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Module design and virtual debugging of automatic chip cleaning machine based on MCD

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Abstract: *The traditional ultrasonic cleaning machine can only clean the ordinary stains on the surface of the sapphire wafer, and it is difficult to remove some stubborn stains or marks with strong adhesion due to grinding processing. Aiming at the characteristics of high hardness, thin wafer and small size of sapphire wafer, this paper discusses the design of automatic sapphire wafer cleaning machine based on MCD. Through the analysis of the functional requirements of the equipment, the method of direct cleaning with nylon brush is adopted, and the process flow of automatic control is designed to determine the working rhythm and time allocation. The overall structure is divided into five core components for modular design: forward component, rotation, cleaning, spray and pneumatic door. The forward component will transport the wafer into the cleaning area, the rotating component will ensure uniform force on the wafer during cleaning, the cleaning component will deeply clean the wafer surface through a brush, the spray assembly uses high-pressure water flow to help clean residual stains, and the pneumatic door assembly controls the air flow to ensure a stable cleaning environment. According to the requirements of full automation of equipment control, Siemens S7-1500 PLC is selected for PLC programming and HMI touch screen design of wafer cleaning machine, and the simulation bridge between NX and PLC is established through MCD function to carry out accurate one-to-one corresponding signal mapping to realize the joint adjustment of mechanical parts, sensors, drivers and motion. The virtual electric mechanical joint debugging of automatic chip cleaning machine based on MCD ensures the feasibility and reliability of automatic chip cleaning machine products, and improves the design efficiency and market competitiveness of products.*

Keywords: *MCD; Sapphire wafer; Cleaning machine; Functional design; Module structure; Virtual debugging*

1. Introduction

With the continuous advancement of the strategy of science and technology power in the world, mainstream semiconductor companies have accelerated the research and development and production of chips. The semiconductor industry is rising rapidly, and its product investment is also rising[1-3]. In this context, semiconductor special equipment enterprises have successfully achieved major breakthroughs in technology, especially in the field of cleaning equipment, and their products have successfully entered the production line of mainstream manufacturers at home and abroad[4-5].

The rapid development of semiconductor industry has put forward higher requirements for the production of semiconductor substrate materials. At present, the substrate materials of semiconductor are mainly sapphire, silicon, etc, of which the chemical composition of sapphire is alumina, and the chemical formula is($\alpha - Al_2O_3$). Sapphire crystal hardness is high, second only to the hardest diamond, it has very good optical properties, physical properties, and chemical properties, and has high wear resistance and corrosion resistance characteristics, has become the most widely used substrate material. Therefore, sapphire wafer seems to be a very important basic material in modern industry, especially in the microelectronics and optoelectronics industry, and the cleaning link in the wafer manufacturing process has become particularly important[4,6].

At present, some non-standard automation equipment companies have begun to focus on the development of cleaning equipment specifically for the surface of sapphire chips. These devices usually use ultrasonic or megasound technology to clean the work [7-13], which not only significantly reduces the processing cost of the chip and improves the work efficiency, but also reduces the damage that may be caused by manual operation on the surface of the sapphire crystal.

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Although ultrasonic and megatonic wave cleaning technology has improved the cleaning efficiency of the crystal surface to a certain extent, for some stubborn stains, especially the marks generated by grinding processing, the adhesion is strong, and ordinary ultrasonic cleaning machines can not be completely and thoroughly cleaned. These stains can affect the performance of sapphire wafers, which in turn affects the quality and reliability of the final product [14]. Combined with the material properties of sapphire substrate, considering the characteristics of high viscosity and difficult to clean after grinding sapphire substrate wafer with polishing liquid, a more direct method than ultrasonic cleaning is needed. In this study, nylon brush is used for direct cleaning.

2. Functional Design

Although sapphire chips are hard, the thinness and tiny size requirements pose a challenge to cleaning. In order to directly clean the stains on the surface of the wafer, the brush is required to be highly wear-resistant, highly elastic and resistant to corrosion. After comprehensive consideration, nylon 612 is selected as the scrubbing tool, the brush adopts the brush roller structure matching with the turntable, and the brush roller also rotates when the turntable rotates. Referring to the semiconductor water-based cleaning agent used in ultrasonic cleaning machines, it is an alkaline liquid and can be used to clean polymer compounds containing grease.

