DYNAMIC ORBIT DISTORTION COMPENSATION FOR THE ELECTROMAGNETIC ELLIPTICAL WIGGLER AT ELETTRA

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Abstract

An Electromagnetic Elliptical Wiggler (EEW) has been in operation at ELETTRA since 1997 providing a source of circularly polarized radiation in the VUV/Soft X-ray region [1]. The helicity can be varied by modulating the horizontal magnetic field at frequencies up to 100 Hz. A feedforward compensation system using correction coils dynamically corrects for field integral errors. In this article we present the latest operational results of a newly developed scheme for the minimization of the orbit distortion, based on the high precision measurements provided by two wideband digital beam position monitors.

1 INTRODUCTION

The EEW combines in one magnetic structure periodic horizontal and vertical fields. The electromagnets are powered by two Pulse Width Modulation (PWM) power supplies featuring low ripple and good stability. The vertical field current is mono-polar (max 200 A) and generated in DC mode, while the horizontal one is bipolar (max ±300 A) and can be generated both in DC and AC mode.

In designing the magnetic structure of the EEW special care was taken to minimize deleterious effects on accelerator performance arising from magnetic field errors. The residual first and second field integrals result in closed-orbit distortion, which is measured and compensated using external correction coils [2]. Four fast power supplies (max ±5 A) featuring 1 kHz bandwidth drive two pairs of horizontal/vertical air-cored coils installed at each wiggler end.

2 EEW CONTROL SYSTEM

The EEW controls are based on the two-level architecture adopted for the new installations at ELETTRA [3]. The low-level control system layout is shown in figure 1. The Equipment Controller is a VME-bus system with a MC68040 host CPU board running the OS-9 operating system, which is in charge of the basic controls and is connected to the ELETTRA control system network by means of a 100 Mbit/s Ethernet link. ADC, DAC and digital I/O VME boards manage the I/O signals to control the two horizontal/vertical field power supplies and the four correction coil power supplies. The ADC and DAC boards provide 16-bit resolution and high stability (±10 ppm-full-scale/°C). A second CPU board equipped with one TMS320C40 Digital Signal Processor (DSP) is dedicated to the generation of the AC waveforms.

Two different operational modes are foreseen: DC and AC. In DC mode the settings of the EEW currents are carried out through slow ramps. A feedforward loop runs during the ramps to compensate for the orbit distortion. The correction values are calculated using a lookup table and continuously applied to the power supplies at 10 Hz data rate. The four values for each pair of horizontal/vertical wiggler settings contained in the lookup table are empirically determined by performing an off-line calibration based on the minimization of the closed-orbit distortion [4]. The tasks in charge of the generation of the ramps and the feedforward loop run on the host CPU and drive the DAC boards through the VME bus.
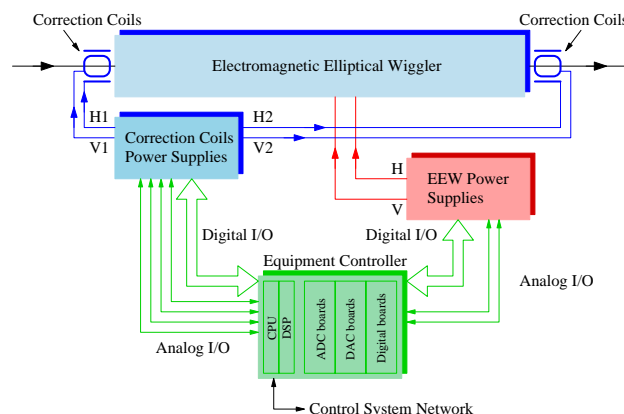

Figure 1: Layout of the EEW control system.

In AC mode the control system acts as an arbitrary waveform generator with five independent channels driving the power supplies of the horizontal field and of the four correction coils; the vertical field current is kept constant. The digital samples corresponding to one period of the waveform for each of the five channels are downloaded into the DSP board via the VME bus. When the EEW is started the DSP board generates the desired waveforms by interpolating the downloaded samples and continuously applying the calculated values on the DAC boards at the rate of 10 kHz. Any repetition frequency from 0.01 to 100 Hz can be chosen.

3 ORBIT DISTORTION MEASUREMENT

The orbit distortion produced by the EEW depends on the shape and on the repetition frequency of the waveform used to drive the horizontal field power supply. This is due to the limited bandwidth of the wiggler electromagnet. As a consequence the lookup table used for the correction in DC mode cannot be employed in AC

since it is determined by minimizing the orbit distortion in static conditions.

