DESIGN AND TEST OF A SAMPLE STAGE WITH A LOW RUN-OUT ROTATION FOR TXM AT NSRRC

Huai-San Wang, Perng-Shen Yaw, Duan-Jen Wang, Tse-Chuan Tseng
National Synchrotron Radiation Research Center
101 Hsin-Ann Road, Hsinchu Science Park, Hsinchu 30076, Taiwan

Abstract

A small run-out sample stage is in development to actualize the two-dimensional reconstruction of 30-nm resolution for the end-station of a transmission X-ray microscope (TXM) at National Synchrotron Radiation Research Center (NSRRC). The main assembly consists of a commercial rotational stage with run-out less than 1 μm, three capacitive sensors, one master ball, one flat and an X-Y table. Error sources (including the profile of the master ball and the rotational run-out of the master ball in horizontal directions) are separated from sensor readings down to the nm level. A feedback method is proposed to compensate systematic errors to make the sample stage with little run-out. The details and tests of the rotational stage at a level of several tens of nm without apparent run-out regularity are here presented.

INTRODUCTION

The transmission X-ray microscope (TXM) at NSRRC is a collaborative design by NSRRC and X-radia. It was installed in September 2004, and was the first zone-plate-based hard X-ray microscope on the synchrotron beamline, operated at 8-11 KeV. It demonstrated a 30-nm resolution X-ray image with a Siemons star employing the third diffraction order of the zone-plate objective, a record in 2006[1]. A hard X-ray microscope has the advantage of greater penetration and higher resolution than an optical or electron microscope. One important application is biological imaging, which also make three-dimensional study possible in vivo.

To process a 3D tomography reconstruction, a sample is seated on a rotational stage; many projection images of a thick sample are collected for image reconstruction. Run-out control of the rotational stage is critical for 3D image resolution, especially for some biological samples with no apparent regularity [2].

Here we propose a sample stage with run-out rotation at a level of tens of nanometres. Capacitive sensors with nm resolution were used to measure the master ball beneath the stage. Error separation schemes were used to separate the error from the master ball, eccentricity offset, tilting error and run-out error. Then a piezoelectric X-Y stage of our design compensates the run-out errors. A prototype is constructed and some analysis algorithm is presented.

SYSTEM SETUP

The main system structure is shown in fig. 1. The sample stage includes an air bearing, a DC motor, a master ball, a flexure mechanism, three capacitive sensors, the compensation mechanism, and the X-Y table. The master ball is seated on the flexure mechanism. The flexure mechanism mounted on the air bearing is designed to diminish manually the run-out error of the master ball to several μm. The dc motor rotates the air bearing and reconstructs a 2D image with the hard X-ray microscope. Three capacitive sensors are installed on the immovable part of the base and distributed every 120^{o}.

Figure 1: the rotational stage.

The X-Y table is designed to compensate the run-out error of the master ball. The structure of the X-Y table is shown in fig. 2. Two PZTs drive the flexure part of the X-Y table in X and Y directions and the motion is up to 60 μm.

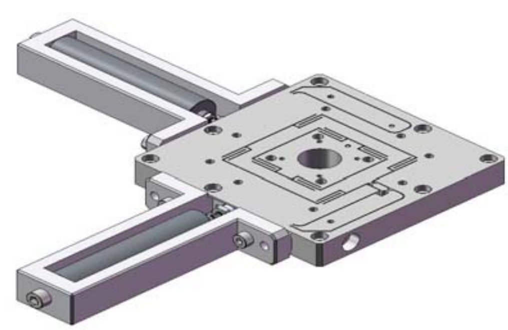

Figure 2: the X-Y table.

ROTATION TEST

For the compensation of the run-out rotation error, two tests are designed to measure this error – involving the rotational stage being mounted on the optical table or on the X-Y table. The measuring process is the air bearing rotated 360^{o} with each step 1^{o} to measure the distance between the master ball and capacitive sensors. Once 1024 raw data are collected and the sampling rate is 1000 Hz, all averages of 1024 raw data per degree are plotted in the ten-turn measurements; results are shown in fig. 3. The repeatability error is 60 nm. Because the master ball is not mounted at the centre of the air bearing, the measurements show sinusoidal distributions and the path of the master ball resembles a heart. The ten-turn measurements almost overlap together.

