Design And Control Of A Novel 3-DOF N+2 Z Stage For Wafer Inspection

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Abstract – Z stage serves a critical role during wafer inspection because it needs to promply and precisely maintain wafer topograph in focus while wafer is moving with high speed. Due to its much larger size and moving mass, N+2 wafer Z stage has to face much more difficult technical challenges: high bandwidth to quickly track wafer topograph while maintain reasonablly low temperature increase; short Z settling time after higher accelerations from X stage; easy and precise adjustment for optics alignment and calibrations. The newly designed N+2 wafer Z stage presented in this paper employed multi-dimensional degree of freedom design concept to have successfully solved above challenges.

I. Introduction

Current 300 mm wafer Z stage in wafer inspection is a single voice coil motor (VCM) actuated cylindrical airbearing stage. It has only one degree of freedom (DOF) and control: translation in Z axis. There are no real-time controls or compensations for rotation about Y axis (pitch motion) and rotation about X axis (roll motion). Since X/Y stage, where Z stage is mounted, is moving with high acceleration during inspection, the disturbances to Z stage introduced by X/Y (especially X) accelerations are significant. The disturbances will cause Z bearing pitching which in turn interacts with X stage airbering rocking mode. Eventually, false defects will happen when the image quality is degraded. Many escaltions from field are related to this issue and tremendous work needs to be done to fix it.

As 450 mm wafer inspection is coming, the newly designed N+2 Z stage, which is 450 ready, should solve current problem whileas have better Z performance statically and dynamically. Therefore, the new Z stage should employ multi-dimensional degree of freedom design concept to be able to provide Z, pitch, and Roll (3 DOF) motions and controls for further requirements from optics design and alignment.

II. Mechanical Design of N+2 Z Stage

Since newly design Z stage has 3 degree of freedom motions and controls, it has to have 3 encoders to measure Z displacement, Pitch angle, and Roll angle. It also has to have at least 3 actuators to achieve movment in Z, pitch, and roll.

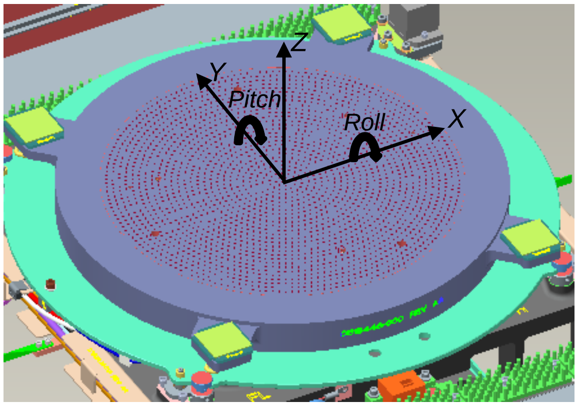

Fig. 1. Overview of N+2 Z stage mounted on X stage

Fig. 1. above Showed the overview of N+2 Z stage on X stage with a 300 mm chuck and cal chips vacuumed on the Z stage. The chuck is vacuumed down on Z stage through a 5 um global flatness Z plate (green disk in Fig. 1.). The

chuck is designed in such a way that it will not only secure a wafer/cal chips, but meanwhile it will stiffen Z plate such that as a whole moving part together, they have reasonably high natural frequency. With this mounting mechanism for chuck, it will dramatically reduce chuck replacement time in the field.

As illustrated in the figure, while X/Y stage is moving, the Z stage can be simultaneously independently controlled in Z translation and rotations about X/Y axes (roll/pitch) respectively.

Fig. 2. Internal view of N+2 Z stage mounted on X stage

Fig. 2. above showed how 3 Z encoders are allocated in Z stage after chuck is removed from Z plate. The 3 orange brackets which hold 3 Z linear encoder scales are mounted on Z plate (moving part) and 3 green Z encoder heads are mounted on X stage (stationary in Z) through 3 grey high stiffness brackets. Therefore, any movement in Z, Pith, and Roll will be measured by these 3 Z encoders.

The moving Z plate is mounted on X stage through a 100 um thick grey flexure which is designed to be stiff in X/Y direction and soft in Z direction. The flexure will mechanically constrain Z plate to allow it only has freedom in Z, Pitch, and Roll.

Fig. 3. below illustrated how the Z stage is actuated by 4 voice coil motors (VCMs). The 4 blue cylinders in Fig. 3. are VCM magnets which are mounted under Z plate (moving part) and their corresponding coils are seated in X stage (stationary in Z). It is believed that 4 VCMs have better controls for dynamics. To minimize thermal expansions and un-wanted disturbances from cabling, the magnets other than coils are mounted under Z plate. The 4 VCMs are arranged in such a way that the combinations of these 4 VCMs motions can change Z stage postion in Z, Pith, and Roll.

