Mechanism and Machine Theory 55 (2012) 34–50

Contents lists available at SciVerse ScienceDirect

Mechanism and Machine Theory

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

Design of a constant-force snap-fit mechanism for minimal mating uncertainty

Yi-Ho Chen, Chao-Chieh Lan *

Department of Mechanical Engineering, National Cheng Kung University, No. 1, University Road, Tainan City 701, Taiwan, ROC

A R T I C L E   I N F O

Article history:
Received 5 December 2011
received in revised form 5 April 2012
accepted 20 April 2012
Available online 19 May 2012

Keywords:
Snap-fit connector
Constant-force mechanism
Compliant mechanism
Plastic part assembly
Contact analysis

A B S T R A C T

For assembling injection-molded plastic parts having complicated geometry, snap-fit mechanisms are preferable to screws and chemical adhesives. The use of snap-fits relies on accurate calculation of interference and the associated mating force. The mating force is proportional to the interference, which is very sensitive to plastic part dimensional error. Insufficient interference would result in loose assembly, whereas excessive interference would impede assembly and possibly damage the thin-walled plastic parts. The possibility of unqualified interference impairs the high-value application of snap-fits to electronic appliances and automobiles. To alleviate the requirement for precise interference and to improve the assembly's robustness, this paper presents a constant-force snap-fit mechanism that maintains a regular mating force against a range of interference uncertainty. We propose a design formulation to find mechanism configurations that produce the most constant mating force. Illustrated simulations and experiments show that the mating force of the constant-force snap-fit is less sensitive to interference uncertainty than are typical snap-fits. Since uncertain mating force is minimized without demanding precise interference, we expect this mechanism to provide a ready alternative to existing snap-fit assembly applications.

1. Introduction

A snap-fit connector (also known as a fastener or mechanism) is used to directly attach one part to another. It consists of a cantilever-like structure with a hook at the free end. When a snap-fit connector is attached to one part, the interference of the hook with another part to be assembled creates a mating force to deflect the cantilever and to interlock the two parts. The use of snap-fit connectors involves far less assembly and disassembly than would screws, chemical adhesives, or other joining methods. Snap-fit connectors can operate for many cycles and are cosmetically more attractive. They are often used to assemble complex injection-molded parts in applications posing stringent space constraints, such as automobile interior parts [1], electronic appliances [2], and building blocks [3]. For micro-electro-mechanical systems for which no other joining methods have been devised, micro snap-fit connectors have been developed to join micro 3D structures [4–6].

Strength, constraint, compatibility, and robustness have been identified [7] as the key requirements of snap-fit design. The first three are essential in the design phase. They can be easily met by following general design guidelines [7–10]. In contrast, robustness must be met in the assembly phase. Robustness refers to the tolerance of dimensional variation. It is unpredictable because dimensions vary according to fabrication and assembly conditions. The most critical dimension variation is the interference between snap-fit hook and mating part. Although very small, the amount of interference determines the mating force and hence the quality of the snap-fit. Since snap-fit connectors behave like cantilevers, the mating force increases with increasing interference. Too little interference, and the associated mating force would cause loose assembly. Too much interference, and the associated mating force would cause difficult assembly or possibly permanent deformation of parts and

* Corresponding author. Tel.: +886 6 2757575x62274; fax: +886 6 2352973.
E-mail addresses: solzeta@gmail.com (Y.-H. Chen), cclan@mail.ncku.edu.tw (C.-C. Lan).

0094-114X/$ – see front matter
doi:10.1016/j.mechmachtheory.2012.04.006

connectors. The failure of parts is more costly. Like many contact-aided mechanisms [11–13], a successful design of snap-fit connectors requires accurate calculation of interference-induced mating force. Mathematical models of this force are found in Refs. [14,15].