The automatic chip cleaning machine needs to meet the requirements of automation, high efficiency and low damage, and the equipment needs to have the following performance:

(1) Ensure convenience: dual control of HMI touch screen control and SB button control.

(2) Ensure safety: through the manipulator can automatically load and unload (open the pneumatic door, put and take the chip, close the pneumatic door).

(3) Ensure precision: the lead screw drives the turntable forward and backward to the exact position.

(4) Ensure environmental protection: the use of active water liquid with nylon brush cleaning 20s; Then use pure water scrub 20s (or pure water spray 20s); Active water liquid and pure water are in the same pipeline and can be switched through the solenoid valve.

3. Process Flow Design

According to the functional design requirements, it is necessary to design the process flow chart. The working process is as follows: First, open the pneumatic door, the manipulator loads the sapphire chip into the turntable, and automatically closes the pneumatic door; Secondly, the turntable is accurately moved to the cleaning position, and the double spray cleaning of liquid medicine and pure water is carried out respectively. Finally, the turntable automatically returns to the initial position, and the chip is cleaned over. The process design flow chart is shown in Fig. 1.

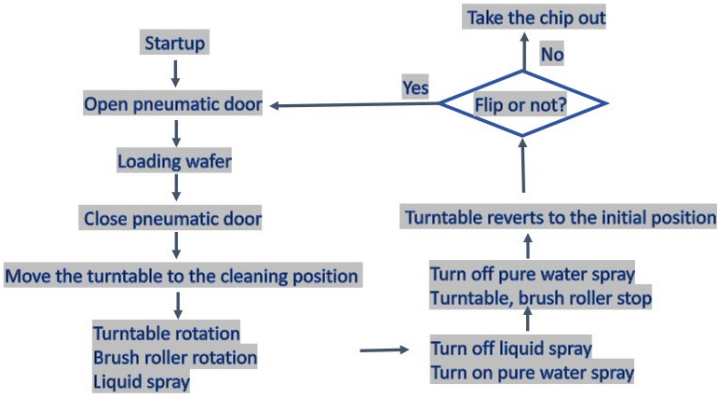

Figure 1: Process flow chart

In the design of digital twin system based on MCD, the working process of the system needs to be subdivided into:

(1) First, the device starts to run, under the control of HMI touch screen or button, the pneumatic door observation cover automatically opens according to the command.

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(2) The manipulator absorbs 15 chips respectively and places them in the corresponding position of the turntable.

(3) The pneumatic door closes automatically according to the instruction, and the PLC begins to enter the cleaning procedure.

(4) The lead screw rotates forward, the turntable assembly moves forward to the cleaning position, and the turntable begins rotating motion.

(5) Cleaning starts to work, on the one hand through the brush roller rotation, the chip is physically cleaned; On the other hand, the spray system is started, and the active water liquid is cleaned chemically on the wafer.

(6) After the liquid spray is completed for 18s, turn off the liquid spray and start the pure water spray.

(7) After the pure water spray is completed for 10s, turn off the pure water spray. At the same time, the turntable stops rotating and the brush roller stops rotating.

(8) The turntable assembly automatically returns to the initial chip installation position, and the pneumatic door automatically opens.

(9) The manipulator flips the chip, repeats the above cleaning steps again, cleans the reverse side of the chip, and completes a complete process.

(10) Each of the 15 chips is removed by the manipulator.

(11)Repeat the cleaning steps on both front and back sides until all chips are cleaned.

4. Beat and time allocation

According to the process design process, the beat time of the equipment should meet the requirements of the enterprise at the same time. The beat time and time should be allocated. The preset beat time is shown in Table 1.

