Tune Feedback System at ELETTRA

A. Carniel, R. De Monte, L. Tosi
Sincrotrone Trieste
Padriciano 99, I-34012 TRIESTE

Abstract:

A tune feedback system used in ELETTRA is presented. By using the quadrupoles in the achromatic arc, the system is able to simultaneously correct eventual drifts in both horizontal and vertical tunes to an accuracy of 10^{-3}. Such a system helps during the energy ramp of the storage ring, in correcting drifts due to power supply fluctuations and changes caused by the gap changes of insertion devices.

1. INTRODUCTION

ELETTRA is the Italian third generation low emittance synchrotron light source, constructed in Trieste. The commissioning of the Storage Ring started in October '93 and within a very short time all the major parameters of the machine [1] were determined.

The tune measurement setup at ELETTRA has been designed in order to allow a tune feedback during energy ramping. Other useful employments of the feedback are compensations for tune changes during the closure or the opening of insertion devices. In this sense, the tune system can be essentially divided into, a measurement part and a feedback part, the required design specifications are reported in Table 2.

The tune measurement is performed by exciting the beam alternatively in the two planes through a single stripline electrodes and sending a processed signal, picked up by four button electrodes, to the spectrum analyzer. The feedback is accomplished via software. The tune corrections are done by acting on the power supplies of two quadrupole families, placed in the dispersive arcs and symmetrically distributed around the ring. Once the feedback software is launched, automatically at each step, the two betatron frequencies are excited and read by the measurement system and the quadrupoles' power supplies' current increments are computed and applied. The correction algorithm has been implemented to perform forward-correction for reasons which will be pointed out in section 3. In this paper, after illustrating the general layout with descriptions of the hardware and software involved, the actual performance of the system with beam will be discussed.

2. TUNE MEASUREMENT

A schematic layout of the tune measurement setup is shown in Figure 1 and the main components are: the spectrum analyzer with associated low frequency amplifier and relays, the shaker, the pickup and the detector.

2.1 Spectrum Analyzer and Amplifier

Table 2
Required Tune System Specifications

Resolution	< 0.001 in tune
Dynamic Range	1 - 400 mA
Acceptable Excitation[1]	24 μm Horizontal 4 μm Vertical
Feedback Tracking Range	± 0.250 in tunes
Correction Rate	≤ 1 /second
Expected Tune Change	0.005 /second

[1] Correspond to 10% of the beam sizes estimated at the center of the insertion devices at 2 GeV.

The low frequency HP 3589A spectrum analyzer, which may work in the 10 Hz - 150 MHz range, was chosen both for speed, accuracy and economic reasons and for the large variety of measurements and performances it offers. The instrument may work in linear swept frequency mode or perform FFTs. Furthermore, it has the possibility of working in gated mode, triggered by an external event. The latter turned out to be useful in the first days of commissioning, before having accumulated beam, where by triggering the instrument with the pulse of the injection elements, the betatron tunes of the injected beam were measured.

Another characteristic which determined the choice is the programmability of the instrument. The measurements were made user friendly, once the instrument parameters were optimized, any operator, even with little experience, could find the betatron frequencies just by running a program. It also speeded up the integration of the instrument in the ELETTRA Control System.

For everyday measurements, the instrument, commanded by the operator from a workstation, works in linear swept frequency mode, scanning the range between 50 and 550 kHz twice (one for each plane). Faster measurements may be performed by the software which reduces the span and centers it on one and then sequentially on the other betatron frequency. The output signal from the spectrum analyzer is amplified by a 10 MHz commercial low frequency linear amplifier (mod. CALMUS), such that the total output power is 20 W in normal operating conditions. The output power is split into four and sent to each stripline electrode through a series of mechanical relays, which permit a 0 or 180 degrees phase inversion. In this way the beam may be excited in either plane.

2.2 Shaker

The shaker is a stripline with four 150 mm long electrodes each terminated by a 50 Ω. The horizontal and vertical gaps are 30 and 43 mm respectively and the beta functions are both

