A FAST LOCAL FEEDBACK SYSTEM TO CORRECT THE BEAM POSITION DEVIATION IN THE ESRF STORAGE RING

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ABSTRACT

A system performing a fast local correction of the beam closed orbit has been implemented in one of the straight sections of the ESRF storage ring. Two low noise BPMs are used to measure the transient variations of the position of the beam at both ends of the 5m straight section. A resolution of 1µm of the position measurement is achieved in a 1 KHz bandwidth. The BPM signals are processed digitally and the correction is applied by a set of four fast steerers; the feedback is applied between 3.10^{-3}Hz and 100Hz. This paper gives a description of the low noise BPM system, of the DSP electronics; the optimisation of the system parameters (noise, bandwidth, feedback algorithm) is discussed; the results achieved in the stabilisation of the beam are presented.

1 INTRODUCTION

The ESRF storage ring beam has now a horizontal emittance $\varepsilon_x = 4.10^{-9}$ m and with a 1% coupling a vertical emittance $\varepsilon_z = 4.10^{-11}$ m. Synchrotron radiation is produced by insertion devices installed in straight sections with ßx= 23 m and ßz= 3 m. The length of the straight section is l=5m so this emittance value will result for the electrons of the beam in incoherent vertical and horizontal orbit deviations at the ends of the straight sections of:

11µm from $\Delta z=\sqrt{(\varepsilon.ßz)}$ 9 µm from $\Delta z'=\sqrt{(\varepsilon.ßz)}.l/2$
264µm from $\Delta x=\sqrt{(\varepsilon.ßx)}$ 110µm from $\Delta x'=\sqrt{(\varepsilon/ßx)}.l/2$

The parasitic motion of the beam due to slow drifts or high frequency vibrations of the quadrupoles support girders must be kept at low enough values to avoid to spoil this emittance figure. We observe two kinds of motions: very slow drifts and vibrations at 7Hz, 30 Hz and 60 Hz as shown in figure 5 a and b. The slow drifts are corrected every 5 minutes by a global correction method using the measurements made over the whole machine by the 224 BPMs of the closed orbit measurement system[1]; The higher frequencies vibrations (3.10^{-3} to 60Hz) cannot be damped by this global method due to the number of position measurement needed over the whole machine at a high acquisition rate.Therefore we use a local correction scheme for their suppression. A set of special e^- BPMs located at each end of the straight section is used to measure the position and angle of the beam orbit in the center of the straight section at a high acquisition rate (2.2 KHz) and with a high resolution (.25 µm). Four fast steerers for each plane are used to produce the closed bumps canceling this deviation. By a correct choice of the low cut off frequency of the loop, the global and local corrections are totally de coupled.

The layout of the system is shown in figure 1.

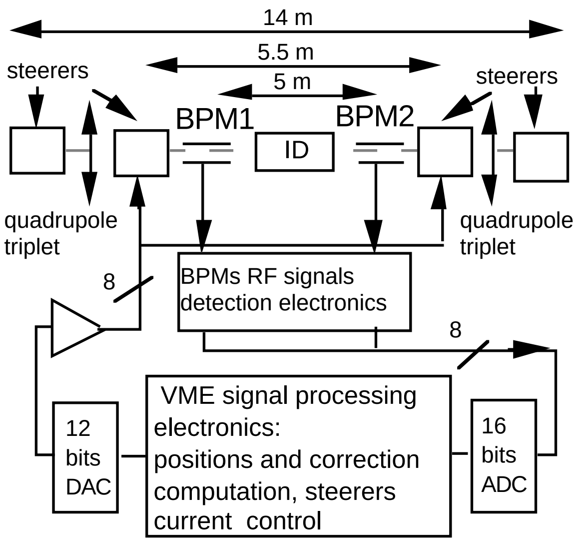


Figure 1: layout of the local feedback system

2 BEAM POSITION MEASUREMENT

The beam position is measured using capacitive electrodes located at both ends of the straight section, as shown on figure 2; the vertical gap inside the chamber is 16 mm. The horizontal distance between the electrodes center and the vertical mid plane is 5 mm.

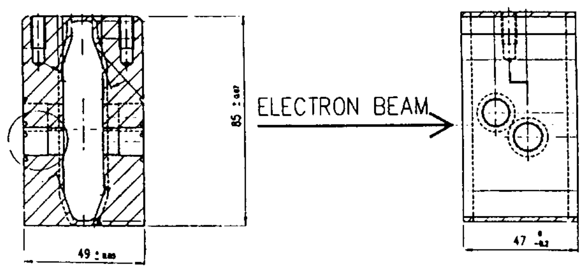


Figure 2: geometry of the BPM electrodes set up

The values of the position offsets Δx and Δz are:
$\Delta z=K_z$ (VA+VB)-(VC+VD)/VA+VB)+(VC+VD)

$\Delta x = K_x (V_A+V_C)-(V_B+V_D)/V_A+V_C)+(V_B+V_D)$, with:
$V_{A,B,C,D}$ = electrodes signals amplitudes
$K_x \sim K_z \sim 8$ mm with our electrodes spacing

At the RF frequency of 352.2 MHz used for the beam signal detection, $V_{A,B,C,D}$= 3mV/mA, if the electrode is connected to a 50Ω load.

