\ 10^{8}$	$390\ 10^{8}$

Table 2: End of run statistics of CP violation experiment.

At this particular beam momentum, 200 MeV/c, the LEAR circulating beam occasionally suffers from an instability that disturbs the stack distribution accompanied by rapid beam loss. Both effects lead to a significant loss in extracted beam intensity. With the feedback system we can - in most cases - compensate these effects and maintain the extracted beam intensity. An example of a spill suffering from such an instability is given in figure 5. The dotted line is without feedback, the continuous line is with feedback. With the feedback system, these particular spills are much shorter in time, as shown in the figure. This partly explains the increased number of spills per day in the table above.

It should be noted that further improvements were made to other subsystems of the LEAR machine and the CP violation detector. These improvements certainly take their part of the credit for the excellent end of run statistics.

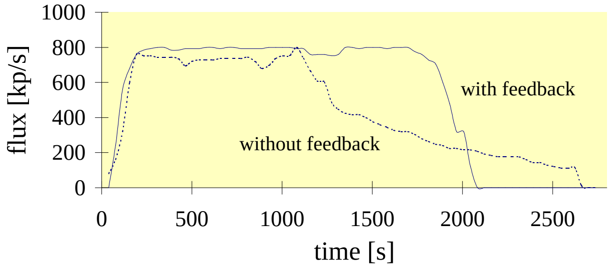

Figure 5: Spill from unstable machine

The system's capacity to compensate for changing machine conditions has allowed the operations team to optimise LEAR parameters during extraction without disturbing the extracted beam.

6 CONCLUSIONS

The feedback system has proven to be reliable and has significantly increased the amount of useful beam given to particle physics experiments. The operational flexibility allows us to rapidly respond to changes in user requirements with respect to beam intensity.

The system further eases the operation of ultra slow extraction at LEAR thus allowing the operation team to concentrate on other machine parameters.

Finally the system was shown to be successful in counteracting the adverse effects on the extracted beam due to a beam instability at 200 MeV/c.

7 ACKNOWLEDGEMENTS

The authors would like to thank the LEAR engineers and technicians for their part in commissioning the ultra slow extraction feedback system.

REFERENCES

[1] G. Molinari, H. Mulder, The Improved Ultra Slow Extraction Noise System at LEAR, Proc. EPAC, London 1994, Vol 3, pp 2376 - 2378

[2] H. Mulder, Spill Control Using Extraction Intensity Feedback (MD of 18.4.1994), CERN/PS/OP/Note 94-42(MD)

[3] S. Jacobsen, H. Mulder, Requirements Analysis for the Ultra Slow Extraction System with Active Feedback, CERN/PS/OP/Note 95-25(tech)