

Floated Wafer Motion Modeling of Clean Tube system

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Abstract: This paper presents a wafer motion modeling of the transfer unit and the control unit in the clean tube system, which was developed as a means for transferring the air-floated wafers inside the closed tube filled with the super clean airs. The motion in the transfer unit is modeled as a mass-spring-damper system where the recovering force by air jets issued from the perforated plate is modeled as a linear spring. The motion in the control unit is also modeled as another mass-spring-damper system, but in two dimensional systems. Experiments with a clean tube system built for 12-inch wafers show the validity of the presented force and motion models.

Keywords: clean tube system, transfer unit, control unit, wafer, mass-spring-damper

1. INTRODUCTION

The semi-conductors are produced in the clean rooms and thus, the typical semi-conductor factory consists of structure of 3 floors, where the first and the third floors are equipped with facilities for generating and ventilating the super clean airs and the second floor is maintained as a super clean room for fabricating the semi-conductors. So, building and maintaining such a clean room factory cost more than the quarter of the total expenses for the fabrication of semi-conductors. Furthermore, since the electronic circuits on the semi-conductor wafer get more and more integrated and the width of the circuit lines gets narrower and narrower very fast, it requires a much more super clean room environment in the near future. However, the current 3 floor structured clean room cannot satisfy those requirements technically and economically any more. So, the clean tube system was proposed as an alternative.

In the clean tube system the wafers are transferred inside the closed tube that is filled with the super clean air, while they are floated by the air ejected from the perforated plate in the tube. Since the wafer make no physical contact with any solids, it does not produce any contamination particles while transferred.

Early in the 1970's, a clean tube system is developed at IBM [1]. But, their system could not be implemented to the actual fabrication factory due to the high cost and the instable wafer motion, even though they introduced the air channels on the tube plate to increase the stabilities. In 1990's Toda and etc. proposed the new prototype of the clean tube system that consists of the control units and the wafer tracks [4, 8]. Their system showed the quite stable motion of a wafer, which became much larger sized than the one in 1970's. They calculated the pressure distribution under a wafer by using the simple force formulations and obtained the relationship between the floating height and the pressures [3, 5]

So far, while there have been the several researches about

the floating force distribution and the stability of the floated wafer by using the fluid mechanics, there has not been reported any researches about the dynamic behavior of the transferred motion of the wafer. So this paper presents a force and motion model of the wafer floated inside the transfer unit and the control unit of the clean tube system and then, we examine its validity by compare its motion with experiments.

2. MOTION MODELLING IN THE TRANSFER UNIT

Suppose that a wafer moves along center-line of the transfer unit as in Fig. 1. Let x denote a horizontal direction (center line) and y denote the vertical direction.

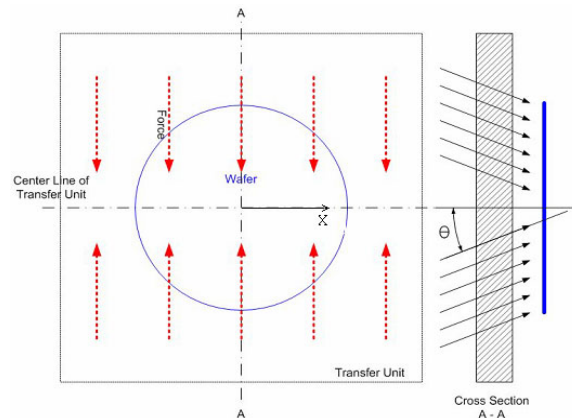


Fig. 1 Wafer Transfer unit

We assume the following to simplify the problem without losing generality.

- ▶ Floating holes are located evenly all over the unit.
- ▶ The air pressure and the volume flow rate ejected from each hole is same and consistent.
- ▶ All the floating holes are very small and consistent compared to the wafer size.
- ▶ Air holes are tilted with an angle (θ) to the center line.

Note that the tilting direction is opposite to that across center

line.

Toda [3] calculated the force to moved wafer horizontally as in (1).

$$F_0 = C_f \frac{1}{2} \frac{\rho q^2}{A} \sin \theta \quad (1)$$

When the wafer is deviated from the center line in y direction the horizontal force distribution changes, because the number of holes acting on the wafer varies. Since the holes are evenly distributed, the horizontal forces are assumed proportional to the area of a wafer over/under the center line.

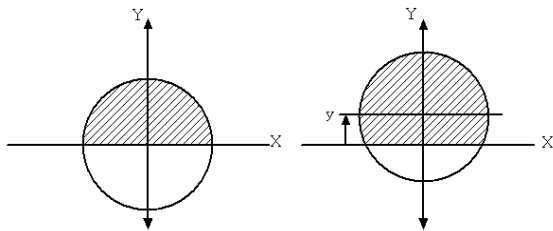


Fig. 2 Wafer that moves to y direction

$$A = \frac{\pi r^2}{2} - (r^2 \cos^{-1}(\frac{y}{r}) - ry \sin(\cos^{-1}(\frac{y}{r}))) \quad (2)$$

And the shaded area of wafer as in Fig. 2 is computed as in (2). Where, r is radial of wafer.

