FAST TUNE MEASUREMENT SYSTEM FOR THE ELETTRA BOOSTER

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Abstract

A major upgrade of the ELETTRA injector is currently on going: the 1GeV Linac will be replaced with a 100MeV Linac and a 2.5GeV Booster Synchrotron, cycling at 3Hz. A new set of diagnostics is under development for these two new machines. The new Fast Tune measurement system for the Booster represents a significant improvement as compared to the present Tune measurement system.

To completely characterise the dynamics of the Booster during the energy ramp, whose duration is 160ms, a set of 25 tune values is required, corresponding to a 6.4ms interval between successive measurements. The accuracy of this measurement is $<10^{-3}$. Such frequency spans are achievable using a Real Time Spectrum Analyser (RTSA) from Tektronix, which is a fast sampling instrument with built-in FFT algorithm and data presentation.

In this paper, after describing the system specifications and architecture, we present the results of the preliminary tests, which have been carried out both in the laboratory and on the Storage Ring.

INTRODUCTION

The new injector, which will replace the 1GeV Linac, is a new 100MeV Linac and a 2.5GeV Booster synchrotron. Full energy injection and top-up operation of the Storage Ring are the driving forces for this major machine upgrade. This new operating condition (constant current and energy) will greatly improve the stability of the ELETTRA light source as both the Storage Ring and the Beam lines will work under stationary conditions.

The development of the new diagnostics has started and it includes a new fast tune measurement system for the Booster synchrotron. Compared to the present Tune System [1], the performance up-grade mainly concerns the tune measurement rate, which will be shifted from the present 0.5Hz to 200Hz.

Actually for sake of reliability there will be two systems measuring the Booster Tunes, independently: the one described in this paper, based on the RTSA, and a second system, based on the Digital BPM Detector, already in use at ELETTRA [2]. The first one is believed to be useful especially during Booster commissioning, due to the convenient data presentation provided by the RTSA [3] as spectrograms. The second one will be installed as an Automatic Tune Measurement system, continuously checking the mean tunes.

In this paper we present the design of the fast tune measurement system based on the RTSA and the tests, performed on the Storage Ring, with the prototype of the new system. Full advantage has been taken from recently available new instruments, called Real Time Spectrum Analyzers. The tests carried out confirmed our expectations on performance improvement.

SYSTEM DESCRIPTION

The specifications for the fast tune measurement system require the real time measurement of horizontal and vertical tune and chromaticity during the energy ramp.

The time variation of the bending magnetic field during the ramping cycle of the Booster produces an eddy current in the metallic vacuum chamber of the bending magnet [4]: the main effect is an induced time-varying sextupolar component. To fully characterize the chromaticity variation and to keep it at the desired values [5], a minimum of 25 measurements per ramp is required, with a frequency resolution of 10^{-3}. The nominal duration of a ramp is 160ms, but it will go up to 1s during the commissioning phase of the Booster, which calls also for the system to be flexible.

Tune excitation and detection

A block diagram of the system is shown in fig. 1. A white noise excitation scheme has been adopted which is band-limited around the expected tune frequencies. The limited bandwidth of the excitation signal allows a more efficient use of the power amplifier.

The output of a white noise generator is band-pass filtered and amplified by a wide-band power amplifier. During preliminary tests, carried out on the ELETTRA Storage Ring at 2GeV, 50W (in a 100 kHz bandwidth) of diagonal excitation produced tune peaks of –71dBm over a noise floor of –95dBm. Therefore, the Amplifier Research model 150A100B, a 150W amplifier with a bandwidth 10KHz-100MHz, has been selected for beam excitation. A strip-line kicker, equipped with four 50Ω electrodes, will be used for both single plane (Horizontal or Vertical) and Diagonal excitation.

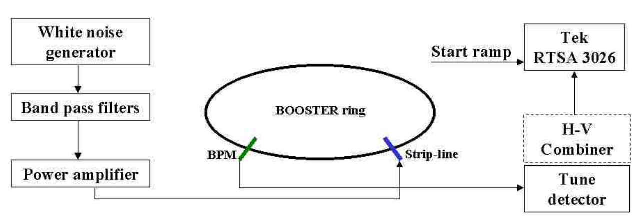

Figure 1: Fast Tune measurement system block Diagram

The transverse beam oscillations will be picked-up by a dedicated Beam Position Monitor placed at a high beta (β_V, β_H) location; the 500MHz signals from the BPM will be down converted by the ELETTRA Tune Detector [1].

The two outputs of the Detector provide the horizontal and vertical components of the betatron oscillations in base band. These signals will be summed up and delivered to the RTSA 3026 from Tektronix.