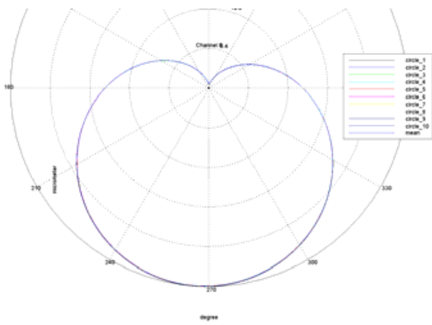

Figure 3: ten-turn measurements.

To eliminate the run-out error of the master ball, the raw data are fitted with a sinusoidal wave; the result of one-turn data is shown in fig. 4. The first plot of fig. 4 has the raw data and its fitting curve; the second is the result of raw data minus the fitting curve, which is still a sinusoidal distribution. The third is the second curve minus its sinusoidal function. The middle curve of the third plot in fig. 4 is an almost straight line. The deviation is ±20 nm between 30^{o} and 330^{o}.

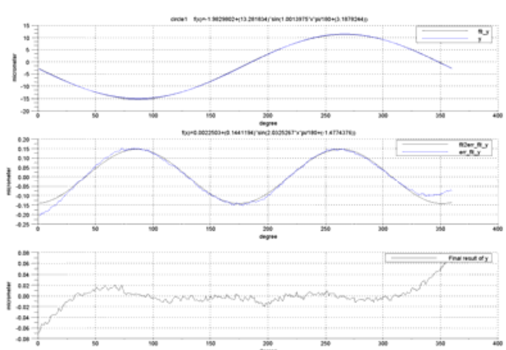

Figure 4: One-turn data and the fitting result with sine wave.

The mean measurements are calculated as a ten-turn measurement sum per degree divided by the ten turns. The ten-turn measurements are minus the mean to eliminate the run-out error. Each turn error is smaller than 30 nm except the first-turn measurements; the result is shown in fig. 5. The warm-up phenomenon of the air bearing causes the path of the first turn data not to be like the paths of other turns. The repeatability of the nine-turn measurements is satisfactory. The paths are like a circle and the run-out error is small.

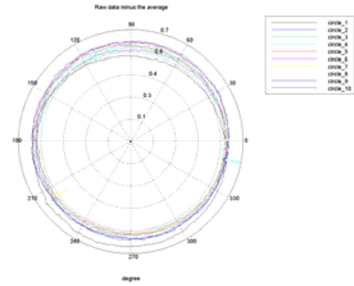

Figure 5: ten-turn raw data minus their mean value.

The other test is for the rotational stage mounted on the X-Y table. The twenty-turn measurements are shown in fig. 6. The overlap phenomenon is not obvious. The repeatability error about 0.7 μm is larger than that of the rotational stage mounted on the optical table. The contours of twenty-turn rotations trend to the centre and the shapes of the contours are similar. The contours of the last turns are centered.

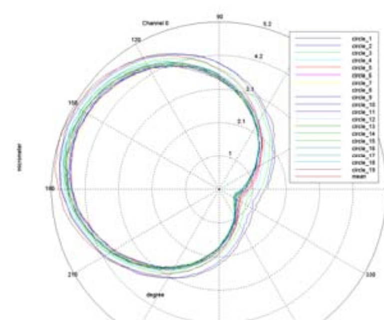

Figure 6: twenty-turn rotation paths.

The twenty-turn raw data minus the mean of the twenty-turn is shown in fig. 7. The repeatability error is still 0.7 μm and does not decrease. The last turns are presented like a circle shape and the repeatability error is 0.1 μm, but all paths do not distribute uniformly.

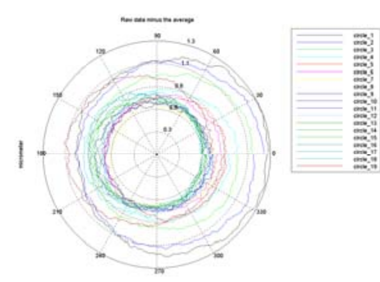

Figure 7: twenty-turn raw data minus the mean of the twenty-turn.