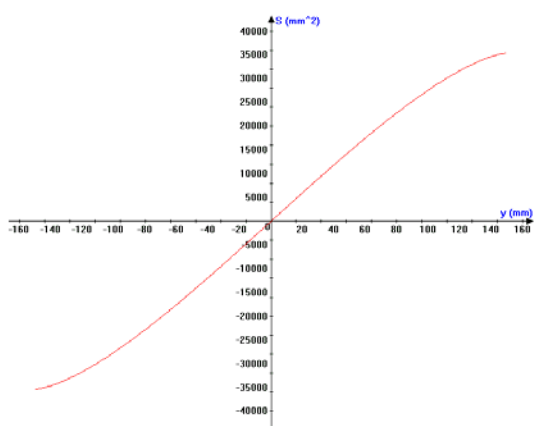


Fig. 3 Area change of wafer

Therefore the force in y direction is almost linear as a spring. Let K denote spring coefficient. Furthermore the friction force on the wafer can be computed as the viscosity friction. Then the system can be modeled as a mass-spring-damper model as in Fig. 4. The motion equation is described as in (3).

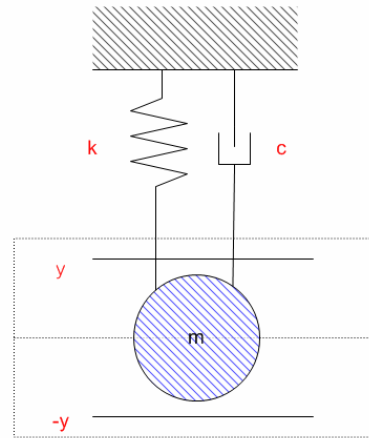


Fig. 4 Y direction exercise modeling of wafer

$$m \frac{d^2 y}{dt^2} + c \frac{dy}{dt} + Ky = 0 \quad (3)$$

3. MOTION MODELLING IN THE CONTROL UNIT

The control unit starts and stops the floated wafer, while the transfer unit simply floats the wafer that is moving from the control unit. The holes for floating a wafer are distributed evenly in the unit, but their directions are four kinds according to their positions, as shown in Fig. 5, which help the deviated wafer from the center of the unit to get back to it.

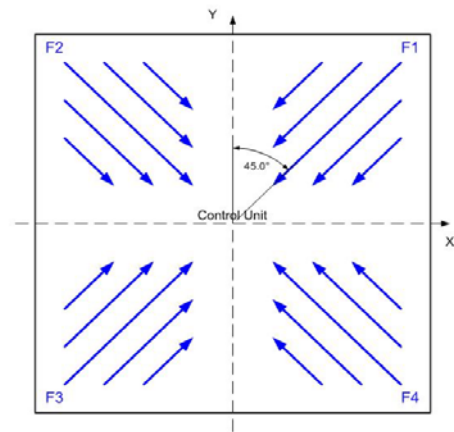


Fig. 5 The recovering force direction in the control unit

Each directional recovering force is denoted as F1, F2, F3, and F4 as shown in Fig. 5. Suppose that the wafer enters to the control unit from the left as in Fig. 6. Then, the wafer begins to be forced by F2 and F3. After it reaches the center of the unit, it is forced by F1 and F4, too.

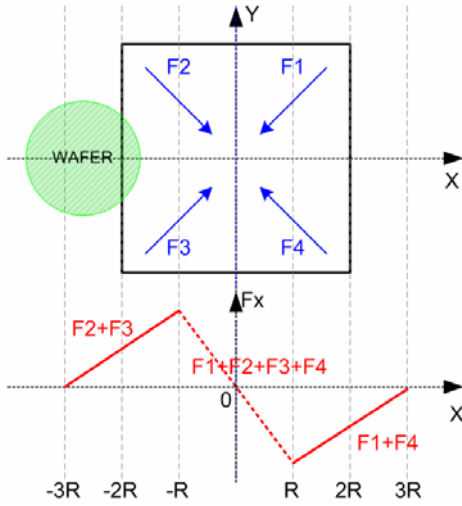


Fig. 6 The recovering force along the wafer motion

Let x denote as the location of the wafer center. Then, the recovering force along x is obtained as shown in Fig. 6. Specifically in $-3R < x < -R$, the recovering force is proportional to the area of wafer that goes inside the control unit. Since the shaded area of circle shown in Fig. 7 is computed as in (4) and increases almost linearly, the recovering force is assumed to increase linearly as shown in Fig. 7.

