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Development of a new noncontact gripper using swirl vanes

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ABSTRACT

In this paper, we proposed a new noncontact gripper called as swirl gripper. It generates swirling air flow to create an upward lifting force. This force can be used to pick up a work piece placed underneath the swirl gripper without any contact. In comparison with conventional pneumatic noncontact grippers, the uniqueness of the new gripper lies in that it is electrically (rather than pneumatically) activated. We carry out this study for clarifying the mechanism of the swirl gripper. First, we show the design of the swirl gripper and briefly illustrate the mechanism by which it forms a negative pressure to create a lifting force. Then, we experimentally investigate the characteristics of the pressure distribution, based on which a theoretical analysis on the swirling flow is conducted. Furthermore, we measure the relationship between the lifting force and gap clearance and reveal that there exists a levitation zone where a work piece can maintain a stable levitation. Finally, we verify the practicability by successfully noncontact handling a Φ300 mm silicon wafer with four swirl grippers.

1. Introduction

A work piece is normally brought into contact with a handling device while it is picked up and moved. Such forms of contact are often accompanied by surface scratching and static electricity. In the semiconductor manufacturing process, in particular, each wafer is handled frequently during repeated loading and unloading. Therefore, the inherent disadvantages of contact handling often lead to defective products. In the manufacturing processes of some foods and medicines, contact is undesirable because it may cause damage and contamination. For these reasons, many noncontact handling approaches have been proposed and proven effective [1–3]. Among them, the use of air flow as the medium to apply a lifting force to pick up and grip a work piece is a common approach, because air flow is free from magnetism and generates little heat. Hence, various pneumatic noncontact grippers are widely employed in practical applications (semiconductor wafer handling, food handling, etc.). Bernoulli gripper, based upon the Bernoulli principle, is the most typical of these implements [4–12]. Recently developed vortex gripper is the other one, which takes advantage of vortex flow to achieve noncontact handling [13–15]. However, given that these noncontact grippers are based on pneumatic methods, they require compressed air supplies and thus have an inherent disadvantage: large energy consumption. In a compressed air supply system, a compressor consumes electrical power to compress air to a high pressure, and then the compressed air is transmitted through a number of components (dehumidifier, pipes, elbows, valves, etc.) and is depressurized to operation pressure of pneumatic grippers, during which there exist mechanical energy loss in the compressor, thermal energy loss due to heat transfers when air being compressed, energy loss due to viscous friction and turbulence in the transmission and depressurization. Because the energy source is electrical energy, these unavoidable energy losses make the total electrical energy of pneumatic grippers rather large. Taking a Bernoulli gripper developed by Davis as an example, it needs an air flow rate of around 1.17×10^{-3} m^3/s (ANR) for generating a 0.2 N lifting force. The compressor normally compresses air to at least 200 kPa (abs.). We can calculate how much energy the compressor supplies the gripper by applying the air power concept proposed by Cai et al. [16]. Air power has a formula of $P_aQ\ln(P_s/P_a)$ where P_a is absolute atmospheric pressure, Q is volume flow rate in standard state (101.3 abs kPa, 20°), P_s is the absolute pressure of the calculated position and all units are SI. The calculation result is 81 W. Given that the compressor normally has an efficiency of around 90%, the total consumed electrical energy is nearly 90 W.

Recently, we proposed a new noncontact gripper designated as the swirl gripper. The uniqueness of this gripper lies in its utilization of swirling air to generate a lifting force while it is electrically (rather than pneumatically) activated. Therefore, it fundamentally avoids energy losses and thereby reduces the total electrical energy consumption drastically in comparison with present pneumatic grippers. For example, our proposed swirl gripper only needs less than 2 W for a 0.2 N lifting force (the voltage is 24 V and the current is 0.08 A).

In order to gain an insight into this new noncontact handling technology, the paper states the basic design principle and

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Nomenclature

F	lifting force
h	clearance distance
P	pressure
P_o	pressure at the center
P_a	atmospheric pressure
u_α	tangential velocity
r	radial position
ω	rotation speed
ρ	air density

mechanism, and studies the basic characteristics experimentally and theoretically.

