A NEW DIGITAL LOW-LEVEL RF AND LONGITUDINAL DIAGNOSTIC SYSTEM FOR CERN’S AD

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INTRODUCTION

In operation since July 2000 [1], CERN’s Antiproton Decelerator (AD) provides the physics program with low-energy antiprotons by decelerating 3 x 10^7 particles per cycle to 5.3 MeV kinetic energy. It will be upgraded and consolidated [2] during the Long Shutdown 2 (LS2) to provide reliable operation to the Extra Low ENergy Antiproton (ELENA) ring. AD will be equipped with a new digital Low-Level RF (LLRF) system before its restart in 2021. Diagnostics to measure beam intensity, Δp/p and Schottky spectra will also be developed. This paper is an overview of the planned capabilities and implementations, as well as of the challenges to overcome.

Table 1: AD Flattop Momentum and Frequency Values

<table>
<thead>
<tr>
<th>Flattop</th>
<th>Momentum</th>
<th>Revolution frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT1</td>
<td>3.57 GeV/c</td>
<td>1.589478 MHz</td>
</tr>
<tr>
<td>FT2</td>
<td>2 GeV/c</td>
<td>1.47728 MHz</td>
</tr>
<tr>
<td>FT3</td>
<td>300 MeV/c</td>
<td>500.465 kHz</td>
</tr>
<tr>
<td>FT4</td>
<td>100 MeV/c</td>
<td>174.155 kHz</td>
</tr>
</tbody>
</table>

Table 1 shows the momentum and revolution frequency values at each flattop. Figure 1 shows the typical AD production cycle including the RF segments, i.e. cycle parts where the RF is active. Energy levels and cycle structure will not change after LS2.

Figure 1: AD production cycle.
Operation of the HLRF System

The wide-band, non-tuneable HLRF system will be based on a Finemet metal alloy. Table 2 shows the available voltage as a function of frequency. Typically 3 kV are needed for deceleration and 500 V at extraction. Operation at $h = 3$ will be required on the third ramp, similarly to what was done with the previous HLRF.

<table>
<thead>
<tr>
<th>Frequency range [kHz]</th>
<th>Max Voltage [Vpeak]</th>
</tr>
</thead>
<tbody>
<tr>
<td>145 – 500</td>
<td>500</td>
</tr>
<tr>
<td>500 - 2000</td>
<td>3500</td>
</tr>
<tr>
<td>Elsewhere</td>
<td>0</td>
</tr>
</tbody>
</table>

Voltage and phase loop for a single decelerating harmonic will be implemented by the LLRF in [I, Q] coordinates. The impact of the new Finemet cavity has been investigated with numerical calculations and longitudinal tracking in the BLonD code [13]. A higher-than-operational intensity of $1 \times 10^8$ antiprotons and low longitudinal emittance of $1eV_s$ was used to look beyond expected demands on the system. The induced voltage caused by the Finemet impedance is expected to be of the order of 1 Volt; tracking simulations show no impact on beam stability. Figure 3 shows a side-by-side comparison of phase space at the start and end of the first ramp.

The LLRF will control in real time the gap relay short-circuiting the HLRF when no voltage is required. Safeguards in the LLRF will prevent overdriving the HLRF and remove the drive signal if the HLRF is not ready.

A sophisticated mechanism will measure the HLRF transfer function during setting-up, compensate for its frequency nonlinearity and cope with the frequency sweep.

LONGITUDINAL DIAGNOSTIC SYSTEM

Introduction

Standard DC beam transformers do not operate at AD’s low beam intensities. Since its start, AD was thus equipped with a dedicated longitudinal diagnostics system [14, 15] processing data from a low noise LPU [9]. The system, strictly linked to the LLRF, measured the intensity $N_p$ for a bunched beam by Fourier analysis; Schottky spectra, $N_p$ and $\Delta p/p$ were also provided for debunched beams. The system was instrumental for operating and optimising the machine. Figure 4 shows the performance summary table available at the end of each cycle. Figure 5 shows the plot of measured $N_p$, $\Delta p/p$ and revolution frequency.
A new longitudinal measurement system will be developed for AD’s restart in 2021. Figure 2 shows the two main system components: the FMC-DSP-Carrier board D and a fast processing module (“ObsBox”) receiving data from it via optical fibre. The new system will provide not only performance monitoring data for machine operators but also advanced information for cooling experts.

**Data Processing in Frequency**

The FMC-DSP-Carrier board D, shown in Figure 2, will process downconverted data derived from the LPU. For bunched beams, bunch length and \( N_p \) will be calculated with the method used in the previous system [14]. These measurements were already successfully deployed for ELENA [7]. Figure 6 shows how bunched beam parameters are derived from two Fourier components, assuming a parabolic envelope. Dependence on bunch shape is a drawback of this method.

\[
N_p = f(A_0) \\
\text{Bunch length} = f(\Delta)
\]

For debunched beams, high-length FFTs will deliver good frequency resolution. The numerical values of \( N_p \) and of \( \Delta p/p \) at specific points in the cycle will allow evaluating machine performance. Waterfall plots of spectra will be available for cooling experts.

**OUTLOOK AND CONCLUSIONS**

AD will restart operating in 2021 equipped with new LLRF and longitudinal diagnostics. The layout of the two combined systems will be validated in the 2020 ELENA run. Many LLRF and diagnostics features have already been deployed in ELENA and the remaining ones, such as the ObsBox integration, will be validated in 2020.

AD will profit from synergy with other machines for essential building blocks, such as the fixed frequency clocking scheme, operation with the new Btrain distribution system, operation with RF segments and integration of settings within an RF cycle editor. In turn, other machines will profit from features deployed in the AD system. An example is the PSB LLRF [17] where adding the ObsBox will allow measuring the bunch length along the cycle.
REFERENCES


[8] ANSI/VITA 57.1 standard


