ARTICLE IN PRESS

Precision Engineering xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Precision Engineering

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

Evaluation of macro sized metal based microgrippers for handling microcomponents

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ARTICLE INFO

Keywords:
Microgripper
Microcomponent
Gripping displacement
Gripping force
Direct metal laser sintering
Micro-welding
Micro-drilling

ABSTRACT

This work presents evaluation of macro sized metal based microgrippers of various shapes such as circular, square and rectangular, which can hold circular, square and rectangular microcomponents respectively. The developed microgrippers can be used effectively as a holding device in mechanical environments and also in the assembly of microcomponents. Microgrippers are designed and analyzed using SOLIDWORKS and COMSOL Multiphysics respectively. Fabrication of microgrippers are carried out using direct metal laser sintering process with six gripping arms to prevent the slipping of the microcomponents during handling. The microgrippers were actuated by means of specially designed actuation system. The fabricated microgrippers are characterized for gripping displacements and gripping forces and the results are compared with that of the simulation and analytical results. It is observed that the displacements of the gripping arms of the fabricated microgrippers are four times higher than that of the input displacements of the actuator. This is found to be in the higher order than that of reported in the literature. Further, the circular based microgrippers were tested in micro-drilling and micro-welding as micro-chuck and micro-electrode holder respectively and they are found to be working satisfactorily.

1. Introduction

Microgrippers are generally designed to hold different shapes of microcomponents with sufficient forces without breaking the components. Microgrippers are essential to handle microcomponents such as microshafts, micronuts, microspiral inductors, micromotors, etc and are also used in the assembly of products in various fields such as electronics, information technology, optics, medicine, etc [1,2]. Microgrippers are basically classified based on the principles of actuation such as thermal [3,4], piezoelectric [5], electrostatic [6], electromagnetic [7], vacuum [8], mechanical [9], etc. Among these, mechanical microgrippers have high mechanical stability and can be used in electrical and thermal environments [10]. The actuation of the metal based microgrippers is carried out by applying mechanical forces [11].

Literature review related to mechanical based microgrippers is briefly presented here. Goldfarb et al. (1999) [9] developed a flexure based microgripper with two arms using wire-electrical discharge machining. The microgripper is actuated by means of piezoelectric arranged in stacks. The maximum gripping displacement of 500 μm at 100 Hz and gripping force of 1 N were obtained. Martinez et al. (2007) [10] developed a polymer based microgripper to manipulate microcomponents in the ranges of 5–50 μm using MEMS based techniques. The gripping displacement of 100 μm was obtained at 50 μm input displacement. Nah et al. (2007) [11] developed a monolithic compliant-flexure-based piezoelectric microgripper which is fabricated using micro-wire electrical discharge machining process. The maximum gripping displacement obtained is 170 μm. Han et al. (2007) [12] developed a microgripper with two gripping arms for manipulating microcomponents in the ranges between 90 and 120 μm using MEMS based techniques. Gripping force of 64 μN was obtained. Bilderan et al. (2008) [13] developed a mechanically actuated microgripper using MEMS based techniques to manipulate microcomponents. The mechanical force was provided by a two piezo-bar assembly. The maximum gripping displacement of 35 μm at 60 mV and gripping force of 1 μN was obtained. Choi et al. (2008) [14] developed micro-tweezers using MEMS based techniques to manipulate microstructures and components. The described microgripper was actuated by means of a micro-drive control knob. It can manipulate microstructures in the range of 10 μm. Gripping displacement of 15 μm and gripping force of 20 mN were achieved.

Conway et al. (1994) [15] developed a microgripper with two cantilever flexible arms consisting of a slide arrangement driven by the

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https://doi.org/10.1016/j.precisioneng.2018.07.010
Received 10 April 2018; Received in revised form 23 July 2018; Accepted 30 July 2018
0141-6359/ © 2018 Published by Elsevier Inc.

servomotor. Mauro et al. (1999) [16] developed a cam operated microgripper with two gripping arms, which is powered by a motor operating through a lead screw and nut drive mechanism. The range of operation is limited by the length of the gripper arm. They have observed that an increase in the length of the gripping arms leads to decrease in the rigidity and also inturn decreases the gripping forces. Ellis et al. (2003) [17] developed a microgripper using MEMS based techniques having linearly actuated grasping mechanisms. The described microgripper can manipulate microcomponents of very small ranges less than 100 μm. Becker et al. (2011) [18] developed a robot gripper with two arms using generative production method. The robot gripper is actuated by an element in the form of bellows for opening and closing of the gripper arms. However, the control of the filling the internal medium of the bellows is found to be difficult.

From the literature review, it is observed that most of the microgrippers have only two gripping arms or with lesser gripping forces, which may lead to the slipping of the microcomponents during handling due to the less contact surface area. If the gripping force is not adequate, it is also very difficult to control the orientation of microcomponents. It is also observed that the available microgrippers are fragile in nature and very delicate to handle in micromachining applications. Frequent breakage of microgrippers is also observed during handling [2]. Most of the microgrippers are manufactured based on MEMS technology, which can handle microcomponents mostly less than 100 μm. However, only few microgrippers have been developed for holding microcomponents of size ranging from 100 μm to 500 μm. It is also observed that no attempts have been made to fabricate the microgrippers using metal based additive manufacturing process. It is also observed that the gripping displacements and gripping forces obtained in the microgrippers are found to be low. In the present work, macro sized metal based microgrippers, which can handle microcomponents of different sizes, from 200 μm to 1000 μm with various cross-sections such as circular, square and rectangular are designed, developed and evaluated.

