ESRF Synchrotron Injector Tune Measurement System .

E. Plouviez, F. Loyer
European Synchrotron Radiation Facility
BP220, F-38043 Grenoble Cedex France

Abstract

The tune measurement system implemented on the synchrotron injector allows the measurement of this parameter during ~2ms periods inside the 50 ms acceleration cycle of the machine.
Requirements for the system are resolutions of 10^{-2} to 10^{-3} in the tune determination for a 1 MHz revolution frequency and .1 to 5 mA intensity in any part of the cycle.

The measurement methods are presented and the components of the system described: beam shaker, beam position pick up, front end and detection electronics, spectrum analyser.

The response of the beam to the shaker can be measured in three modes :

-a slow frequency sweep mode where the beams response to the shaker is measured during 2 ms at one frequency per acceleration cycle with a 1KHz resolution bandwidth.

-a fast swept frequency mode where the measurement is made in a 1.6 ms/500 kHz frequency sweep with a 17 kHz resolution bandwidth.

-a FFT mode where a 40 kHz span of the response spectrum is analysed in 1 ms scans with a resolution of 1 KHz

Advantages and disadvantages of these methods regarding the measurement speed , beam shaker strength required, precision ... are discussed and results of the measurements performed on the beam during the synchrotron injector commissioning are presented.

1. INTRODUCTION

The booster synchrotron of the ESRF injector brings electrons bunches produced by the 200 MeV linac up to the nominal 6 GeV energy of the storage ring. The acceleration cycle has a duration of 50 ms and is repeated at a frequency of 10 Hz. One important point when setting the parameters of the acceleration cycle (values of the current in the dipoles and quadrupoles, variation law of the RF field amplitude) is to avoid to cross transverses resonnances which would cause beam losses during the cycle . In order to avoid to cross these resonnances it is nescessary to measure the value of the integer and fractionnal parts of the value of the tune as a function of the time during the acceleration cycle; the time resolution needed is ~2ms. Integer part of this number is obtained by a Fourier analysis of the transverse beam position measurement along the closed orbit but the determination of the fractionnal part of this number by that method is not accurate enough; so the fractionnal part of the tune value is measured using a dedicated measurement system. This system measures the amplitude and frequency of the transverse beam position oscillations at two beam position pick-up location: one for the horizontal oscillations and one for the vertical oscillations; the position oscillations are excited by small wide band dipole magnets . These position measurements are sampled measurements done at the revolution frequency of the beam; for this reason they only give the value of the fractionnal value of the tune.
The operating conditions of the system are:

Beam current	.1 to 5mA
Beam energy	.2 to 6 GeV
beam postion oscillation amplitude	<1 mm
Tune measurement duration	< 2ms /cycle
Tune measurement error	$<2\ 10^{-3}$

2. LAYOUT OF THE SYSTEM

The layout of the system is given in the figure 1
The different components of the system are:

- The beam position pick-up electrodes the detection of the vertical and horizontal beam position oscillations

-Two shakers dipoles and a 0 to 500 KHz power amplifier to excite the position oscillations of the beam.

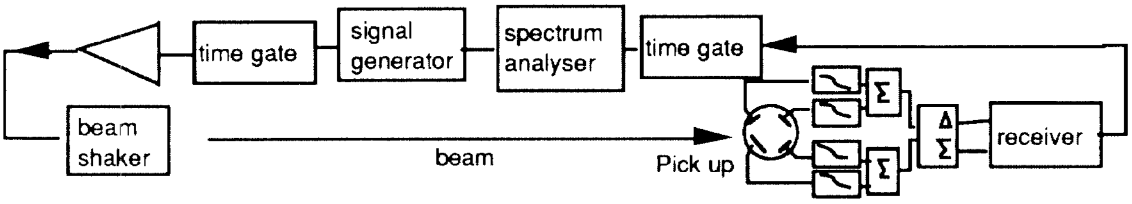


Figure 1: Layout of the tune monitor components

-The electronic circuits for the reception of the signals of the vertical and horizontal beam position oscillations

-The instrument used to analyse the frequency and amplitude of the pick-up signals modulation.