In order to minimize heat generation from 4 VCMs, 4 soft counter-balance springs are also designed to balance the weight of the whole Z stage such that control effort only needs to deal with small amount of movements around equilibrium point.

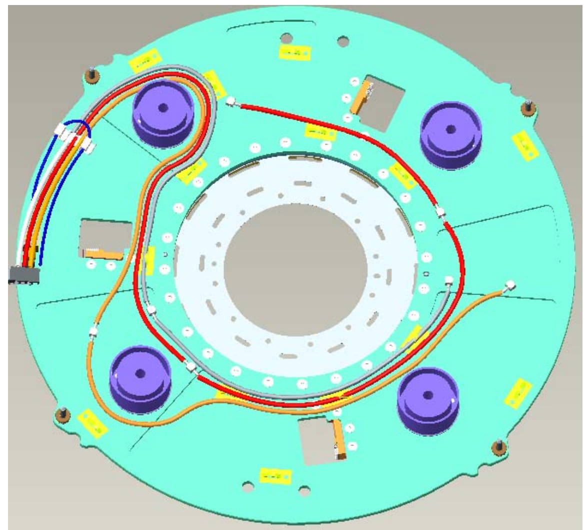

Fig. 3. Back view of N+2 Z stage

With 3 Z encoder real-time measurement data, Z stage control system can servo Z stage to any desired Z postion, pitch angle, and roll angle by applying different magnitude and direction of force for each of 4 motors.

III. Control System Design of N+2 Z Stage

3 independent servos need to be designed to control Z, Pith, and Roll respectively. The model for each axis is straight forward: spring, mass, and damper, which can be easily acquired from Pro/E model and experimental data. However, the Z, Pitch, and Roll measurement need to be converted from 3 Z encoder readings. On the other hand, the control force from each control axis needs to be correctly distributed to each of the 4 motors in real time. Therefore, the first step in this control system design is to correctly calculate conversion factors for 3 encoders and 4 VCMs.

The diagram of N+2 Z stage encoders and

motors locations are shown in Fig. 4. Where, e1, e2, and e3 denote 3 Z encoders and M1, M2, M3, and M4 denote 4 Z VCMs. The distance from encoders to X/Y axis are d1, d2, and d3. Similarly, D1 and D2 are distances from motors to axes.

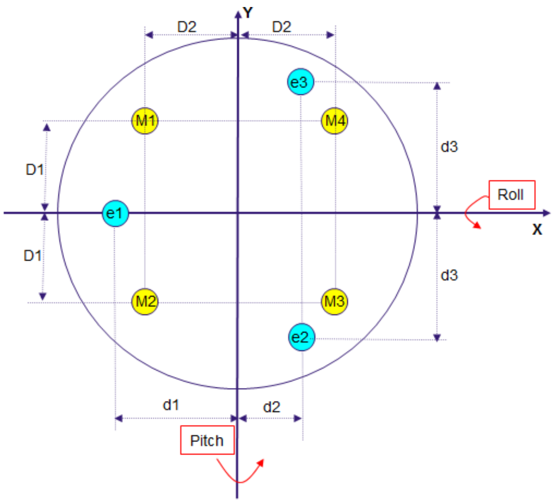

Fig. 4. Diagram of N+2 Z stage encoders and motors

The conversion matrix ***S***: from 3 Z encoders to Z, Pitch, and Roll is shown as following:

$$\begin{bmatrix} Z \\ Pitch \\ Roll \end{bmatrix} = \begin{bmatrix} \frac{d_2}{d_1+d_2} & \frac{d_1}{2(d_1+d_2)} & \frac{d_1}{2(d_1+d_2)} \\ \frac{1}{d_1+d_2} & -\frac{1}{2(d_1+d_2)} & -\frac{1}{2(d_1+d_2)} \\ 0 & -\frac{1}{2d_3} & \frac{1}{2d_3} \end{bmatrix} \begin{bmatrix} e1 \\ e2 \\ e3 \end{bmatrix}^{\#} \quad \textbf{(Eq. 1)}$$

The conversion matrix ***F***: from Z force, Roll torque, and Pitch torque to 4 Z VCMs is shown as following:

$$\begin{bmatrix} M1 \\ M2 \\ M3 \\ M4 \end{bmatrix} = \begin{bmatrix} \frac{1}{4} & \frac{1}{4D1} & \frac{1}{4D2} \\ \frac{1}{4} & -\frac{1}{4D1} & \frac{1}{4D2} \\ \frac{1}{4} & -\frac{1}{4D1} & -\frac{1}{4D2} \\ \frac{1}{4} & \frac{1}{4D1} & -\frac{1}{4D2} \end{bmatrix} \begin{bmatrix} F_z \\ T_x \\ T_y \end{bmatrix}^{\#} \quad \textbf{(Eq. 2)}$$

Where in Eq. 2, Fz, Tx, and Ty denote the controller output Z force, Roll torque, and Pitch torque respectively.

