Modelling and Control of a High Speed, Long Travel, Dual Voice Coil Actuator

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Abstract - This paper describes the modelling and control of a dual voice coil actuator which is used in semiconductor packaging machines for both high speed short stroke motions and low speed and long travel on the same axis. This arrangement is particularly difficult to control because it has problems of mechanical motion coupling and undesirable mechanical characteristics on the small voice coil motor (VCM). To overcome them, this paper proposes to investigate the full control model of the dual voice coil actuator, and to use this knowledge as compensation blocks in the control system to reduce the control nonlinearities and coupling effects. Due to the non-conventional geometry of the dual VCM actuator, a novel method of obtaining the model parameters has been developed. Results show that the proposed control structure has substantial improvement over traditional dual PID control in terms of speed, accuracy, disturbance rejection and control robustness.

I. INTRODUCTION

Semiconductor assembly machines (e.g. wire bonders and die bonders) require high speed short stroke motions and lower speed and longer stroke travels on the same axis [1,2], as shown on the chip-on-board (COB) assembly in figure 1.

For this purpose, a dual VCM actuator can be used. The large VCM is user to carry the main load for low speed and long travel, while the small VCM is responsible for fast and short motion strokes. The structure of such a device is shown in figure 2. To reduce motion coupling disturbance on the small VCM, the small VCM is designed to have most of its mass aligned perpendicular to the direction of movement. In spite of this, the coupling disturbance is still a dominant factor to the controller.

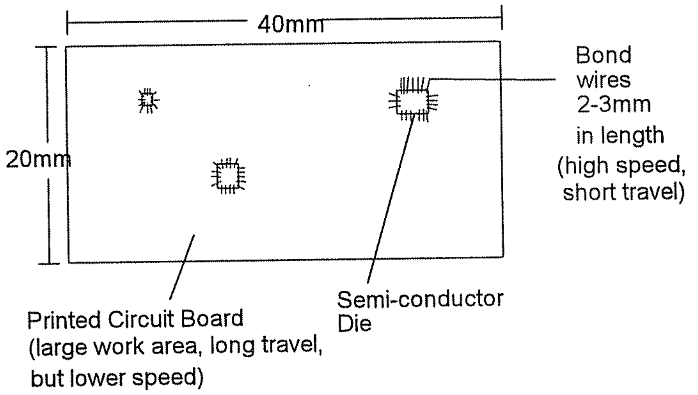


Fig.1 The bonding wires of a COB assembly

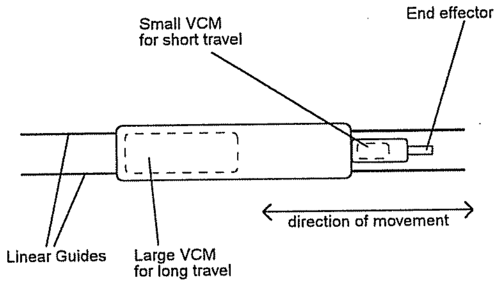


Fig.2 Construction of the dual VCM actuator

Most existing wire bonding machines use PID and acceleration feedforward [3] as the motion control algorithm. However, this method does not propose satisfactory result for the dual VCM actuator. Due to the small size and small travel displacement of the small VCM, spring, friction, inertia, and other mechanical characteristics become a dominant factor in the motion dynamics [4].

To provide accurate and high speed motion control with long travel and little disturbance coupling, this paper proposes to investigate and obtain an accurate control model of the dual VCM actuator, and to use this model as compensation blocks for the motion controller. Traditional methods of obtaining modelling parameters from a motor [5] cannot be applied to the dual VCM actuator, due to its short displacement limit, complex construction geometry, and the difficulties of tapping mechanical measurements from such a structure.

In this paper, a novel method of obtaining the system model is developed. The model is partly constructed by considering the motion geometry of actuator and partly constructed by estimating the parameters from a few open loop motion profile measurements.

Hardware implementation of the proposed modelling and control strategy has shown that there are substantial improvements over traditional PID control method in terms of accuracy, speed, disturbance rejection, and system robustness.

