Analytical Model and Computing Optimization of a Compliant Gripper for the Assembly System of Mini Direct-Current Motor

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ABSTRACT

This study proposes a combination of kinematics-based design method, statistic method, and TLBO algorithm to solve computing optimization for a compliant gripper. It is employed in an assembly system of mini direct current motor. First, the kinematic models of the gripper are developed. The static model is paid attention. Next, the dynamic model is established based on Lagrange's principle. Then, a multi-criteria optimization for the gripper is conducted by Taguchi method integrated with TLBO algorithm. Finally, the FEA and experiments are implemented to verify the optimal results and evaluate the performances of the compliant gripper. The results indicated that theoretical models are in good accord with the results from simulations and experiments. Additionally, the performance of the present method is superior to PSO algorithm. The results revealed that the compliant gripper allows a displacement up to 3000 μm and the amplification ratio of 12 times. The compliant gripper is a potential application for the mini direct-current motor assembly system.

KEYWORDS

Compliant Gripper, Kinematics-Based Design Method, Multi-Criteria Optimization, Statistic Method, TLBO Algorithm

INTRODUCTION

Basically, the structure of the mini DC motor including many parts is assembled together as a metal end cap, magnet, and shaft, core, as shown in Figure 1. To create a competitive quality product, the accuracy of each assembly is important. Especially, the process of installing the shaft of the motor is into the core of motor. This process requires a quite high precision while their size is quite small. In reality, their dimensions are usually ϕ 0.6mm×10mm for the shaft and ϕ 2.5mm×3mm for the core. Since the 1983s, direct current motor (DCM) has been discovered by British scientist William Sturgeon. Mini DCMs are used in tools, toys, and equipment (Chung et al., 2002; Akagi et al., 2008; Sensorwiki, 2016).

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With factual production conditions in some manufacturing plant, this operation largely depends on human manipulation. Thereupon, the production efficiency and product competitiveness are not high. To overcome these difficulties, assembly systems with gripper are studied for the application. These grips can be designed based on pneumatic and hydraulic systems (Chen et al., 2016; Dameitry and Tsukagoshi, 2017; Zhong et al., 2019), or are proposals based on compliant mechanism (Jain et al., 2013, 2018; Ho et al., 2019). Existing grippers are developed based on pneumatic or hydraulic systems and they always have a noise during operation. The limitations of these grippers make them expensive and have low flexibility. Contrary to the above restrictions, the proposed designs based on compliant mechanism are considered as the most potential candidates. It needs to be applied in modern assembly systems for reasons such as monolithic fabrication, small, and high precision, reduce noise pollution, improve production efficiency and product cost. Notwithstanding, a research on the literature review found that the application of compliant gripper (CG) into assembly process of mini motor has been a lack of interests.

From the survey results of previous studies, the CG design process often faces some challenges, including a wide displacement stroke, a stable force, a large resonant frequency, a lightweight structure but must guarantee a stress under an allowable stress. In fact, depending on the target on each specific design goal, these requirements are usually resolved through an optimal design process to improve the characteristics of the design (Liu et al., 2017; Niaki and Nikoobin, 2017; Ho et al., 2018; Nam et al., 2019). Besides, Harmony search optimization method was used to optimize the architecture parameters of compliant mechanism (Ding, Yang, Zhang, & Xiao, 2017) and a modular method was developed to design of micro-positioning stages with advantages of low cost and ease of upgrading (Ding, Yang, Xiao, & Zhang, 2019).

Nowadays, several approaches have been proposed to designing and optimizing a gripper. There are two commonly used methods: structure optimization method (Lu et al., 2005; Reddy et al., 2010; Zhu et al., 2013; Mahanta et al., 2019), and kinematics-based design methods (Qingsong, 2015; Xu, 2015; Ling et al., 2016, 2018, 2019; Dsouza et al., 2018; Tashakori et al., 2018). The structural optimization consists of three types: (a) the topology, (b) the size, and (c) the geometry (Lu et al., 2005). Notwithstanding, the results obtained from this method may provide a CG that can be very sensitive to manufacturing errors (Zhu et al., 2013). So, the kinematics-based method is proposed in this article due to its simplicity. In order to solve a multi-criteria optimization design, the statistical-based and metaheuristic algorithms were developed as the Taguchi method (TM) (Roy, 2010), NSGA-II (Fossati et al., 2019), response surface method (RSM) (Bezerra et al., 2008), PSO algorithm (Bhattacharya, Chattopadhyay, Chattopadhyay, & Banerjee, 2019; Carvalho, Bernardino, Hallak, & Lemonge, 2017; Chatterjee et al., 2017) a hybrid approach (Wang and Tai, 2010; Rezaeian et al., 2011), or improved PSO (Shen et al., 2009). However, some of them are limited by convergence speed and computational cost. In this study, a HTLBO (Ho et al., 2018) was suggested in optimizing of the gripper with a fast computational speed and reliability. Modelling of kinematics and dynamics of the proposed gripper provides the mathematical models. And then, weight factor of objective function is computed by the statistical method. At last, using the established mathematical models, a multi-criteria optimization (MO) process can be implemented through the HTLBO.

Purpose of this article is to propose an approach of kinematics-based design method, statistic method and TLBO algorithm for multi-criteria optimal design of a gripper. A suitable structure of gripper is designed. Kinematic models are established to determine the positions and relationships of motions of joints and links. The static model analyzed based on theory of elastic beam, which can determine the gripping force, stiffness, ratio of amplification, and stress. A dynamic model is developed using Lagrange's principle, which can identify the resonant natural frequency. The weight factor is determined. Based on the mathematical models found out, the optimization process is carried based on the HTLBO to improve overall the performances. A FEA is conducted to assess analytical and optimal results. Behavior of the present method is evaluated in comparison with PSO algorithm. Finally, a prototype is manufactured and experimental tests are implemented to verify the FEA and analytical results.