USE OF SNAP-FIT FASTENERS IN THE MULTI-LIFE-CYCLE DESIGN OF PRODUCTS

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Introduction

This paper describes the design and the use of snap-fit fasteners for the multi-life-cycle design of products. The advantages, drawbacks and general design considerations on snap-fits are listed. The paper emphasizes that unlike the design and use of conventional fasteners, every snap-fit used in a product must be designed from scratch. Issues of material strength, fastener geometry, part stiffness, attachment strategy and manufacturability are addressed. This paper also presents the use of compliant mechanisms i.e., design for no assembly in designing a new single piece snap fit fastener, which might be injection molded as a one-piece flexible structure. The conceptual design of a new snap-fit fastener which can be disassembled by using a simple tool is presented.

I. Background

Any useful product is usually assembled from two or more components and the assembly of components may be carried out using mechanical fasteners or adhesive bonding. When assembling two parts, snap-fits offer simple, cost-effective and a quick method for their assembly. Snap-fits can decrease the assembly time of a product by as much as 60 percent. Moreover, their use reduces parts inventory and eliminates the need for external energy sources. Snap-fits are also one of the more environmentally friendly forms of assembly because of their easy dis-assembly. Therefore, there has been an increased emphasis lately to use integral fasteners. Traditionally these fasteners have been used in low stress and non-critical assembly areas. But recently snap fits are replacing screw fasteners in critical assembly areas. The complexity and the cost of assembling structures using integral fasteners can be further simplified and reduced. Despite the wide acceptance of snap-fits, research related to their design is still in the stage of infancy.

Traditional methods of fastening include non-adhesive bonding procedures where external energy is applied to melt or plasticize the joint region in order to form a bond. The assembly process for all these joining technologies requires the positioning and holding of components, so that the joining process can be performed. This needs tools such as assembly fixtures, adhesive templates, drilling jigs, inductive heaters etc. These tools and the joining technologies themselves add considerable complexity, development time and direct and indirect cost to assembly of each joint in the product. In addition, the design for disassembly is critical for the overall product recyclability. Regular fasteners are used in applications for strength, appearance and reusability. Reusability is often a consideration since many assemblies may need to be taken apart for maintenance, service and repair, and nowadays for reuse, refurbishment or recycling. This paper studies the design procedures and the selection of snap-fits and integral attachments for the multi-life-cycle design of products and suggests conceptual design for new snap-fits suitable for disassembly.

II. Snap - Fits / Integral Attachments

Referred to as snap-fits or integral attachments, considerable interest has been shown in the use of integral fit joint designs in polymer-based components. Based on Messler [1], a snap-fit can be characterized by the geometry of its spring component. These are grouped into three major types: cantilever, hollow cylinder and distortion. Cantilevers are beam-like features, which deflect

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under assembly loading; hollow cylinder snap fits are used to join tubular structural components; distortion joints include all shapes that are deformed or deflected to pass over the interference locking element [2]. It is important to distinguish between integral and non-integral attachments. Integral attachments are features belonging to a part itself, i.e. an assembly without separate fasteners, whereas the non-integral attachments are the use of separate fasteners. Examples of non-integral attachments include traditional threaded fasteners such as screws, and non-threaded fasteners such as plastic Christmas tree clips, cotter pins, rivets, and snap-type fasteners.

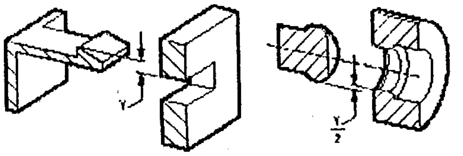


Fig. 1: Cantilever and Cylindrical Snap-Fit

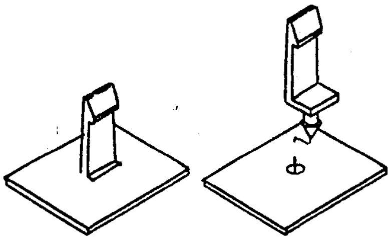
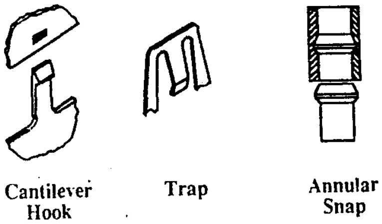
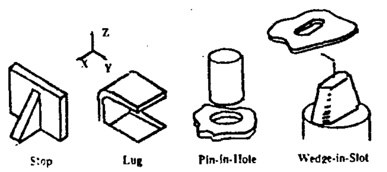


