Residual Vibration Analysis and Suppression for SCARA Robots in Semiconductor Manufacturing

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***Abstract*—This paper investigates residual vibrations of industrial SCARA robots in wafer handling applications. Due to rapid point-to-point movements, SCARA robot arms exhibit large vibrations after reaching the destination position. A mathematical model particularly suitable for residual vibration analysis is developed. The validity of the mathematical model is confirmed by the close match between experimental results and robot arm trajectories generated by the model. The root cause of residual vibrations is analyzed using the model. Based on the root cause analysis, a practical solution to suppress vibrations is proposed. The solution utilizes an acceleration smoother to smooth the commanded trajectory, and it can be easily implemented in practice without redesign the robot hardware or control system. Experimental results show over 40% reduction in both vibration amplitude and settling time.**

***Index terms*—Industrial robot, Vibration, Modeling, Control.**

1 INTRODUCTION

The robots studied in this paper refer to industrial SCARA (Selectively Compliant Articulated Robot Arm) robots for wafer handling as show in Fig. 1. Rapid point-to-point movements for the robot arms are usually involved in manufacturing environments. To transfer a wafer from one point to another, the robot arm needs to go through a series of motions involving accelerating to a required operational speed and decelerating to a full stop. The abrupt changes in acceleration or deceleration often result in residual vibrations. Figure 1 shows a laser recorded vibration plot (scale: 0.4mm/div) at robot's end-effector after the arm reachs the destination. The vibration may cause wafer slippery and lead to long system settling time.

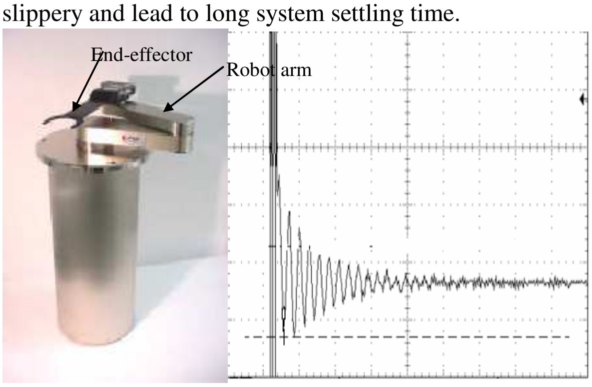

Fig. 1. A SCARA industrial robot and residual vibration.

To improve quality and efficiency of the manufacturing process, it is desired to understand the dynamics involved in the process and to develop efficient methods to suppress the vibration. The first thing is to identify the root cause of the vibration by creating and studying its dynamics model. Unfortunately, no well-developed models for studying the residual vibration of such robot arms are available in the open literature. The existing techniques of modeling SCARA robots are mainly for motion control as opposed to vibration control. In this paper, a dynamic model for vibration study of this type of industrial robots is first presented. Based on the dynamics model, a solution is then proposed to suppress the vibration. The dedicated modeling provides a good reference for similar industrial robots. The generic solution for vibration suppression can also be applied to other industrial applications.

The robot arm discussed here is driven by DC motors with high gear ratios for power transmission. The end-effector in the robot arm is connected to the motor through a number of pulleys. The pulleys are connected through timing belts. One advantage of this type of indirect drive system is its variation-isolation effect since the inertial changes on the payload have little effect on the actuator due to high reduction ratio. Besides backlash and additional friction in the transmission system, another disadvantage of the indirect drive system is that the lumped elasticity of the transmission system makes the robot arm work like a flexible manipulator and isolates the direct motor control and position feedback from the robot's end-effector. The residual vibration resulting from the elasticity (translation or rotation spring impact of the timing belt) of the transmission system sometimes becomes quite significant in a high-speed point-to-point motion. There are a couple of existing approaches to reduce or eliminate the vibration of a flexible structure:

- Increase damping by structural design or adding dampers: to ensure big damping, high natural frequency and stiffness [1][2];
- Open loop approaches: including trajectory smoothing input shaping and feed-forward approaches. The typical *trajectory smoothing* approaches (also called S-curve motion profiling) employ a multi order polynomial in time for trajectory generation [3][4]. Trajectory smoothing reduces the residual vibration by providing a smooth acceleration/deceleration and accounting for motor amplifier's electrical saturation feature. *Input shaping* approach convolves a sequence of impulses to produce a shaped input as the motion command. It reduces residual vibration by generating an input that cancels its own vibration [5][6][7][8]. *Feed-forward*

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