DIAGNOSTICS AND OPTIMIZATION PROCEDURES FOR BEAMLINE CONTROL AT BESSY

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ABSTRACT

Experimental requirements at a 3rd generation light source translate to very high demands on storage ring stability, insertion device control and monochromator performance. Especially the “scanning mode” of combined undulator and monchromator movement is very demanding. Experimental Physics and Industrial Control System (EPICS) based software provides the interface to control the elements of the new BESSY-Beamline at the UE112-low energy Plane Grating Monochromator (PGM). The performance of the monochromator control system has been improved by evaluating waveform records for diagnostics and optimization of position feedback, servo data of the monochromator as well as the complex motions of helical undulators. Algorithms have been implemented for the determination and minimization of quadrature errors of the encoder system (RON905, Heidenhain) that runs on a Linux based EPICS Soft-IOC. A new servo algorithm has been designed to run on a motion controller (PMAC2-VME, Delta-Tau) for robust performance and proper compensation of non-linearity characteristics of in-vacuum piezo motors (Nanomotion).

INTRODUCTION

A BESSY-Beamline is a system of an insertion device (undulator) and a complex optical mount with the monochromator as its central part. Based on the fact that sample preparation at the experimental chamber is very time consuming BESSY normally installs more than one beamline for each undulator. A switching mirror unit (SMU) is used to guide the beam from the light source (undulator) into the interchangeable monochromators. A schematic for the beamlines at the UE112 undulator is shown in figure 1.

Combined movement of monochromator and undulator is required for scanning the photon energy of the light source. BESSY users frequently come with their own experimental chamber and data acquisition software that remotely controls the beamline if the BESSY developed OS/2 based measurement program is not used.

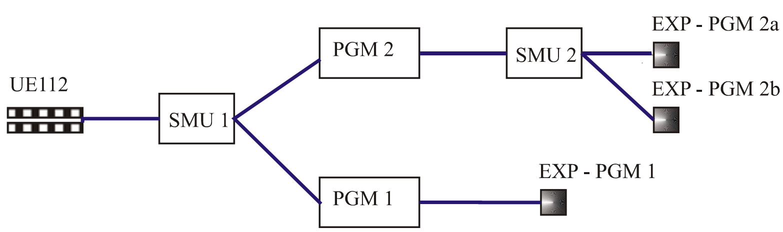

Figure 1: Schematic of the BESSY Beamline at the UE112 undulator. The low photon energy monochromator at U112-PGM2 has been designed to meet the requirements for high flux and high resolution at a photon energy range from 5eV to 250eV [3] that complements the U112 - PGM1 beamline with a photon energy range from 15 eV to 600eV

BEAMLINE CONTROL AT UE112 – LOW ENERGY PLANE GRATING MONOCHROMATOR (PGM)

The software runs on a VxWorks based EPICS IOC (MVME 162, Motorola). The movement of the monochromator runs fully automated on a motion controller (PMAC2-VME , DeltaTau). The monochromator IOC provides the insertion device IOC with commands and parameters for the movement of the magnetic structures of the undulator. The IOCs are connected via CAN bus. This interface uses the LowCAL protocol and its application layer, the wiggler-undulator protocol (WUP)

[4]. The BESSY user interfaces the beamline using either EPICS and Channel Access (CA) or the AMC protocol over Ethernet or serial connection [5].

Motivation

New mechanical concepts have been incorporated at the BESSY beamlines U125/2-10m Normal Incidence Monochromator (NIM) [1] and at U112-PGM/2[3]. The friction based drive (Nanomotion) of the monochromator makes closed loop feedback of a high precision angular encoder system indispensable. It has been proved difficult to compensate the non-linear properties of the piezo-ceramic drive used at U112-PGM/2 and U125/2-NIM especially when short linear motions (e.g. 300 nm) are performed. The compensation run of the IK320 counter card fails due to vibrations that are inherent of the drive. A desired accuracy of the monochromator rotation drive of about 0.02 arcsec makes a correction of quadrature signals of the angular encoder indispensable.

Major Software Function of the Monochromator IOC

The software generates a set of variables that describe the current state of the insertion device and the monochromator. These parameters are mapped to EPICS records. Waveform records provide the elegant means to display data with high dynamics and high data acquisition rates. One of the major difficulties is the task synchronization of the Monochromator Control Program MCCP with monochromator and insertion device movements. Two monochromator related tasks are required to run on the IOC at relatively high priority:

- The position feedback task that reads positions from the IK320 counter cards (Heidenhain) and writes the position data to PMAC's memory mapped DPRAM at data rates up to 4kHz.
- The monochromator driver task that handles communication to PMAC.

