ISBN: 978-3-95450-200-4 doi:10.18429/JACoW-PCaPAC2018-FRCC4

MAINTENANCE AND OPTIMIZATION OF INSERTION DEVICES AT NSLS-II USING MOTION CONTROLS

Christopher Guerrero, Richard Farnsworth, Dean Hidas, Yuke Tian, John Escallier
Brookhaven National Laboratory, 11793 Upton, NY USA

Abstract

The purpose of this project is to demonstrate the effective improvements on insertion device performance via upgrades on the motion control software. The insertion devices installed inside the National Synchrotron Light Source II (NSLS-II) storage ring are currently operating at sub/micron resolution with slow speeds, which can limit the scope of user experimentation preferences. We can manipulate the devices with adaptive tuning algorithms to compensate for varying electromagnetic forces throughout motion scans. By correcting positional feedback with encoder compensation and redefining motion programs, we can safely increase the speed to run the same motion trajectories in less time.

INSERTION DEVICES

Introduction

An insertion device (ID) is used at NSLS-II as a photon source for beamlines. These devices include in-vacuum undulators (IVU), elliptically-polarizing undulators (EPU), damping wigglers (DW), and three-pole wigglers (3PW). With the exception of the 3PWwhich has a fixed gap between the three magnetic poles, all insertion devices adjusts the distance between parallel arrays of magnets. This distance is called the ID gap, and EPUs have additional degrees of freedom that can be adjusted horizontally, which controls the polarization of photons produced. This type of adjustment is called the ID phase.

Motion Control System

The motion control system used for the insertion devices comprises of both hardware and software. The hardware used for IDs at NSLS-II are: 64-bit Linux computers; Delta Tau Programmable Multi Axis Controller (PMAC-2) modules [1]; Delta Tau/in-house built power supply modules; Stepper/servo motors (and brakes where needed); Renishaw optical glass linear positional encoders [2]; embedded rotary positional encoders (for some IDs); Ethernet, motor, and encoder cables. The ID software is mainly divided into three parts: configuration on the PMAC, software Input Ouput Controller (IOC), and user interface via Experimental Physics and Industrial Controls System (EPICS) communication [3]. IOC has EPICS applications to channel access interface with motor controllers. The user interfaces for IDs are operator interface (OPI) screens on Control System Studio (CSS) software used facility-wide [4]. These OPIs can set and monitor kinematic parameters of the motion control system. In summary, the major control system components (seen on Fig. 1) are: the drive assembly connected by motors, the motor controller and driver, the IOC, and the OPI.

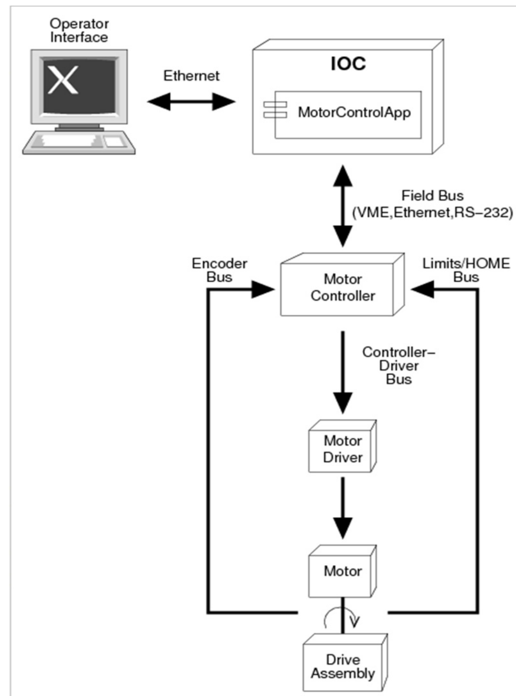

Figure 1: Motion control system components.

3PW/DW Motion Control Setup

The simplest motion control system for an ID at NSLS-II is that of a 3PW since it only involves one motor. A 3-phase stepper motor runs at 2 Amps to rotate the drive assembly. This assembly contains a motor, a gearbox, and a ballscrew, which moves the actual magnetic device horizontally on double supported rails. The direction of this motion in reference to the accelerator beam is inboard (positive direction) and outboard (negative direction). We set the fully outboard position to zero, and the 3PW reaches the fully inboard position when it is aligned with the beam passing through a flattened beampipe chamber section.