Fig. 2: Integral Versus Non-Integral Attachment

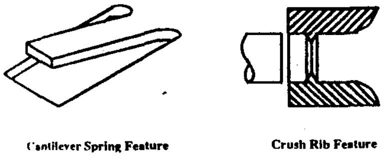
The key attribute of an integral attachment feature is that it should be an integral part of the component itself and provide some attachment functionality. Snap-fits are a special class of integral attachments and perform their function by elastically deforming or deflecting during part assembly and then recovering to their original state to lock or trap the mating part. Integral attachment features perform several functions [3, 4, 5] which are: to provide attachment between parts; establish part location, alignment, and orientation; transfer service loads; eliminate degrees of freedom, and; absorb tolerance between parts. Luscher [4] has identified three types of integral attachment features: locator, lock and compliant or enhancement. Locator features reduce degrees of freedom between parts, transfer joint loads and define datum planes; lock features provide the final attachment between components; compliant features absorb any tolerance stackup or misalignment within the joint [2, 4, 6]. Examples of a locking features are cantilever hooks, bayonet-fingers, annular snaps, or compressive beams. Locating features are stops, ribs, bosses, wedges, or pins. The compliant features include guides, crush ribs, darts, tapered features, limiters, and assists.



Examples of Lock Features



Examples of Locator Features



Examples of Compliant Features

Fig. 3: Typical Locking, Locating and Compliant Integral Attachment Features

II.A Elements of an Integral Fastener

An integral fastener joint is defined by three elements: insertion, clamping and locking. These three elements fulfill specific functions and indicate structural behavior within an integral fastener joint that need to exist for an effective integral joint. The insertion elements are geometric features and the material properties that comprise the structural subelements of a component, which are inserted into the joint region for attaching the component to another. The clamping elements are the geometric features and the associated material properties of a component that provide the clamping force to provide the integral fit between components. This force must be overcome in order to disassemble the joint. The locking elements are the geometric features and their specific material properties which insure, that insertion elements be not extracted from a clamping element by eliminating motion, deflection or misalignment in the joint.

II.B Snap-In Or Snap-On Systems

Another type of snap-fit assembly system, which can sometimes be molded into the part, is know as snap-on or snap-in. It is used most often on round parts. Often larger portions of the part or even the entire part flexes, but the deflections are usually very small [7].

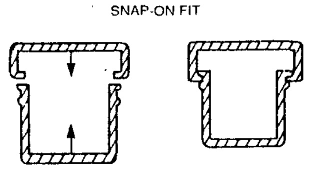


Fig. 4: Snap-on fits

III. Product Design using snap-fits

For any product, components are joined together in order to achieve a function, or to achieve structural efficiency, which includes optimizing the material selection and utilization, and minimizing the cost of the manufacture and assembly. Some major issues in the first stage of a product design are the requirements of a fastener. Because they fulfill more than one function; the method of assembly which can range from a simple manual operation to a complex automated process; and the parts to be assembled and their integration in the assembly process. In order to assemble structures and systems, different technologies have been applied to join components together. Two joining technologies are the use of discrete mechanical fasteners and adhesive bonding. The major consideration is usually the reduction of the overall assembly time [8]. Therefore, the number of integral fasteners in use is increasing rapidly. The complexity and the cost of assembling structures using integral fasteners is considerably lower than for discrete mechanical fasteners. The use of integral attachment is often a key element in the development of designs, which are easy to manufacture and assemble. In addition, no extra materials or external energy sources are needed for assembly when using integral fasteners. In all snap-fit designs, some portion of the molded part must flex like a spring, usually past a designed-in interference, and quickly return to its unflexed position to create an assembly between two or more parts. For a successful snap-fit design, it is important to have sufficient holding power without exceeding the elastic or fatigue limits of the material. By nature, integral attachments have an insertion direction that causes the elastic deformation of the snap feature, followed by the elastic recovery and entrapment of the two parts. This leads to assembly in which the parts are brought together and secured in a simple linear motion versus the more complex helical insertion motion for threaded fasteners [3, 7].

