UPGRADES TO THE DIGITAL RECEIVER-BASED LOW-INTENSITY BEAM DIAGNOSTICS FOR CERN AD

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Abstract

The CERN AD Low-Intensity Beam Multi-Diagnostics (LIMD) has been upgraded as planned since 2001 by adding tune measurements during ramps and plateaus, based on the Beam Transfer Function (BTF) method. This relies on transversally exciting the beam by a deflector and deriving the BTF and coherence function from FFTs of excitation and beam response recorded by digital receivers (DRX). These, continuously tuned to a betatron sideband, pass data to a digital signal processor (DSP) on the DRX board for data processing. The upgrades discussed also include increased longitudinal frequency range, noise reduction measures and digital flags for setup of Data Acquisition (DAQ) and processing parameters.

INTRODUCTION

The Antiproton Decelerator (AD) has been successfully operating for over two years [1]. LIMD [2,3] has been instrumental in the various phases of AD operation. It was recently upgraded to include tune measurement, and to improve its performance by abating parasitic noise from cables and by extending the frequency range covered.

HARDWARE UPGRADES

Figure 1 is a simplified description of the system; many details described in [2,3] are omitted but all the upgrades are indicated. Both NIM and VME crates are located in the AD control room, some distance from the actual Pick-Ups (PU) in the AD Ring Hall. The new components, indicated by a red line, are labelled (a) through (g). The Low Frequency Longitudinal PU (a) (LPULF) expands the detectable frequency range, in conjunction to the original High Frequency PU, LPUHF. The LPULF's response bandwidth is between 0.02 and 3 MHz; its lowest noise level is 2 pA/Hz$^{1/2}$ in the 0.1-1 MHz range. The outputs of the 2 LPUs are low-pass and high-pass filtered, respectively, and combined by the Summing Unit SU (b) to give a flat frequency response over the (0.02 – 30) MHz bandwidth. Both LPUs are connected to the SU by a 100 m-long, low-attenuation, doubly shielded coaxial cable (c), to minimize parasitic noise. The Cooling Status Unit CSU (d) is an in-house board translating the stochastic/electron cooling voltages into digital values specifying the cooling status (ON/OFF). This information
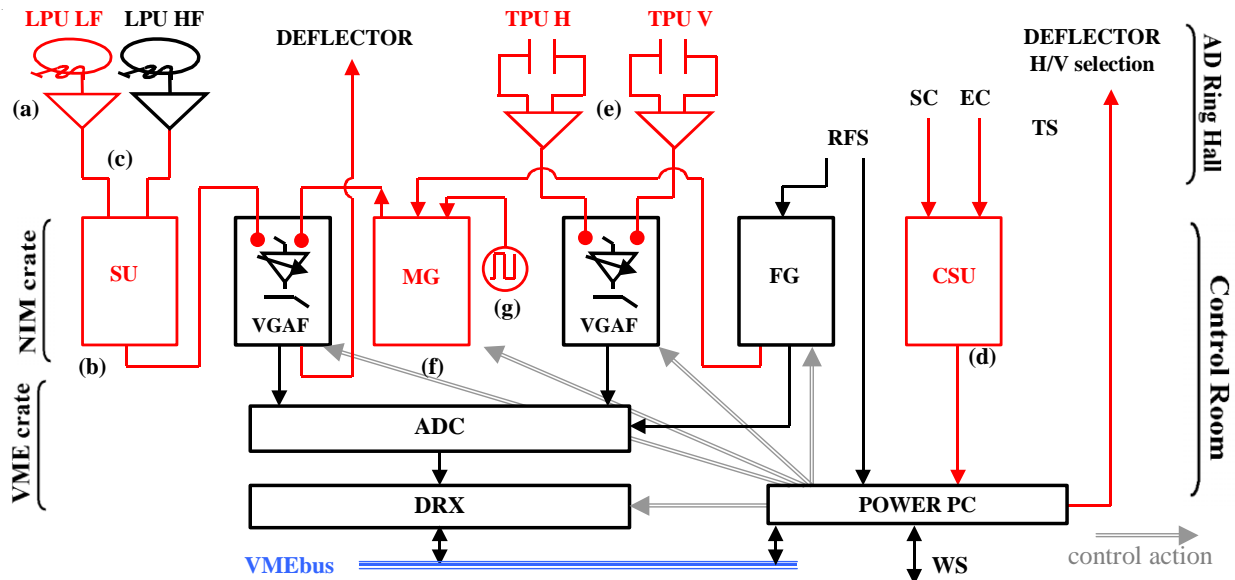

