Design and Contact Force Control of a Flip Chip Mounting Head system

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Abstract: This paper contributes to development of a new chip mounting head system for flip chip. Recently, the LDM(Linear DC Motor) has been widely used, because it has particular merits than the rotary type motors. In this paper, we proposed a macro/micro positioning system for force control of a chip mounting system. In the proposed macro/micro system, the macro actuator provide the system with a gross motion while the micro device yields fine tuned motion to reduce the harmful impact force that occurs between very small sized electronic parts and PCB surface. In order to prove the effectiveness of the proposed macro/micro chip mounting system, we compared the proposed chip mounting head with the conventional chip mounting head equipped with a macro actuator only. A series of experiments were executed under the mounting conditions of various access velocities and PCB stiffness. As a result of this study, a satisfactory voice coil actuator as the micro actuator has been developed , and its performance meet well the specifications desired for the design of the chip mounting head system and show good correspondence between theoretical analysis and experimental results.

Keywords: surface mounting system, macro/micro actuator, force control, position control, impact control

1. INTRODUCTION

Recently, chip packaging methods of the surface mount technology has been variously studied particularly for flip chip. Flip chip packaging method is usually the method that makes the chip bumping on the module substrate. That is the newest technology that has some characteristic for instance, the shortest connecting length, low heat resistance, low permittivity, ultra-small size, a lot of yields and low cost. In 40 years history, flip chip technology is extremely interesting again due to display industry activity and used as one of the most advanced packaging technology.

Flip chip has features generally such like ultra-thin film and light weight. So it is easily to be broken during manufacturing process. But, currently, the commercial chip mounting head system can not carried out precision force feed back control. As the previous chip mounting head system is composed of only macro actuator, it can not effectively the contact force occurred at high speed contact between a small chip and the printed circuit board. Therefore we need the precision force feed back control to put a flip chip on the printed circuit board printed. Practically, a new chip mounter capable of precisely controlling mounting force in order to mount electronic parts involving flip chips in high speed needs to be developed in industry. The concept of the macro/micro manipulators has been proposed as one of the method to solve these problems. A macro actuator acts merely as a position-controlled transportation system, while a micro actuator acts a force-controlled device. As micro actuators, ultrasonic piezo motor, VCM(voice coil motor) motor and etc have been used.

In this paper, we used the VCM as a micro actuator. The VCM has been recently used to Hard disk and optical disc drive. It utilizes the Lorentz force. Linear VCM has simple structure and is easy to control, and reduce undesired nonlinear effects such as backlash. Therefore, its features are low mass, high resolution and low friction, fast response, and linearizable force generation. In this research, we adopted linear encoder and load cell for precision position and force control. The proposed chip mounting head mechanism is tested to evaluate the performance of the macro and micro actuators and analyze the effects of various mounting conditions. Based on the experimental results, performance of the proposed mounting head system, that is ,the performance of impact force control is discussed in detail.

2. DESIGN OF THE CHIP MOUNTER HEAD SYSTEM

In Figure 1, the chip mounter consists of macro and micro actuators. The macro part used the usual AC servo motor and the micro part used the VCM.

In Figure 1, the rotational motor is attached to the vertically moving part of the macro actuator which is together linear guide and transfers rotational force to the micro actuator block using linear guide. A linear encoder is used to measures the position of the micro actuator. Resolution of the linear encoder is 0.1 μm .

