# ORBIT CORRECTION IN THE LNLS UVX ELECTRON STORAGE RING

J.G.S. Franco, L. Jahnel, Liu Lin, C. Scorzato and P.F. Tavares*, LNLS, Campinas, Brazil

*Abstract*

The orbit measurement and correction system of the LNLS synchrotron light source is presented. Recent changes to the system including the addition of 12 vertical correctors and the use of 16 bit DACs to control the corrector magnet power supplies have improved the vertical orbit repeatability from fill to fill from ±70 µm to ±3 µm. The improved resolution also allowed the implementation of automatic orbit corrections at 24 second intervals, thus reducing orbit variations along a user's shift from ±70 µm to ±5 µm.

## 1 INTRODUCTION

The LNLS synchrotron light source, based on a 1.37 GeV electron storage ring, has been delivering beam for routine user operation since July 1997. It became clear from the early stages of beamline commissioning that orbit reproducibility from fill to fill as well as orbit stability over long periods (several hours) are critical performance figures of the light source from the user's point of view. Those user demands were the driving force behind a long term program aimed at identifying and correcting orbit variations, which included reviewing the vast number of topics related to the subject, applied to our specific case, such as: orbit stability requirements, techniques to identify undesirable sources of beam motion, capabilities of orbit monitoring equipment at LNLS (e.g. position measurement dependence on beam current), parameters for automatic orbit correction, relation between beam stability at the monitors and at the beamline source points, correlation of orbit drifts and oscillations with temperature variations etc. This program started even before the machine was officially delivered to users [1], with the identification of orbit drifts correlated to magnet temperature variations and the implementation of an orbit feedback system, which was able to keep orbit variations below ±70 µm along a user's shift (orbit stability) as well as from shift to shift (orbit reproducibility) with orbit corrections being performed once every hour.

All along 1997, further improvements were implemented in this system, including better knowledge of the ring optics and additional flexibility in the control software. Even though those improvements made the system more reliable and robust, they did not address its basic limitations, namely the correction and monitoring hardware. The beam position measuring system used RF switches to multiplex the monitor signals onto the BPM electronics. This choice (dictated by cost considerations) along with the fairly low resolution (±8 µm) of the 12 bit AD converters that read the BPM electronics output signal, made it necessary for the system to perform time consuming averages in order to obtain good resolution, which reduced its bandwidth. Also the RF switches were a constant source of connection problems and compromised reliability. Finally, the number of vertical correctors as well as the corrector strength adjustment resolution were found to be insufficient to guarantee orbit repeatability from fill to fill within the required tolerances.

In 1998, after theoretical work [2] demonstrated the need for additional vertical correctors, a hardware upgrade program was started that included the addition of 12 new vertical corrector magnets (actually, already existing coils in the quadrupole magnets were used), implementation of higher resolution in the steering magnets power supply controls, the implementation of a temperature stabilization system for the storage ring magnets (that is kept running even when the magnets themselves are turned off) and improvements to the orbit measuring system through the addition of new BPM electronics eliminating the need for RF multiplexing. In the following sections, we describe the present orbit measurement and correction system as well as the results obtained so far, concentrating on the improvements due to the upgrade started in June 1998.

## 2 NEW BPM ELECTRONICS AND CALIBRATION PROCEDURE

The storage ring has 23 beam position monitors (striplines) distributed along its six superperiods. Up until December 1998, the stripline signals were processed by 6 commercial electronic readout modules (manufactured by BERGOZ, France). Since there was only one read-out module per superperiod, each module must read four different BPMs. This was accomplished by multiplexing those signals via a computer controlled RF switchboard, which allowed the four monitors to be read in any order set by the high level control system. The total time for a complete scan of all four BPMS in a superperiod was dominated by the time needed by the RF switches to stabilize their output signal and it was 400 ms. Recently new BPM modules were installed providing one module per BPM and eliminating all RF switches. At the same time, sets of variable attenuators were added to the input of the BPM electronics so as to allow better equalization of beam signals (to compensate for different cable lengths

*E-mail: pedro@lnls.br

and connector attenuations) and to bring the signal intensity down to the range where the electronics is mostly insensitive to beam current variations.

The geometrical BPM offset and gains were determined in a characterization bench where the beam was simulated with a stretched wire. An off-set and gain were also determined for the BPM electronics (in fact, this offset and gain include the effects not only of the electronics, but also of the cables and connectors). In the original installation (1996), the offset was determined with an equalized (better than 0.01 dB) four-way splitter fed by a 476 MHz signal and connected to the same cables, RF switches and connectors that take signals from the BPMs to their electronics (this measurement takes place in the machine hall). The measured dc voltages (horizontal and vertical) at the output of the BPM electronics gave directly the off-set. The gain was determined by adding attenuators to two of the output ports of the four-way splitter and again measuring the voltages delivered by the BPM electronics. When installing the new BPM electronics, a new calibration procedure was used that proved to be more precise and substantially reduced the spread in measured gains of the various electronic modules. In the new procedure, the offsets and gains are determined from a set of five measurements: first we measure the BPM output signal when the inputs to the BPM electronics come from the equalized splitter; next we add a single attenuator to each of 4 input channels of the BPM and again measure the BPM output signal. We model the experiment with the equations