Table 1: Schedule of beats

Beat	Beat content	Time
Pneumatic door	On	1s
	Off	1s
Chip placement	Loading/unloading	15s
Screw mechanism	Forward	4s
	backward	4s
Cleaning spray	Liquid medicine spray	18s
	Pure water spray	10s

The total theoretical calculation time of the beat is:

$$T_{theory} = 1 + 1 + 15 + 4 + 4 + 18 + 10 = 53s$$

Considering that in the actual work process, the current transmission of PLC has a signal delay, so the total time of the actual beat is 1.1 times the theoretical time, that is:

$$T_{reality} = 1.1 \times T_{theory} = 1.1 \times 53 = 58.3s < 60s$$

In summary, the actual beat time of 58.3s is smaller than the 60s required by design, which basically meets the device beat requirements.

5. Modular Structure Design

Based on the MCD system design of automatic cleaning machine, the mechanical structure of the automatic cleaning machine needs to be modular design, which is divided into five components: forward component, rotating component, cleaning component, spray component and pneumatic door component. The characteristics of its modular structure design are as follows:

(1) The ball screw nut drive is selected for the forward component, and the gear motor is used to drive the forward and backward turntable components, as shown in Fig. 2(a) .

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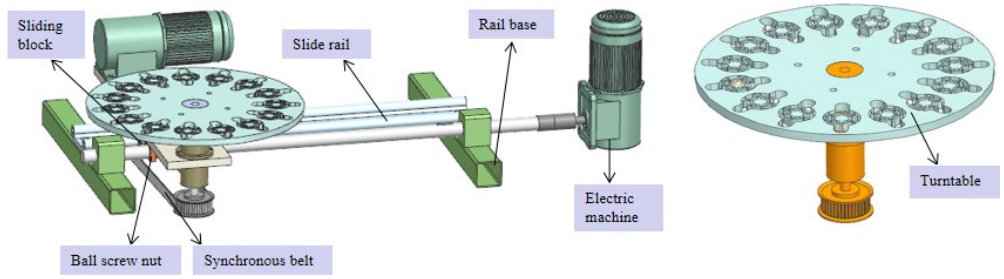
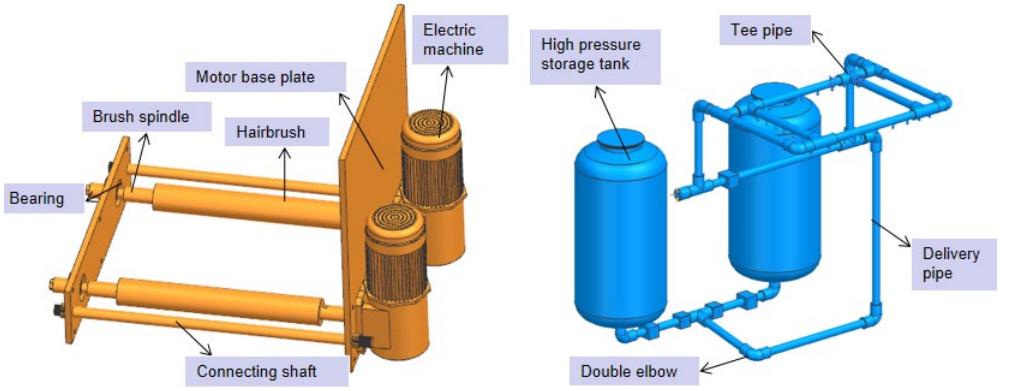
(2) In order to ensure the smooth and accurate rotation of the turntable, the rotating assembly adopts a synchronous belt transmission mechanism. In Fig. 2 (b), the turntable is designed to place the chip in 15 grooves, the depth of the groove is 0.5mm (common sapphire wafer thickness 1mm), so that it is easy to brush cleaning, and add 4 through holes on the turntable tray to make a tray with high water permeability, which is easy to remove impurities and liquid medicine.



