NSLS-II BEAM APERTURE SLIT VIBRATION STUDIES

C. Spataro, C. Amundsen, H. Bassan, S. Sharma
Brookhaven National Laboratory, Upton, NY 11973 USA

Abstract

Beam aperture slits mounted on stepper-motor driven X-Y stages are used in NSLS-II frontends to define the beam size and to limit thermal loads on downstream optical components. The X-Y stages have positional and resolution requirements of 1 μm and 0.1 μm, respectively. This is achieved by micro-stepping the stepper motor by a Delta-Tau GeoBrick-LV-NSLS-II controller. During the initial operation of the X-Y stages unacceptable levels of vibration when the stages were in motion, and an intermittent sharp squealing when they were at rest, were discovered. In this paper we present the studies that were undertaken to investigate these issues and the solutions that were implemented.

INTRODUCTION

The NSLS-II frontend slit assembly consists of an invar stand, a baseplate, X-Y stages, and water cooled Glidcop slit (Fig. 1).

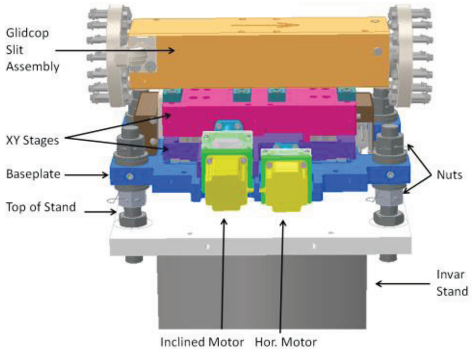

Figure 1: NSLS-II Frontend Slit Assembly.

A pair of slit assemblies is used for the adjustment of the beam size exiting the front end. The L-shape aperture of the upstream slit trims the lower and left edge of the beam while a similar aperture of the downstream slit trims the upper and right edge of the beam. X-Y stages provide the required motion in the horizontal and vertical directions taking into account the coupling of the two motions by the inclined stage. In canted beamlines one pair of slits is used (total of 4 slits) to trim each beam independently. The slit assembly is mounted on a thermally stable invar stand to meet the long term positional stability requirements of 1 um.

XY STAGE MOTOR CONTROLLER

The X-Y stages have position and resolution requirements of 1 μm and 0.1 μm, respectively.

A stepper motor system incorporating a Delta Tau GeoBrick-LV-NSLS-II controller with relative encoders are used for precise positioning of the slits. The horizontal and inclined axis motors are identical. The horizontal position is controlled by the horizontal axis motor. The vertical position is controlled by the horizontal axis motor and the inclined axis motor which is at a 14 degree angle to the horizontal plane. This design was implemented to minimize the vertical size of the slit assembly, thus improving its mechanical and thermal stability. The motors have a micro-step resolution of 160 nm. Both stages are equipped with Renshaw optical encoders with a resolution of 40 nm.

PRE-INSTALLATION TESTING

The motors were installed and configured on the X-Y stage assembly before installation. Extensive tests were performed on the X-Y stages to verify their performance, vibration characteristics, and number of cycles to failure. A slit was mounted on the stages during these tests but the water lines and bellows were not connected. The tests were deemed successful as all performance specifications were met.

RUNAWAY VIBRATION

After the slit assemblies were installed in the SR tunnel, initial testing and calibration revealed that there was a vibration problem which did not occur during the laboratory tests. A homing test routine was used for calibration in which the stages were exercised in both horizontal and vertical directions. During execution of the homing routine, the stages often experienced runaway vibrations, causing the controller to quit the routine. With two slit assemblies side by side, the excessive vibrations from one stage in motion caused the other to move as well. The large vibrations between the stages were being transmitted through the vacuum and water connections.

One of the potential sources of this vibration was identified as the electrical noise picked by long instrumentation wiring. At NSLS-II, the controllers are located on top of the storage ring tunnel about 20 meters away from the motors. However, electrical noise was ruled out as a source when the same vibration problem occurred even when the motors were run locally by an identical controller brought in a close proximity to the motors.