Because of the difference between joint technologies, a metric can be used to quantify the load carrying performance as well as to define a relative measure to compare different types of joints. In any given joint the stress can be obtained by dividing the joint load by its effective load-bearing area. Using the joint stress as a basis, a measure of the effectiveness of the joint compared to the rest of the structure can be defined. Referred to as joint efficiency, the metric specifies the relative performance of the joint under service loads versus the overall structure and is defined by:

$$\mathit{Joint\ Efficiency} = \frac{\mathit{Joint\ Stress}}{\mathit{Stress\ in\ the\ Structure}} \cdot 100\% \qquad (1)$$

Values for joint efficiency ratings can vary from less than 10% for bonded joints to over 100% for fasteners. The smaller the effective load-bearing area of a joint, the greater is the joint efficiency. An integral fit joint can be designed with optimum load-bearing area thus directly enhancing the joint efficiency. Since the materials used in a joint do not affect the joint efficiency metric, an additional factor can be computed to assess joint technologies of different materials. Based on the works of Tsai [15], a proportional ratio can be used to measure the design performance of a joint. Hence the strength/stress ratio R is defined as the ratio between the maximum or ultimate strength and applied stress:

$$\{\sigma\}_{max} = R\,\{\sigma\}_{applied} \qquad (2)$$

Because of this definition, R is a positive number where, R = 1 indicates that failure will occur at the applied load, R > 1 specifies the factor of safety at the given load level and R < 1 demonstrates that the applied load is greater than the material strength. Since this ratio includes the allowable ultimate strength, the yield limit of different material systems can be used for this strength level. This ratio can be applied to different types of integral fits. For instance, the increase in contact surface area within an integral fit joint provides a greater load bearing capacity for sustaining applied joint loads while the problem of fastener hole drilling and developing alignment tools is also avoided due to self alignment in the joint.

III.A Design Methodology For Snap - Fits

To select proper application of a snap-fit fastener, it is important to know, how the snap-fit is designed, how the parts mate with each other, and which plastic material is selected [1]. Bonenberger (GM) has developed a methodology for snap-fits that establishes the rules and engineering principles to support the design of fundamentally sound snap-fit interfaces. The purpose of this methodology is to produce an attachment:

- for an application having a certain *functionality*.
- between components of defined *basic shapes*.
- using *constraint* and *enhancement features* in an interface between components.
- brought together in a selected *install direction*.
- through a specific *assembly motion*.

Snap-fit features are subject to the same rules of design as any other features of an injection molded part [9]. When designed correctly, snap-fits can be assembled and disassembled many times without any adverse affect on the assembly. However, the designer should be aware that snap-fits do have some limitations. These include a possible clearance condition due to the tolerance stack-up of the two mating parts, and low pullaway forces. Snap-fits can increase the cost of an injection-molding tool if slides are needed in the mold. The designer can eliminate the need for slides by adding a slot directly underneath the snap ledge or by placing the snap at the outside edge of the part.

1) Cantilever and Cylindrical Snap Fits

Figure 1 illustrates the typical cantilever and cylindrical snap-fit designs. Most applications use the cantilever snap-fit design. The cylindrical design can be employed when an unfilled thermoplastic material is selected, for example in aspirin bottle/cap assembly. It is important that the design has sufficient holding power without exceeding the elastic or fatigue limit of the material.

Figure 5 shows a typical snap-fit design. Using the standard beam equations, the maximum stress during assembly can be calculated. During flexing of the cantilever part, if the stress stays below the yield point, it will return to its original position after snapping in. But in practice, the rapid assembly can generate bending stresses far higher than the yield point stress. Hence, the material momentarily passes through its maximum deflection or strain. Therefore it is convenient to calculate strain rather than stress for snap fits and comparing it to the allowable dynamic strain for the particular material. The dynamic strain for the straight beam is given by:

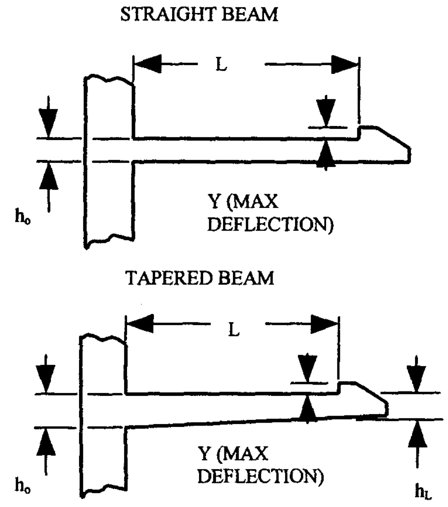


Fig. 5: Snap-fit Designs for Cantilever Beam

$$\varepsilon = \frac{3 \cdot Y \cdot h_o}{2 \cdot L^2} \qquad (3)$$

For the tapered beam, the dynamic strain is given by,

$$\varepsilon = \frac{3 \cdot Y \cdot h_o}{2 \cdot L^2 \cdot K} \qquad (4)$$

Proportionality constant K is given by Figure 6. When designing a cantilever snap-fit, there may be several iterations necessary such as changing length, thickness, deflection dimensions in order to design a snap-fit which results in a strain lower than the allowable strain of the material. For most applications the uniform section cantilever is sufficient. A tapered section beam is desirable if additional deflection is desired. Figure 5 shows a typical snap-fit design. Using the beam equation, the maximum stress during assembly can be calculated. If it stays below the yield point of the material, the flexing finger returns to its original position. However, for certain designs there is not enough holding power due to low forces or small deflections. With many plastic materials, the calculated bending stress can far exceed the yield point stress if the assembly occurs rapidly. In other words, the flexing

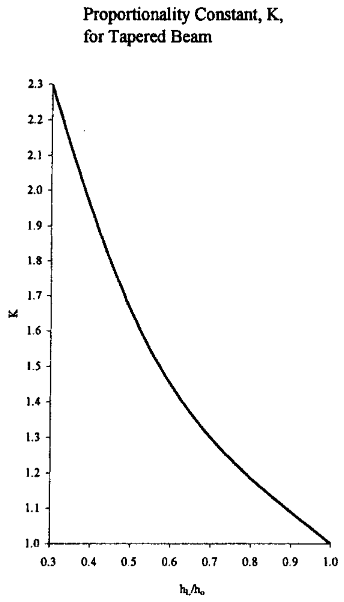


Fig. 6: Proportionality Constant K

finger just momentarily passes through its maximum deflection or strain, and the material does not respond as if the yield stress has been greatly exceeded. Thus, a common way to evaluate snap-fits is by calculating strain rather than stress. In designing the finger, it is extremely important to avoid any sharp corners or structural discontinuities, which can increase stress. A tapered finger provides a more uniform stress distribution and is advisable where possible.

Compared to a screw fastener, in the snap-fit design process every snap-fit used in a product must be designed from scratch. Complicated issues of material strength, fastener geometry, part stiffness, attachment strategy, tolerances, and manufacturability must be addressed to define the feature. Addressing these issues takes considerable time and effort and incurs many risks. Accurate analysis and testing, coupled with a logical design process, eliminates snap feature failure and provides benefits such as, elimination of costly mold rework, shortening of product time to market and elimination of costly product recalls, warranty claims, and lost customer satisfaction. One of the serious disadvantages of integral attachment design is that the integral attachments cannot be tested until the first prototype part is molded. Since integral attachments are formed by steel molds in an injection-molding machine, the mold must be reworked if the dimensions of the feature need to be changed. For many products, the plastic part tooling is the longest lead-time item and is, therefore, very critical because if the molds need to be reworked, this extra time will increase the product's time to market.

III.B Software Solutions

There are several software programs available to design snap-fit. One example is the Cantilever Snap-Fit Design Analysis Program from Eastman. The snap-fit calculator program dramatically simplifies the design of cantilever latches. Running on a PC in a windows environment, it is based on two critical constraints: the snap length and the deflection, and the latch deflection must return to zero position after engagement to prevent stress relaxation (creep) [10]. Another software is the Closed Loop Solutions, Inc. (CLS) with the program Snap Design™, a Windows based software for snap-fit attachment design and analysis. The program can pinpoint the most appropriate design without subjecting all iterations to lengthy and costly finite element analyses or tedious hand calculations. It has the capability to solve more than 100 different cases. The CLS approach allows to compute snap-fit dimensions (thickness, width and length), loads (deflection, engagement and pullout forces) or the most suitable material for a given design. The whole stress-strain curve is stored so the forces are accurately determined with the secant modulus [11].

IV. Disassembly with Snap-fit fasteners

Integral attachments, as they are typically implemented, often make disassembly more difficult. However, with proper attention to design, they can be designed for easy disassembly. More importantly, because they are made of the same material as the parts they join, no separation during recycling may be necessary, an advantage they possess over separate fasteners. For high-volume production, molded-in snap-fit (integral fastener) designs provide economical and rapid assembly. In many products, such as inexpensive houseware or hand-held appliances, snap-fits are often designed for only one assembly with no nondestructive means for disassembly. Where servicing is anticipated, provision is made to release the assembly with a tool. Other snap-fit designs, such as those used in battery compartment covers for calculators and radios, are designed for easy release and reassembly over hundreds or even thousands of cycles.