$$X_0 = K_x \frac{\alpha_1+\alpha_2-\alpha_3-\alpha_4}{\alpha_1+\alpha_2+\alpha_3+\alpha_4}$$

$$X_1 = K_x \frac{\gamma\alpha_1+\alpha_2-\alpha_3-\alpha_4}{\gamma\alpha_1+\alpha_2+\alpha_3+\alpha_4} \qquad X_2 = K_x \frac{\alpha_1+\gamma\alpha_2-\alpha_3-\alpha_4}{\alpha_1+\gamma\alpha_2+\alpha_3+\alpha_4}$$

$$X_3 = K_x \frac{\alpha_1+\alpha_2-\gamma\alpha_3-\alpha_4}{\alpha_1+\alpha_2+\gamma\alpha_3+\alpha_4} \qquad X_4 = K_x \frac{\alpha_1+\alpha_2-\alpha_3-\gamma\alpha_4}{\alpha_1+\alpha_2+\alpha_3+\gamma\alpha_4}$$

where $X_0$ is the voltage measured when no attenuator is added to the splitter, $X_i$ is the voltage measured when we add an attenuation $\gamma$ to the ith BPM input channel and $K_x$ is the gain constant. The attenuation factors $\alpha_i$, represent the effects of differences in cable lengths and connectors and the BPM offset can be calculated as a function of these factors. The same equations apply for the vertical voltage, with a different gain factor $K_y$ but equal attenuation factors $\alpha$. In this model, the horizontal and vertical offsets are not independent and by measuring X and Y voltages we actually get a cross-check of our results. Given this set of five measurements, the attenuation factors and gain constants can be determined by solving the set of five coupled equations, which can be reduced to solving a fourth-order polynomial root. Once the attenuation and gain constants of the setup are determined, the offset and gain of the BPM electronics can be calculated by considering the expressions for the voltages induced in each stripline by a (slightly) off-centered beam.

If we take the horizontal plane, the voltage on the ith strip is (given that the BPM's are in a cylindrical chamber of radius b and are aligned at 45 degrees with respect to the plane of the orbit)

$$V_i = V_0\left(1+\frac{\sqrt{2}\Delta}{b\psi}\sin\psi\right),$$

where $V_0$ is proportional to beam intensity, $\Delta$ is the beam offset and $b\psi$ is the stripline width. Using those voltages we get for the BPM (horizontal) output voltage

$$X = K_x H + \left(1-H^2\right)K_x\left(\frac{\sqrt{2}\sin\psi}{\psi}\right)\Delta,$$

where $H = \dfrac{\alpha_1+\alpha_2-\alpha_3-\alpha_4}{\alpha_1+\alpha_2+\alpha_3+\alpha_4}$

and if we define the BPM gain (i.e., the gain determined solely by the BPM geometry) as

$$G_{GEO} = \frac{\sqrt{2}\sin\psi}{\psi}\frac{1}{b}$$

we get the BPM electronics gain and offset

$$G_E = (1-H^2)K \qquad O_{XE} = K_x H$$

Note the correction factor $(1-H^2)$ to the gain for a non-zero offset. As a result of this new calibration procedure, the spread of gains between different electronics was considerably reduced and measurements of the dispersion function, which previously presented unexpected asymmetries now fit better the theoretical expectations (Figure 1).

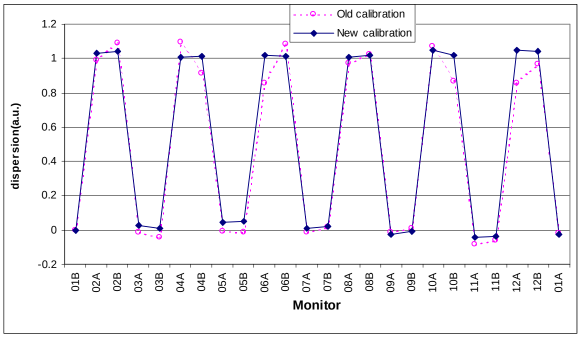


Fig. 1: Dispersion function measurement with the old (circles) and new (dots) BPM electronics calibration.

The BPM absolute accuracy is determined by the alignment procedure and is better than ±0.1 mm. The BPM resolution is determined by the electronic noise and by the resolution of the AD converters used to read the BPM output voltages. At the moment the 12 bit converter resolution determines the resolution of ±8 µm. The overall resolution can be improved to ±2 µm by averaging over 5 seconds.