2.1 Beam position pick-ups

The beam position pick-ups are the same capacitive electrodes blocks as those used for the beam position measurement system [1].We use a different set of electrodes (and shakers) for the vertical and horizontal measurement , located in places where the beta function is maximum for both planes (β_x = 10 m and β_z = 12 m). The amplitude of the 352.2 MHz component the ouput signal of one electrode is .5 mV/mA

We combine the output signals S_A, S_B, S_C, S_D of a four electrodes block to produce the signals:

$S_{\Delta z} = (S_A + S_B) - (S_C + S_D)$ (up and down difference)

$S_{\Delta x} = (S_A + S_C) - (S_B + S_D)$ (right and left difference)

The amplitude of these signals for small oscillations Δx or Δz of the vertical or horizontal beam position is:

$S_{\Delta x} = S_{\Delta z} = 50\ \mu V/mA/mm$

2.2 Shakers magnets

The shakers are air magnets enclosed in a ferrite shielding. Their magnetic strength is .17 G.m/A. The magnets are matched to a 50 Ω impedance in the 0 to 500 KHz bandwidth by including them in a low pass LC network. β_x = 10 m and β_z = 11 m at shakers locations. The beam position variation Δx or Δz at the pick-up location for an angular deviation ∂x or ∂z is given by:

$\Delta = \partial .(\beta_{shaker} \cdot \beta_{pick\text{-}up})^{1/2}$

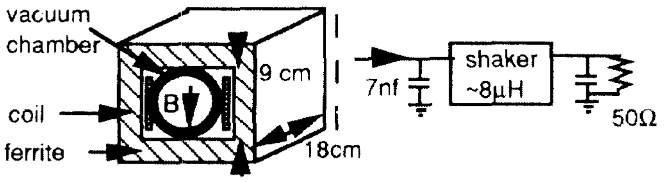


Figure 2: Shaker magnets layout and matching circuit

2.3 Pick-ups signal receiver

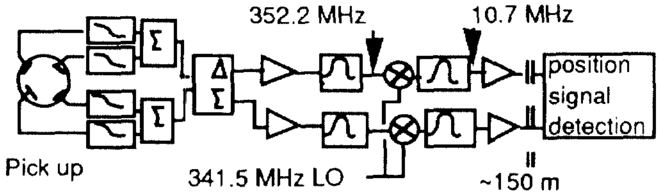


figure 3: pick-up signals receiver layout.

The distance between the signal analyser located in the ESRF control room and pick-ups is large: 150 m. In order to have a good signal to noise ratio at the input of the analyser we have chosen the following layout for the receiving electronics: Large gain, low noise amplifiers are put as close as possible to the electrodes in order to lower the total noise factor of the receiver. Signals are carried between the pick-up proximity and the control room 10.7 MHz. At this intermediate frequency the attenuation in coaxial cables is low and these cables offer a good isolation against the spurious signals present in a pulsed accelerator environment.The amplitude modulation of the 10.7 MHz Δ signal is detected with a synchronous detection circuit close to the signal analyser.

2.4 Signal analyser

To perform the analysis of the beam response to the shaker excitation we have considered the two most widely used instruments for this application:

1- a FFT digital signal analyser

2- a swept frequency spectrum analyser

The first solution is intrinsically faster than the second :

The sampling time t_s needed for a FFT analysis as a function of the frequency resolution f_r of the FFT is given by the equation:

$f_r = 1 / t_s$

The minimum sweeping time t_{sw} as a function of the resolution bandwidth RBW in a swept frequency analysis is given by the equation:

$t_{sw} > A.\ RBW^{-2}$

with .5 < A < 4 depending of the technology of the filter at the imput of the analyser amplitude detector and of the accuracy required for the amplitude measurement. Measurents in a 2ms time window in the accelerating cycle with a 2 10^{-3} resolution is not possible in a single acceleration cycle since the smallest RRW value acceptable would be ~20 KHz In a mode called "gated sweep mode" a measurement with RBW =1KHz will takes ~500 time windows of 2ms ; at 10 Hz of accelerating cycle repetition rate a tune measurement takes 50 s.

The disadvantage of the FFT is that it requires a much higher shaker power than the swept frequency methods since the whole analysed spectrum must be excited simultaneously:

To excite the beam for a 1ms FFT analysis we can use a fast 1 turn excitation of 1µs or a 1ms wide band excitation. To excite the beam oscilation for a swept frequency analysis we use a swept frequency signal; the sweeping of the analyser and of the excitation are synchronised. The power of the signals needed to obtain a 1mm amplitude oscillation of a 6 GeV beam in these different modes are given below. We assumed a .5 ms damping time for the oscillations.

slow sweep:	50 W (50 s gated sweep)
fast sweep:	500 W (1.6 ms sweep)
FFT:	50 KW (noise) or 500KW (1µs pulse)

We decided that a good compromise could be to use a 500 W solid state power amplifier to excite the shaker magnet. It is the highest power available with a standart product. This power is not sufficient to provide excitation for FFT analysis in a 500 KHz span with a 6 GeV beam with a sufficient signal to noise ratio. So we have implemented three different modes of analysis for the beam signal:

-a slow frequency sweep mode where the beams response to the shaker is measured during 2 ms at one frequency per acceleration cycle with a 1KHz resolution bandwidth.