V. New Fasteners

The main thrust in our project is the design and development of new fasteners, which can be easily assembled and also disassembled. The focus is the use of this type of fastener under static load for application like computer housing, monitors, telephones, etc. A fastener design was created with these objectives. The design is a single piece fastener. This designed fastener is made of plastic and works by using an undercut in one part. The circular 'lip' of the fastener snaps into the undercut during the assembly. For the disassembly, the fastener is pushed down by a vertical disassembly force, which causes deformation in the fastener at the groove location, and the two parts are easily disassembled. The disassembly force can be applied by any simple tool such as a bar with circular cross section.

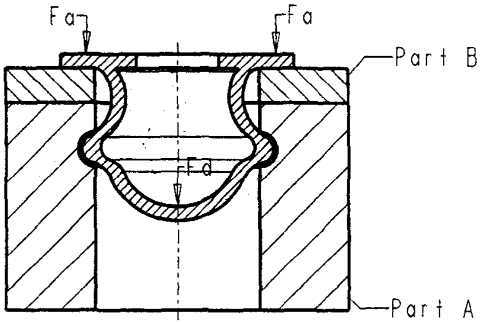


Fig. 7: Fastener Design

VI. Conclusions

This paper describes the design and the use of snap-fit fasteners for the multi-life-cycle design of products. The advantages, disadvantages and general design considerations are listed. Unlike the design and use of conventional fasteners, every snap-fit used in a product must be designed from scratch. While designing snap-fit fasteners, complicated issues of material strength, fastener geometry, part stiffness, attachment strategy, tolerances, and manufacturability need to be addressed. This paper also presents the use of compliant mechanisms i.e., design for no assembly in designing a new single piece snap fit fastener, which might be injection molded as a one-piece flexible structure. The new design can be disassembled by using a simple tool.

Acknowledgements

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References

[1] L. Wang, G.A. Gabriele and A.F. Luscher, "Failure Analysis Of A Bayonet-Finger Snap-Fit," Proceedings of ANTEC '95, Conference of the Society of Plastic Engineers, Boston, MA, 1995, Vol. 3, pp. 3799-3803, Paper 425

[2] D.E. Lee and H.T. Hahn, "A Survey of Integral Fit Joint Technologies for Composites," ASC 96: CIF Joint Survey Paper http:/ime.ucla.edu/~david/papers/asc96/csurvey.html

[3] G.A. Gabriele, A.F. Luscher, R.W. Messler and D. Lee, "Integral Fastening Program Mission Statement and Organization," Rensselaer Polytechnic Institute, 1995

[4] A.F. Luscher, G.A. Gabriele, R.W. Messler and P.R. Bonenberger, "A Classification Scheme For Integral Attachment Features," Proceedings of ANTEC '95, Conference of the Society of Plastic Engineers, Boston, MA, 1995, Vol. 3, pp. 3783-3787, Paper 618

[5] A.F. Luscher, G.A. Gabriele and P.R. Bonenberger, "Attachment Strategy Guidelines For Integral Attachment Features," Proceedings of ANTEC '95, Conference of the Society of Plastic Engineers, Boston, MA, 1995, Vol. 3, pp. 3771-3782, Paper 619

[6] S. Genc, R.W. Messler and G.A. Gabriele, "Issues In The Selection Of Locking Features In Integral Attachment Design Using Snap-Fits," Proceedings of ANTEC '97, Conference of the Society of Plastic Engineers, Toronto, Canada, 1997, Paper 322

[7] Hoechst Celanese - Engineering Plastics Division, "Designing with Plastics - The Fundamentals"

[8] F.M. Keeley, "Engineering Design Guides - Miscellaneous Fasteners (03)," Published for the Design Council, the British Standards Institution and Council of Engineering Institutions by Oxford University Press

[9] P.R. Bonenberger, "The Role Of Enhancement Features In High Quality Integral Attachments," Proceedings of ANTEC '95, Conference of the Society of Plastic Engineers, Boston, MA, 1995, Vol. 3, pp. 3788-3792, Paper 294

[10] Eastman, "Cantilever Snap-Fit," Design & Engineering Handbook, http:/www.eastman.com/ppbo/design/cantil.shtml

[11] Closed Loop Solutions, Inc., "Snap Design™ software," http://www.rust.net/~cls/index.html