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Performance Improvement of a Wafer Stage System by Iterative Feedback Tuning (IFT)

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Abstract— For the fabrication of integrated circuits (ICs), a fine portion of crystalline silicon called wafer is used in the electronic industry. Lithographic wafer scanners (otherwise called as steppers) are complex equipments for the automated production of ICs. In the assembling as well as in the fabrication process, the wafer must be accurately positioned. For that purpose, the data-driven approaches are more promising than the model-based conventional approaches. Data-driven approach avoids the necessity of modeling and based on the measured data, it enables the direct tuning of the controller. Iterative Feedback Tuning (IFT) is an adaptable closed loop optimization methodology that accomplishes multiple experiments without any requirement of a parametric model. IFT has been successfully applied in many applications including robotics, process industry, servo systems, etc. An important field of application where data-driven controller tuning is appealing is in the high-precision motion control. For the purpose of precise tuning of the motion in the wafer stage system, IFT is used. Through IFT, controller settings, robust stability analysis, convergence of the parameter, error minimization and the time-domain response are evaluated and corresponding simulation results are analyzed.

Index Terms— Lithographic wafer Scanners, Wafer stage system, model-based control, Data-driven approaches, Iterative Feedback Tuning (IFT).

I. INTRODUCTION

Semiconductors act as an essential part in the electronic technologies. The electronic components prepared with semiconductor materials are crucial in modern consumer electronics comprises of smart-phones, laptops, DVD (Digital Video Disc) players, audio players etc.. To create most semiconductors commercially, silicon is used. So, silicon manufacturing has to be done precisely.

A wafer is a fine slice of semiconductor substance, used in electronic industries for the manufacture of integrated circuits (ICs). Numerous semiconductor devices can be built on the silicon wafers. Figure 1 shows a silicon wafer with many semiconductor devices. Only a thin layer on the surface of a silicon wafer is used for assembly of electronic components; the rest of the section serves as a mechanical support.

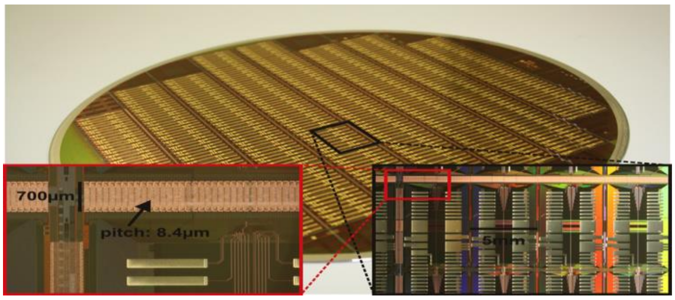


Figure 1: An in depth view of silicon wafer.

Lithographic scanners are extremely complicated machines used for the development of ICs. A Lithographic scanner is shown in Figure 2. The typical lithographic scanner has a light source, reticle loading section, reticle alignment system, projection optics, wafer loading part and a wafer alignment system. The circular silicon wafer (typically 200 or 300 mm in diameter) is mostly made of clean crystalline silicon. The chip developing industries are demanding to incorporate more and more tasks into each IC. This directs to a key influence on the capability of memory chips and the operating speeds of microprocessors.

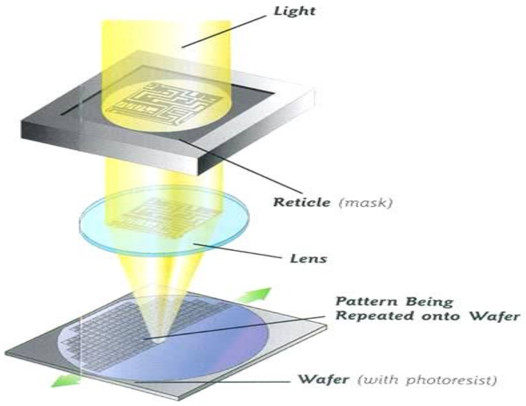


Figure 2: The pattern printing procedure in a lithographic scanner

For the creation of integrated circuits, the lithography process is used. Generally, optical lithography is used to build integrated circuits by means of ultraviolet light rays to depict the desired IC patterns on the surface of a wafer. During photolithography, really the patterns are printed with a light sensitive polymer known as a photo-resist. Light from a light source passes the reticle which is held in a reticle stage system to the wafer. The light passes the projection optics part that forms the desired image on the wafer, which is supported by a wafer stage system. The reticle, as well as the wafer, is movable by a positioning system in the lithographic stepper.