DISCUSSION

Two experiments show that the deviation of the rotational stage mounted on the X-Y table is larger than for the mounting on the optical table. There are two main reasons for these large repeatability errors. One is that the X-Y table does not support well the rotational stage; the master ball is not located exactly at the centre of rotation. The deviation of the master ball is large when the master ball rotates. The distributions of the master ball paths are wide because the stiffness of the X-Y table is small. The other reason is vibration; some vibrational frequencies measured on the optical table are shown in fig. 8 at NSRRC, such as 3 Hz, 4 Hz, 7 Hz and 15 Hz. The integration between 1 Hz and 100 Hz is 0.155 µm. The master ball vibrations measured with capacitive sensors are shown in fig. 9 and 10 in two situations such that the rotational stage is mounted on the optical table and on the X-Y table respectively. The vibrational maxima when the rotational stage is mounted on the X-Y stage are induced between 25 and 50 Hz. These do not exist for the rotational stage mounted on the optical table; integrations between 1 and 100 Hz are 0.176 and 0.253 µm respectively. The vibration increases to 77 nm, which affects the stability of the master ball rotation. The result shows that the stiffness of the X-Y table is inadequate for the rotational stage [3].

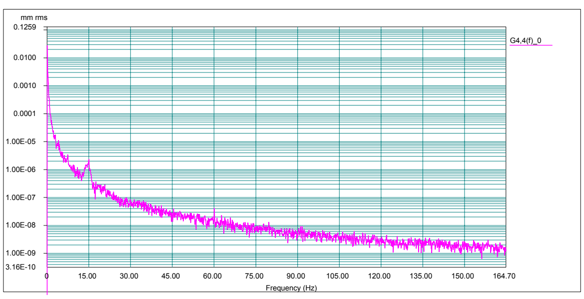

Figure 8: vibrations measured on the optical table.

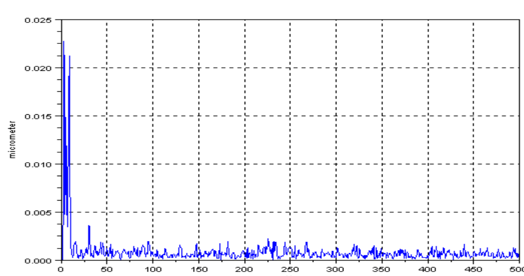

Figure 9: spectrum of the rotational stage mounted on the optical table [4].

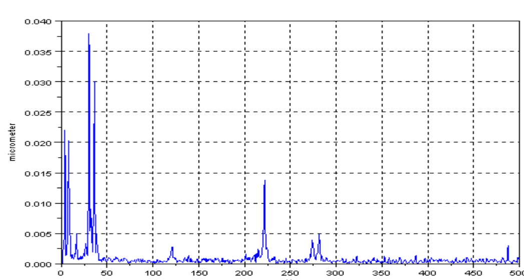

Figure 10: spectrum of the rotational stage mounted on the X-Y table.

CONCLUSION

A sample stage achieving 30-nm run-out resolution uses an X-Y table to adjust the master ball position, but the small stiffness of the X-Y table results in large vibrations induced in the optical table and makes the repeatability error of the rotational stage exceed the resolution. An anti-vibration algorithm is being developed for the rotational stage at NSRRC to decrease the vibration and to increase the stiffness of the X-Y table.

REFERENCES

[1] Gung-Chian Yin *et al.* Applied Physics Letter. 89,221122, 2006

[2] Duan-Jen Wang[1], Liren Tsai[2], S.Y. Perng[1], and Huai-San Wang "Ultra precision rotation stage for TXM at NSRRC"

[3] S. S. Rao, Mechanical Vibrations, 4th ed. Upper Saddle River, NJ: Pearson, 2004, pp. 687–690.

[4] Petre Stoica and Randolph L. Moses, Introduction to Spectral Analysis, Upper Saddle River, NJ:Pearson, 1997, pp. 3-49