$$A = r^2 \cos^{-1}\left(\frac{r-x}{r}\right) - r(r-x) \sin\left(\cos^{-1}\left(\frac{r-x}{r}\right)\right) \quad (4)$$

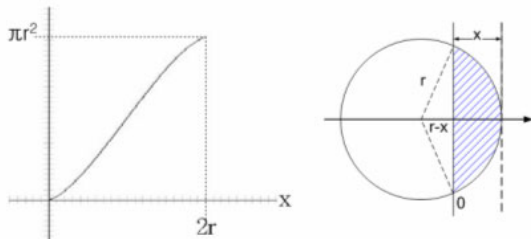


Fig. 7 Area of a wafer that goes in the control unit

In $-R < x < R$, the recovering force decreases twice as quickly as in the previous range. And in $R < x < 3R$, the recovering force has the same magnitude but the opposite direction as that in $-3R < x < -R$.

Besides the fact that the recovering force changes linearly along x , the viscous friction force acts on the wafer in the opposite direction of its motion. Thus, it is noted that the wafer motion can be modeled as a mass-spring-damper system as in (5).

$$m \frac{d^2x}{dt^2} + c \frac{dx}{dt} + kx = 0 \quad (5)$$

4. EXPERIMENTS

An experimental clean tube system as in Fig. 8 that consists of two control units and a transfer unit was built in order to show the validity of the proposed model.

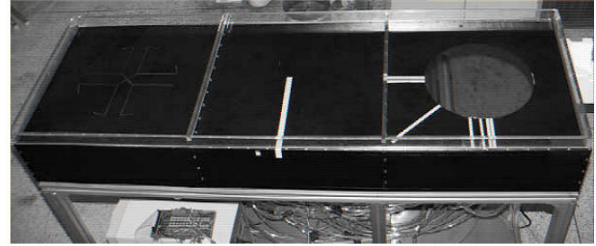


Fig. 8 The experimental clean tube system

Air is supplied from the air compressor to holes via several steps, as shown in Fig. 9. The two-port solenoid valves are used to turn on and off the air supplies to the holes in the experimental system.

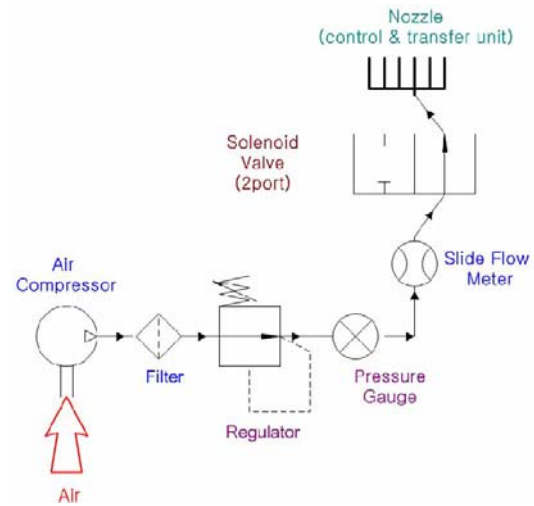


Fig. 9 Air inflow to nozzle

4.1 EXPERIMENTS IN THE TRANSFER UNIT

Forces on the wafer in the transfer unit are measured with the load cell that is located as in Fig. 10.

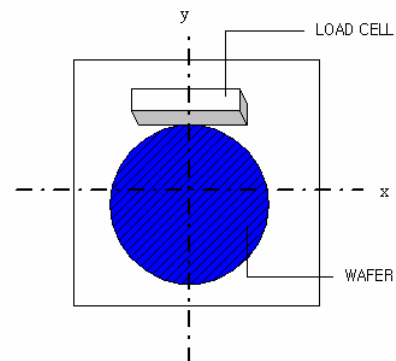


Fig. 10 Measurement of y direction force

Fig. 11 shows that the force in y direction increases very

linearly along with the deviation from the center line and those can be modeled as a linear spring force variation.

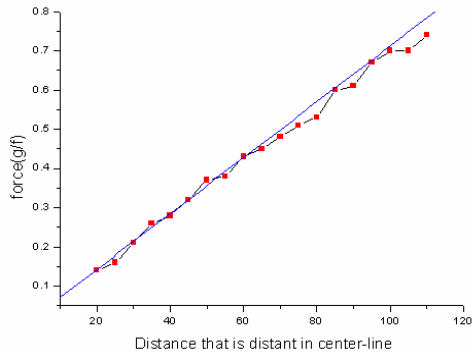


Fig. 11 force variation along the displacement in y direction

The transfer unit is a square plate whose side edge is 500mm long. When the wafer rests initially at $y = 100\text{mm}$ it oscillates.