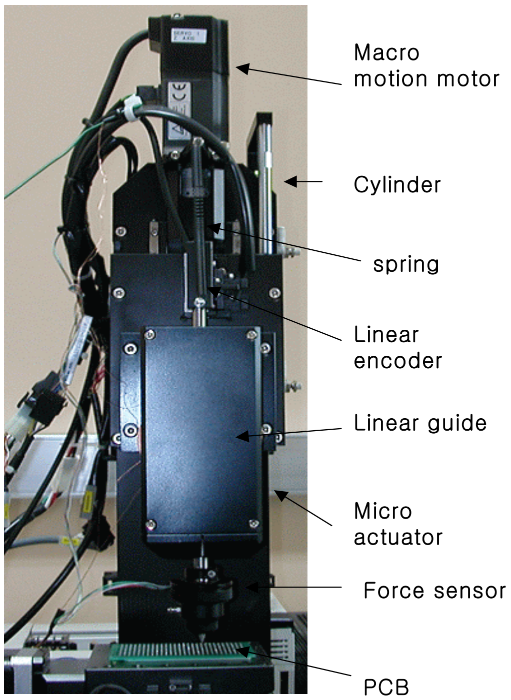


Fig.1 The experimental rig of macro/micro actuator

A sensitive force sensor is required to measure force generated when a chip is mounted. The force sensor is necessary to regulate the contact force at a desired force level. A load cell is used as the force sensor and it measures the contact force.
We selected a washer type load cell as the force sensor inside nozzle shaft section as shown Figure 1.
This sensor can measure compressive force up to 100N. Dimension of the sensor is 25.4mm[diameter] x 3.81 mm[thickness]. The micro actuator has such advantages as low inertia, low friction, and active compliance as stated in the above, but it has relative short stroke

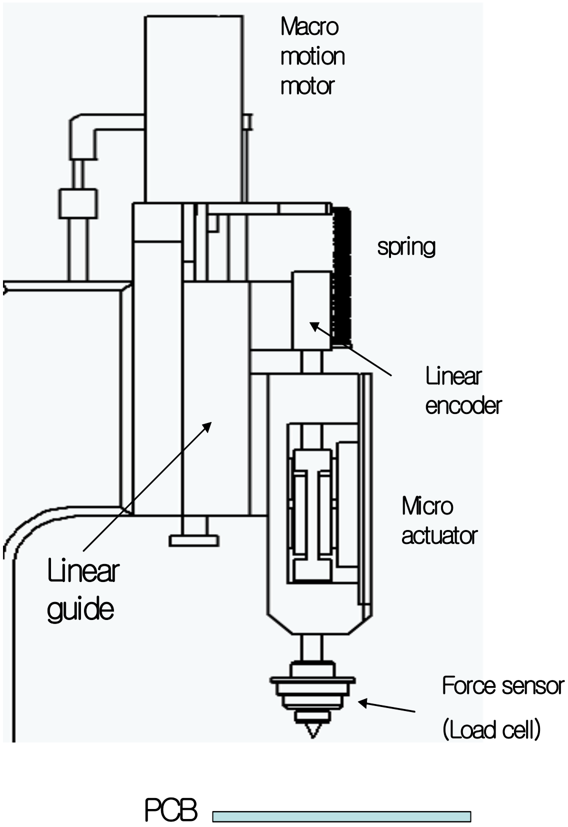


Fig.2 The structures of Chip mounter

However, the macro actuator can extend the reachable distance of the micro actuator by the macro/micro structural configuration.
Figure 2 shows the proposed chip mounting system with the macro/micro actuator in detail. The specifications of the prototype of the micro actuator are as follows; coil diameter of the micro actuator is each 0.25mm, the number of winding turns is 1200 and the coil resistance is approximately 26 Ω. Weight of the moving part of the macro actuator is about 2500g and that of moving part of the micro actuator in the macro/micro actuator is about 300g. The stroke of the macro actuator is 55mm and that of the micro actuator is 6.4mm

3. DESIGN OF THE MICRO ACTUATOR

3.1 Moving principle of the micro actuator

A VCM is used in the proposed chip mounting head system. The VCM generates linear force proportional to the current. Figure 3 is the photograph of the proposed chip mounting head system.