A synchronous device support for EPICS standard records provides the internal interface to the monochromator driver.

Hardware Details

A programmable multi-axis controller PMAC2-VME is used to control the elements of the grating unit. The rotation drive is a piezo motor (Nanomotion, 2*HR8) situated at the end of the lever arm of grating and mirror. The same type of drive is used for the exchange mechanisms of gratings and mirrors. A combination of IK320 counter cards and RON905-UHV angular encoder (Heidenhain) is used as position feedback of the monochromator and a combination of linear in-vacuum sensing heads (RGH25F, Renishaw) and digital interfaces (RGF2000, Renishaw) are used as servo and velocity feedback of the piezo drives. An absolute position measurement of the exchange mechanisms is done by Laser Triangulators (Keyence, LK-2000) after power on/reset to avoid collisions of grating and mirror stages.

Program Structure

The derived program structure of the MCCP is shown in figure 2 (left). Most action has to be done at start and stop of each combined move of the monochromator and insertion device. This is easily done by the use of the EPICS event scanning feature. A state notation language (SNL) program is used to handle MCCP-IDCP communication. The SNL program monitors several EPICS variables and is triggered by a record that is processed if a start event is fired by the MCCP (figure 2).

A start event will be fired if any valid command is sent to the monochromator IOC (e.g. by setting a new target wavelength). The MCCP simply remains in running state until insertion device and monochromator return to ready state. A stop event will be fired during the transition from running to ready. The stop event is used to trigger records for data acquisition and to get new values for a set of monochromator status variables that include waveforms of position feedback data of the servo system.

In the scanning mode, the Monochromator and Undulator are moved through a series of steps. Task synchronization can be achieved by using the start and stop events of the Monochromator IOC or by polling the monochromator status variable at a rate of at least 5Hz.

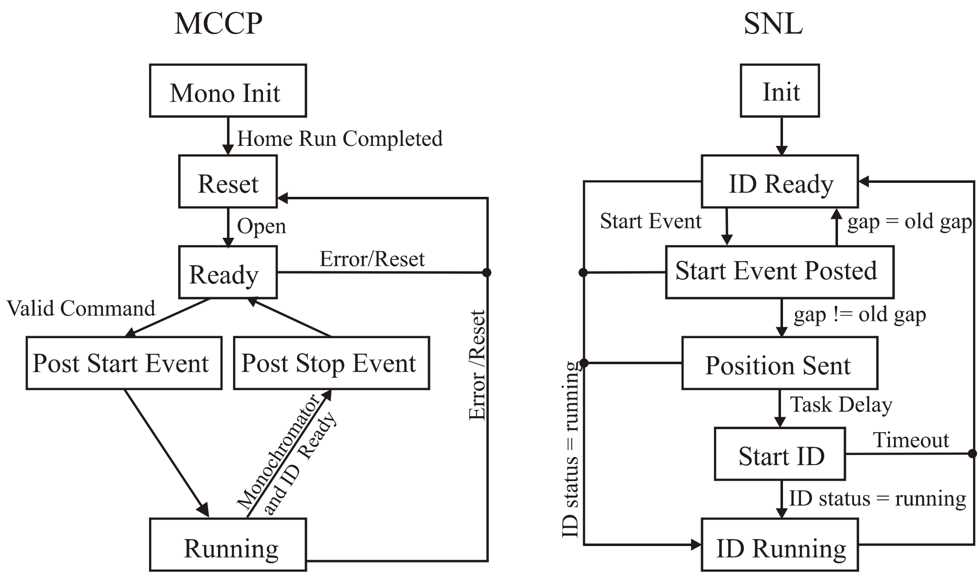

Figure 2: State transition diagrams of the Monochromator Control Program MCCP (left) and State Notation Language SNL Program (right).

EPICS SOFT-IOC FOR DETERMINATION AND CORRECTION OF QUADRATURE ERRORS

The accuracy of quadrature encoders that are commonly used in positioning systems is restricted by the generated sinusoidal signals and the interpolation circuit. The Heydemann correction is a widely used compensation method for 1st order periodic deviations on quadrature encoder systems [6]. These encoder errors are determined by elliptical fitting. The method is not suitable to compensate all periodic errors but higher order periodic deviations appear to be negligible.

Each wavelength scan of the monochromator uses a particular region of the angular encoder. This region should use its own set of compensation parameters. The required experimental data is acquired on the fly by moving the motor slowly over the region of interest. The data rate has to be fast enough to see all relevant spatial frequencies that are present in the uncompensated system but is limited by the IK320 counter cards to 4 kHz. EPICS waveform records are used to store the data from the Monochromator IOC after data acquisition.