In this paper a brief description on the silicon wafer and the wafer scanner equipment is described. This paper is organized as follows: The second section describes a literature survey based on the application area and the Iterative Feedback Tuning Algorithm. The third section describes the methodology and algorithm employed for completion of the work. The fourth section describes the simulation results and discussion and the fifth section describes the conclusion.

II. LITERATURE SURVEY

A. Constrained Iterative Feedback Tuning for Robust Control of a Wafer Stage System

Marcel F. Heertjes et al. [1] proposed as model–based approaches take much time and intricate in its functionality, data-based controller tuning is demanding in the case of high-accuracy motion control. Data-driven approaches avoid the necessity of modeling and enable direct tuning of the controller. While using Iterative feedback Tuning (IFT), there is no necessity of a parameter or a disturbance model. A new approach for constrained IFT is the main contribution of this paper. In this paper a constraint is included in the optimization criterion and via a penalty function, the gradient-based IFT scheme is split into a well-known IFT gradient and the gradients with respect to this penalty function is employed. To create the machine-specific fine-tunings of the feedback control design in addition to the nominal loop shaping tuning process is done using the constrained IFT method in this paper.

B. System identification and robust control for next-generation motion control of a wafer stage

T. Oomen et al. [2] proposed the motion control of the next generation framework. The obtained framework is especially suitable for next generation motion systems which use several inputs and outputs. As the difficulty came in the model does with uncertainty, it will not boost even if the number of inputs and outputs gets increased.

C. Iterative Feedback Tuning of uncertain state space systems

J. K. Huusom et al. [3] explained that the direct controller tuning is a better alternative, when control loop fine tuning or while a degrading loop performance is analyzed. By using the transfer function description for the feedback controller in the closed loop state-space system derived, Iterative Feedback Tuning is also applicable for state space control systems. Formulation of state space is done in relation to the tuning method is demonstrated with the simulation examples in this paper. Closed-loop data is used to calculate an unbiased estimate of the cost function gradient with respect to the parameters which are meant to control and by uses that estimate. The obtained estimate is then used in the gradient search algorithm. To tune lower level controllers that have linear control parameters, the iterative feedback tuning methodology is designed.

D. Improving Convergence of Iterative Feedback Tuning

Huusom et al. [4] found that Iterative Feedback Tuning is the desirable tuning method for control loop processes, even without an exact process model. It is a totally data-driven approach which optimizes the closed loop performance. As an extension to the Iterative Feedback Tuning algorithm, this paper imposes external probing signals to the predefined experiments. When tuning for disturbance rejection, perturbed Iterative Feedback Tuning can be used.

E. Performance Improvement of State Feedback Control Systems for Single Input Processes

Mircea-Bogdan Rădac et al. [5] presented an extension of the Iterative Feedback Tuning (IFT) approach for the performance improvement of state feedback control systems. The general framework for tuning the state feedback Control Systems by means of Iterative Feedback Tuning is explained in this paper. Also, IFT-based angular position controller for a DC servo system by using an actuator dead zone and the control signal saturation is described as a case study in this paper.

III. PROPOSED METHOD

The high-accuracy synchronous motion of row and column scanning motors and the maintainability of the precise positioning accuracy between the reticle alignment section and the wafer alignment section are the major functions of the wafer stage system of lithography.

Wafer stage system assemblies composed of a wafer loader section, wafer stage system, wafer alignment area, reticle loader section, reticle stage, reticle alignment system, projection optics and the illumination system. The two modules incorporated with the wafer stage are 1) the long stroke module which controls the long stroke motions with positioning accuracy in micrometer level and 2) the short stroke module which controls the short stroke motions with positioning accuracy in nanometer level. For positioning purpose, wafer stage actuator systems use linear motors as well as the voice coil motors. Linear motors are employed to control the long stoke motions of the long stroke module and voice coil motors are employed to control the short stroke motions of the short stroke module.

The motion control modules are controlled in six logical axes (Six degrees of freedom) that is in the up-down direction, left-right direction, forward-backward direction, roll axis, pitch axis and yaw axis. The block diagram of a simplified motion control in the wafer stage system is shown in Fig. 3. The linear time-invariant wafer stage plant P has output y, which is corrupted by the unmeasured disturbances v. These disturbances are assumed to have a stochastic nature.