Final Integration of the System

The fast tune measurement system will be integrated in the new injector control system by means of client/server architecture (see fig.2). Nevertheless, as the presentation of the measurement data by means of spectrograms is convenient for the machine operators, the RTSA monitor will be made available in the Control Room, through a VGA fibre optic extender.

The RTSA functions will be accessed through macro-tasks, eliminating the need for the end user to be aware of all the settings and commands of the instrument itself.

A Motorola MVME 5100 VME CPU, running Linux [6], will control the fast tune measurement and interface it to the control system through the main Ethernet port. A GPIB [7] card from National Instrument (directly plugged into the PMC port of the CPU) will control both the RTSA and the power amplifier: a dedicated software driver is currently under development. The second Ethernet port, linked to the RTSA Ethernet port, will allow the direct download of the saved data without accessing the LAN. A digital I/O port will control the switch box for the selected excitation scheme (single plane or diagonal).The measurement macro-tasks will run on the low level CPU as requested by the operator.

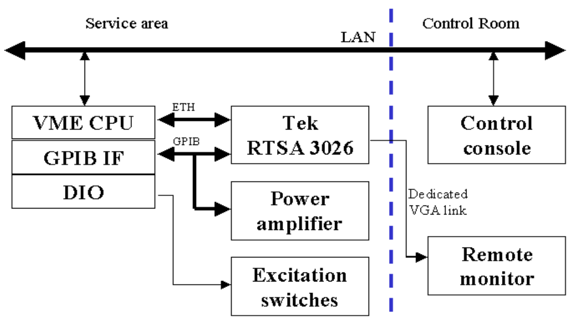

Figure 2: Integration of the system in the control system

THE RT SPECTRUM ANALYZER

The RTSA performs a real time frequency analysis of the input signal from its time samples, taken at 25.6 MS/s; the results are displayed on a spectrogram which is a 2D colour plot showing subsequent spectra vs. time, in much same way as on the Tektronix 3052 [8]. On each line of the spectrogram, a spectrum is represented; the amplitudes of the frequency components of each line are represented with colour grading. The measurement results can be stored on a local disk. Two operating modes are available: in Roll mode the instrument continuously acquires, computes and presents the data at a low refresh rate. In Block mode the RTSA, after having acquired all the necessary data to build the spectrogram over whole time interval, performs the calculations. By doing so the Block mode assures the maximum time resolution of the spectrogram where subsequent spectra are taken at fixed time intervals. With a 1024 point FFT a new 200 KHz spectrum is obtained every 400µs. Furthermore, in Block mode the acquisitions can be triggered by an external signal

Description of the Block Mode

In Block mode each measurement session is made up of a predefined number of blocks (fig. 3), each block starting with the predefined trigger event. In a similar way, each block is made up of a predefined number of frames, each frame holding one spectrum. The time resolution of the spectrogram is the time distance between each frame.

At the end of each acquisition the RTSA computes the spectrum of each frame and presents the data.

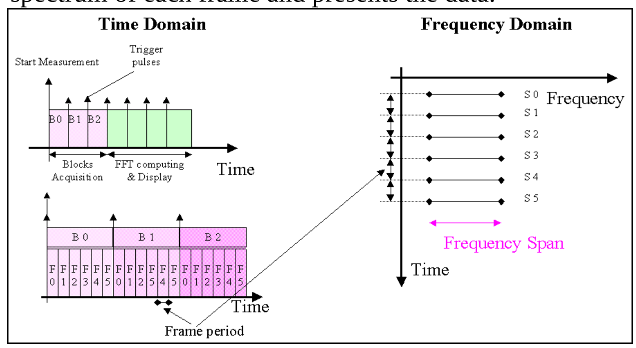

Figure 3: block mode acquisition

According to the FFT algorithm, once the number of points of the spectrum (N) has been fixed, they are obtained from twice as much samples (2N). Therefore, the narrower the spectrum span, the longer the frame duration according to the relation

$$\Delta T = \frac{1}{\Delta f} = \frac{1}{Span/N} = \frac{N}{Span}$$

where N is the number of the spectrum points (fixed by the manufacturer, N=640), ΔT is the frame length and Δf is the spectrum resolution.

Therefore, the higher the frequency resolution is, the longer the frame duration. Successive frames can be either adjacent or separated in time. The time between two successive frames is the frame period.

RTSA SET UP FOR THE BOOSTER

Single or multiple ramp block mode acquisitions have been foreseen for the Booster tune measurement, each block triggered by a “Start Ramp” pulse. With the following frequency spans (200, 100 and 50 KHz) a minimum frame period of 400µs is achievable. With the 20 KHz span this minimum frame period is 4ms: up to 40 spectra per ramp can be acquired for a maximum number of 25 consecutive ramps.