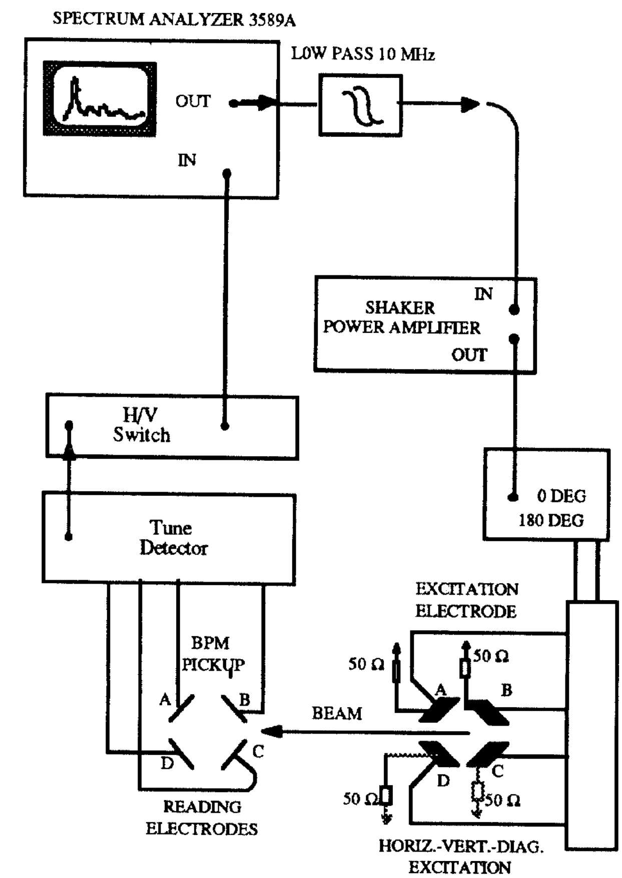

Figure 1: Block diagram of tune measurement.

equal to 6 m. The stripline transmits a travelling wave giving a beam angle deviation per turn $\partial\Phi = 2eVl/(E\ g)$, where e is the electron charge, V the voltage in the gap, g the gap dimension, l the gap length and E the electron energy. Even though for our case the horizontal gap is smaller than the vertical one, due to the particular geometry of the stripline whose all four electrodes are embedded in the upper and lower halves of the vacuum chamber, excitations were found to be more effective vertically than horizontally.

2.3 Beam Position Pick-Up and Detector

The beam position pick-up is made of four capacitive buttons similar to those used for the beam position monitoring system [2] and is located one achromat beyond the shaker.The four RF voltages from the electrodes are brought to a detector, shown in Figure 2, and transformed in the RF Processing Circuit into the horizontal, the vertical and the sum signals according to :

$$x = -((V_A + V_D) - (V_B + V_C))/2$$
$$y = -((V_A + V_B) - (V_C + V_D))/2 \qquad (1)$$
$$\Sigma = -(V_A + V_B + V_C + V_D)/2$$

These signals are filtered by Chebyshev filters with two poles having a center frequency at 499.654 MHz and a 3dB

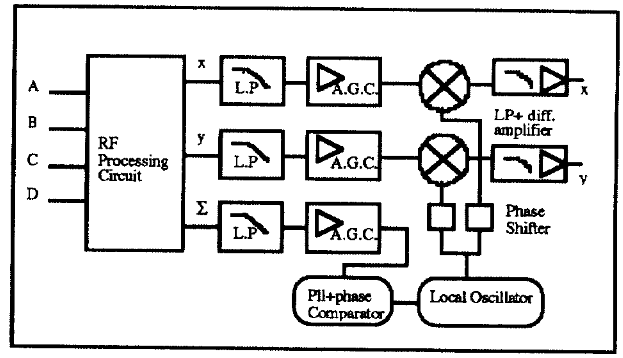

Figure 2: Block diagram of the tune detector electronics.

bandwidth of 20 MHz. The stopband of the filters extend up to 4 GHz in order to avoid saturation of the first amplifier when operating in Single Bunch. The filtered signals are individually applied to a two stage Automatic Gain Control amplifier with equal gains, whose control is arranged in such a way that the sum signal is constant over the system's full dynamic range.

The coherent demodulation of the x and y signals to base band is achieved with a local oscillator synchronized with the sum signal. The appropriate phase for each demodulation is determined in the laboratory and may be adjusted by the phase shifters. The demodulated signals, filtered by a 1 MHz low pass filter, pass through a differential amplifier. The output impedance is 120 Ω. An analog multiplexer selects the horizontal and vertical detector signals and also performs the impedance adaptation for the 50 Ω input impedance of the spectrum analyzer. The amplitude of the demodulated signals are approximately equal to $-15 + 20\,\mathrm{Log}(m) + 20\,\mathrm{Log}(u / \Sigma)$ dBm where u stands for x or y and m is the modulation level.

3. TUNE FEEDBACK

The tune system in ELETTRA has been designed keeping in mind the necessity of having to perform rapid corrections to the betatron tune values during energy ramping. The feedback must be capable of acquiring the betatron frequencies, compute the currents to set on two quadrupole families and to apply the increments found to the relative power supplies, all in a very short period of time. The quadrupoles chosen for this purpose are those in the dispersive arcs both for their decoupled tune sensitivities and for their supersymmetric arrangement in the ring. The latter avoids the creation of new resonance stopbands due to the breaking of the optical supersymmetries. The tune feedback is done via software and makes full use of the programmability of the spectrum analyzer and of the tune measurement system. The schematic layout of the system is presented in Figure 3 and may be divided into: a user interface, a set of low-level processes and the board to drive the quadrupoles' power supplies.

