Beam Tests of a Stochastic Slow Extraction System Prototype in the U70

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Trace: ED106–DM24,26–SS30
Resonance: $3Q_x = 29$
Monitoring: BLM-106
Classical SE. Actuating: via lens Q38 [or decay of $H$]
Stochastic SE. Actuating: via aux. 200 MHz RF system @ SS44
the Classical SSE

First proposal and its author

S. van der Meer. *Stochastic Extraction, a Low-Ripple Version of Resonant Extraction.* CERN/PS/AA Note 78–6, March 1978

Simon van der Meer, N.P. in physics 1984

[CERN Courier, Dec 2003, v.43, no.10]

a Drift or a Diffusion?

\[
\Phi = -fV
\]

\[
\Phi = -D \frac{\partial f}{\partial x}
\]

\[
\frac{\delta \Phi}{\Phi} \leq \omega t_s \left( \frac{a}{A} \right) \frac{1}{\Gamma}
\]

\[
\frac{\delta \Phi}{\Phi} \leq 3\omega t_s \left( \frac{a}{A} \right)^2 \frac{1}{\Gamma G}
\]
the Classical SSE: details (1)

1. A lengthy spill lasting for 10 sec – 10 hr

CERN LEAR, antiprotons, 200 MeV, from 1–2 to 10 hr, $10^6 - 3 \times 10^4$ anti-p.p.s.

CERN PS, protons, 24 GeV, 8–9 sec

[CERN PS 40th anniversary booklet, 2000]

[CERN PS 40th anniversary booklet, 2000]

[Proc. 11th HEACC, 1980, p.335]
2. Waiting beam is azimuthally uniform

3. Controlled depletion of waiting beam stack with a swept cutoff frequency of noise power spectrum

4. Use of a dedicated “chimney” region with an enhanced noise power around the extraction resonance to increase, locally, speed of entering the resonance
SSE from the U70: details (1)

1. Shorter spills and operation close to a short-time applicability limit of the SSE technique proper

\[
\begin{align*}
t_s & \propto \Delta p_m^2 / D, \quad D \propto P \\
\max P & \propto \max \sigma^2 / \Delta \omega, \quad \Delta \omega \propto \Delta p_m
\end{align*}
\]

\[
\min \left( \frac{t_s}{T_0} \right) < \frac{20q\alpha}{\max \left( \frac{\sigma_u^2}{V_{RF}^2} \right)} \left( \frac{\Delta p_m}{p_0} \right)^3 \left( \frac{\gamma E_0}{e} \right)^2
\]

2. A highly non-linear motion. Waiting beam is kept circulating in a close outer vicinity of empty 200 MHz RF buckets.

PHYSICAL ANALOGUES:
- inverted beam halation
- extraction of a bunched beam refilled from the outer stack
3. Use of noise with a variable level $P_0$ and fixed shape of $P(\omega)/P_0$ extended over the entire frequency portrait of waiting beam

Spectrum of $\varphi$–noise

4. Use of a stronger functional counterpart of a noisy “chimney” band — of a fast (finite cyclic) motion inside RF buckets — to increase, locally, the speed of entering the resonance
MD Run of the U70, 2004 (1)

Block-diagram of experimental setup #1

Noise power spectrum

Signal from DCCT

Signal from BLM-106

Spill ripple
Static response functions

Calculation

Experiment

A simplified small-signal theory of a proportional feedback in t-domain (spill flat top, ripples)

\[ \Phi(t) = G(t) \phi_0 \left( \int_0^t G(t') dt' \right) \]

\[ \int \delta \Phi^{(tot)} (t') dt' = \frac{\int_0^t \delta \Phi^{(ext)} (t') dt'}{1 + K \Phi_0 \left( \int_0^t G_0 (t') dt' \right)} \]
MD Run of the U70, 2005 (1)

Block-diagram of experimental setup #2

Analogue electronics: high-precision, low self-noise, protected from mains frequency harmonic interference, bandwidth of AM regulation 0–500 Hz

[R&D and assembly of electronics: O. Lebedev]

<table>
<thead>
<tr>
<th>Module 1:</th>
<th>Pre-shaping of the feedback signal</th>
</tr>
</thead>
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<tr>
<td>Module 2:</td>
<td>Controlled amplitude modulator</td>
</tr>
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<td>Module 3:</td>
<td>White noise generator</td>
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<tr>
<td>Module 4:</td>
<td>Shaping of base-band spectrum of the random carrier</td>
</tr>
</tbody>
</table>
Feedback loop open

- Actuating noise
- Beam intensity
- FB signal
- Spill

Saturated regime

$t_s = 2.2$ sec

eextraction of 84% of beam
Spectrum of ripples: continuous, no (coherent) mans harmonic lines, flat over 5-500 Hz. Almost, a white Gaussian noise

(extrapolation: 80% over 2.6 sec)

<table>
<thead>
<tr>
<th>Extracted beam fraction, %</th>
<th>43</th>
<th>80</th>
<th>86</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of a spill, sec</td>
<td>1.40</td>
<td>1.40</td>
<td>2.10</td>
</tr>
<tr>
<td>Average extraction rate $\Phi_{dc}, 1/c$</td>
<td>0.31</td>
<td>0.57</td>
<td>0.41</td>
</tr>
<tr>
<td>Ratio r.m.s. $\delta\Phi/\Phi_{dc}$</td>
<td>0.20</td>
<td>0.27</td>
<td>1.06</td>
</tr>
</tbody>
</table>
Outcomes & Conclusions (1)

- The SSE from the U70 was tested experimentally (on a system prototype), was understandable, operational and well controllable

- There are a few inventive features implemented:
  - Steinbach diagram with empty RF buckets
  - Technique of actuating the operational noise

- There are new possibilities opened to tune the machine:
  - Stationary currents to feed magnetic optics
  - No sweep over $p$ (hence, stationary beam trace along transfer lines and fixed beam impact point at an external target)
  - No sweep over $a_x$ (hence, stationary $f(\Delta X)$ over impact parameter at ED106 given $\Phi =$ const)
  - Freedom of choice in direction of beam-footprint motion over the tune diagram

\[
\begin{align*}
\Delta \tilde{Q} &\propto (-0.03; +0.02) \\
SSE &\propto (\chi_x; \chi_y)
\end{align*}
\]
Outcomes & Conclusions (2)

- **New options** become available for beam consumers:
  - **Lengthier spills**: [from 0.5] to 3–5 sec, and longer
  - **Higher quality** of extraction time structure: lower ripples, no cutoffs, no mains harmonics
  - **Good** cycle-to-cycle **reproducibility** of spill pulses: effective stabilizing FBck + background beam conditioning with the actuating noise
  - Possibility to increase **Intensity** of SE: threshold of self-bunching is $\propto (\Delta p/p_0)^2/N$ and increases in course of the SSE (+ smearing effect of actuating noise ever present)
  - Possibility of a simultaneous (parallel) **operation** of the SSE + internal targets, a background co-extraction (<10%), at the “negative” radii

SSE = is a functionally novel extraction system from the U70 PS of IHEP