A closer mechanical inspection of the slit assembly revealed some twist in the baseplate. This occurred because the final set-screw adjustments for alignment were performed after the nuts were already torqued, causing distortions in the baseplate. The alignment procedure was modified so that most of the torque was applied after final adjustments. The vibration levels were reduced but not sufficiently to eliminate the runaway incidences.

An experiment was then performed in which a viscoelastic pad was added to the top of the slit to help dampen out the vibrations (Fig. 2). This reduced the peak vibration levels but at the expense of broadening the bandwidth. The runaway vibration problem was still not resolved.

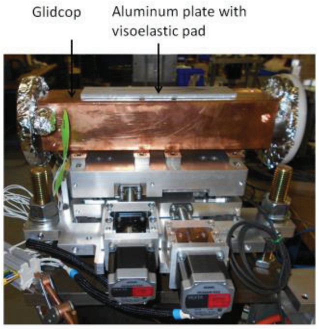

Figure 2: Slit assembly with viscoelastic pad.

A detailed inspection of the slit assembly revealed gaps between the slit body and the outside stainless steel (SS) bars. The solution was to add 2 set screws and tapped-holes to the two outside bars (Fig. 3). By turning the set screws, the SS bars were pushed tightly against the slit body. This reduced the vibration levels considerably and eliminated the runaway vibration occurrences.

Figure 3: Set screws for raising the outside SS bars.

VIBRATION MITIGATION

Numerous tests were done both in the storage ring tunnel and in the laboratory to further mitigate the vibration levels. It was discovered that the motor current tuning and the PID loop tuning in the laboratory did not provide the best response in the tunnel due to the added forces from the vacuum and water connections.

Current tuning of the motors followed by the PID loop tuning was done to get a better response. It was found that when moving the motor by a small number of encoder counts (for instance, 25 counts, which is equivalent 1 micron in position) the motor actually moved up and down over one thousand counts (±40 microns) before arriving to the desired position (Fig. 4).

Figure 4: Actual and Commanded Position vs Time.

The motors were re-tuned and this reduced the unwanted excursion to 14 microns, which is still large but much better than the original tuning.

A large factor in the vibration was the default motor velocity. Tests were performed at various velocities. It was found that there was a linear correlation between vibration levels and the default motor velocity. After numerous rounds of tests, a reduced velocity of 1/3 of the default velocity was deemed to be a good compromise which reduced the vibration levels by a factor of three (Fig. 5 and 6).

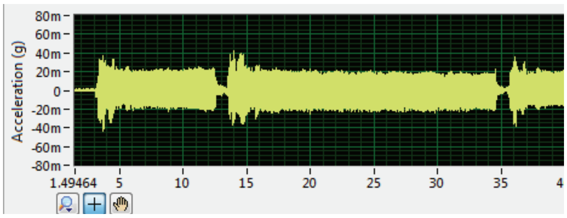

Figure 5: Acceleration vs Time - Default Velocity.

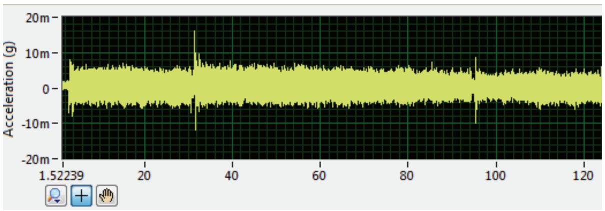

Figure 6: Acceleration vs Time - 1/3 Default velocity.

INTERMITTENT SQUEALING

The motors in the tunnel were often found to be squealing with a high frequency pitch (like a jet engine revving up for take-off). The squealing could be stopped by opening and closing the feedback loop. This was only a temporary solution, as the problem surfaced again and again over time.