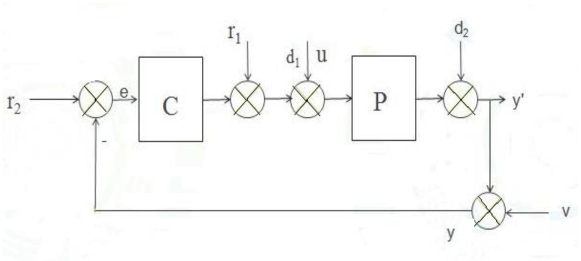


Figure 3: Block diagram of a simplified wafer stage motion control context

The closed loop error, e = r_2-y , i.e., the difference between the reference command r_2 and the system output. And the d1 and d2 are the unknown disturbances at system input and output respectively.

A. *Model-based approach*

Modeling based approaches are the methodologies which are being used to stimulate the massive wafer manufacturing machines. Modern control theory includes linear as well as nonlinear control theories. Zero-pole assignment, LQR design, and robust control are incorporated in linear control design. Controller design methods include Lyapunov-based controller designs, back-stepping controller design, feedback linearization, etc. for non-linear systems. In model-based control design, the first step is modeling of the plant, or identifying the plant model, and then designing the controller is done based on the plant model. The modeling and identification of the plant are compulsory crucial for the model-based control theory (or model-based approaches). Also, model-based approaches are time-consuming as well as challenging process, data-driven controller tuning is an appealing approach in high-precision motion control.

B. *Data-driven approach*

Modeling processes have become more challenging with the development of information science and technology, practical processes in chemical industry, metallurgy, machinery, electronics, electricity, etc. For this reason, traditional model- based control theory has turned into unrealistic for control issues. So, the formation and progress of data-driven control theory is urgent issues both in theory and application. The process in a data-driven control, its starting point and target are both data. Iterative Feedback Tuning (IFT) is such a data-driven control mechanism.

IV. PROPOSED ALGORITHM

Iterative Feedback Tuning is a typical data-driven control. According to an estimated gradient of a control performance measure, iterative optimization of the fixed controller parameter is involved. The estimate is constructed in each iteration from a finite set of information. From a normal operating condition of the closed-loop system and partly from a special experiment in which the output of the plant is fed back in the reference signal, the information is obtained. A closed loop control system using IFT procedure is shown in Figure 4.

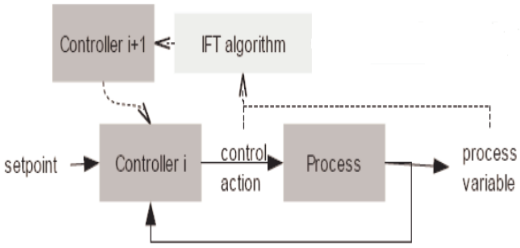


Figure 4: A closed loop control system using iterative feedback tuning

Through Iterative Feedback Tuning, controller parameters can be tuned without any necessity of a parametric model. IFT is used to find the optimal set of controller parameters. The adaptation, which is made from the IFT approach is used for the computation of stability analysis, controller’s fine tunings, Integral Square Error (ISE), Integral Absolute Error (IAE) and the Integral Time Absolute Error (ITAE).

V. SIMULATION RESULTS

The main objective to satisfy are four goals. The four main goals are Controller settings, Stability analysis, Parameter convergence and the time-domain performances are plotted and evaluated through the Iterative Feedback Tuning algorithm.

A. *Controller settings:*

Controller settings are done in three main steps. First step is the design of the plant model (here taken the values of a silicon wafer plant). After that assigned the input data, r_1 and r_2 from the below shown equation 1.

$$[r_1^{<1>}(t)\ r_2^{<2>}(t)] = Q\sum a_k \mathrm{Sin}(\omega_k t+\phi_k) \qquad (1)$$

After this assigning process, examined detailed variations that coming in the input signal graphs by changing the controller value settings. By using the inputs plant state space model is created, where u is the input vector or the control vector ,y is the output vector, A is the system matrix. B is the input matrix, C is the output matrix and D is the Feed-forward matrix.

$$\dot{x} = Ax+Bu \quad (3)$$

$$y = Cx+Du \quad (4)$$

Then, converted the state space model to the transfer function.