For the 3PW, we use a 50-nanometer resolution Renishaw absolute linear encoder for positional feedback. This is directly read on the PMAC on power on, so we always recover the last known position. The software does not require coordinated definitions on the PMAC configuration, so we directly change the position to the axis using jog commands. These move commands are transferred via setpoint and go fields in the OPI seen on Fig. 2 below. We can also enter the desired position using the move in/out command buttons to fully insert/retract the device.

ISBN: 978-3-95450-200-4 doi:10.18429/JACoW-PCaPAC2018-FRCC4

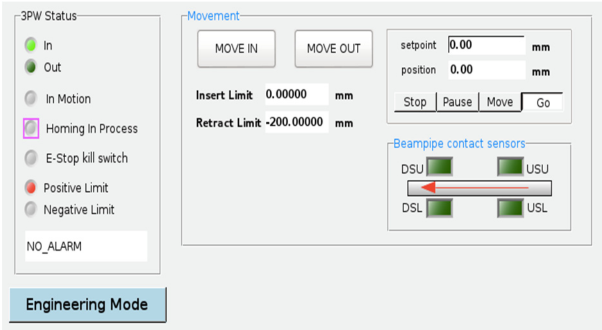

Figure 2: 3PW OPI.

The 3PW OPI can also show status of limit switches, inboard/outboard position, proximity switches to the beampipe chamber, soft limits, and position readbacks.

We are currently using 7 3PWs at cells 4, 6, 7, 11, 12, 17, and 22 of the NSLS-II storage ring. This means we create a motion control sub-system for each 3PW, create an IOC for each 3PW, and run all softiocs within the same IOC server.

IVU/EPU Motion Control Setup

The motion control systems for undulators are more complex and require solid knowledge of coordinated motion to correctly adjust the gap size. For our IVUs of magnetic assemblies that are 1.5 meters or 2.8 meters long, the control system is designed to drive four shafts using ballscrew supported by fixed bearings. The 3 meters long IVU and EPUs have a control system to drive a one piece shaft supported by fixed-free bearings. The shaft assemblies are interconnected with motor assemblies through worm reducers, as seen on Fig. 3 below.

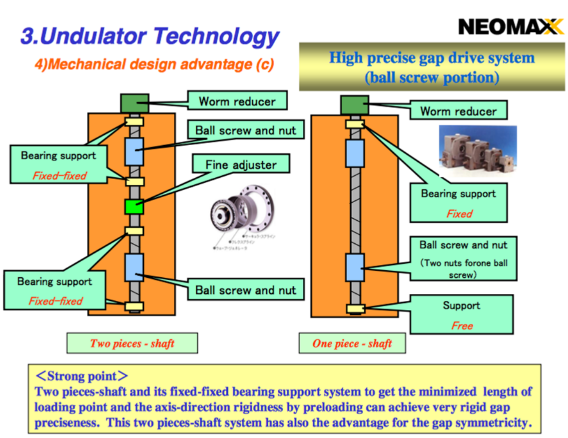

Figure 3: Neomax Undulator Mechanical Design.

The IVU devices are configured to simultaneously drive one motor on the upstream position and another motor on the downstream position in reference to the beam direction. The other IVUs have controls that allow us to move two (upper and lower) motors on each side. By moving the motors together, we can incrementally open/close the gap. These undulators require two encoders for each motor: a linear absolute feedback mounted externally of the shaft alignment, and a rotary incremental feedback directly coupled to the motors. In total, the undulators' controls systems provide four linear feedbacks for gap position, and four rotary feedback for motion commands and status. The OPI for IVUs' motion controls seen on Fig. 4 allow operators to set the gap by entering the value and starting a motion program that executes the synchronous move and updates the actual to the new setpoint. There is a fine positional adjustment program that can be enabled for IVU control systems, this is labelled as the correction function on right of the OPI.

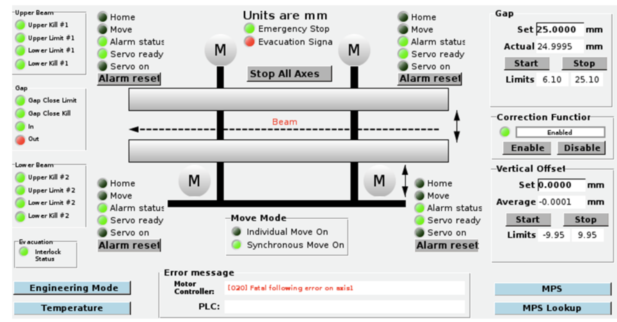

Figure 4: IVU OPI.