## 3 NEW VERTICAL ORBIT CORRECTORS AND CONTROLS

The orbit correctors are 10 cm long C-type (vertical) and H-type (horizontal) magnets. Originally there were 11 vertical and 18 horizontal correctors, capable of producing up to 70 gauss.m of integrated field, corresponding to 1.5 mrad deflection at 1.37 GeV. The corrector strengths could be adjusted in steps of 0.7 µrad. In June 1998, 12 new vertical correctors were added (by powering correcting coils inside quadrupoles) and in December 1998 new higher resolution A/D converter boards were installed to control the steering magnets power supplies reducing the smaller correction step to less than 0.05 µrad. Also the orbit correction software was changed to implement each correction as a sequence of small steps so as to minimize transient orbit perturbations. This improved the orbit repeatability from fill to fill from ±70 µm to ±3 µm and allowed us to implement a faster orbit feedback loop, with one correction every 24 seconds. Figure 2 shows the orbit stability along one user's shift before and after the upgrade of the orbit correction system. We see that the orbit stability has improved from ±70 µm to ±5 µm.

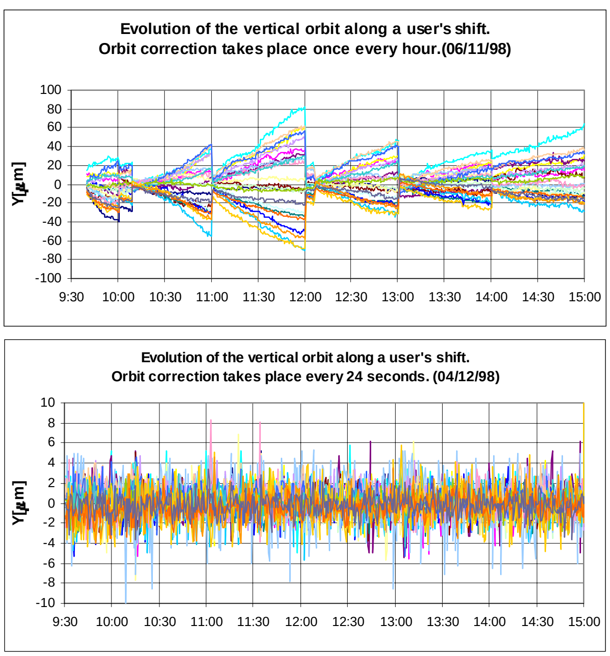


Fig. 2: Evolution of the vertical orbit along a user's shift before (a) and after (b) the orbit correction upgrade. All 23 monitors are plotted.

In figure 3 we show the results of an experiment performed to determine the vertical angular stability of the orbit with the new correction system. In this experiment, the X-ray beam intensity was measured behind a thin slit with a scintillator (hard X-rays were select by means of 1.2 cm thick aluminum plates). The beam was then let to drift freely for about 20 minutes and the corresponding drift in X-ray intensity (normalized to beam current) was registered. At that point the correction system was turned on. The action of the correction system in correcting the slow orbit drift is clear.

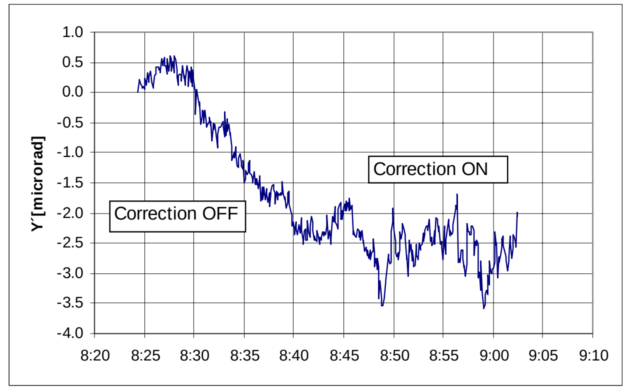


Fig. 3: Vertical angular stability with and without orbit correction. The angular variations are calculated from measured hard X ray intensity variations in a 10 meter long beam line with a thin slit.

## CONCLUSIONS

The orbit measurement and correction system of the LNLS synchrotron light source has been upgraded with the addition of 12 new vertical correctors, new BPM electronics modules and changes to the orbit control software. All those changes have allowed the implementation of an automatic correction procedure that improved orbit repatability (±3 µm) as well as orbit stability along a user's shift (±5 µm). Future work will concentrate on improving BPM measurements (better ADC resolution) and studies of the origins of slow orbit drifts. In particular, changes to the air conditioning control system are foreseen that should bring the daily experimental hall temperature variation from ±2 °C down to less than ±1 °C.

## REFERENCES

[1] R.H.A. Farias, L.C. Jahnel, Liu Lin, D. Macedo, F.S. Rafael, A.R.D. Rodrigues and P.F. Tavares, *Orbit Measurement and Correction in the LNLS UVX Storage Ring* , PAC 1997, Vancouver Canada.

[2] Liu Lin, *Análise de um Novo Sistema de Correção de Órbita Vertical para o UVX*, LNLS CT-08/98.