B. *Stability analysis:*

Plotted bode diagram with gain margin = -93.1db at 1.16*e^{-9} and phase margin = 90^{0} at 0.000143 rad/sec. Also the frequency response with respect to the input signals are also plotted. Figure 5 shows the bode plot with phase margin and gain margin.

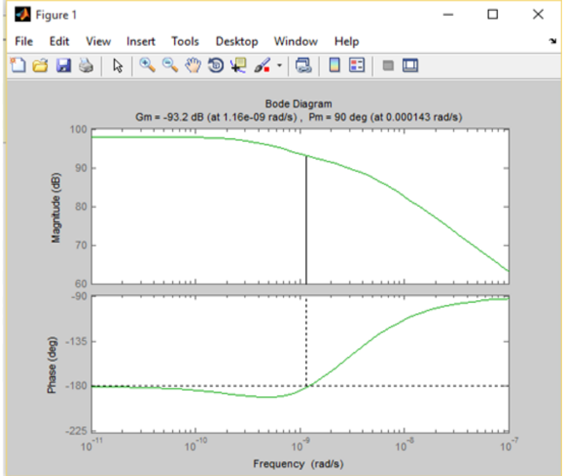


Figure 5: Bode plot with phase margin and the gain margin.

The gain margin is the amount of gain raise or fall essential to make the loop gain unity at the frequency ω_{gm} where the phase angle is –180° (modulo 360°). Similarly, the phase margin is the difference between the phase of the response and –180° when the loop gain is one. The frequency ω_{pm} at which the magnitude is one is called the unity-gain frequency or gain crossover frequency.

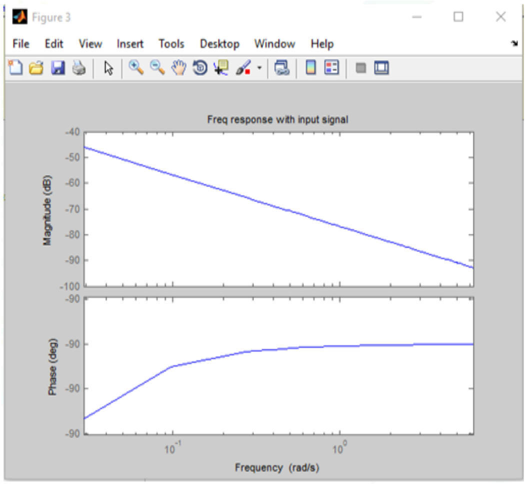


Figure 6: Frequency response with respect to the input signals

The frequency response according to the input signals are shown in figure 6. This bode plot is plotted in relation to the varying input signals. Closed loop response is plotted with amplitude in the y axis and time in x axis shown in figure 7.

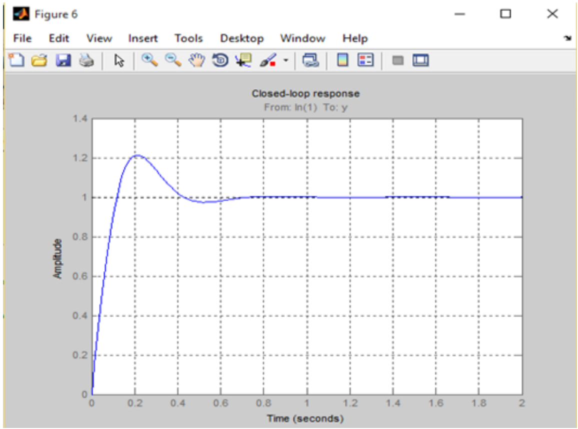


Figure 7: Closed-loop response

A Closed-loop control System is a control system that uses the concept of an open loop system as its forward path but has more than one feedback loops or paths between its input and its output. Feedback simply means that some portion of the output is returned back to the input to form part of the systems excitation.

Normally, closed-loop systems are demonstated to automatically achieve and maintain the desired output criteria by comparing it with the actual criteria. This is done by generating an error signal which is the difference between the output and the reference input. In other words, a closed-loop system is a fully automatic control system in which its control action being dependent on the output in some way.