INSERTION DEVICE ISSUES

Issues with 3PW

The main issue with controlling motion of the 3PWs was due to small PID gain, motor driving current, and low operational speed values. These parameters are configured internally in the Delta Tau software. Most 3PW devices were running at 0.2 millimeters per second, which would take about 15 to 20 minutes to complete full range of motion. From fully inserted to fully retracted and vice-versa, this range of motion is approximately 190 millimeters.

After re-evaluation of the mechanical assembly of the motor, gearbox, and ballscrew, we found there was slack between the nut and setscrew that connected the coupler with the ballscrew. The loose assembly caused poor control conditions and possible mechanical hazard if the motor shaft disconnects.

Issues with Undulators

The main issues from undulator controls are caused by:

- Linear encoder feedback not matching rotary encoder feedback
- Mechanical gearbox and springs on IVUs
- Virtual IOC server too slow for processes and commands containing all ID softiocs
- Operational error on CSS

The rotary encoders are mounted directly on the motor axes, whereas the linear encoders are mounted externally to the outer ends of the girder. This can cause geometrical issue on the cantilever motion for systems with two motors. For example, if the motors open the gap and the downstream encoders report a gap distance greater than the distance between upstream encoders, the positions report a tilt effect. To compensate for this tilt, the Delta Tau gains adjust the position of the motors to eliminate the imbalance. However, the cross coupled gantry configured on Delta Tau's does not take into account that the

ISBN: 978-3-95450-200-4 doi:10.18429/JACoW-PCaPAC2018-FRCC4

linear encoders are not inline with the gap positions from the leadscrew axes that we wanted to monitor and drive.

The mechanical setbacks encountered with undulators are: bent shafts or angular misalignment in the drive train, and the meshing of spur and bevel gears internal to gearboxes.

RESULTS

3PW Motion Controls Update and Mechanical Corrections

3PW motor performance is evaluated using the Delta Tau PewinPro PID tuning software. This software allows a motion trajectory to be exercised for a certain distance and period with input PID gain values to optimize motor performance. This test was exercised for all 3PW devices before any changes to the mechanical or control setup. The plot below (Fig. 5) is an example of poor performance of the 3PW motor due to issues.

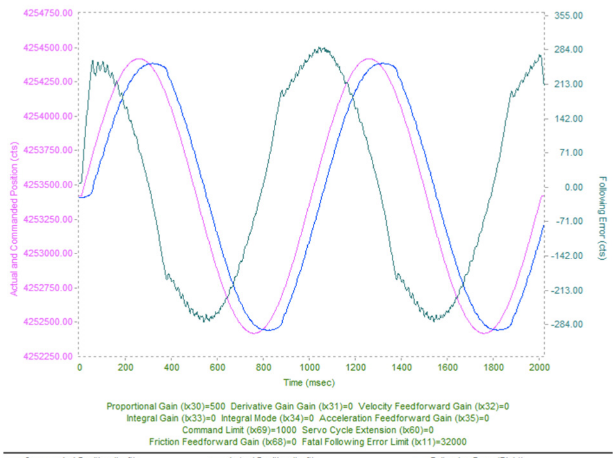

Figure 5: 3PW Sinusoidal Motion Plot with Loose Ballscrew.

The sinusoidal motion trajectory can easily display how far off the (blue) actual position trajectory was from the (pink) commanded position trajectory. The 3PW controls were updated to drive the motors with approximately 2 Amps, proportional gain was doubled, and the new operational speed set to 2 millimeters/second. This was applied to every 3PW controller after the setscrews and nuts were securely fastened to the ballscrews. With the updated configuration, we can move the devices ten times faster and complete full range of travel in less than 2 minutes.

Undulator Motion Controls Update and Mechanical Corrections

Repair of IVU controls and hardware had the highest priority due to scheduled maintenance and shutdown periods of NSLS-II. We ran diagnostic software to evaluate motor performance for all IVUs and pinpoint issues on each device. The diagnostic software plots contain DAC outputs from the Delta Tau controller. Using the plots from DAC output data, we can observe torque ripple 3illimetr. The ripple is an oscillatory modulation of the torque required for motion with constant speed.