The graphical user interface, created with CPE [3], runs on a UNIX workstation and communicates with the VME via the standard TCP-IP communication protocol. The user may

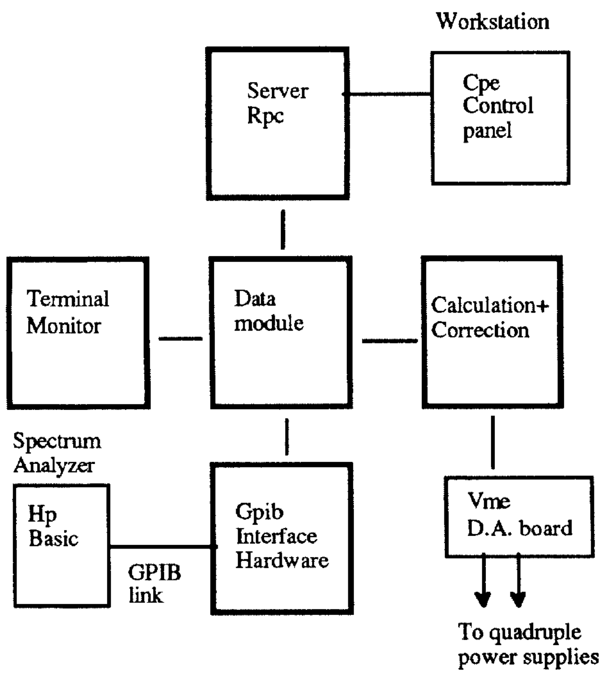

Figure 3: Schematic layout of the software configuration.

enable/disable the measurement or the feedback and change the configuration parameters.

All the low level processes run simultaneously and have access to a common data module containing all the necessary variables. The latter may be divided into: the variables containing the results and the necessary informations (betatron frequencies, tunes, the corrections applied, parameters for the spectrum analyzer) and the status variables which define the action to be taken.

The software driving the spectrum analyzer communicates with the instrument via a GBIP link and, according to a status variable, will provide initialization of the instrument, setting of parameters and to receive the peaks found or to perform a loop of automatic acquisitions. The same program provides to the switching of the excitation planes and allows the synchronism with the acquisitions.

According to a status variable, a second low level process computes the values to be applied for the feedback to the quadrupoles' power supplies using the last acquired betatron frequencies. The original algorithm simply solved the bidimensional system $\Delta Q = (\partial Q/\partial I)\ \Delta I$,where $(\partial Q/\partial I)$ is the tune sensitivity matrix in Amp^{-1} and ΔQ, ΔI are two vectors containing the difference in tunes with respect to the reference ones and the quadrupoles' current increments. This algorithm proved to be efficient in the energy ramping only up to 1.7 GeV, where the vertical tune suddenly began to vary at a high rate with energy [4]. On top of this, the tune sensitivity matrix in terms of the current depends on energy, giving thus a linear decrement of the system's gain. To obviate both problems a forward-correction scheme has been implemented, for which the correction to apply depends on all the past acquisitions and the system predicts and corrects for what the tunes should be at the next acquisition. Such algorithm has proven to work extremely well on all the energy ramping range and is much more efficient in terms of noise and of uncertainties.

In order to finally close the feedback loop, the computed currents converted to voltages are applied to the quadrupole families by two 16 bits D/A converters. The maximum applicable value is ± 10 V at the ouput of the boards, which correspond to ± 10.5 A. In order to eliminate ground loop problems, the connection between the D/A boards and the power supplies is isolated using an optical interface.

The feedback can start only under approval of the operator after having checked the consistency of the tunes found and it automatically stops if the beam is lost or if the frequencies found are outside a user-defined window.

4. PERFORMANCES

The tune measurement has been found to perform well in the full dynamic range. However, attenuators had to be added to the four inputs of the detector, whose first amplifiers showed a tendency of saturating as the beam current increased Measurements have proven that the system is accurate within 100 Hz with the parameters set automatically and within a couple of hertz if commanded manually. New low level routines will be installed in the near future, which will give the full possibility to the operator to set any desired measurement parameter by the workstation.

For the feedback, the time between one correction and the next could not be made less than 1.4 s. This, however, does not constitute a problem for the energy ramping. With the actual forward-correction scheme, the system always keeps the betatron frequencies within 1 kHz from the reference values in the full energy ramping range. Some large deviations, multiples of the synchrotron frequency, occured on some occasions when the machine was ramped with a beam suffering from longitudinal instabilities or when the two tunes were near the coupling difference resonance. In both cases, the operator had just to decrease the spans over which the acquisitions were made.

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