-a fast swept frequency mode where the measurement is made in a 1.6 ms/500 kHz frequency sweep with a 17 kHz resolution bandwidth.

-a FFT mode where a 40 kHz span around a preselected center frequency of the response spectrum is analysed in 1 ms scans with a resolution of 1 KHz; the beam is excited by a signal at the center frequency of the span modulated by a 0 to 20KHz frequency span white noise signal.

The last two modes are used when a fast tune measurement is needed; a rough tune measurement using the fast frequency sweep allow to determine the center frequency for a higher accuracy FFT analysis.

To implement these modes we use a HP 3588 spectrum analyser [2]. This analyser allows both the regular frequency sweep analysis and the FFT zoom mode. A few external circuits have been added:

- gates at the amplifier and analyser inputs for the selection of the time windows for beam excitation and response signals.

-a noise generator and an analog multiplier circuit to generate the 40 KHz span flat spectrum noise signal for the beam excitation in the FFT zoom mode.

- a VCO generating a 0 to 500 KHz frequency swept signal in a 1.6 ms sweep to excite the beam in the fast sweep mode since the internal generator of the HP3588 can not be used at such a high sweeping rate.

TUNE MEASUREMENTS DURING THE COMMISSIONING OF THE BOOSTER

The tune measurement system described in this paper has been used during the commissioning of the ESRF booster synchrotron. Figures 4 to 5 show displays of obtained with the HP3588 at various energies in the different operating modes of the analyser. Under .6 GeV the tune spread due to energy spread at the output of the linac is still very important making accurate tune measurement impossible. At .6 Gev one sees an important modulation of the frequency of the betatron resonnance at the synchrotron frequency due to the acceleration process. At 3 Gev this effect is much reduced. The excitation signal amplitude needed is not very different at 2 Gev and 6 GeV because the stronger effect of the damping at lower energy counteract the better efficiency of the shaker.

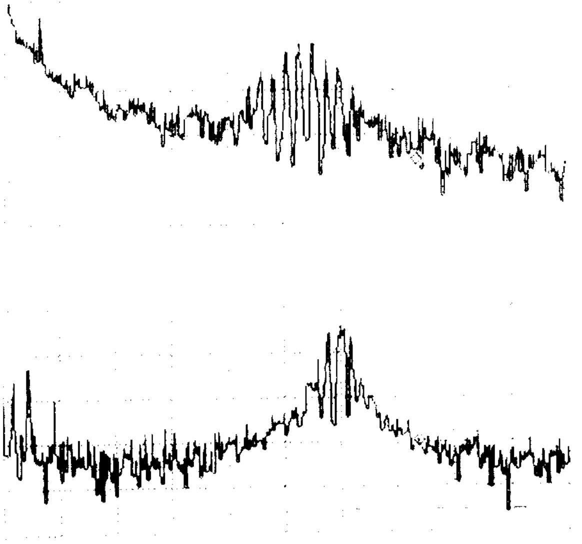
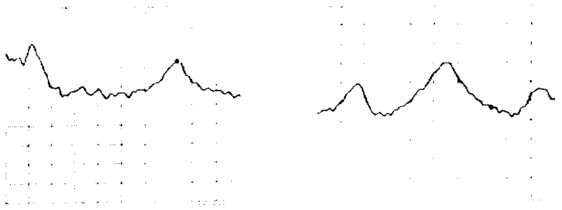


Figure 4: tune measurements in the slow sweep mode at .6 GeV and 3 GeV with a shaker power level of 25W.
10dB/div, 50KHz/ div, gating time 1 ms / cycle



fast sweep FFT zoom

Figure 5: tune measurements in the fast sweep and FFT modes at 5 GeV with a shaker power of 50 W.
50 KHz/div, sweeping time =1.6 ms in fast sweep
4KHz/div, recording time = 1ms in FFT

CONCLUSION

A system allowing a time resolved measurement of the tune during the acceleration cycle of the booster synchrotron has been designed and implemented. With a proper choice of the signal analysis parametyers a fast measurement of the tune is possible using only a low power beam shaker .The system has allowed the tune measurement in most of the operation condition encountered during the ESRF injector commissioning.

REFERENCES

[1] K Scheidt ,"ESRF Synchrotron injector Beeam Position Monitor System: concept & results", this conference

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[3] M.Serio, "Transverse betatron tune measurements",Joint US-CERN school-Capri ,october 1988