With matrix ***S*** and ***F*** in place, 3 independent control systems can be designed for Z stage. The control diagram is shown in Fig. 5.

It can be seen from the diagram that Z stage has 2 servo modes in Z position control: encoder servo and NSC servo. NSC (normalized S curve) servo is used during wafer inspection, its signal is from auto focus system which is always trying to servo wafer topgraph in focal plane as wafer is moving. The encoder servo signal is coming from 3 Z encoder sensor readings. This servo mode is used during focus freez or Z stage init. With the control structure implemented as below, NSC servo and encoder servo can be easily switched in control system (see the switch in Fig. 5.) from one swath to another swath.

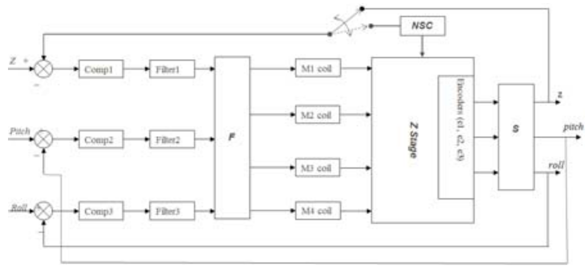

Fig. 5. Diagram of N+2 Z stage control

Pitch and Roll servo make it possible to easily fine tune field tilt through automatic calibrations for image system. After calibration, Pitch and Roll angle will be servoed to the desired angles. To minimize disturbances from stage accelerations, “X to Pitch” or “Y to Roll” disturbances can be directly fed forward to 4 Z VCMs to cancel the disturbances such that servos only need to correct minor “residual” disturbances.

Digital filters are designed in control loops to notch out unwanted resonances from mechanical or electrical components. Eventually, all the 3 axes are in close loop control with bandwidth of about 110 Hz and phase margin of around 35 degrees.

IV. N+2 Z Stage Performances

The newly designed N+2 Z stage is implemented in WIN Denali and Tesla platforms. The test results are summarized as following:

- Z software travel range: +/- 250 um
- Pitch/Roll software travel range: +/- 150 urad
- Z encoder servo peak-to-peak noise: 25 nm
- Z NSC servo peak-to-peak noise (3 s): 30 nm
- Z NSC servo peak-to-peak noise (60 s): 40 nm

One of the NSC test results are shown in Fig. 6. which showed the peak to peak noise is less than 40 nm in 60 seconds. Its FFT in Fig. 7. Indicated that most vibrations are in 100~200 Hz rang which includes many possible mechanical and acoustic resonances. Investigations are still in progress trying to find as many vibrating sources as possible.

Fig. 8. showed NSC peak to peak noise is about 26 nm when wafer is moving at 148 mm/s.

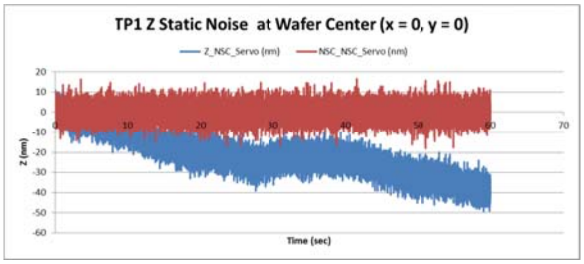

Fig. 6. Tesla proto1 NSC static noise

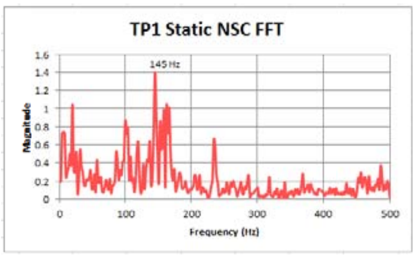

Fig. 7. Tesla proto1 FFT of NSC static noise

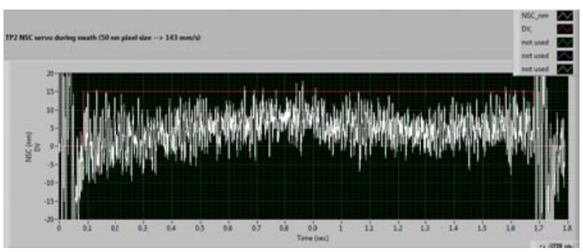

Fig. 8. Tesla proto2 NSC noise during swath

V. Conclusion

A novel high precsion 3-DOF N+2 Z stage is presented in this paper. The mechanical design and control algorithm are aslo illustrated. The test results from Tesla prototype tools validated the design concept. It is believed that same design concept can be used in other product lines.

Acknowledgment

Authors want to acknowledge the contributions from everyone in WN stage team to successfully implement this design concept into N+2 platform.

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