Research in Engineering Design (1998)10:84–93

Research in
Engineering
Design

A Systematic Approach to Integral Snap-Fit Attachment Design

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Abstract. *Traditional integral snap-fit attachment design focuses almost exclusively on the individual locking features, such as cantilever hooks, bayonet-fingers, compressive hooks and others. The positioning and orientation of other significant features on parts, such as those that facilitate or enhance engagement and eliminate unwanted degrees of freedom left by locking features, i.e. locating features and enhancements, are not considered. This paper builds on relatively new methodologies and guidelines for arranging all attachment features on plastic parts comprising snap-fit assembly. Classification of features into categories of locking features, locating features and enhancements of these is used as the basis for discussion. A systematic approach to attachment design is presented.*

Keywords: Design methodology; Integral attachment; Snap-fits

1. Introduction

Use of snap-fit integral attachments is often a key element in the creation of plastic part designs that are easy to manufacture and assemble. The major goals of Design for Manufacture and Assembly (DFMA) methodologies can be summarized as eliminating as many parts as possible and simplifying the assembly of remaining parts to the greatest extent possible. Such methodologies strongly recommend the use of integral attachment features, including snap-fits, in a product. As examples, Chow [1] and Boothroyd et al. [2] recommend integral attachments as substitutes for separate fasteners, particularly for injection molded plastic parts, but, increasingly, for parts made from other materials and by other processes as well. Simplification of assembly without overly complicating detail part design and manufacture is clearly possible using integral attachment methods, but the state-of-the-art or, more properly, the state-of-practice, needs study and development.

To understand the state-of-the-art and state-of-practice in the integral snap-fit attachment design process, the available literature was searched, designers were interviewed, and industry and company design method were reviewed. From this, the design process for placement of snap-fits was found to be more of an art than an engineering science. Most likely, this is so because the issues involved in the placement of integral snap-fit attachments are complex and old rules for traditional fastening are being applied to this new approach, despite not being appropriate.

Snap-fit attachment feature placement is influenced by many variables which, until recently, were not recognized or organized in a useful manner. These include real and representative part shapes, installation directions and assembly motions, loading directions and degrees of freedom or constraint, molding direction, and part stiffness and tightness (through tolerance). Little design information or guidance was found in the published literature, or even within trade or company design manuals, to help with these concerns. In fact, most existing snap-fit design guides do not even discuss determining the type and location of snap-fit features as part of the design process [3,4].

Of the half dozen diverse-industry companies surveyed, General Motors had the most formalized approach to the assembly of parts. GM considered and considers the integral attachment interface as a system, and uses a so-called 'attachment-level approach' as opposed to the traditional feature-level approach [5–7]. From this foundation, research has continued to attempt to create a formalized attachment strategy. On the way to defining that strategy, a systematic approach to integral snap-fit attachment

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design has been developed. That approach, now complete, is described in this paper.

2. Integral Snap-Fit Attachment Features

For the purpose of this paper, integral snap-fit attachments refer to the specific, detailed features molded into a plastic part to actually provide attachment functionality. These features can be further sub-classified based on sub-functions within attachment or assembly. This approach is important, since designers often do not know the full range of snap-fit features available to them. Because of this, the best feature for a particular application is often not selected, with the consequence that problems are encountered during product assembly or during service. The following definitions and classifications were originally presented by Luscher et al. [8], and are summarized here in order to increase understanding of the features that can be found on plastic parts. Fundamental definitions can also be found in other papers [9,10].

Integral attachment features are formed into parts to enable mechanical joining of those parts by: (1) establishing part location, alignment and orientation; (2) eliminating degrees of freedom and/or absorbing the tolerances between these parts; (3) locking the parts into an assembly; and (4) transferring service loads. The two key attributes of any integral attachment feature are that it be integral to a part, and that its primary purpose be to provide some joining or attachment functionality. The term 'feature' emphasizes that such attachments are an integral portion of a part, and are not a separate part (e.g. a fastener).

The special integral attachments referred to as *snap-fits* accomplish attachment by elastically deforming or deflecting during part assembly, and then recovering to their original undeflected state to lock or trap the mating part. The process of recovery is often accompanied by an audible or tactile 'snap' indicating both the attachment features, and, therefore, the mating parts are properly engaged.