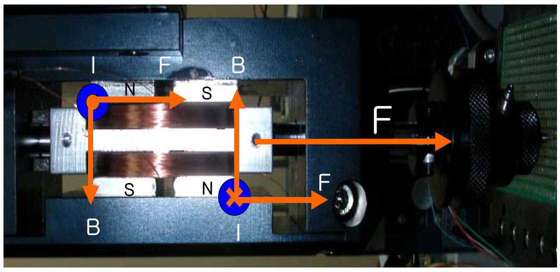


Fig.3 Micro actuator by the VCM

The micro actuator is composed of four rectangular magnets and two moving coils as shown in Figure 3. The actuator is designed with only one degree of freedom for translational motion by adopting the linear spline bearing. The actuator consists of five parts; 30x20x5mm four rectangular magnets, two circle coils, two linear spline bearings, a shaft and a cover. Magnet is made of the cylindrical NdFeB. The shaft and cover are made of aluminum.

3.2 Position,Force calibration and Current relation

Actuating force of the micro actuator is changed according to current input I in the coil and the relative position between the magnet and the coil.

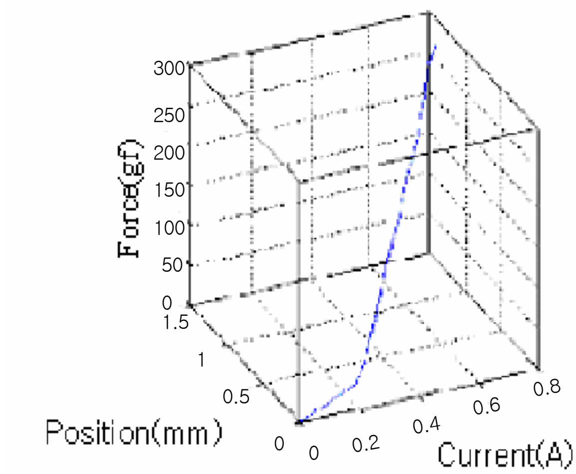


Fig.4 Relationship among position, current input, actuating force

Figure 4 shows the experimental data in order to analyze the relationship between the position and actuating force of the proposed micro actuator and the input current to the coil.
To obtain experimental data, the moving part of the macro actuator is strictly fixed at a location. At this condition, the end tip of the micro actuator is made in contact with the precision load cell by making its travel a certain distance x. The distance x means the relative position between four inner magnets and two moving coil of the micro actuator

3.3 Modeling of the micro actuator

The chip mounting head system is identified for control after the attached sensors are calibrated. The total system including a VCM driver, sensors, an amplifier and filters is identified to control the chip mounting head system effectively. Figure 5 shows a block diagram of the total system. It consists of a VCM as a micro actuator to drive the chip mounting head system, load cell to monitor the contact force and linear encoder to measure displacement of the VCM.

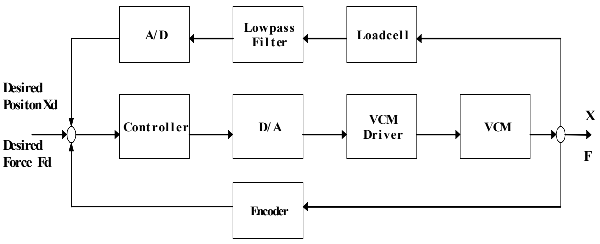


Fig.5 Block diagram of the microactuator

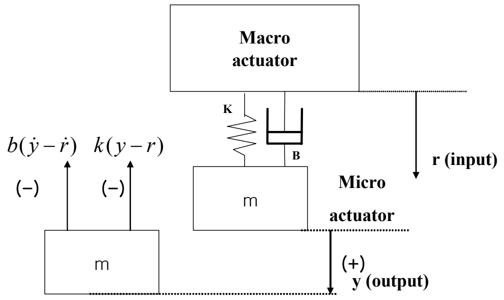


Fig.6 System modeling of microactuator

$$\sum F = m\ddot{y} \qquad (1)$$

$$-k(y-r) - b(\dot{y}-\dot{r}) = m\ddot{y} \qquad (2)$$

$$\therefore m\ddot{y} + b\dot{y} + ky = b\dot{r} + kr \qquad (3)$$

$$\frac{Y(s)}{R(s)} = \frac{bs+k}{ms^2+bs+k} \qquad (4)$$

Figure 6 represents the system model of the micro actuator. Eq. (1),(2),(3),(4) shows equations of the transfer function of the micro actuator.