A multi waveform record (mwf-Record) with multiple CA input links with a synchronous device support routine is used to read and write data arrays into a shared memory region on the Linux based Soft IOC. In addition to the instrument I/O like communication via shared memory the record has input links to the waveforms of the Monochromator IOC.

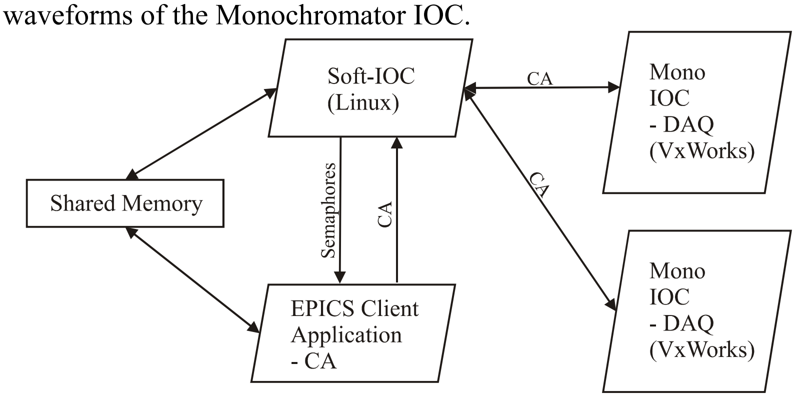

Figure 3: Communication and concept of Soft IOC for determination of quadrature errors.

The EPICS Client Application

An EPICS client application written in C is used to realign the acquired data and to calculate the Heydemann correction parameters by elliptical fitting. The task runs at relatively low priority. Task synchronization between EPICS record processing and data processing is simply achieved by semaphores as a signaling device (figure 3). The client application uses Channel Access to trigger the desired action after data processing. Using this mechanism a large set of data regions can be automatically scanned in a sequence. This is necessary if the Heydemann correction parameters slowly change over the range of the encoder system.

Experimental Verification

This correction has been applied to the quadrature signals of a RON905 angular encoder of the 10 m NIM at U125/2. Each channel of the encoder has to be corrected separately. Spectrographically recorded absorption data has been compared to the absolute wavelength scale of the encoder system. The same periodic error of the feedback system of about 2µrad shows up in the recorded spectra as well as in the calculated quadrature error.

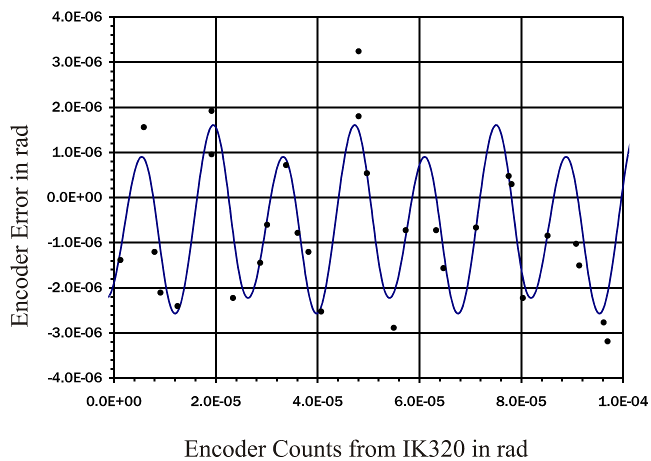

Figure 4: Experimental verification of the quadrature error. Dots are determined from Hydrogen absorption spectra.

PID SERVO ALGORITHM WITH COMPENSATION OF NON-LINEARITIES FOR PMAC

The algorithm has been designed for the situation that system dynamics can be well described by a linear system while there are static non-linear characteristics of the input of the system. This kind of nonlinear model is called a Hammerstein model [12]. Figure 5 illustrates the control loop.

Basic Approach

In a non linear black box model of a single input single output (SISO) system previous data of open loop information is used to map the system response to the input. This mapping has the simple structure $\bar{u} = f(u)$. The servo algorithm uses a generalized model in the form of a look-up table to calculate $f(u)$ at every servo clock interrupt.

The method to obtain f requires real-time capturing of the control output u and the position x as a function of time to obtain a data set $u(1),y(1)\ldots u(N),y(N)$, where $y=dx/dt$. This data is recorded during a specifically designed identification experiment. The choice of the input signal and the interpretation of the data set is critical and will affect the balance between robustness and performance especially when an increased level of both, robustness and performance, is needed. The most difficult part is to determine a suitable model from the observed data which can be done in two different approaches:

- Using least squared estimation to fit and validate a parameterized model to the data.
- Realign and low pass filter the data set in order to obtain the inverse function $f^{-1}(u)$. This function has to be a bijective mapping between u and y. f can be obtained numerically.