Development set-up

The RTSA is a field test instrument dedicated to cellular phone systems with some features not directly linked to our application that may render it not of immediate use. Furthermore, we decided to thoroughly test the RTSA and its command set before its final use.

Therefore, a Man-Machine Interface (MMI) has been developed as a NI LabVIEW application and some post processing tools have been implemented to check data transfer from the instrument (i.e. Tune frequencies vs. time). This system will be installed on the ELETTRA storage ring for a complete test before its final implementation on the Booster.

MEASUREMENT RESULTS

First a complete characterization has been carried out in the laboratory (fig. 4) to test the different operation modes of the RTSA, its sensitivity both in time and frequency.

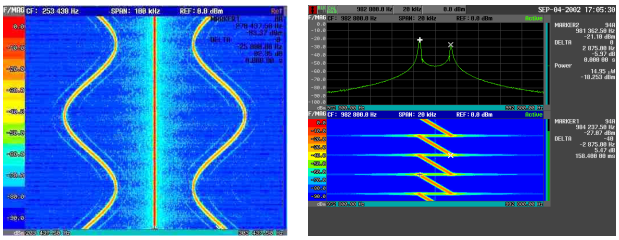

Figure 4 LEFT: spectrogram obtained in the laboratory showing a 250 KHz carrier, amplitude modulated (F_{mod}=25 KHz±10 KHz). RIGHT: laboratory spectrogram of a frequency swept carrier (f_C=982.8 KHz) with a 160ms ramp (Δf=±1.5 KHz).

Then, a series of measurements have been carried out on the Storage Ring to fully characterize the excitation schemes including the Power amplifier. Finally, real beam measurements have been performed to define the RTSA final configuration.

In figure 5, the effect on the vertical tune due to a periodic perturbation of a vertical corrector is shown. In figure 6, a dynamic measurement of the vertical (left) and horizontal (right) tune is shown during an energy ramp of the Storage Ring: a strong deviation of the horizontal tune is visible which led to a partial beam loss.

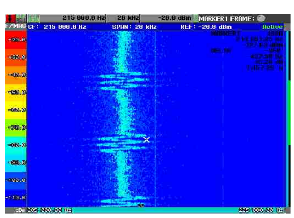

Figure 5 Measurement of the Vertical Tune: a variation was induced in the beam using a vertical corrector; 3 cycles of sine burst were applied at 20Hz. $\Delta f_{pk\text{-}pk}$=2770Hz

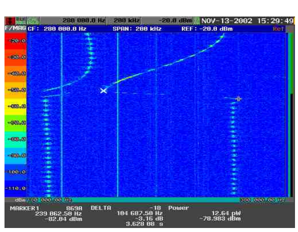

Figure 6: Dynamic measurement of both tunes during an energy ramp, horizontal tune is on the right. The cursor is located after the resonance, which can be easily recognized after amplitude increase (-59dBm). The dotted traces are due to the 1Hz switching of the excitation plane, used on the Storage Ring.

Dynamic Measurement of the Chromaticity

To further analyse the capabilities of the new system, in particular the dynamic ones, a preliminary dynamic measurement of the chromaticity has been performed on the Storage Ring. By applying an external modulating signal (f=3 to 5Hz) to the Master Generator of the Storage Ring Radio frequency system, with a peak to peak RF frequency change of 4kHz. The SR chromaticity was set to +2.2 in both planes. Measurement results are shown in figure 7 for the vertical plane.

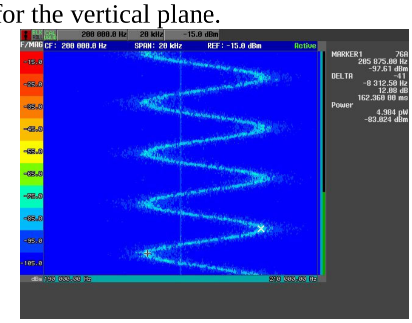

Figure 7: Chromaticity Measurement Vertical plane

The peak-to-peak changes of the tune have been compared to the values measured with standard tune measurement system (static measurement). The dynamic measurement showed a smaller tune variation, by 30%. Further measurements are foreseen to complete our experiment.

CONCLUSIONS

The Real Time Spectrum Analyzer 3026 proves to be adequate for the fast tune measurement of the ELETTRA Booster. Its frequency analysis characteristics and its data presentation in form of spectrograms have allowed rapid development of the prototype system. Integration in the final control system will start as soon as the on-field use phase will be completed.

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