For sub-classification of integral attachment features, attachment functionality was defined as one of three primary tasks accomplished by attachment features when two parts are connected. These three primary tasks are: (1) *location* of the parts relative to each other to remove degrees of freedom and transfer service loads; (2) final *locking* of the parts together during assembly; and (3) *enhancement* of the attachment by enhancement features [8]. This first level of classification is shown in Fig. 1.

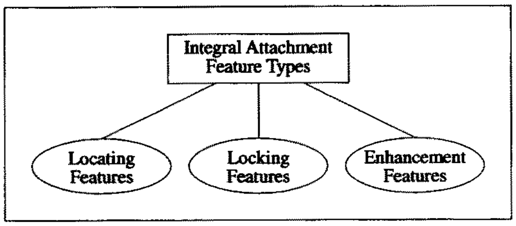

Fig. 1. Three primary classes of integral attachment features.

In this hierarchy, *locating features* or *locators* eliminate degrees of freedom between parts, transfer the service loads, and establish the major reference or datum planes or points which locate parts relative to each other. Several locating feature types commonly found in plastic parts are shown in Fig. 2. Locating features often differ greatly in their topology since each is designed for a very specific loading situation. For example, the 'stop' feature only contains motion which is inward and normal to its large surface (in the negative x-direction in Fig. 2). It does not constrain motion in any other direction (y or z) or outwardly normal (positive x) to its large surface. The stop feature is designed to make planar contact with another flat surface or line contact with a curve surface. The 'pin-in-hole' feature, on the other hand, constrains all planar motion normal to its centreline in both x and y directions. A 'pin-in-hole' feature, however, will allow inplane rotation around the pin. The 'wedge-in-slot' feature limits motion to along the slot, i.e. z direction.

Locking features or *locks* are features used to provide the final attachment between two parts through their elastic deflection and recovery. The locking feature classification represents the most common integral attachment seen in products and they are most closely associated with the term 'snap-fit'. Several common locking features are shown in Fig. 3.

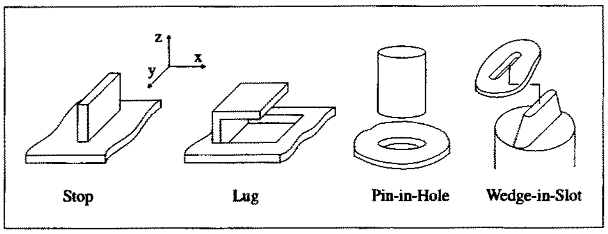

Fig. 2. Examples of types of locating features.

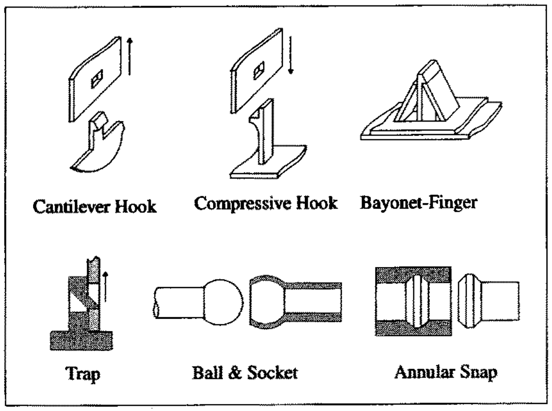

Fig. 3. Examples of several major types of locking features.

It is proposed that locking features are made up of the following two functional units, a *deflection mechanism* and a *retention mechanism.* Examples are shown in Fig. 4 for the cantilever hook feature. These two mechanisms are defined as follows: A *deflection mechanism* is the portion of a locking feature which accommodates the elastic deflection necessary for assembly insertion. Deflection mechanisms can be classified by the deflection which occurs (e.g. torsion, bending) and the shape or topology of the structure. Deflection mechanisms are commonly called *latches.* A *retention mechanism* is the portion of a locking feature which provides the interference necessary to prevent separation. The most common type of retention mechanism is called a *catch*, and consists of two planar faces, called a retention face and a insertion face, molded into the end of the deflection mechanism.

Enhancement features (or *Complaints*) [8,12] or *enhancements* are features or, more precisely, attributes of constraining (locating or locking) features that add robustness or user-friendliness to a snap-fit attachment. Enhancements divide into four categories: (1) *assembly enablers*; (2) *disassembly enablers*; (3) *performance enhancers*; and (4) *manufacturing enablers* [12].