The existing Beam Position Monitors (BPM) installed at ELETTRA do not provide the required precision and bandwidth to measure the orbit perturbations at the high EEW operating frequencies. Two new-type Low Gap BPMs (LG-BPM), however, have been installed in 2001 in straight section 2 to carry out orbit feedback tests using a prototype setup. They take advantage of a new low-gap sensor designed at ELETTRA and digital receiver electronics developed in collaboration with the Swiss Light Source (SLS) to provide fast position measurements with sub-micron resolution [5]. A VME crate hosts the LG-BPMs' electronics that gives X and Y position samples at 10 kHz data rate via the VME bus. A DSP board is in charge of locally processing the data acquired from the LG-BPMs, which are transferred to the control room workstations via the network.

4 FEEDFORWARD OPTIMIZATION PROCEDURE

An iterative procedure employing the LG-BPMs is currently used to optimize the corrections when operating in AC mode. It assumes that measuring and suppressing the orbit perturbation in two machine locations where the monitors are installed is sufficient to assure that the whole closed-orbit is corrected. The betatron phase advance between the two monitors is about 35° in the horizontal and 91° in the vertical plane.

Figure 2 shows the setup used for the optimization of the correction system. As the time relationship between the horizontal field waveform and the produced orbit distortion is fundamental to find the optimal correction values corresponding to each point of the curve, a synchronized data acquisition of the LG-BPMs is necessary. The EEW horizontal power supply provides a zero-crossing signal made of 10μs-long pulses generated on the positive-slope side of the current waveform. This signal is transmitted by means of a 4-20 mA current-loop link to the LG-BPMs' VME crate where it is first conditioned and then acquired by the DSP board.

A workbench based on Matlab has been developed to support the optimization procedure from the control room. A set of Matlab commands allows to operate the EEW and to acquire data from the LG-BPM system. In the same environment, this data is processed and the results graphically displayed.

The first step of the optimization procedure is the determination of the response matrix of the two pairs of horizontal/vertical correction coils with respect to the LG-BPMs. The response matrix is empirically obtained by separately exciting each correction coil and measuring the corresponding horizontal/vertical orbit difference at the monitors; the resulting 4x4 matrix accounts also for possible cross talk between the two planes. The inverted response matrix is used to calculate the current in the coils to correct a given orbit error at the LG-BPMs.

The second step is the measurement of the orbit distortion during one period of the horizontal current waveform while the EEW is running in AC mode. The zero-crossing pulses are used to precisely relate each point of the horizontal field waveform to the corresponding position errors at the LG-BPMs. In order to filter out the background noise of the beam, which overlaps to the perturbation due to the EEW, the acquired positions are averaged over many periods by the DSP. In this way non-periodical disturbances or periodical components at frequencies different from the EEW switching frequency and its harmonics are attenuated. The samples of one averaged period are passed to Matlab where unwanted components are further reduced by low-pass filtering and applying notch filters centred at 50 Hz and its harmonics. Interpolation is then performed in order to obtain four arrays of fixed length. The reference DC orbit value is eventually subtracted from each of them to get four data arrays representing the horizontal and vertical orbit errors measured at LG-BPM #1 and #2 over one period.
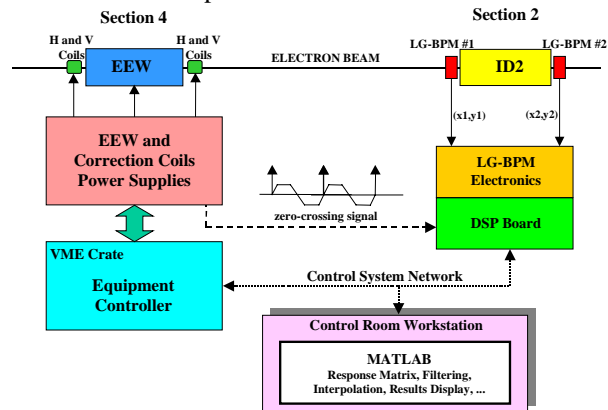

Figure 2: Correction optimization setup.

The correction curves to compensate for the measured orbit distortion are calculated by multiplying the four arrays above by the inverted response matrix. These new values are added to the pre-existing correction waveforms (zero at the first iteration) and downloaded into the EEW DSP board. This procedure is iterated until the residual error is minimized.

A Matlab script has been developed to carry out the above procedure that is normally executed automatically.

5 OPERATIONAL RESULTS

Figure 3 shows an example of the achieved optimization. The EEW horizontal current is modulated between ±260 A using a sinusoidal waveform at 1 Hz, the vertical current is set to 160 A. The blue curves are the averaged horizontal/vertical orbit perturbation at the LG-BPMs without feedforward correction. After four iterations of the procedure the perturbation is reduced to a negligible level (red curves).

