Unilateral Fixtures for Sheet-Metal Parts With Holes

Kanakasabapathi Gopalakrishnan, Ken Goldberg, *Senior Member, IEEE*, Gary M. Bone, Matthew J. Zaluzec, Rama Koganti, Rich Pearson, and Patricia A. Deneszczuk

***Abstract*—In this paper, we introduce *unilateral fixtures*, a new class of fixtures for sheet-metal parts with holes. These fixtures use cylindrical jaws with conical grooves that facilitate part alignment; each jaw provides the equivalent of four point contacts. The fixtures are unilateral in the sense that their actuating mechanisms are restricted to one side/surface of the part, facilitating access to the other side/surface for assembly or inspection. We present a two-phase algorithm for computing unilateral fixtures. Phase I is a geometric algorithm that assumes the part is rigid and applies two-dimensional (2-D) and three-dimensional (3-D) kinematic analysis of form closure to identify all candidate locations for pairs of primary jaws. We prove three new grasp properties for 2-D and 3-D grips at concave vertices and define a scale-invariant quality metric based on the sensitivity of part orientation to infinitesimal relaxation of jaw position. Phase II uses a finite element method to compute part deformation and to arrange secondary contacts at part edges and interior surfaces. For a given sheet-metal part, given as a 2-D surface embedded in 3-D with e edges, n concavities and m mesh nodes, Phase I takes $O(e + n^{4/3} \log^{1/3} n + g \log g)$ time to compute a list of g pairs of primary jaws ranked by quality. Phase II computes the location of r secondary contacts in $O(grm^3)$ time.**

***Note to Practitioners*—This paper was motivated by the problem of holding sheet-metal parts for automobile bodies but it also applies to other sheet-metal components that have cut or stamped holes. Existing approaches to fixturing such parts generally have contacting mechanisms on both sides of the sheet that restrict access for welding or inspection. This paper suggests a new approach using pairs of grooved cylinders, activated from only one side of the part (hence "unilateral"). These cylinders mate with opposing corners of holes in the sheet and push apart to hold the sheet in tension, thus acting as both locators and clamps. In this paper, we mathematically characterize the mechanics and conditions for a unilateral fixture to hold a given part. We then show how such fixtures can be efficiently computed; this can allow a computer-aided design (CAD) system (with finite element capability) to automatically generate and propose unilateral fixtures for a given part. Preliminary physical experiments suggest that this approach is feasible but it has not yet been incorporated into a CAD system nor tested in production. In future research, we will address the design of unilateral fixtures that hold two or more parts simultaneously for welding.**

***Index Terms*—Assembly, fixturing, form closure, grasping, modular fixturing, sheet metal, welding, workholding.**

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K. Gopalakrishnan and K. Goldberg are with the Department of Industrial Engineering and Operations Research, University of California at Berkeley, Berkeley, CA 94720 USA (e-mail: gopal@ford.ieor.berkeley.edu; goldberg@ieor.berkeley.edu).

G. M. Bone is with the Department of Mechanical Engineering, McMaster University, Hamilton, ON L8S 4L7, Canada (e-mail: gary@mcmaster.ca).

M. J. Zaluzec is with the Ford GT Advanced Manufacturing, Manufacturing and Vehicle Design Research Laboratory, Ford Motor Company, Dearborn, MI 48121 USA (e-mail: mzaluzec@ford.com).

R. Koganti, and P. A. Deneszczuk are with the Ford Motor Company, Dearborn, MI 48121 USA (e-mail: rkoganti@ford.com; pdeneszc@ford.com).

R. Pearson is with the National Center for Manufacturing Sciences (NCMS), Ann Arbor, MI 48108 USA (e-mail: RichardP@ncms.org).

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I. Introduction

SHEET-METAL parts are created by stamping and bending, and often contain holes that can be used for holding. To assemble industrial parts such as automotive bodies and large appliances, sheet-metal parts need to be accurately located and held in place by fixtures to permit assembly, welding, or inspection. Existing sheet-metal fixtures are generally bulky (limiting access to the part), nonmodular (requiring dedicated material and storage), and designed by human intuition (often resulting in suboptimal designs).

We propose *unilateral fixtures*, a new class of fixtures for sheet-metal parts with holes. These fixtures use cylindrical jaws with conical grooves that facilitate part alignment; each jaw provides the equivalent of four point contacts. The fixtures are unilateral in the sense that their actuating mechanisms are restricted to one side/surface of the part, facilitating access to the other side/surface for assembly or inspection. In contrast, conventional (bilateral) fixtures are actuated by mechanisms that approach the part from both sides a bilateral fixture consists of complex and/or bulky holding elements and mechanisms on either side of the sheet-metal part and can limit access. Fig. 1 illustrates an example.

We present a two-phase algorithm for computing unilateral fixtures. Phase I is a geometric algorithm that assumes the part is rigid and locates pairs of primary jaws at part hole concavities. For every pair of concavities, we apply a set of sufficient conditions to test the part for immobility. We prove that a rigid three-dimensional (3-D) part can be immobilized by jaws at these concavities if its two-dimensional (2-D) projections onto two orthogonal planes containing both concavities are immobilized by the projections of the jaws and if the conical grooves of the jaws prevent rotation about an axis through both concavities.

In Phase II, we consider applied forces and compute part deformations using a finite element method (FEM). We add secondary contacts at the mesh nodes that maximally restrict local part displacement. We iterate, adding secondary contacts until we find a contact set that satisfies the tolerance requirements or until no more contacts can be added.

Unilateral fixtures align the part into the desired orientation as the primary jaws are engaged. We develop a scale-invariant quality measure and show that it is consistent with a physical experiment measuring part angular displacement as the distance between primary jaws is relaxed.