Having a graphical or analytical representation of *f* the procedure to update the lookup-table of the feedback loop can be easily automated.

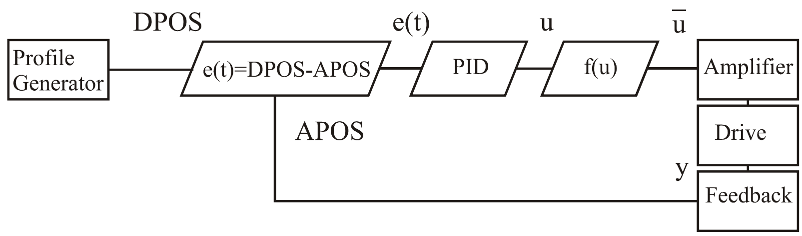

Figure 5: Structure of the user programmed feedback loop for PMAC2-VME. Amplifier, drive and feedback can be described by a Hammerstein model [12]. The error of the system is determined by the difference of the desired position (DPOS) and actual position (APOS). A linear PID Filter / Feedforward control calculates u which is mapped to ū. PMAC outputs ū to the to the amplifier box of the drive.

Compensation of Non-Linearities of In-Vacuum Piezo Motors (Nanomotion)

This section addresses the following needs in improving the motion control techniques for the Nanomotion drive at the BESSY beamlines UE112-PGM2 and U125/2-10mNIM:

- High tolerance to vibrations and dynamic changes in friction and external forces.
- High performance in terms of forcing the motor to the desired position quickly and accurately.
- A simple tuning process for the operator.

The monochromator is operated at motor speeds below 20mm/sec for long moves and with minimum acceleration for small steps. Based on the recorded inputs *u* and outputs *y* of the system we developed a adequate non linear model of the voltage *ū (t)* to velocity *y(t)* profile of the system:

$$\overline{u}(t) = f_1(u(t))$$

where

$$f_1(u) = \begin{cases} c \cdot |u|^{\alpha} \cdot sign(u) + offset & |u| > \delta \\ \dfrac{c}{\delta^{(1-\alpha)}} u + offset & |u| \le \delta \end{cases}$$

with 0<α<1, such that

$$x(t) = \int y(t)dt \approx const. \cdot \int u(t)dt$$

Due to stiction and preload of the motor there is a certain deadband where no motion occurs [7]. The effect of f_1 is increased sensitivity to position errors for compensation of the static friction while the linear part of f_1 makes the output smoother. It has been experimentally shown on parabolic velocity profiles that the motor can effectively controlled using the non-linear compensation and a proportional control (P-filter).

Unfortunately, this compensation is limited to static non-linearities as described above. Because of the non-linear dynamics and the time-variant behavior of the Nanomotion drive the biggest lag between desired position and actual position will be at the beginning of the motion. This makes a proportional-integrational control for short steps and accurate positioning necessary while almost no integrational gain for long movements is desired. Using the notation

$$e_T = |TPOS + Offset - APOS|$$

where TPOS is the target (end) position we introduce a non-linear integrated error *I*:

$$I = f_2(e, e_T) = \begin{cases} C \cdot \sum \left(e(t) e_T^{\beta}(t) \right) & e_T > DB \\ 0 & e_T \le DB \end{cases}$$

where *DB* is called the dead zone [11] and *DB > 0*.

Putting $\beta = -1$ we optimize the parameter C in such a way that the integration time, that is needed to overcome the motor's deadband smoothly at constant time, is about 0.3 seconds. This will minimize vibration and acceleration which is always high at this point of movement. f_2 implies a deadzone mechanism that sets the motor command to zero when the actual position is within a certain range DB. The offset in e_T is needed for movements with varying dynamics due to gravity forces.

Test Results

Compared to a solution of the control problem proposed by Nanomotion [11], the filter is less sensitive to noise and disturbances. Small tracking errors can be achieved while forcing the motor into a desired trajectory. The positioning time has been decreased by a factor of 4 while the noise and disturbance limited resolution of the motor has been improved to a value better than 100 nm.

CONCLUSIONS

New software has been written for beamline control, diagnostics and optimization. A set of EPICS variable can be used to monitor the current state of the beamline. Waveform records are used for diagnostics of position data at acquisition rates up to 9 kHz. A Linux based EPICS Soft-IOC has successfully been used to correct Heidenhain RON905 encoder signals using the Heydemann algorithm.

A non-linear servo filter was developed to increase the performance of in-vacuum piezo motors (Nanomotion) in terms of positioning time and accuracy and to simplify the tuning procedure for the operator.

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