Section II of this paper describes the method of obtaining the control model; section III describes the control system structure; sections IV and V are the actual implementation and the results of the proposed system.

II OBTAINING THE DYNAMIC MODEL OF THE ACTUATOR

In this section, a full model of the dual VCM actuator is constructed. The model includes inter-axis coupling effect, spring effect, friction, and inertia.

A. Calculation of spring effect

The movement of the VCM has a nonlinear relationship with the spring position, as shown in figure 3. In this project, the force-position relationship of this spring effect is calculated from the geometry of the VCM and the spring constant. This relationship has been used in the spring compensation block of the controller.

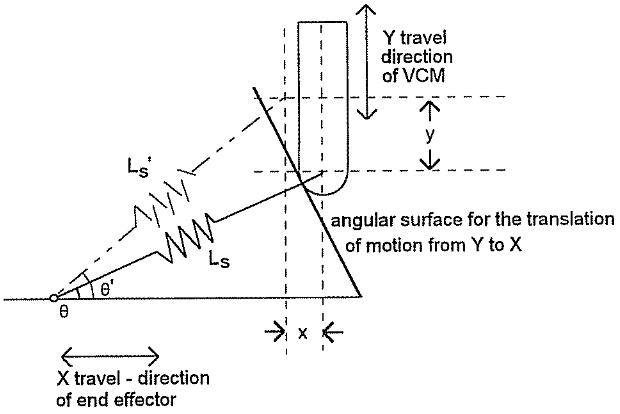
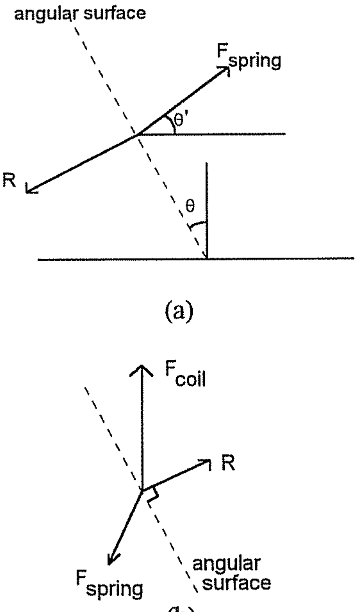


Fig. 3 Geometry of the VCM

The amount of spring force induced on the voice coil is calculated by considering the free body diagram of the wedge and the coil bearing as shown in figure 4(a) and 4(b).



(a)

(b)

Fig. 4 Free body diagram of (a) the spring in relation to the angular surface, and (b) the coil bearing

B. Estimation of friction on the small VCM

Due to the small size and the geometry of the small VCM, friction becomes a dominant factor. It has been found that friction is a discontinuous nonlinear function which depends on the velocity of the small VCM.

To estimate the amount of frictional force on the small VCM, a friction learning program has been developed to run the small VCM in open loop mode. By applying different current profiles to the small VCM, the acceleration, position, and current profiles at various velocities are recorded. The friction vs velocity profile is then found from these measurements. Spring effect is deducted from the measurements to obtain the net friction effect.

The friction profile variates on different VCMs and it is prone to change with time. Therefore the friction learning program is being run at regular intervals to update the friction compensation profile of the controller.

C. Inertia of the VCMs

The inertia of the VCMs are obtained by applying a constant current (i.e. force) to the voice coil and measure its increase in velocity. To keep the frictional effect to a minimum, the voice coil must be driven by a very large force with the increase in velocity measured during start up, or when the velocity is low. For the small VCM, the spring effect needs to be deducted from the measurements to obtain the net inertia value.

D. The intercoupling effect of the two VCMs

Since both VCMs travel on the same axis, movement of one VCM will unavoidably affect the other. Due to the small size and the less stiff control structure, the small VCM is much more prone to disturbance than the large VCM.