Figure 1: The LIMD system - upgrades are shown in red. Keys: SC – Stochastic Cooling, EC – Electron Cooling, PU – Pick-Up, TPU – Transverse PU, LPU – Longitudinal PU, LF – Low Frequency, HF – High Frequency, TS – Timing System, RFS – Radio Frequency System, SU – Summing Unit, DRX – Digital Receiver Board, VGAF – Variable-Gain Amplifier & Filter, CSU – Cooling Status Unit, MG – M-shaped Noise Generator, FG – Frequency Generator, WS – Workstation.

is used for the proper setup of DAQ and processing parameters by the Real Time Task RTT [2]. The horizontal and vertical (TPUH/V) transversal PUs (e),

now operational, are devoted to tune measurement by the BTF method. They are electrostatic devices, resonant at 5.6 MHz, with a low noise of 1 pA/Hz$^{1/2}$ between 5.3 and 6.2 MHz [4]. The noise generator MG **(f)** produces the analogue excitation used for BTF measurements. It is an in-house board that generates an analogue band-limited M-shaped noise signal by filtering the output of a white
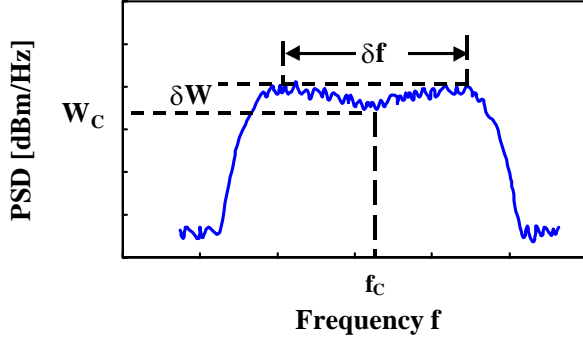

Figure 2: Power Spectral Density PSD vs. frequency f plot for the M-shaped BTF excitation signal. Keys: f_C - central frequency, δf – bandwidth, W_C – central power density level, δW – shoulder height increase.

SOFTWARE AND METHODS

Longitudinal DAQ and processing were discussed in [2,3] thus only upgrades are described here; transverse data are detailed for the first time.

Longitudinal Data Software

The RTT running on the PowerPC (Figure 1) has been upgraded to include the readout from the CSU board and the corresponding action. The CSU output is used to adapt the observation window during plateaus to the beam width, which decreases considerably owing to cooling actions (electron/stochastic), thus maintaining sufficient resolution in the computation of the momentum spread $\Delta p/p$ in each plateau. For each plateau, the user can select two different observation windows and the threshold, expressed as percentage of the cooling length, where the window width has to be changed.