We operate the micro actuator by giving an input of sweep frequency in order to solve the transfer function for position. The transfer function identified from really measured data is described in Equation(5). We used Matlab and consequently resulted in the following 2nd order equation.

$$Tr = \frac{0.7096s + 2.053}{s^2 + 2.019s + 0.1853} \qquad (5)$$

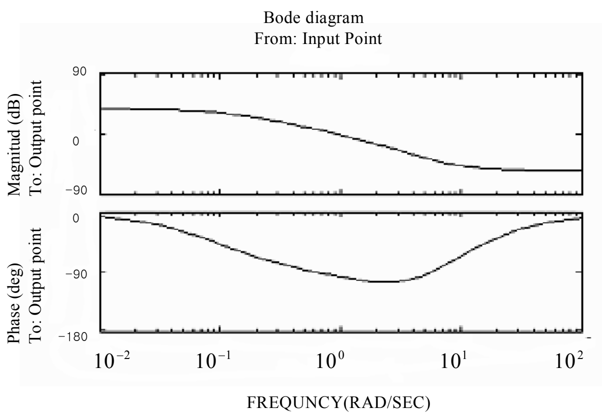


Fig.7 Bode plots equation.(5)

Figure 7 shows bode plots of the real and identified systems. The stable operation range is selected from 0.1 - 1Hz based on the system identification. The output signal can be get from the position sensor, encoder.

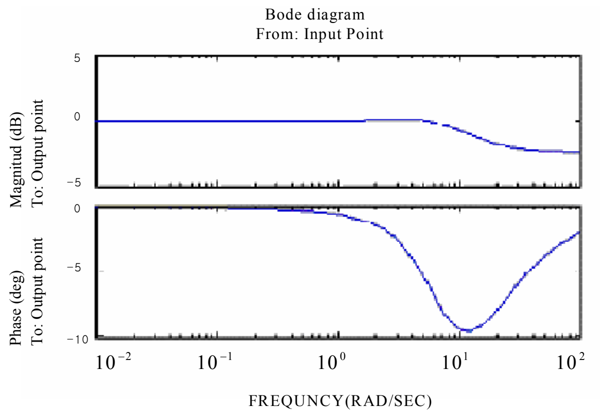


Fig.8 Bode plots including PID controller of the microactuator

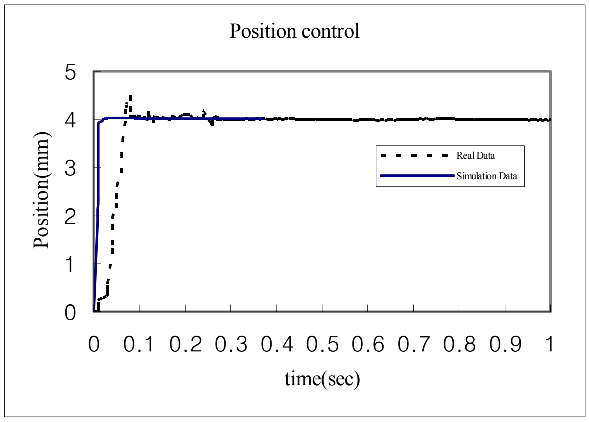


Fig.9 Step Response

Figure 8 shows bode plots of the case of PID controller. The stable operation range is enlarged to 0.1 - 50Hz .

Figure 9 shows step response of Equation (5) including the PID controller in the micro actuator. Figure 9 shows a little difference between the simulation and real data. We know that the transfer function of Equation (5) is accurately obtained.

4. DESING OF THE FORCE CONTROLLER

In the surface mounting, electronic parts contacts with the surface of the PCB. As the mounting head contacts at high speed, electronic chip is easily damaged by impact force. So, it is necessary to make the chips smooth contact with PCB within given tact time.

In the chip mounting head with the macro/micro actuator, the macro actuator moves the micro actuator to the near position of PCB, and the micro actuator is simultaneously accelerated while macro actuator is decelerated. Then, the micro actuator moves with constant velocity until it contacts with the PCB.