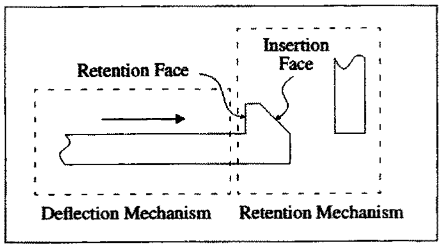

Fig. 4. Deflection and retention mechanisms on a locking feature, or a latch and a catch.

1. *Assembly Enablers* include *guides*, which ensure smooth engagement and latching of mating parts, and *feedbacks*, which provide an audible or tactile signal to verify that the attachment has been properly made.
2. *Disassembly Enablers* include *visuals*, which provide information about the attachment feature's location, function, operation, or disassembly, and *assists*, which provide a means for manual deflection of manual locks.
3. *Performance Enhancers* include: (1) *limiters*, which protect sensitive locks, provide local strength, and/or improve lock performance (i.e. locking integrity); (2) *compliance*, in the form of the feature's design or attribute of its design to allow manufacturing tolerances to be taken up and provide and maintain a tight fit to prevent vibration or rattle without violating constraint requirements; and (3) *dual attachments*, in which features provide a back-up or secondary means of attachment should the primary locking feature(s) fail. Examples of assembly enablers, disassembly enablers, and performance enhancers are shown in Fig. 5.
4. *Manufacturing Enablers* are not physical devices, rather design philosophies that enhance snap-fit performance. There are two such philosophies: (1) *preferred design practices*, which follow recommended and preferred practices of the design of plastic parts; and (2) *process-friendly design*, in which specific practices enable easy mold adjustments. Examples of each are shown in Fig. 6.

3. Designing Parts with Integral Attachment Features: Integral Attachment Design

Designing parts with integral attachment features occurs at two fundamental levels: attachment-level design, and feature-level design. Attachment-level design deals with higher level issues, and focuses on interacting surfaces, assembly motions, and selection and placement of attachment features, while feature-level design deals with detailed issues such as sizes and tolerances of features. These two levels in integral attachment design correspond to conceptual design and detail design, respectively [13]. Since in a formalized design process (e.g. Pugh's method [13]), identification of design specifications, such as constraints and objectives, is a design activity, this step needs to be handled prior to the

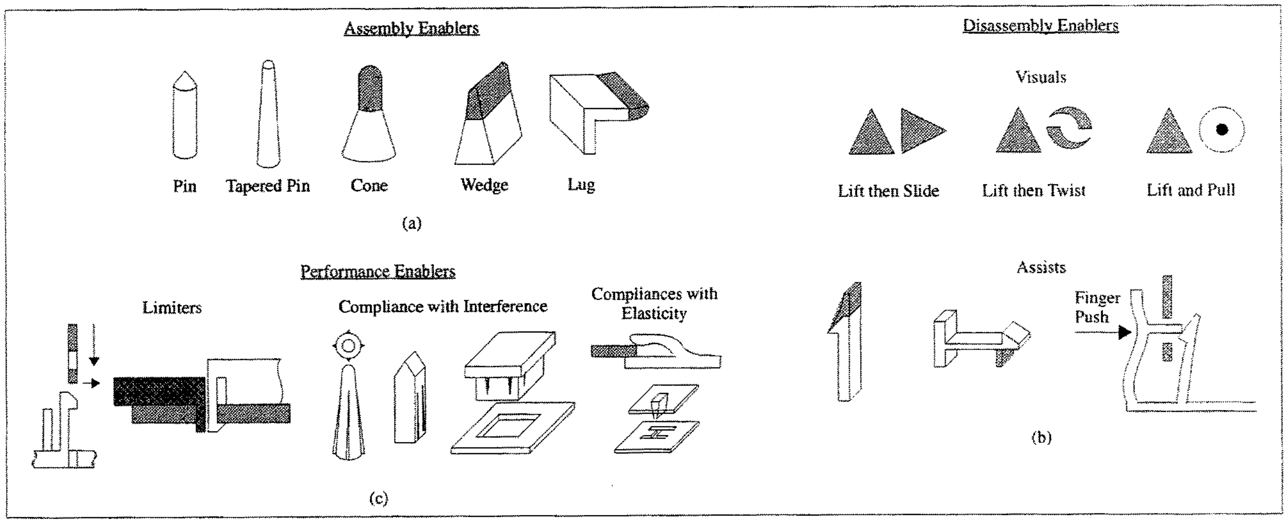

Fig. 5. Examples of enhancement features. (a) Assembly enablers, (b) disassembly enablers, and (c) performance enhancers.