Figure 3 plots the number of circulating particles N_p, $\Delta p/p$ and f_{REV} over a whole typical AD cycle. The LPULF upgrade has improved the quality of N_p data while the doubly shielded cabling has lowered the noise level, hence the fluctuations in N_p data during plateaus.
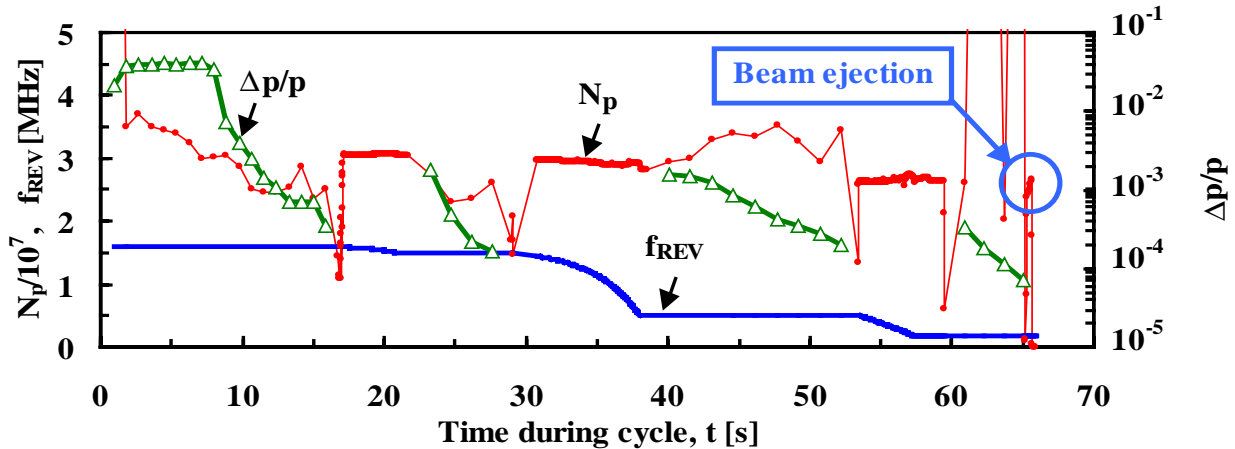

Figure 3: Number of particles, revolution frequency and momentum spread obtained by LIMD during an AD cycle.

noise diode. The board receives as inputs a constant-frequency (f_T) sinewave from a signal generator **(g)** and the central frequency $f_C = \alpha \cdot f_{REV}$ (Figure 2) from the Frequency Generator FG. Thus f_C tracks the revolution frequency f_{REV} as it varies on the ramps. Actually f_C, a good initial guess of a given betatron frequency (see *BTF Method*), is chosen so as to reside in the TPU low-noise region; typically the n=4 harmonic is used in the first ramp. Both α (hence f_C) and the M signal bandwidth δf, as well as the M shoulder height increase δW are user-selected via software. For $\delta f = 0.1 \cdot f_T/(2^m)$, the integer m = 0, 1...7 is user-selected, while δW is varied among -8, -14, -20 and -25 dB. The central power density W_C is constant at -52 dBm/Hz, thus changing δW varies the shoulder height $W_C + \delta W$. The Variable-Gain Amplifier and Filter (VGAF) applies an additional multiplier to the M-shaped noise from MG.

Consequently also $\Delta p/p$ values, that are linked to N_p data, are more reliable. In plateaus three and four between 40 and 65 s of the AD cycle, N_p takes large values; this is an artefact, likely caused by coherent instabilities or noise from RF cavities filtered through the longitudinal BTF. This will be investigated in the upcoming campaign. Finally, the apparently constant $\Delta p/p$ in the first plateau is due to the first observation window bandwidth, which had been left rather large to measure correctly N_p at injection.

Intensity (N_p) Calibration

A particular effort was devoted to the intensity calibration; a crucial task since absolute overall RF gains are difficult to obtain to better than ±2 dB. The calibration of the intensity, expressed by N_p, is made at ejection against a single pass charge measurement in a calibrated beam transformer recently installed in the ejection line. This approach is convenient since it is always available

during routine operation. The bunched beam intensity measured by LIMD just before ejection (Figure 3) is compared with the extracted beam intensity and is used for calibration assuming a lossless extraction. The calibration factor obtained is used at other f_{REV} on ramps assuming the gains of all elements in the DAQ chain are frequency-independent. This condition is satisfied to ±0.2 dB from 0.174 MHz to 16 MHz.

LIMD may also be calibrated with protons on 1000-fold higher N_p values, which are measured by a calibrated DC beam current transformer. This is impractical, as it requires complex operations and dedicated machine time; it is therefore scheduled only once, typically at startup.