(a) Schematic diagram of the forward assembly *(b) Schematic diagram of rotating components*



(c) Schematic diagram of cleaning components *(d) Schematic diagram of spray assembly*

Figure 2: Module structure design

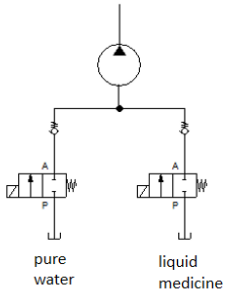


Figure 3: Hydraulic schematic diagram

(3) The cleaning component adopts a dual-drive brush roller structure, as shown in Fig. 2(c) . The brush roll is used together with the turntable, and the brush roll also rotates when the turntable rotates, which can improve the washing efficiency. The rotating roller brush has the characteristics of line contact, suitable for washing thin and micro-sized wafers, and the combination of liquid medicine and pure water can achieve a more uniform and thorough cleaning effect.

(4) The liquid medicine and pure water of the spray component share the same conveying pipe, and the two fluids are respectively transported through the solenoid valve, and the one-way valve prevents liquid flow to achieve accurate control of liquid medicine and pure water, as shown in Fig. 2(d). When the solenoid valve of the liquid branch gets power, the liquid flows through the one-way valve, the centrifugal pump is opened, and the liquid is transferred upward to the combined nozzle to realize real-time liquid spraying, as shown in Fig. 3. After spraying for 18s, the solenoid valve of the liquid branch is powered off, and the solenoid valve of the pure water branch is powered off to realize the pure water spraying for 10s.

In order to make the spray uniform, it is necessary to install multiple crossed spray heads on the upper delivery pipe of the spray assembly. At the same time, the general fan nozzle is selected, so that the spray

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coincidence coverage can reach 20%-30%.

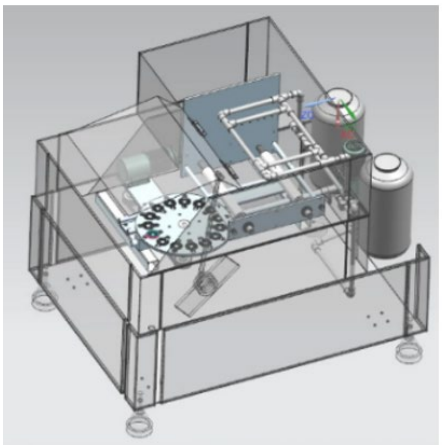
(5) Pneumatic door assembly adopts rotary cylinder and lever transmission principle. Due to the high opening frequency of the pneumatic door and the fast reaction time, the direct acting solenoid valve is used to realize the intelligent control of the pneumatic door.

6. Virtual debugging based on MCD

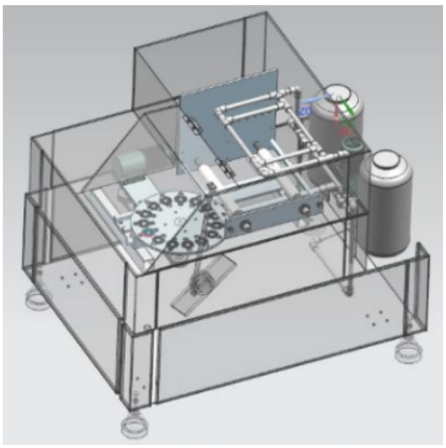
The traditional design mode is mechanical structure design and electrical control PLC control of two independent serial design modules, this design adopts digital twin technology [15-17]. Digital twin is the establishment of digital virtual models of physical entities to simulate the properties and behaviors of physical entities in the real environment. Based on the design of the two modules, MCD can realize the joint adjustment of mechanical parts, sensors, drivers and motion, and ensure the feasibility and reliability of the joint motion.

Firstly, the signal is created in MCD to create the rigid body and collider of the basic electromechanical object, set up the motion pair, select the sensor and the actuator object and control the position. Secondly, the hardware configuration of Siemens S7-1500 (CPU 1511C-1PN) was carried out in Botu TIA, and the variable creation, address allocation and PLC programming were carried out according to the control requirements, and the touch screen screen was designed. Next, the signal adapter is created, ready to connect with the signal in the MCD, the Siemens S7-PLCSIM Advanced V4.0 software is used to connect with the signal in the MCD, the communication between the MCD and the PLC is connected, the signal mapping is realized, and the results can be viewed in the electromechanical navigator.