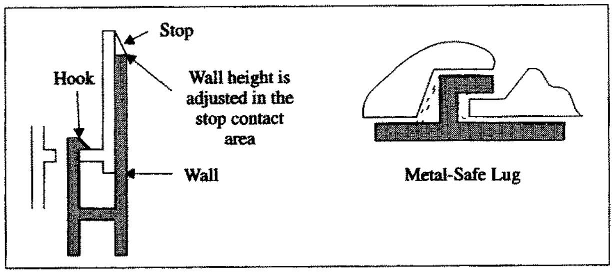

Fig. 6. Manufacturing enabler philosophies for design enhancement.

attachment-level in integral attachment. Figure 7 shows how integral attachment design fits into the overall design process.

The first task of integral snap-fit attachment design (i.e. development of an attachment concept, during attachment-level design) has as its goal the formation of an effective attachment concept for the parts to be joined. To create an attachment concept, a designer considers overall part geometry, service loads to be carried between the parts, limitations on assembly direction, joint strength, and tolerance. Based on these, the designer must specify: (1) interface geometry or part geometry involved in the attachment process; (2) an assembly procedure to bring the parts together; and (3) attachment feature information such as position, orientation and type, etc. (see Fig. 8). This entire level of design, however, is often overlooked in terms of product design or is approached in a very ad hoc manner.

The second level, called feature-level design, has as its goal the specification of the geometry of all the individual features in the attachment concept.

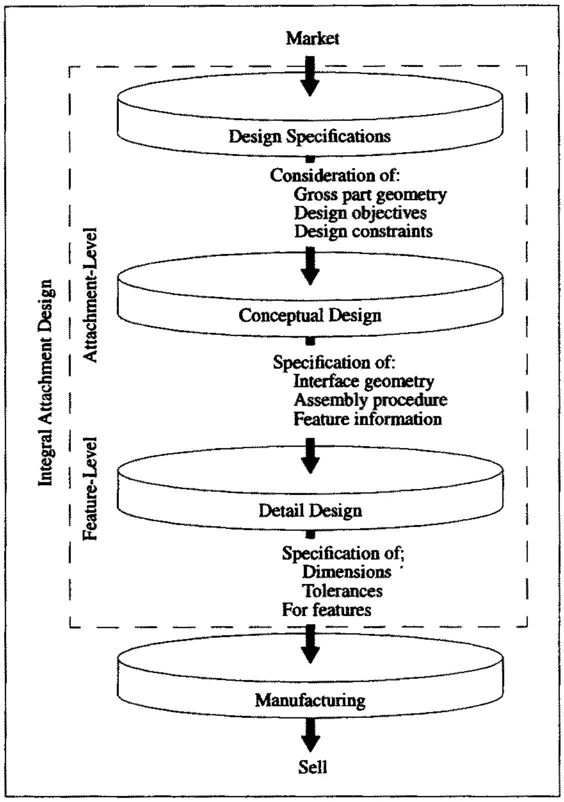

Fig. 7. Integral attachment design within the overall design process.

Figure 8 shows information flow in integral attachment design. Each integral snap-fit attachment feature is designed to support load(s) in specific direction(s), absorb a certain amount of variability (i.e. provide tightness), and provide a certain structural stiffness. On the basis of these considerations,