Such a matching is very inefficient which has led us to design a selective RF transformer as shown in figure 3 to improve the matching of the electrodes and get 20mV/mA in a 5 MHz bandwidth around 352 MHz.

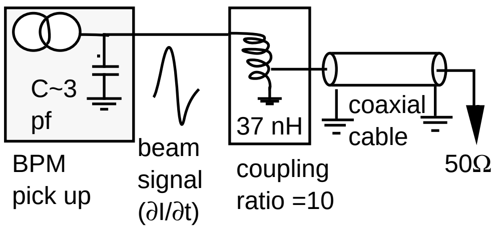


Figure 3: principle of the electrodes RF transformer

The added advantage of the selectivity of this transformer is to reduce the relative level of the peak signal produced by the beam when the storage ring is filled with a limited number of high intensity bunches.

The electrode signals are detected with the now classical RF multiplexing system shown in Figure 4.

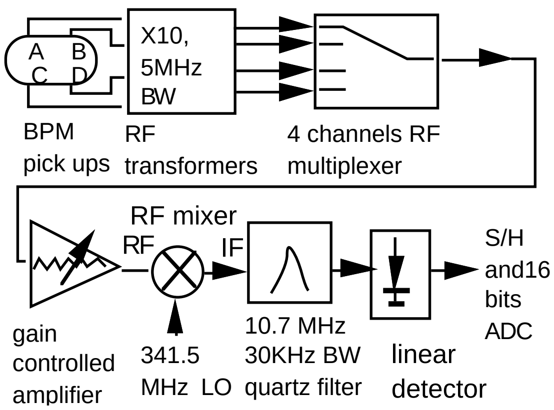


Figure 4: layout of the BPM RF signals detection

The beam positions in both planes are computed by the feedback digital signal processor after acquisition of the sampled electrode voltages.

Special features of our design are:

- use of a high level RF mixer (17dBm LO level) to improve the noise figure by reducing the gain needed at 10.7 MHz.
- multiplexing frequency f_{mux} at a sub harmonic of the beam revolution frequency f_{rev} in order to avoid the production of spurious signals in the feedback bandwidth by harmonic mixing of f_{mux} and f_{rev}.

This scheme is not the most efficient as far as the noise figure is concerned (compared for instance to a scheme using RF combiners to produce the Δ and Σ signals). However, it requires less electronics modules and is much simpler to calibrate and maintain and, with this scheme, we still achieve a noise floor in the position detection of 15 nm/√Hz for currents above 30mA and 30nm/√Hz between 5mA and 30mA. This is fully adequate for our application: the noise added by the BPM for the 100Hz cutoff frequency that we use in our feedback is 140nm at high current and 500nm at low current.

3 FEEDBACK

3.1 Orbit corrections

The correction bumps are produced by four air cored coil steerer dipoles located symmetrically at both ends of the straight sections according to Figure 1. The steerers are powered by wide band voltage controlled power supplies and are able to produce up to 100 μm bumps in a 1 KHz bandwidth. These bumps must be perfectly closed. Since the bumps include quadrupole magnets the relative values of the power supply control voltages required to produce closed bumps are affected by the machine optics settings. They are computed using closed bumps coefficient determined by measuring, for these different optics settings, the machine response to kicks coming from each steerer. These calibrations and the need to easily modify the dynamic parameters of the loop has led us to implement a digital signal processing of the feedback signals.

3.2 Digital signal processing

The algorithm that we use to compute the correction bumps is a proportional integral algorithm, with the proportional coefficient cancelling, at low frequency, the loop delay due to the signal multiplexing and processing. The computing rate needed for the execution feedback algorithm is determined by the necessity to have a stable loop and a sufficient damping of the beam motion. In order to damp the beam motion up to 30 Hz we need a cut off frequency of about 100Hz. The delay between the position acquisition and the correction are due to the multiplexing of the BPM electrodes signals, and the digital signal processing. The delay due to the finite bandwidth of the analog components of the system (RF receiver, steerers amplifiers, eddy currents), is negligible. The digital signal processing takes one multiplexing period; the delay due to the multiplexing/demultiplexing process is equal to half a period. The effect of the delays due to the signal multiplexing and processing is to add a phase shift to the response. To have a stable and noiseless loop, the additional phase shift at the cut off frequency of the loop must be negligible (20° is the maximum according to our simulations and experiments), which means that the signal multiplexing and processing rate must be at least 2 KHz for a 100 Hz cut off frequency; we use 2.2 KHz which is an easily produced sub harmonic of the 355 KHz revolution frequency of the storage ring. In addition, in the lower part of the spectrum, the DC correction is cancelled by measuring the average of the steerers currents: we calculate the angle and position offset equivalent to these currents and remove them from the loop settings with a 1 minute time constant in order to keep the average action of the steerers null.The feedback algorithm is executed for both planes by a 68040 CPU board with code written in C.