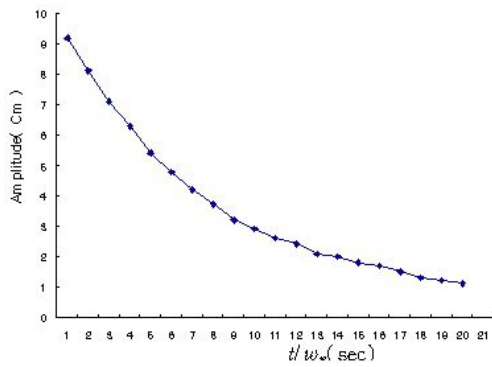


Fig. 12 Amplitude decrease of wafer motion

Fig.12 shows the amplitudes of each period. And the damping coefficient(c) and the spring constant (k) are calculated as in (6).

$$k = m(\omega_n)^2 \quad c = 2m\omega_n\zeta \quad (6)$$

Therefore, the wafer motion y direction is solved as the following.

$$y(t) = 10 \times e^{(-0.016 \times 0.07661t)} \sin(0.766t + 89) \quad (7)$$

The motion modeled by (7) matches very well with the experiment result as shown in Fig. 13.

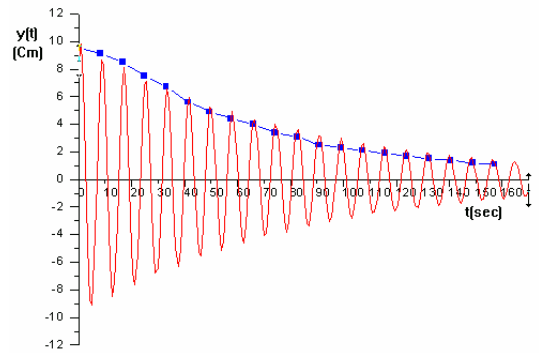


Fig. 13 Motion of y direction wafer

4.2 EXPERIMENTS IN THE CONTROL UNIT

When the wafer deviates from the center of the control unit, the recovering forces are measured with a load cell as in the transfer unit. Fig .14 shows measures the force along with the varying wafer location and the varying air pressure. It is noted that the recovering force increases linearly, as the wafer deviates from the center. It was the expected result from the section 3. The spring constant is obtained as 0.02338 N/m from Fig. 14, when the air pressure is $200 \text{ mmH}_2\text{O}$ which is used in the most experiments.

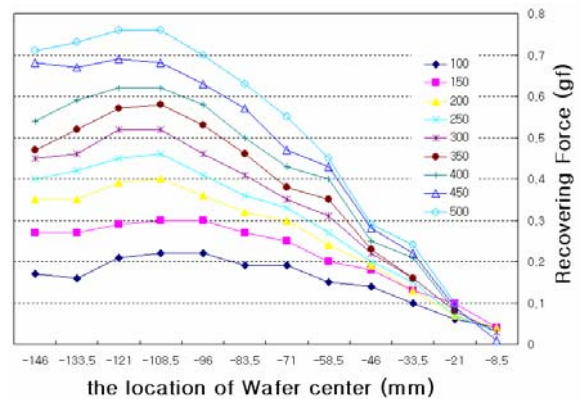


Fig. 14 The recovering forces along the wafer motion

When the wafer deviates initially from the center, its motion decayed like a viscosity damped free vibration. Fig.15 shows the amplitude of each period while the recovering force acts on the wafer. The decreasing width of the amplitude is about 9% and the period of motion is about 10 seconds. The damping ratio, ζ is obtained as $0.0463 \sim 0.0236$ at the air pressure of $100 \sim 500 \text{ mmH}_2\text{O}$. This motion is significant in that the wafer's motion is not amplified but converges, since the friction force is very small between track and wafer.

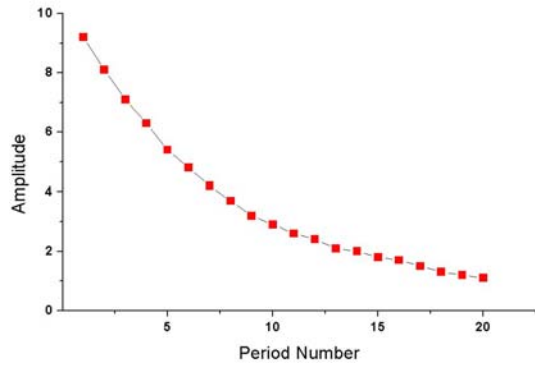


Fig. 15 The exponential decay of the wafer motion

5. CONCLUSION

In this paper, we presented the force model of the transfer and the control unit in the clean tube system. The recovering force from the holes for floating wafers was modeled as a linear spring, and thus the system was modeled as a mass-spring-damper system, due to viscous friction. We found that the experimental data such as amplitudes of each period are very similar to those from the simulation by proposal model.

We believe that the proposal model would be the basics to understand the wafer motion in the clean tube system and to control it.

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