Mechatronics 21 (2011) 1222–1233

Contents lists available at SciVerse ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

Development of 2-DOF tilting actuator with remote center of rotation for human operated non-contact handling tool

Ewoud van West *, Akio Yamamoto, Toshiro Higuchi

The University of Tokyo, School of Engineering, Department of Precision Engineering, Advanced Mechatronics Laboratory, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

ARTICLE INFO

Article history:
Received 19 February 2010
Accepted 8 August 2011
Available online 15 September 2011

Keywords:
Levitation
Tilting
Acceleration compensation
Haptic device
Human–machine collaborative system
Pick and place

ABSTRACT

This paper describes the development of a new and unique 2-DOF tilting actuator that has a remote center of rotation. The tilting actuator is part of a non-contact handling tool that allows thin contact sensitive objects like silicon wafers or coated sheet metal to be manipulated without any contact between the tool and the object. Tilting is necessary to keep the object aligned with the levitator during large planar accelerations, similar to how a waiter tilts a tray of beverages during transport. A feed-forward tilt implementation based on known acceleration eliminates the need of sensor, but it requires that the center of rotation coincides with the center of mass of the levitated object to avoid disturbances by the tilting action. This is realized by a mechanical solution of a dome-shaped structure that is supported by three ball bearings on the inner surface. The tilting actuator is attached to an in-house developed admittance controlled SCARA-type haptic device, which allows both automated and human operated manipulation. In this collaborative system, where the haptic device assists the human operator in real time, the human operator can successfully perform the manipulation task with ease and without failure, which would not have been possible without the haptic assistance.

1. Introduction

Levitation techniques can be used in manipulation systems to handle contact-sensitive objects like silicon wafers or sheet metal plates *without contact*. This avoids contact-related issues such as contamination, structural deformation, and damage. In levitation systems, the levitator maintains the object at a certain stable position (constant gap) by exerting a controlled force that can compensate the gravitational force and inertial disturbance forces. Since levitation systems are generally more complex and expensive compared to contact-based handling techniques, they are only of interest to environments where contact avoidance is essential to realize high quality products such as in the semiconductor industry. Another example is the sheet metal industry where the surface quality degrades when it is transported over rollers. There are several levitation techniques that are used in these fields, such as magnetic levitation [1–10], electrostatic levitation [11–13], acoustic levitation [14,15], and levitation using air flow [2,16–20]. Each levitation technique is based on a different principle and therefore has limitations regarding the shape or material of the levitated object [21]. As the direct contact force is missing in these levitation systems, the objects behave differently when compared to regular contact-based gripper handling. The holding stiffness that can be realized is significantly smaller compared to the case of holding with physical contact. Furthermore, there is a limited range of both force and position (gap) that can be realized. This means that levitation systems are much more sensitive to external disturbances that can occur in the manipulation process.

The handling of thin wafer-like objects is mostly automated in the semi-conductor industry to realize high speed and high accuracy. However, in certain environments, the manipulation tasks are still performed by human operators when the cost of automation is too high. Examples can be found in research and development laboratories or highly specialized production processes where the conditions or the products often change. For both human operated systems and fully automated systems, using non-contact levitation techniques will introduce new problems as the sensitivity of levitation systems to external disturbances is higher. Two problems are shown in Fig. 1:

(1) The lateral holding force for levitation systems of thin, flat objects is very weak, limiting the allowable planar accelerations.
(2) The motion induced by the operator during a human-operated manipulation task is a large disturbance source.

The reason for the first problem is that in case of levitation systems for thin flat objects, the holding stiffness is direction dependent. The holding forces opposing gravity are actively controlled and

* Corresponding author. Tel.: +81 3 5841 6466; fax: +81 3 5841 3018.
E-mail address: ewoud@aml.t.u-tokyo.ac.jp (E. van West).
URL: http://www.aml.t.u-tokyo.ac.jp (E. van West).

0957-4158/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mechatronics.2011.08.001