The chip mounting head system is operated by PID controller as follows:

Macro actuator:

$$f_1 = K_{P1}e_1 + K_{I1}\int e_1 dt + K_{D1}\frac{de_1}{dt}$$

$$e_1 = x_{1d} - x_1$$

Micro actuator:
Position control mode

$$f_2 = K_{P2}e_2 + K_{I2}\int e_2 dt + K_{D2}\frac{de_2}{dt}$$

$$e_2 = x_{2d} - x_2$$

Force control mode

$$f_2 = K_{Pf}e_f + K_{If}\int e_f dt + K_{Df}\frac{de_f}{dt}$$

$$e_f = F_d - F_c$$

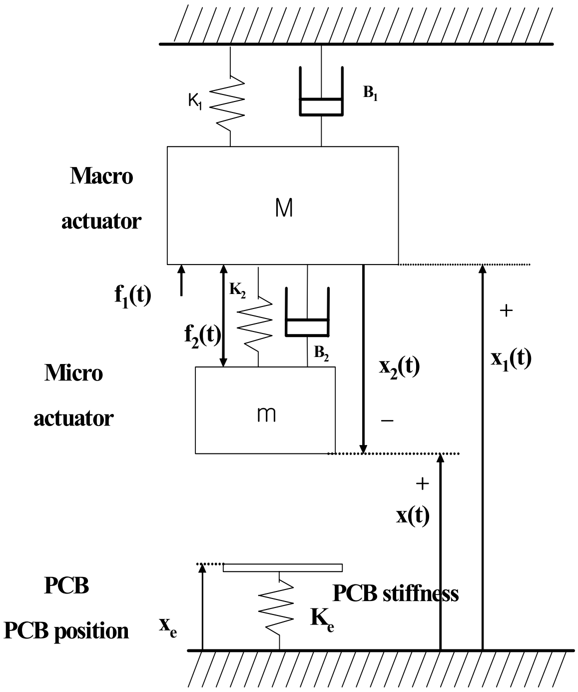


Fig.10 Configuration of coordinate axis

Figure 10 illustrates a model of the proposed system configuration. Here, x1(t) denotes the absolute position of the macro actuator with respect to the fixed frame, and x2(t) describes the relative position of the moving part of the micro actuator with respect to the moving frame of the macro actuator. The position of end tip is described by x(t), which is calculated by x(t)=x1(t)-x2(t). Each spring and damping elements are used for counterbalance due to gravity. The spring K2 and damping B2 is used to compensate the weight and the inertia force according to the deceleration of the macro actuator.

In the first mode, fast motion control of the macro motion device is accomplished to approach near to the target position. In the second mode, searching motion control of the micro motion device is carried out to decrease the initial impact force. Figure 11 illustrates the overall control system block diagram. The control block consists of the PID position control parts for macro actuator and the PID force control part for micro actuator. As shown in the figure, the controller of the micro actuator switches "position control mode" to "force control mode" when contact force is larger than the predefined threshold force f1. Then, the micro actuator executes the force control task by a PID force control algorithm