Diagnostics of IVU Motor Performance

To repeat the motion plot for multiple IDs, we need software that can automatically generate move commands on the EPICS level and run data gather on the Delta Tau software buffer. The software to interactively tune and record motion trajectories has been internal to the Delta Tau software. This can only be done one motor at a time, for a predefined duration (distance in counts and gather period). To run the data gather more efficiently, we collect motor position data while repeating move commands on higher level of software. Using the Asyn interface via EPICS, data gather and collection can be defined simultaneously and remotely. A python shell script is executed to generate scripts for each gap move commands. For IVUs, the script changes gap setpoints for a full range motion scan. These scans can be arranged for 3illimetre increments or longer. Each scan executes a Python script that runs a buffer, saves linear and rotary encoder readbacks (as well as DAC outputs of each motor) to registers in the controller memory, reformats and processes the data, and saves this in a text file. The file is then plotted using Matplotlib (a Python package) to generate comparisons between linear and rotary encoder feedbacks. As proof of concept, Fig. 6 below demonstrates partial gap motion of IVUs from four linear encoder feedbacks and repeatability of this software.

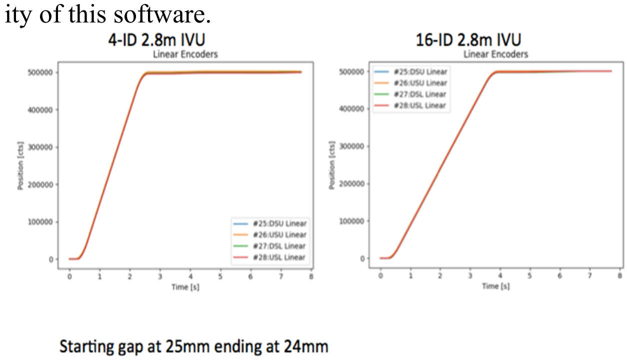

Figure 6: Gap Motion Plots of IVUs.

It would take a few hours to collect and plot this data with Delta Tau's PewinPro software. Using Python scripts, this data is recorded and plots are generated within minutes. Therefore, this software allows for a more rapid plotting and analysis of motor performance than that of the PewinPro PID tuning software. The software is maintained at: https://github.com/dhidas/IVUTests.

CONCLUSION

The corrections to motion control software have:

- Allowed 3PWs to move faster to satisfy operational requirements
- Diagnosed mechanical issues on IVUs by exercising motion and recording encoder feedback and torque command values
- Eliminated hang-ups on communication between IOC server and ID softiocs
- Identified future solutions to the non-linear forces acting on IDs

ISBN: 978-3-95450-200-4 doi:10.18429/JACoW-PCaPAC2018-FRCC4

The vendors of the devices provided the last updated version of IVU motion controls in 2008-2010. This latest version of software is out-dated due to the NSLS-II controls programming standards [5]. To keep motion control software running, we will have to re-write most of the configurations, test changes, and verify operational readiness of code.

FUTURE WORK

EPU Phasing Correction

When the phase of an EPU is moving past full repulsive forces, the directions of the forces flip. If the tuning of the axis is "soft", there will be significant axis movement. Integral windup has to compensate the force direction change. The Delta Tau controllers do not understand the non-linear nature of the external forces. Therefore, the PID tuning has to be "softened" to keep stability throughout the range of motion. We are correcting the phase errors by using the rotary encoders to drive and rigidly control motor positions with compensation tables that add to the desired positions and reduce the actual position errors. Another possible solution to the phasing issue is to write an "adaptive" tuning algorithm that can adjust the PID gain values as a function of gap position and direction of motion.

Cantilever Geometry Correction

In addition, correction of the cantilever geometry from encoder feedback will:

- Give true ballscrew locations
- Remove positional error from cross couple gantry algorithm
- Allow higher proportional gain to reduce following error
- Eliminate need to install encoders directly on ballscrews

Motion Control Software Version Control

In continuation with this project, the motion controls of insertion devices will undergo configuration revisions. Version control is documented on Gitlab [6].

ACKNOWLEDGMENTS

I would like to acknowledge the contributions of all members in the Insertion Devices Task Force at NSLS-II. This project was funded by Brookhaven Science Associates.

REFERENCES

[1] Delta Tau Turbo PMAC, http://www.deltatau.com/DT_Products/ProductDetailDescription.aspx?CatID=100-BRICK%20CONTROLLER

[2] Renishaw RESOLUTE, http://www.renishaw.com/en/resolute-encoder-series--37823

[3] EPICS, https://epics.anl.gov

[4] Control System Studio, http://controlsystemstudio.org

[5] NSLS-II PMAC Programming and Configuration Standards, https://ps.bnl.gov/acc/controls/Shared%20Documents/MotionSystems/Standards/PS-R-XFD-STD-BL-MC-002_Rev1.docx

[6] NSLS-II ID Gitlab, https://gitlab.nsls2.bnl.gov/ID