Even if the interference and associated mating force are accurately reflected in the design, imperfect fabrication and assembly introduce additional uncertainty. Injection-molded thin-walled parts are usually much larger than snap-fit connectors. Maintaining their required dimensions is more difficult than snap-fit connectors. One common cause of dimensional error is shrinkage of the part after molding. The shrinkage of common plastics is nearly 0.5–2% [16] of their original size. This percentage variation seems small, but the part sizes are large enough to directly alter the amount of interference. For typical interference, a dimensional error of 0.05 mm is already sufficient to affect the mating force. Thus, an unpredictable dimensional variation has a great influence on mating force.

Previous research has focused on the design of new connector geometry or material to improve assembly and disassembly [17–19]. A connector geometry design to overcome interference-induced mating uncertainty has not yet been explored. Without imposing costly precision requirements on injection-molded parts, this paper proposes a constant-force snap-fit connector. It exhibits a constant mating force against a range of interference uncertainty. The idea is similar to the design of a constant-force mechanism (e.g., Refs. [20–22]), where an originally bistable mechanism (e.g., Refs. [23–25]) is geometrically modified so that its force to deflection curve shows an obvious range of constant force. Like constant-force mechanisms, the proposed snap-fit connector is a closed structure that provides a range of constant reaction force when subjected to an uncertain input displacement. We focus on the snap-fit connectors used to join vehicle-interior plastic parts, where the quality of assembly can strongly influence a vehicle's market value.

In what follows, the snap-fit mating force is first characterized through a new analysis method. An optimization formulation is then presented to design the shape of the constant-force snap-fit connector, the aim of which is to create a mating force that is least sensitive to interference uncertainty. Finally, prototypes are fabricated and validated experimentally by comparison with typical snap-fit connectors.

2. Characterization of mating force and analysis of typical snap-fits

2.1. Characterization of mating force

Fig. 1 shows typical snap-fit connectors (hereafter referred as clips) used to assemble automobile-interior parts. The clips can be metallic or plastic. They are made of a single substance to allow fabrication by injection molding or metal forming. As shown in Fig. 2(a–b), they are inserted onto the base to provide standard mating motion. The dimensional error (e.g., mold shrinkage) of the large thin-walled base in the planar direction directly causes interference to deviate. The interference deviation results in overly loose mating (Fig. 2(c)) or overly tight mating (Fig. 2(d)), depending on the mating configuration.

Fig. 3 shows detailed views of target and clip. The interference δ measures the distance from the tip of the clip to the bottom surface of the target. During the insertion process, the reaction force from the clip to the target may be decomposed into the x and y directions. The force in the x direction is denoted as the insertion force (F_i), and the force in the y direction is denoted as the insertion gripping force (F_{gi}). Similarly for the retention process, the force in the x direction is denoted as the retention force (F_r), and the force in the y direction is denoted as the retention gripping force (F_{gr}). These four are the mating forces. For a specific interference, they are functions of the relative positions of target and clip. Fig. 4 illustrates the force curves of the retention process. At the assembled position, there is sufficient F_r and F_{gr} to lock the parts together despite external disturbance. The forces F_r and F_{gr} increase to maximums as the clip moves away from the target. The maximums are denoted as F_{rm} and F_{grm}, respectively. The F_i and F_{gi} force curves of the insertion process will similarly have maximums, denoted as F_{im} and F_{gim}, respectively. A sound design requires that the maximums of these force curves be kept within a specific range.

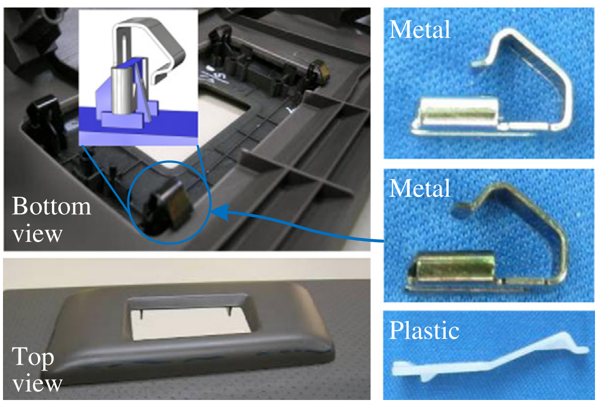

Fig. 1. Typical snap-fit connectors used for vehicle-part assembly.