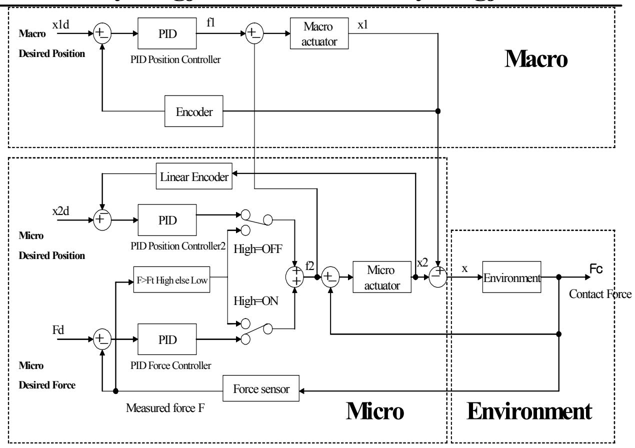
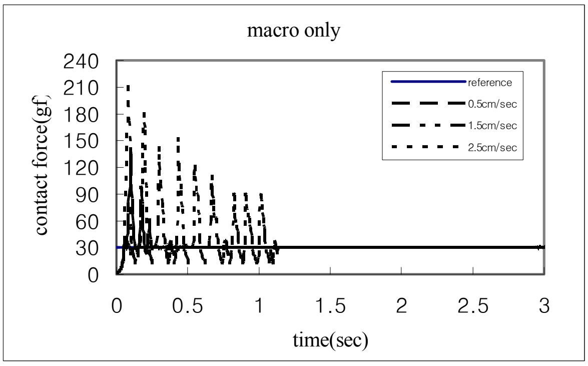
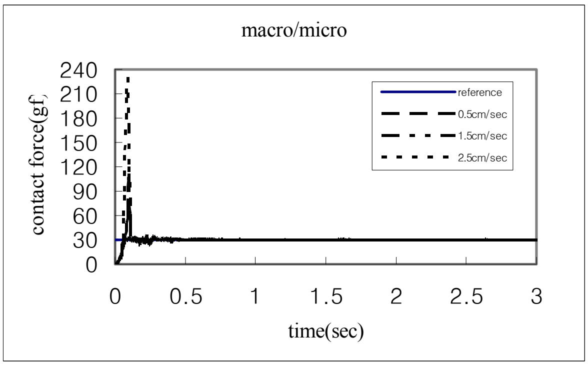


Fig.11 The propsed control block diagram

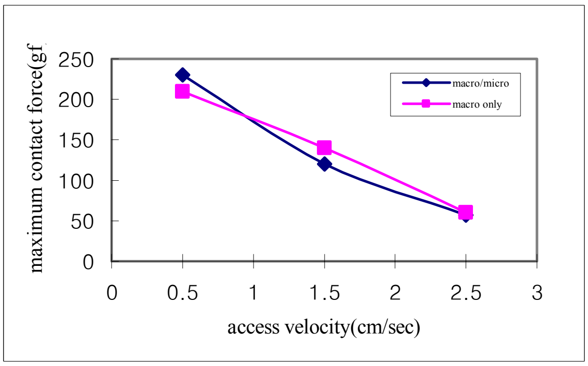
5. EXPERIMENTS



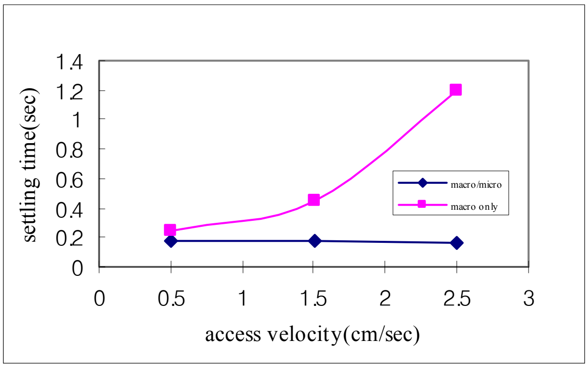
(a) Contact force according to acess velocity