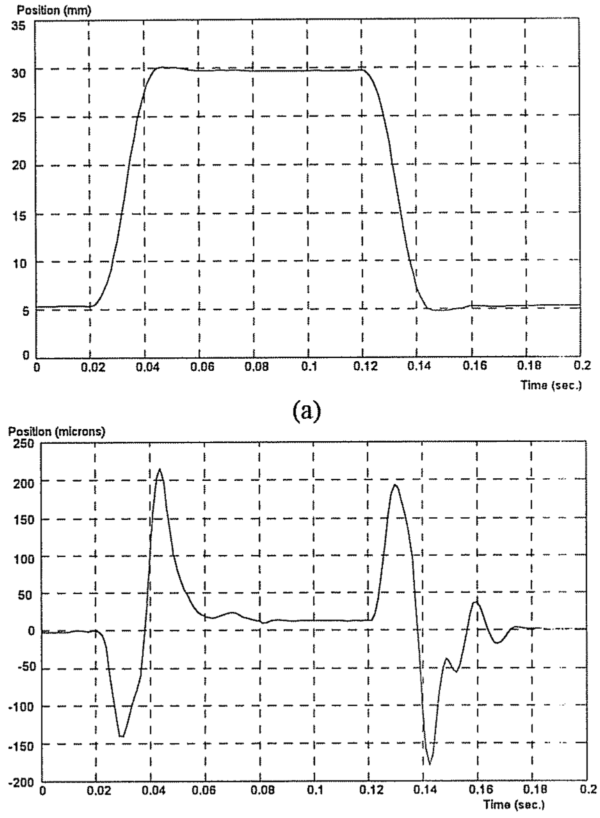
To reduce this disturbance effect, a decoupling compensation block is added to the small controller. To obtain the disturbance model, the small VCM is assumed to operate on a moving platform. The motion of the moving platform, together with the dynamics of the small VCM, are used to build disturbance decoupling compensation block. Figure 5 shows the disturbance of the small VCM caused by the motion of the large VCM.

II THE PROPOSED CONTROL STRUCTURE

Figure 6 shows the proposed control structure of the dual VCM actuator. The structure consists of two trajectory controllers and compensation blocks for friction, inertia, spring force and inter-VCM decoupling.

III IMPLEMENTATION

The controller system is implemented on a DSP system. Optical encoders are used as position sensing. PWM current amplifiers with a chopping frequency of 20KHz are used as the output driver. The sampling frequency of the control loop is 4KHz. Figure 7 shows the experimental setup of the dual VCM actuator control.



(a)

(b)

Fig.5 Disturbance of the small VCM (shown in Fig.6b), due to the motion of the large VCM (shown in Fig.6a)

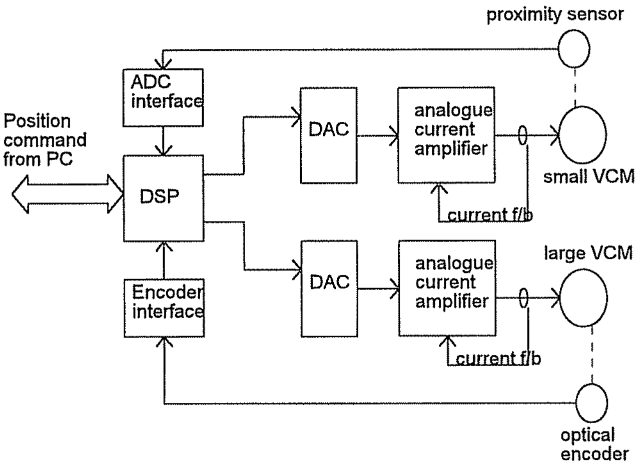


Fig.7 Setup of the experimental system

IV RESULTS

Figure 8 shows the trajectory control of the small VCM with inertia compensation only. When spring effect compensation is added to the controller, there is a substantial improvement in offset elimination and start up acceleration, as shown in figure 9. When friction compensation has been added, there is a big improvement in position tracking, and it achieves near perfect tracking, as shown in figure 10.

All the above measurements has been obtained with the large VCM remained stationary. To verify the effect of the decoupling compensation block, the large VCM is commanded to move with a high acceleration profile, and the small VCM remains stationary.

