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Experimental and Theoretical Study of Dynamic Characteristics of Bernoulli Gripper

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Highlights

- We found squeezing-film damping is the cause for stable flotation of workpiece.
- A dynamic model considering the squeeze-film damping is proposed.
- The dynamic model can well predict the motion of workpiece during pick-up process.
- Small initial gap height and large outer diameter aids in stabilizing workpiece.

Abstract

The Bernoulli gripper, which is widely employed in automated production lines, is a pneumatic manipulator capable of noncontact suction and gripping. Previous studies of Bernoulli grippers have focussed on its steady state suction force. This study experimentally and theoretically investigates the dynamic characteristics of the Bernoulli gripper. In practical applications, the gripped workpiece is lifted by placing the gripper immediately above the workpiece and then supplying compressed air to the gripper. In our pick-up experiment, the workpiece started to oscillate vertically after lifting, and then, the oscillation amplitude decreased until the workpiece became stable. Based on this experimental observation, we propose a mass-spring-damper model in which the steady state suction force is considered a spring and the squeeze-film flow exerts an additional damping force. Furthermore, the effects of the initial gap height and outer diameter on the motion of the workpiece are individually investigated. It was found that a small initial gap height and a large diameter aids in reducing the oscillation amplitude. In addition, the mass-spring-damper model could accurately predict the motion of the workpiece despite changes in the initial gap height and outer diameter.

Keywords: Bernoulli gripper, Dynamic characteristics, Squeeze-film damping

1. Introduction

The Bernoulli gripper is a pneumatic manipulator that can grip a workpiece through suction. Unlike a traditional rubber vacuum cup, which uses a contact seal to prevent leakage and maintain negative pressure in the vacuum chamber, the Bernoulli gripper generates negative pressure using outward exhaust flow. As shown in Fig. 1, the main component of the Bernoulli gripper is a disk, with a hole at the centre, placed immediately above the workpiece to be gripped. Under upstream pressure, compressed air flows through the central hole and then into the axisymmetric gap between the gripper and workpiece after changing its direction. While flowing through the axisymmetric gap, the air slows down because of the increase in sectional area. According to Bernoulli’s principle, the pressure increases with decreasing flow velocity, which means that the pressure on the inner perimeter is lower than that on the outer perimeter. Since the pressure tends to be atmospheric pressure as the air approaches the periphery, the pressure on the inner perimeter should be sub-atmospheric. The negative pressure on the inner perimeter exerts an upward suction force on the workpiece, and therefore, the workpiece is able to float under the gripper. In addition, several stoppers are installed at the periphery to prevent the horizontal motion of the workpiece during the gripping operation. As a result, the workpiece can be safely lifted only with physical contact on the side. Because of the Bernoulli gripper’s noncontact suction and gripping, it is widely used to handle fragile flat workpieces such as solar panels and silicon wafers, whose surfaces need special care [1-4]. Furthermore, since it is free of vacuum leakage, the Bernoulli gripper has significant advantages in handling rough and irregularly shaped workpieces, such as soft and rough leather [5, 6] and slices of foodstuff such as tomatoes and bread [7, 8].

The Bernoulli gripper has been continuously researched because of its practical applications. The earliest study on the Bernoulli gripper was reported by Welanetz and Syosset in 1956. They illustrated the mechanism by which the Bernoulli gripper generates negative pressure and suction force [9]. After that, Waltham *et al.* used momentum conservation and common friction factors to quantitatively predict main features of Bernoulli levitation [10]. Furthermore, to eliminate the repulsive force resulting from the impact of the supplied air flow on the workpiece in the central region, many researchers introduced a deflector (also called the ‘core’ or ‘cone mill’ by Giesen *et al.* and Brun and Melkote, respectively) [2, 4, 5] at the centre of the gripper. Another function of such a deflector is to increase the velocity of the air flow when it enters the gap, so that the deceleration of the air flow is enhanced and, therefore, the suction force is increased. Recently, Li and Kagawa examined the factors affecting the suction force of the Bernoulli gripper [1]. They noted that the negative pressure on the inner perimeter is due to the effect of inertia, while the viscous effect generates a positive pressure on the relatively outer perimeter and decreases the suction force. Based on their study, Shi and Li optimized the outer diameter of the Bernoulli gripper [11]. They presented a mathematical expression for the optimal outer diameter to maximize the steady state suction force.