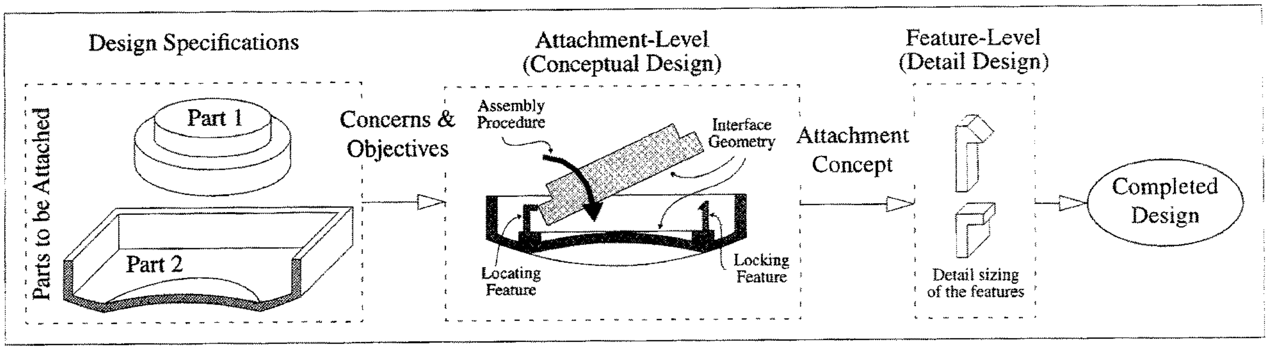

Fig. 8. Information flow in the integral attachment design process.

the integral snap-fit attachment features' dimensions and tolerances must be calculated. As currently practiced, feature design has many limitations. These include, but are not limited to: (1) imprecise analytical or numerical methods for predicting behavior; (2) insufficient materials property data for use in analysis; and (3) tedium, i.e. the need for design and analysis of every feature every time (as opposite to selection of standard fasteners). At the feature level, design guidelines and mathematical or empirical models are available, and readers are urged to refer to studies by Mobay [3], Lewis et al [14,15] and Knapp et al [16,17] for each approach, respectively.

4. An Attachment-Level Design Approach or Methodology

The focal points of attachment-level design, as stated earlier, are issues such as: (1) the geometry of parts (or interface geometry) that can be brought together with an appropriate assembly direction and motion; (2) selection of an assembly procedure (i.e. installation direction and assembly motion) associated with geometry of parts to be attached; and (3) attachment feature information (i.e. the number, location, orientation, type and general style or form). The following approach proposes a formalized procedure to identify these three issues. Designing parts at the attachment-level includes the following steps: (1) identification of parts (or classification of parts); (2) consideration of allowable (or permissible) combinations of parts; (3) stipulation or selection of installation direction and assembly motion; (4) selection of features; (5) constraining parts; and (6) evaluating alternative design options. These steps are shown in Fig. 9 and will be described in detail in the following subsections.

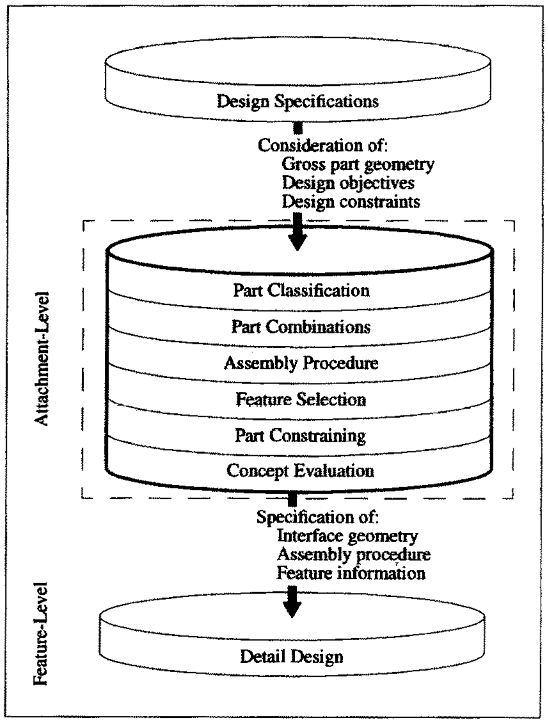

Fig. 9. Attachment-level design steps.

4.1. Identification of Part Geometry: Part Classification

Identification of the geometry of each part to be attached into an assembly comprises the first step in the process of integral attachment design. The procedure listed below assumes that all or some portion of a product consisting of multiple components uses integral attachment features to accomplish mechanical attachment. For such attachment, the term *part geometry* refers to the sub-assembly or to some portion of the product. Selection of an appropriate assembly procedure for the parts, and selection

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