2. Mechanism and design

Fig. 1 shows a schematic of the proposed swirl gripper. It mainly consists of a motor, a set of swirl vanes, and a circular swirl chamber. With the exception of a number of air inlets, the top of the chamber, to which the motor is fixed, is closed. The swirl vanes, each of which is characterized by a curved shape, are installed on the motor shaft and arrayed vertically and symmetrically. Rotation of the motor along the curved direction of the vanes causes the air in the chamber to swirl. The centrifugal force due to this swirling pulls the air from the center to the periphery of the chamber, and creates negative pressure in the central area. Thus, when a work piece is placed under the gripper, a lifting force acts on the work piece and picks it up. Simultaneously, the curved, rotating vanes suck air from outside the chamber through the upper air inlets, and discharge air via the base of the chamber. Therefore, as shown by the blue arrows in Fig. 1, the work piece must maintain a clearance from the gripper while being lifted, in order that air can be discharged. In other words, the swirl gripper achieves noncontact handling.

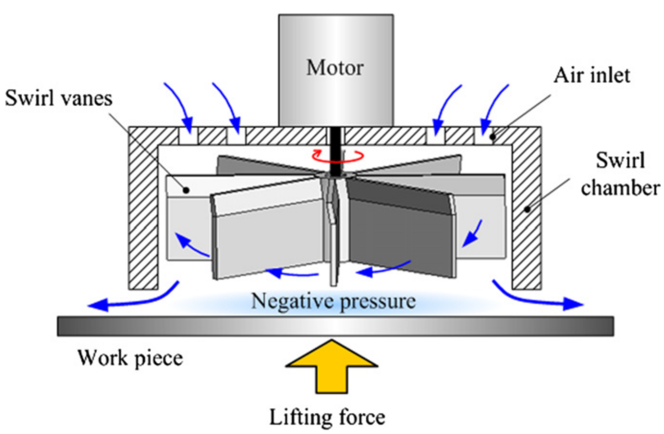

Fig. 1. Schematic of the proposed swirl gripper.

Fig. 2 shows a photograph of the trial swirl gripper used for the experiments, along with the dimensions of its components. Some qualitative design principles are given here, as the optimization of the design parameters is beyond the scope of the present work. The selected motor can reach a maximum speed of up to 10000 rpm. The swirl vanes are fabricated by fused deposition modeling (FDM), which involves the extrusion of the semi-liquid plastic material acrylonitrile butadiene styrene (ABS) used to fill the cross section of the swirl vanes. Eight vane pieces are arrayed vertically and symmetrically about the shaft of the motor. Their curved shapes give the swirling air a downward velocity component so that air is sucked from the air inlets into the swirl chamber and then discharged via the base of the chamber. In theory, this function can be achieved by any curve angle in the range of 0°–90°. Considering the limited space between the vanes, each piece is curved by about 10°. The swirl vanes are located inside the swirl chamber, which is composed of a cover board and a cylinder. Eight air inlets, each with a diameter of 1.5 mm, are arranged symmetrically on the cover board. The diameter of the air inlets is an important factor in determining how much air will be sucked into the chamber. Enlarging the size would increase the flow rate sucked into the swirl chamber. Furthermore, the position of the air inlets also has a certain effect on the suction flow rate. As will be discussed in next section, the maximum negative pressure appears in the central area. Therefore, setting the air inlets close to the center of the swirl chamber would increase the suction flow rate because of the pressure

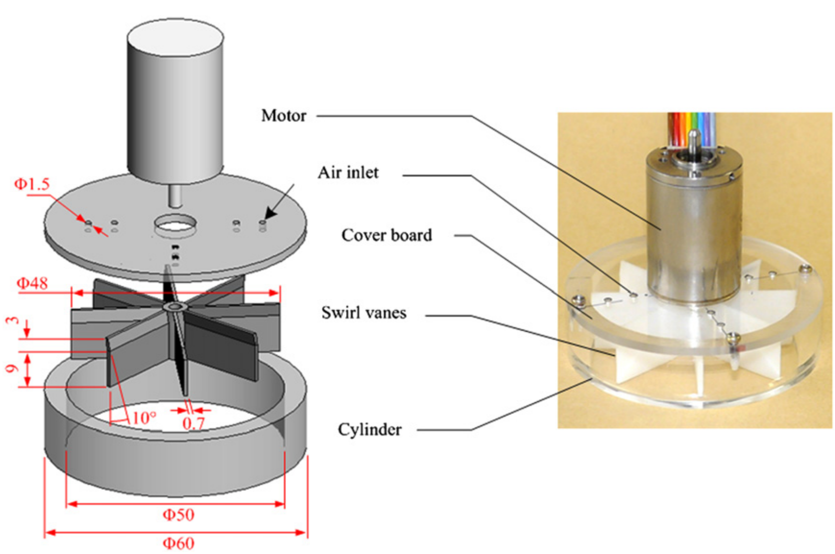

Fig. 2. Trial swirl gripper used for discussions in the paper.