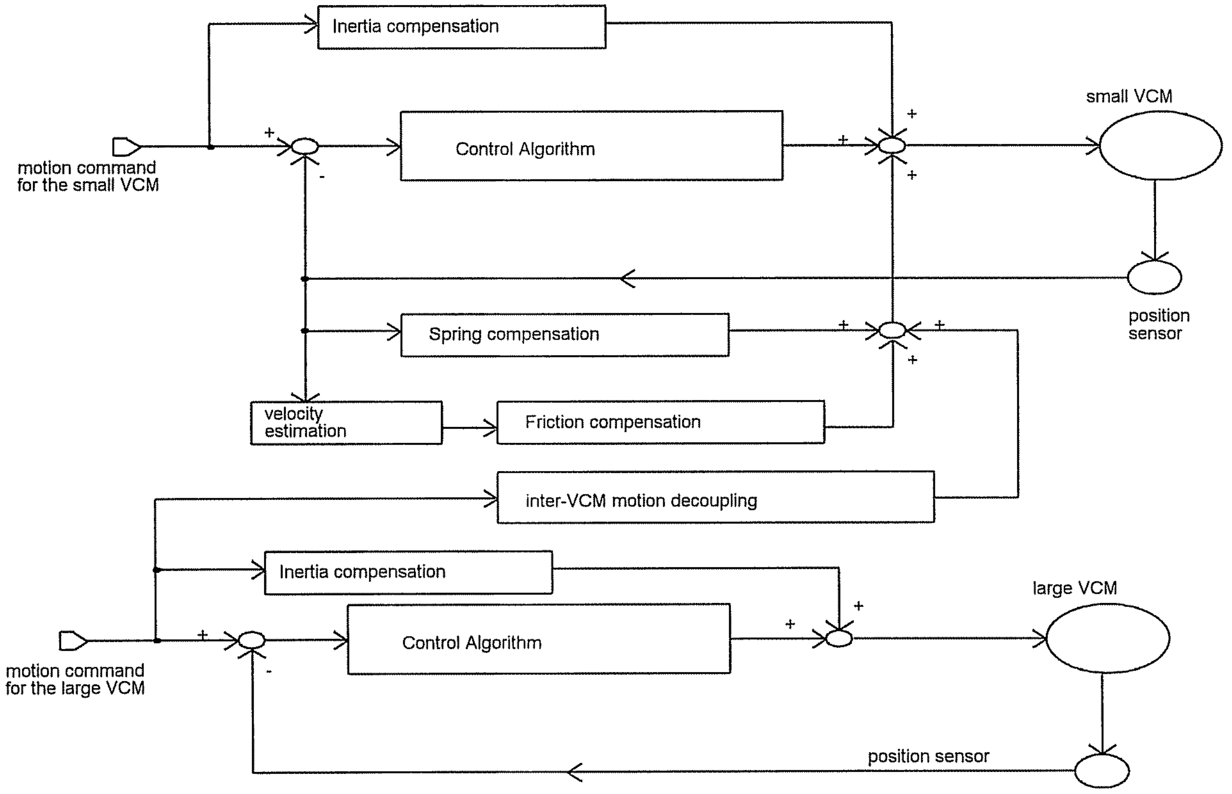
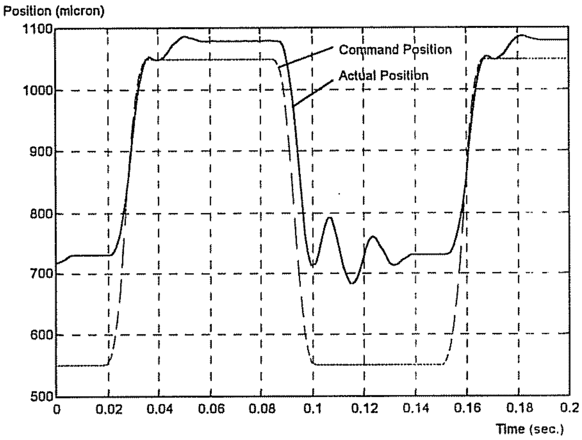
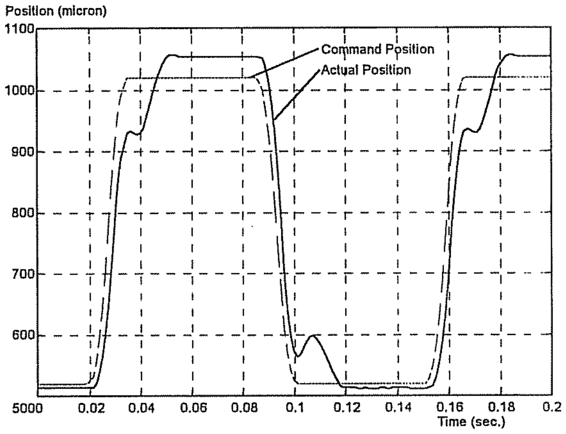