When the MCD and PLC signal connection is complete and checked, the virtual simulation can be started. The practice shows that MCD can realize the simulation of the whole process of opening and closing the pneumatic door, positive and negative rotation of the lead screw and cleaning according to the established working process. (Fig. 4(a) shows the opening of the pneumatic door, Fig. 4(b) shows the closing of the pneumatic door, Fig. 4(c) shows the cleaning state, and Fig. 4(d) shows the reverse state of the lead screw). Through continuous optimization and improvement, we finally obtained a virtual simulation model with complete function, stability and reliability of the automatic chip cleaning machine, which improved the efficiency of the mechatronic joint design.



(a) Pneumatic door open



(b) Pneumatic door closed

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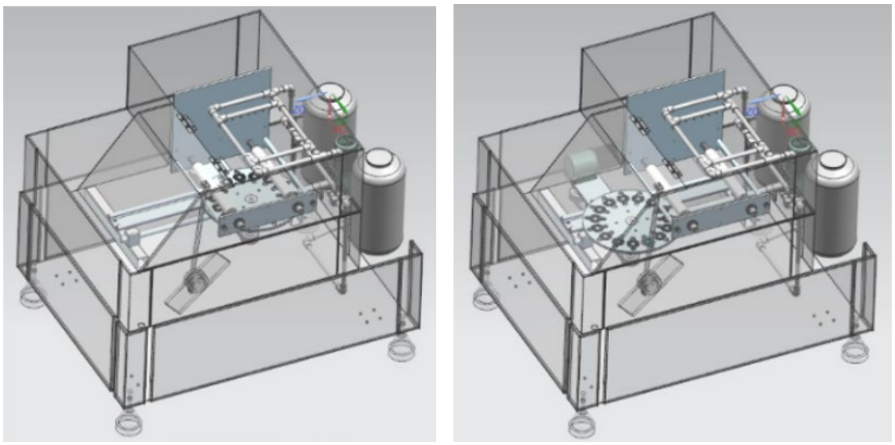

(c) Cleaning status *(d) Lead screw reversal state*

Figure 4: Virtual simulation diagram

7. Conclusion

This research project aims at the design of an automatic cleaning machine for sapphire wafer, which can not be completely and thoroughly cleaned by ordinary ultrasonic cleaning machines. Aiming at the characteristics of high hardness and high wear resistance of sapphire wafer material, the method of direct cleaning by nylon double-bristle brush roller is designed. Considering the product characteristics of sapphire chip thickness of 1mm, relatively thin and small size, the robot and pneumatic system are used to automatically load the chip. In light of the characteristics of stubborn stains with strong adhesion generated during the grinding process of sapphire wafers, we adopt the dual spray cleaning process involving liquid and pure water, and utilize the method of electromagnetic valve to control the transmission and check valve to prevent liquid flow, which can enhance the cleaning effect.

According to the functional requirements of sapphire wafer automatic cleaning machine, modular design was carried out based on MCD, and the overall structure was divided into five core components, namely, forward, rotating, cleaning, spraying and pneumatic door. Through three-dimensional simulation, no interference between components was ensured, and a digital prototype was successfully built.

According to the fully automated control requirements of the chip cleaning machine, the process design was carried out to determine the rhythm and time allocation, and Siemens S7-1500 PLC programming was used to achieve automatic control, and HMI touch screen screen design was used to achieve visual and accurate control of equipment control.

In order to ensure the feasibility and reliability of the automatic chip cleaning machine, the mechanical and electrical joint motion simulation and virtual debugging were completed based on the digital twin technology of MCD. Through S7-PLCSIM Advanced, MCD signal and virtual PLC signal are mapped one by one to realize communication connection, and realize the joint adjustment of mechanical parts, sensors, drivers and motion. The results show that the automatic chip cleaning machine based on MCD can realize the functional requirements of convenience, safety, accuracy and environmental protection. Through the virtual electromechanical joint debugging of the automatic chip cleaning machine, the design efficiency and market competitiveness of the product are improved.

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