BTF Method on Transverse Data

At typical AD pbar intensities and low momentum, transverse Schottky signals are too low to produce a useful S/N ratio. The tune is then measured by a variation of the BTF method [5]. Our implementation involves exciting the beam with a band-limited M-shaped noise, by means of a transverse damper deflector, and recording the deflector excitation and the transverse beam response. These are then FFT-processed to yield the tune. In this way it is possible to measure tunes at lower intensities and during the ramps, by keeping the sampling frequency f_S equal to a multiple of f_{REV}. The M-shaped excitation is chosen so as to minimise transverse beam blow-up, by setting f_C very close to a betatron frequency. The beam response is measured by the TPUs, located very close to the beam ejection point and about $3\pi/2$ away (clockwise i.e. for antiprotons) from the transverse deflectors. This method was tested prior to its implementation, on plateaus only; preliminary feasibility results are given in [4]. The LIMD BTF replaces a swept BTF technique that was slow, would only work on plateaus and was only used during the start-up phase.

The user may select up to 10 BTF measurements on a given AD cycle but only one deflector, either horizontal or vertical. The user selects the number of averages the DSP performs, the observation window and its centre via the RTT. This also selects the observation harmonic and sign so that the measurement falls into the low-noise region of the TPU. To avoid exciting unnecessarily the beam, the RTT turns off the excitation when the data acquisition is completed. BTF phase and magnitude, as well as the coherence function are made available to the user, together with PSD of both beam and M noise. The first three contain the information needed to determine the beam tune, which corresponds to the centre of the π phase shift (Figure 4). The coherence function may indicate correlation, or lack of, between excitation and beam response, with a value of 1 for perfect correlation and zero for totally unrelated data. The BTF data are judged acceptable for coherence values close to 1. The TPUH data in Figure 4 are 5 averages of overlapping FFTs at the beginning of the second ramp, with f_{REV} starting at 1.4979 MHz, on the slow wave sideband and 4th harmonic. From a fractional horizontal tune initial guess of 0.45 the measured tune was 0.454. This was a test of the method
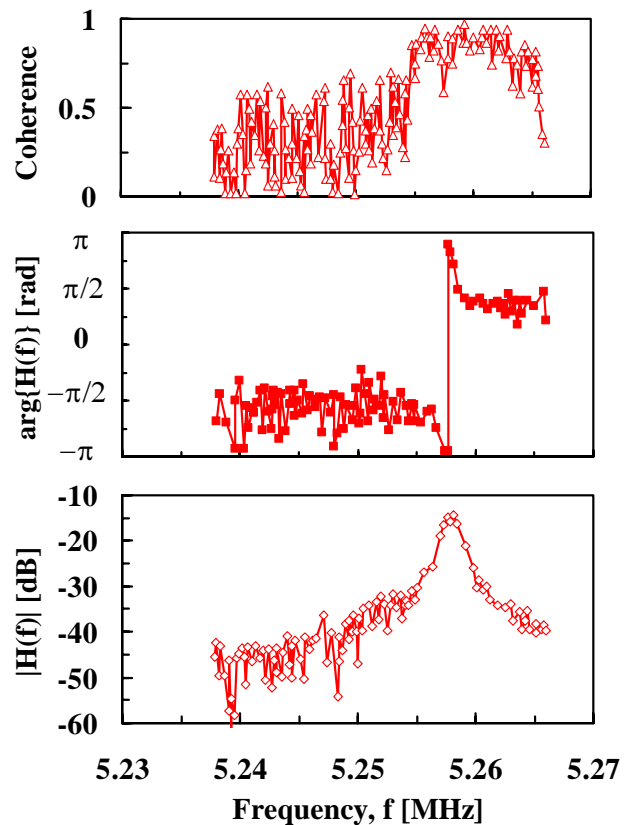

Figure 4: Plot of horizontal BTF phase arg{H(f)}, amplitude |H(f)| and coherence function vs. frequency f, showing a π phase shift centred at about 5.25765 MHz.

with a very good initial guess; hence the result is only a small refinement. Poor initial guesses are mastered with larger δf and observation window.

CONCLUSION

LIMD is now ready for full-steam operation. The various diagnostics it includes could be exported to other new systems, for example to Schottky-based diagnostics for CERN's LEIR.

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