Fig.6 Control structure of the dual VCM actuator

Figure 11 shows the disturbance response of the small VCM when the decoupling compensation block is switched off, and when it is switched on. The result shows that the decoupling compensation block reduces the inter-VCM disturbance to one fifth its original value.



Fg.8 Trajectory profile of the small VCM with inertia compensation only



Fg.9 Trajectory profile of the small VCM with inertia and spring compensation

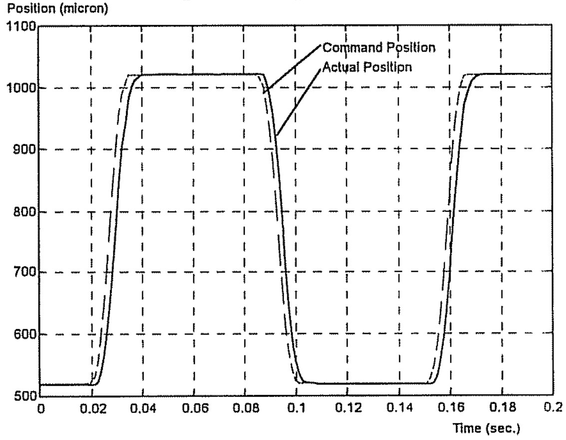


Fig.10 Trajectory profile of the small VCM with inertia, spring, and friction compensation

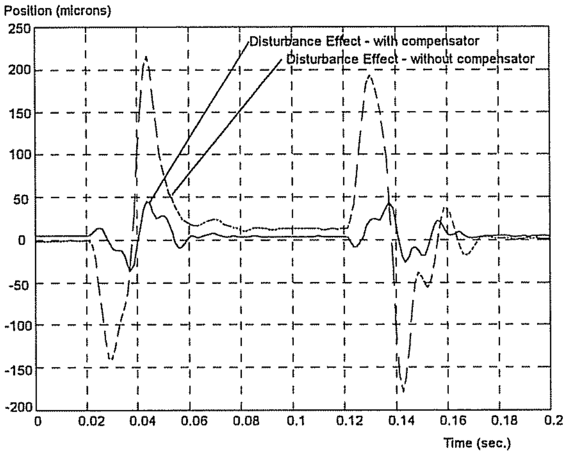


Fig.11 Reduction of inter-VCM disturbance due to the compensation block

V CONCLUSION

This paper has described the modelling and control of a dual VCM actuator. Due to the non-conventional structure of the actuator, the device suffers control problems of high friction, spring nonlinearity, and inter-VCM motion disturbance. This paper solved these problems by addition of compensation blocks to the control structure. The paper also proposes a list of procedures to obtain the model parameters for the compensation blocks. The proposed control structure has been implemented on a DSP. Results shows that the proposed control structure can significantly reduce the nonlinearities and disturbances of the mechanical system, and is much superior to traditional PID controllers used in industry today.

VI REFERENCES

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VII POSTSCRIPT

Mathematical derivation and further experimental results will be provided in the full paper, and at the conference.