(b) Contact force according to acess velocity

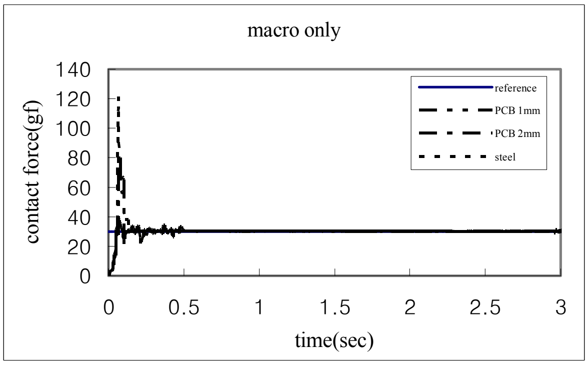


(c) Effects of access velocity

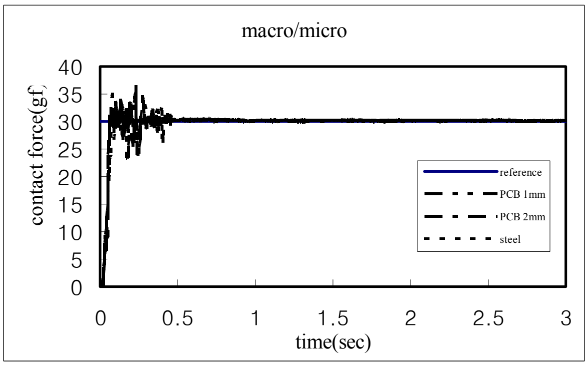


(d) Effects of access velocity

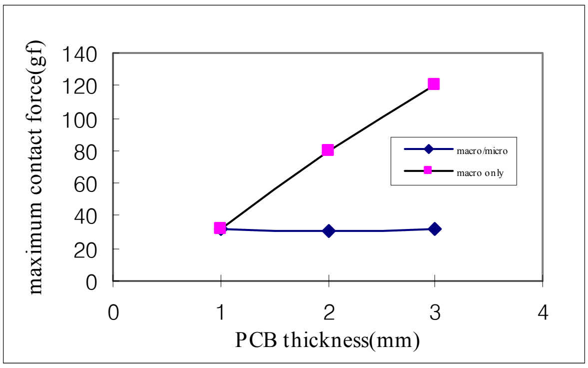
Fig.12 Contact force and effects according to velocity



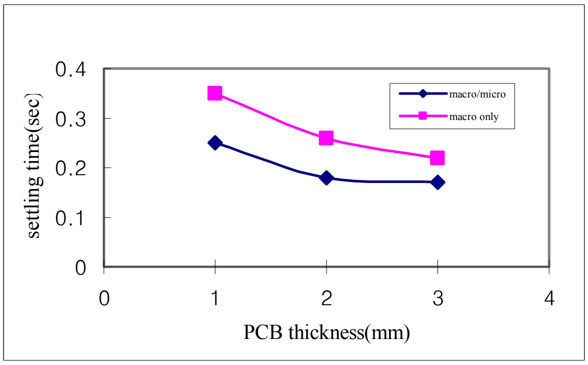
(a) Contact force response according to PCB stiffness



(b) Contact force response according to PCB stiffness



(c) Effects of PCB stiffness



(d) Effects of PCB stiffness

Fig.13 Contact force response and effects according to PCB stiffness

The maximum contact force and the settling time are shown in Figure 12 (a),(b),(c),(d). Desired force at the flip chip bonding process was set to be 30gf. In these results, faster access velocity results in higher maximum contact force and shorter settling time. The maximum contact force in the case of using the macro/micro actuator is much smaller than that of the only macro actuator and the settling time is shorter.

Fig 13 (a),(b),(c),(d). illustrates the force control responses of the proposed mounting head according to the various stiffness of PCB. Figure 13 shows the maximum contact force and the settling time for two cases. In these results, stronger stiffness results in higher maximum contact force and shorter settling time. However, the settling time is little changed regardless of the stiffness. In conclusion, the maximum contact force of the macro/micro actuator is much smaller than that of the macro actuator only. In addition, the settling time of the macro-micro actuator is shorter.

6. CONCLUSION

In this paper, we developed a new macro/micro chip mounting head system more safe than previous system.

The micro device is used to make a very fine motion with high reliability. Therefore, impact force can be drastically reduced by force control of the micro actuator. The advantages of this micro actuator are showed to be low mass, low inertia, low friction, and active compliance, high resolution, fast response, and linearizable force generation.

To investigate the effect of the parameters on the actuating force of the micro actuator, the relation between current input to coil, the magnet position and actuating force are obtained through a series of experiments. We confirmed the performance of the proposed flip chip mounting head system with macro/micro actuator via various experiments. However, the proposed system can be controlled within limited conditions. To enlarge the performance of the proposed chip mounting head system, more advanced controller such like fuzzy or adaptive control must be developed.

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