In order to verify these results in another location of the ring, the position of the photon beam generated by the

undulator in section 6 has been measured using a Photon BPM (PhBPM). The plots in figure 4 are the horizontal and vertical positions measured in three different cases: feedforward correction system inactive, active and EEW stopped.
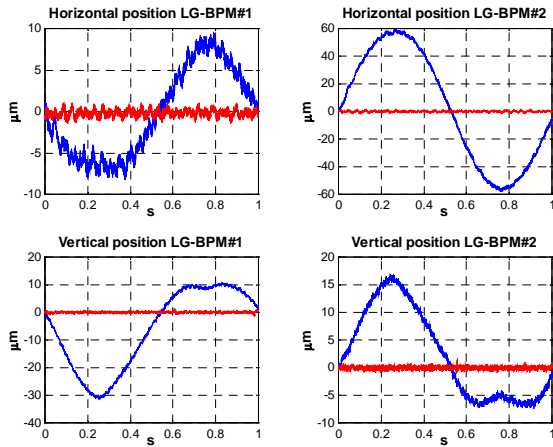

Figure 3: Orbit distortion at the LG-BPMs when the EEW is operated with a sinusoidal waveform at 1 Hz.
Blue line: without feedforward correction.
Red line: with optimized correction.

The feedforward correction system has been optimized for several AC waveforms. For each combination of waveform, frequency and vertical current a dedicated optimization is executed to find the respective correction coils arrays. Trapezoidal waveforms at 0.1 Hz with one-second ramps between flat-tops and sinusoidal waveforms running at 0.1 and 11 Hz are examples of AC operational modes requested by the beam line users.
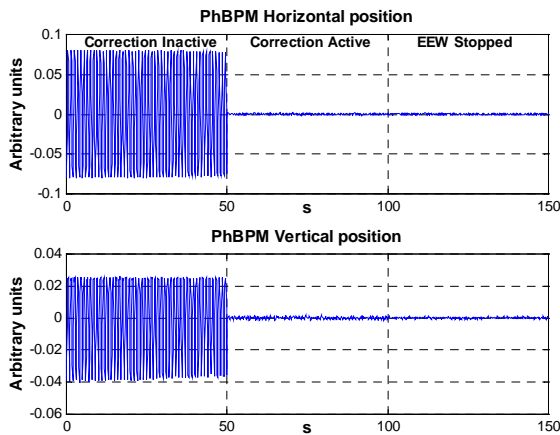

Figure 4: Photon BPM's horizontal and vertical readings showing the action of the feedforward correction system when the EEW is modulated with a sine-wave at 1 Hz.

Analysis of the residual orbit distortion can be made also in the frequency domain where the orbit noise components due to the EEW can be easily distinguished from the background noise of the beam. Figure 5 shows the spectra of the vertical position measured by one LG-BPM without/with correction. In this case the wiggler was operating with a sinusoidal waveform at 90 Hz. The noise components due to the modulation of the horizontal current (±260 A) are represented by the spectral lines at 90 Hz and its multiples. The lower plot clearly shows that no residual perturbation due to the EEW is present on the beam when the feedforward correction system is working. Similar spectra can be also measured using the PhBPM.
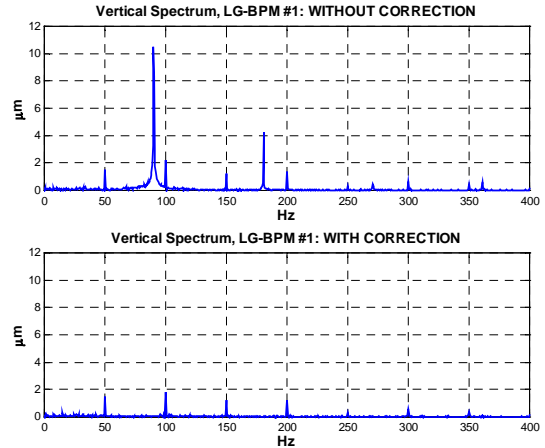

Figure 5: Vertical position spectra from the LG-BPM #1 showing that the harmonics of the EEW switching frequency (sine waveform at 90 Hz) are eliminated by the feedforward correction system.

6 CONCLUSIONS

A procedure to optimize the feedforward correction system of the EEW has been developed and successfully implemented. The optimized system effectively compensates the closed-orbit distortions allowing the EEW to produce circularly polarized radiation with modulated helicity at frequencies up to 100 Hz.

Degradation of the correction performance in the long term has been observed requiring periodical optimizations of the system. Further investigations are foreseen in the near future to understand the causes of this effect and improve system reproducibility.

7 REFERENCES

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