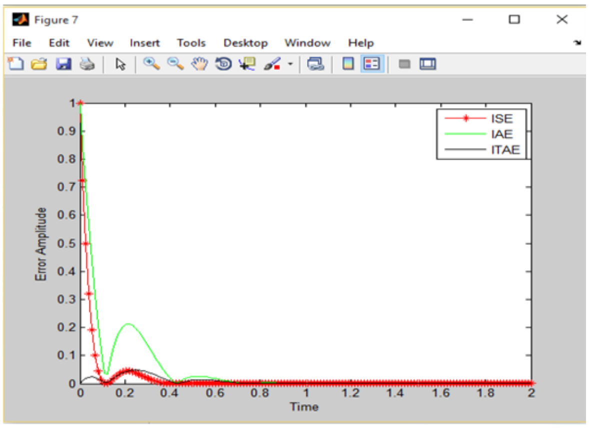
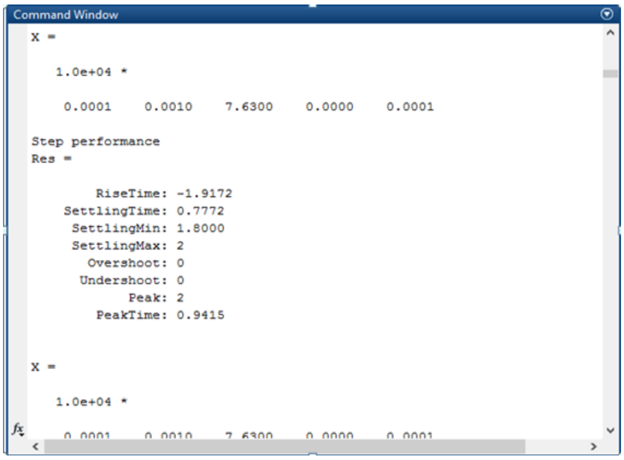


Figure 8: Error minimization with ISE, IAE and ITAE

The three generally used error minimization measures includes Integral Squared Error (ISE) minimization technique, Integral Absolute Error (IAE) error minimization technique and Integral Time-weighted Absolute Error (ITAE) error minimization technique. Integral Square Error (ISE) is a measure of system performance. It is formed by integrating the square of the system error over a fixed interval of time. ISE performance measure and its generalizations are commonly used in linear optimal control and estimation theory. ISE integrates the square of the error over time. Integral Absolute Error (IAE) is used for measuring the performance of real control systems.



```
x =

   1.0e+04 *

    0.0001    0.0010    7.6300    0.0000    0.0001

Step performance
Res =

        RiseTime: -1.9172
    SettlingTime: 0.7772
     SettlingMin: 1.8000
     SettlingMax: 2
       Overshoot: 0
      Undershoot: 0
            Peak: 2
        PeakTime: 0.9415


x =

   1.0e+04 *

    0.0001    0.0010    7.6300    0.0000    0.0001
```

Figure 9: The time domain response

The time taken by a signal to change from a particular low value to a specified high value is known as the rise time. The settling time of an output device is the time elapsed from the application of an ideal step input to the time at which the output has entered and maintained within a specified error level. Generally, it is symmetrical about the final value. A transient response is the response of a system to a change from an equilibrium or a steady state. A transient response is otherwise known as a normal response.

The transient response is not essentially tied to on/off events but to any event that affects the equilibrium of the system. A system's step response in a given initial state composed of the time derivation of its outputs when its control inputs are step functions. Step response is the time behavior of the outputs of a normal system when its inputs transform from zero to one in a very short time. Overshoot is the occurrence of a signal or function exceeding its target. It arises especially in the step response in band-limited systems.

Fall time (otherwise called as pulse decay time) is the time taken for the amplitude of a pulse to fall from a particular value to another specified value. Commonly, from 90% of the peak value to 10% of the maximum value exclusive of overshoot or undershoot. The values obtained for rise time , settling time, Minimum and maximum value of the settling time, overshoot, undershoot and peak time is shown in figure 9.

VI. CONCLUSION

The Iterative Feedback Tuning (IFT) algorithm has been developed to improve the performance of the wafer stage system. This optimization technique aims at conducting multiple experiments without any explicit necessity of a model. IFT is used for precise tuning of motion of the wafer stage system. Through IFT, controller settings, robust stability analysis, convergence of the parameter, error minimization and the time-domain response were evaluated and corresponding graphs were plotted.

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