Tests were performed in the laboratory to try to duplicate the squealing condition. It was surmised that the squealing could be duplicated by changing the microstepping or the holding current because this would affect the holding torque. After some testing, it was discovered that the squealing could be duplicated by lowering the holding current. A PLC runs in the background of the motion program. After a move is completed, the holding current is reduced to 50% of the nominal current for motion (2A). By dropping the holding current to 5%, the squealing could be duplicated every time.

When the holding currents for both motors are dropped to 5%, the high frequency noise starts within 15 seconds. When the holding current is first dropped to 5% and then immediately brought back up to 50%, no noise was produced. It was also found that it was the inclined-axis motor that was the cause of the squealing. When the holding current on only the horizontal-axis motor was dropped, no squealing occurred.

A holding current vs temperature test was performed. The holding currents for both motors were set to 99% of the nominal and monitored for over 4 hours (Fig. 7).

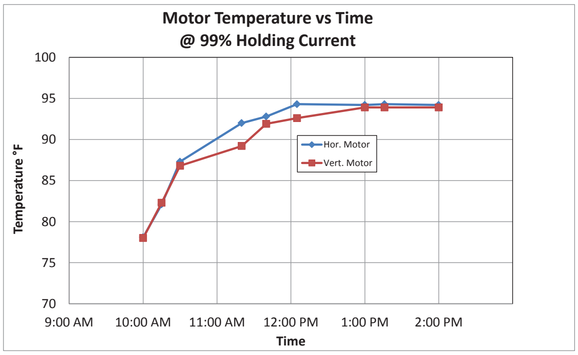

Figure 7: Motor Temperature vs Time.

Temperatures reached equilibrium within two hours and were within specifications. This meant that the holding current could be increased without overheating the motors.

The intermittent nature of the problem is likely to be caused by the reduction in the motor torque when microstepping is used. At the 32 usteps/step setting of the motor, the torque drops to 5% of its rated value (Fig. 8).

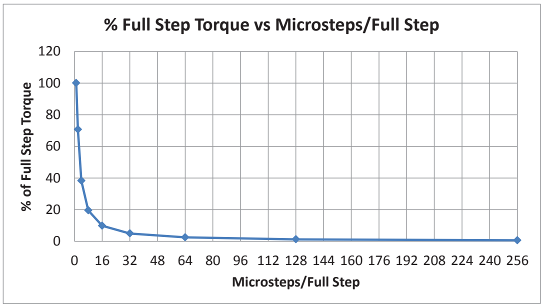

Figure 8: % Full Step Torque vs Microsteps/Step.

Depending on the exact position in relation to the motor steps, the torque will vary, so in some micro-stepping positions the torque is higher and the motor does not squeal, where as in other positions, the torque is lower and the motor starts to squeal. While reduced torque has been established as the cause of motor squealing, the sequence of events in terms of motor current, pulse counts, and position, is still under investigation.

It is now planned to increase the holding current and reduce the number of micro-steps for the inclined-axis motor. If the motor squealing persists then 90^0 worm-gear reducers will be used to increase applied torque to the stages.

CONCLUSIONS

Although the NSLS-II slit assemblies with the X-Y stages met all performance specifications in laboratory tests, their implementation in the SR tunnel revealed three vibration-induced problems. First, there were incidences of runaway vibrations that caused the Delta Tau controller to exit calibration routine. This problem was resolved by stiffening the ends of the slits using set screws that raised the SS support bars.

Secondly, high levels of slit vibrations were observed when the X-Y stages were in motion. These were traced to incorrect current and PID-loop tuning of the motors as well as to their higher than optimal velocity. Once the motors' tuning was optimized and their velocity was reduced by a factor of three, the vibration levels were reduced substantially.

A third problem was frequent squealing of the inclined-axis motor due to a low holding torque in certain microstepping positions. This problem will be resolved shortly by a combination of measures, namely, increasing the holding current, reducing the number of microstepping, and using a 90^0 worm-gear reducer.

ACKNOWLEDGMENT

The authors would like to thank M. Brietfeller, L. Doom, J. Duff, J. Escallier, A. Jain, F. Lincoln, and A. Munoz for their help and insight.