2. Design of the microgrippers

Microgrippers for holding circular, square and rectangular microcomponents of various sizes (200 μm–1000 μm) are designed using SOLIDWORKS software as per the Design for Manufacturing rules for Direct Metal Laser Sintering (DMLS). The various parts of the microgrippers are fixed part (anchor), gripper arms and flexures (Fig. 1).

The details pertaining to design of circular and square microgrippers are described below. Microgrippers for holding circular and square microcomponents consist of a hexagonal shaped rod at the centre (Fig. 1a). The hexagonal rod is connected to twelve flexures (2 layers on each side). The flexures are then connected to the gripper arms. The fixed part is used to connect the microgripper to the actuator. The actuation system consists of a DC motor and a lead screw. The lead screw of the actuator is allowed to move in forward and backward directions for the opening and closing of the gripper arms. During the clockwise rotation of the DC motor, the central rod of the microgripper moves forward. The flexures connected to the central rod tend to become perpendicular with the central rod and push the gripper arms from the centre. During this motion, the microcomponents are inserted into the gripping hole. Thereafter, the counterclockwise motion is given to the lead screw. During the counterclockwise rotation of the lead screw, the central rod of the microgripper moves backwards and releases the gripper arms (Fig. 2). The overall dimension of the microgrippers for holding circular and square microcomponents is 17 × 17 × 34.2 mm (Fig. 1a–c). Circular and square holes of various sizes such as 200 μm, 400 μm, 600 μm, 800 μm and 1000 μm are provided at the top of the microgrippers to hold circular and square microcomponents (Fig. 1a–c).

The details pertaining to design of rectangular microgripper is described below. The overall dimension of the microgripper to hold rectangular microcomponents is 44.7 × 16 × 25 mm (Fig. 1d). This microgripper has square shaped central rods (3 Nos) (Fig. 1d). The square rods of gripping arms are connected together by means of a common base block. The square rods are also connected with four flexures each. The flexures are connected to the gripper arms. The microgrippers for holding rectangular microcomponents are designed with three sets of parallel gripping arms in order to increase the area of contact with the microcomponents (Fig. 1d).

The dimensions of all the three types of the microgrippers such as diameter of the flexure (d) (1.5 mm), angle of the flexure with respect to the central rod (θ) (25°) and length of the gripping arm (L) (21 mm) are selected by performing a simulation analysis considering three levels of parameters with Design of Experiments (DoE) approach using L_9 orthogonal array (Table 1). Similarly, in order to achieve maximum gripping displacement and minimum stress, the number of gripping arms (6 Nos), number of layers for flexures (2 Nos) and cross-sectional length (3.25 mm) of the gripping arms are selected by considering three levels of parameters using L_9 Orthogonal array as per maximum Multi Response Performance Index (MRPI) [19] (Table 2).

3. Analysis

The following sections discuss about analytical and simulation analysis of the designed microgrippers.

3.1. Analytical analysis

The analytical analysis is carried out by performing structural mechanics studies on the microgrippers considering the gripping arm as a 2D cantilever beam. The schematic of the typical microgripper arm with central rod and flexures is shown in Fig. 3. In Fig. 3, the gripper arm is represented by AB. Force F acts on the central rod of the microgripper. The force F is further resolved into two forces P_1 and P_2, which act on the gripping arm by means of the flexures at the points C and D. 'l' is the length of the gripping arm. The distance between the fixed part A and C on the gripping arm is considered as 'a'. The distance between the fixed part A and D on the gripping arm is considered as 'b'. The angle between the flexures and central rod is considered as 'θ'. The total deflection (y_B) at B to B′ is obtained from equation (1). The total gripping displacement (Y) is twice that of the total deflection (y_B) at B, since both the arms move in the opposite directions.

$$y_B = \left[\frac{P_1 sin\theta a^3}{3EI} + \frac{P_1 sin\theta a^2}{2EI}(l-a)\right] + \left[\frac{P_2 sin\theta b^3}{3EI} + \frac{P_2 sin\theta b^3}{2EI}(l-b)\right] \tag{1}$$

Where, P_1 - Force acting on the gripper arm at Point C.

P_2 - Force acting on the gripper arm at Point D
E - Young's modulus, Nmm^{-2}
I - Moment of Inertia, $Kgmm^2$
l - Length of the gripping arm, mm
a - Distance between the fixed part A and point C, mm
b - Distance between the fixed part A and point D, mm
θ - Angle between the flexures and the central rod, deg

The details pertaining to the derivation of the analytical equation are represented below.

Based on the Law of equilibrium of forces and moments, it is found that F = 1.812 P_1, where P_1 = - P_2.

The deflection at 'B' due to the force P_1 is given by,

$$y_C = \left[\frac{P_1 sin\theta a^3}{3EI} + \frac{P_1 sin\theta a^2}{2EI}(l-a)\right] \tag{2}$$

The deflection at 'B' due to the force P_2 is given by,

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