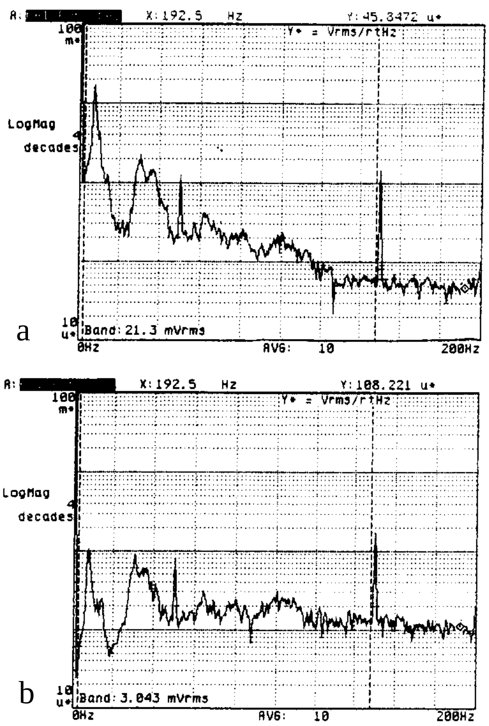
3.2 ADC and DAC resolution

Since the range of the bumps amplitude is +/- 100 µm a 12 bit (2.5 10^{-4}) resolution is sufficient for the steerer power supply current control.

For the BPM signals we use 16 bit ADCs for the acquisition of the individual signals of each electrode. For our multiplexed RF scheme system, the Δ/Σ value is computed by the processor. The resolution for a 10 Volts ADC range, and a 4 Volts nominal electrode signal level, is 250nm, with K= 8mm.

4 RESULTS

Spectrums of the beam motion in both planes with and without feedback applied are shown below in the Figures 5 a,b,c,d.



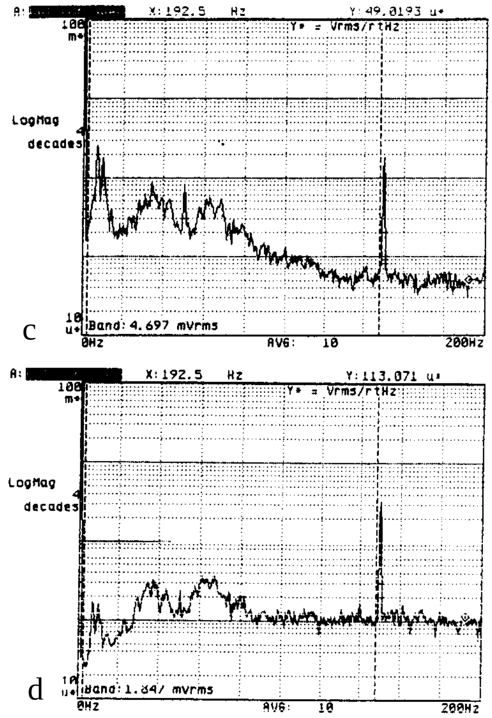


Figure 5: spectrums of the BPM signals in the horizontal and vertical plane with feedback off (a,c) and on (b,d); (.5mm/V, 1 decade/div., 0 to 200 Hz)

The beam motion in the ESRF operation beam intensity range of 50 mA to 200 mA, is damped from 9 µm rms to 3 µm rms in the horizontal plane and from 3 µm rms to 1.5 µm rms in the vertical plane.

5 CONCLUSION

A local feedback system operating from 3.10^{-3}Hz to 100Hz has been tested on a straight section of the ESRF storage ring to cancel beam motion due to mechanical vibrations. If carefully designed the electron BPM can have a resolution which is adequate for this application. The digital signal processing of the signals is mandatory in order to produce correctly closed correction bumps.

ACKNOWLEDGMENTS

I would like to acknowledge the contribution of the colleagues of the diagnostics group who participated in the design of this system. Special mention to P. Arnoux for his contribution to the tedious optimisation of the RF circuits and to C. Basso for the design of the steerers power supplies.

REFERENCES

[1] L. Farvacque, Beam stability, CERN accelerator school on synchrotron radiation sources and free electron lasers (1996)