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OPTIMAL DESIGN OF HEAT-REVERSIBLE LOCATOR-SNAP SYSTEM FOR NON-DESTRUCTIVE DISASSEMBLY OF ELECTRICAL APPLIANCES

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ABSTRACT

Recent legislative and social pressures have driven manufacturers to consider effective part reuse and material recycling at the end of product life at the design stage. One of the key considerations is to design and use joints that can disengage with minimum labor, part damage, and material contamination. The objective of this paper is to present a unified method to design high-stiffness reversible locator-snap system that can disengage non-destructively with localized heat, and its application to external product enclosures of electrical appliances. During disassembly, in-plane thermal expansion constrained by locators and temperature gradient along the wall thickness are exploited to realize the out-of-plane bulging of the enclosure wall that releases the snaps. The design problem is posed as an optimization problem to find the orientations, numbers, and locations of locators and snaps, and the location and size of a heating area, which realize the release of snaps with minimum heating area while satisfying motion and stiffness requirements. Screw Theory is utilized to pre-calculate a set of feasible orientations of locators and snaps, which are examined during optimization. The optimization problem is solved using a genetic algorithm coupled with structural and thermal FEA. The method is applied to the two-piece enclosure of a DVD player with a T-shaped mating line. The resulting locator-snap system exhibits snap disengagement with minimum heating area and sufficient stiffness to withstand its own weight. Although the method is applied on a simplified shape,

Keywords: Design for Disassembly, snap-fit joints, Screw Theory

1 INTRODUCTION

Recent legislative and social pressures have driven manufacturers to take responsibilities for reducing the amount of materials that end up in waste stream at product retirement. As such, products are now designed with increased emphasis on effective part reuse and material recycling at the end of product life using Design for Disassembly (DFD) [1-4] guidelines. One of the key considerations in DFD is the design and use of joints that can disengage with minimum labor, part damage, and material contamination.

Reversible snaps, often found at battery covers in electrical appliances (see Figure 1 for examples), are good candidates for such joints. They allow easy, non-destructive and clean detaching between mating parts at a desired time. However, these snaps are prone to accidental disengagement since they must sacrifice stiffness for the ease of disengagement, which is achieved by the displacement of locking surfaces by the auxiliary force on joint features such as tab, lever, and boss. Also, when used in external product enclosure, the aesthetic appeals of the product can be damaged due to the exposure of the joint features to which the unlocking force needs to be applied.

Figure 1. Remote control covers utilizing locators and reversible snaps

Accordingly, the objective of this paper is to present a unified method for designing a high-stiffness, reversible locator-snap system that can be disengaged non-destructively with localized heat, and its application to the external product enclosures of electrical appliances. The proposed heat-reversible locator-snap system consists of locators and snaps molded on the internal surfaces around the mating line of a thin-walled enclosure part. While assembled, the locators and the snaps respectively engage with the protrusions and the catches molded on the mating part, thereby constraining their relative motions. During assembly, the elasticity of the thin-walled parts is exploited to enable the snapping action. During disassembly, in-plane thermal expansion constrained by locators and temperature gradient along the wall thickness are exploited to realize the out-of-plane bulging of the enclosure wall that releases the snaps.

The design problem of the high-stiffness, heat-reversible locator-snap system is posed as an optimization problem to find the orientations, numbers, and locations of locators and snaps, and the location and size of a heating area, which realize the release of snaps with minimum heating area while satisfying motion and stiffness requirements. Screw Theory is utilized to pre-calculate a set of feasible orientations of locators and snaps, which are examined during optimization. The governing equations are general and can be used for complex as well as simple geometries. The optimization problem is solved using a genetic algorithm coupled with structural and thermal FEA. The method is applied to the two-piece enclosure of a DVD player with a T-shaped mating line. The resulting locator-snap system exhibits snap disengagement with minimum heating area and sufficient stiffness to withstand its own weight.

2 RELATED WORK

2.1 Analysis and Design of Snap Fits

Snap fit is a preferred joining method for design for disassembly since it does not need extra parts for joining, is easy to assemble, can be disassemblable with clean separation between parts [7 - 9].

Early work on snap fit design focused on the analysis of particular types of locking features such as cantilever hooks [10], bayonet-fingers [11], and compressible hooks [12]. More recently, Genc *et al.* [13 - 15] discussed a feature-based method to snap fit design, which classified snap-fit features into three categories: locating features, locking features, and enhancing features. Luscher *et al.* [16] discussed a similar classification based on assembly motions. These works, however, did not address the reversible snap-fit designs that are actuated by thermal deformation.

2.2 Design of Reversible Joints

Chiodo *et al.* [17] developed the concept of active disassembly using smart materials (ADSM), where heat-induced disassembly is realized by self-disengaging fasteners made of shape memory polymers (SMP) and compression springs. Li *et al.* reported topology optimization of heat-reversible cantilever snaps [18-20], where unsnapping is realized by the local transient thermal deformations of the cantilevers. Although effective in the presented examples, these works have not found many applications due to the need of special, costly, and unstable materials [17] or snaps with unpractically small locking surfaces and low stiffness [18-20].

In our previous work [5, 6], we have introduced an initial concept of high-stiffness, heat-reversible locator-snap systems that realizes non-destructive disassembly of plastic automotive body panels from aluminium frames with no special material. Similar to the design concept presented in this paper, it converts the in-plane thermal expansion of a body panel constrained on a rigid frame by locators, to out-of-plane bulging large enough to unlock the snap that locks the panel and the frame. However, the concept is specifically developed for assemblies of an elastic panel and a rigid frame. Also, the design method discussed in [5, 6] only optimizes the numbers and locations of locators and snaps and the area of heating, for fixed orientations of locators and snaps given as inputs. This paper generalizes the concept in [5, 6] to be applicable to any thin-walled enclosure assemblies with arbitrary mating lines, and extends the design method in [5, 6] to include the orientations of locators and snaps as additional design variables.

2.3 Screw Theory in Motion and Constraint Analsysis

The screw theory, a pioneering work by Ball [21], is used for motion and constraint analysis of rigid bodies. Waldron [22] utilized the screw theory to build a general method to determine all relative degrees of freedom (DOF) between two rigid bodies making contacts to each other. Extending the work by Konkar and Cutkosky [23], Adams and Whitney [24, 25] developed a method to determine the status (over-, under or fully constrained) of rigid body assemblies with mating features. Their method also determines the motion type and range of under constrained rigid body assemblies. Lee and Saitou [26] applied their method for designing 3D assemblies with prescribed in-process dimensional adjustability. Our previous work [6] outlined the use of Screw Theory to analyze relative motion constraints on a panel and a frame imposed by locators and snaps of given orientations, which is utilized in this paper for pre-calculating a set of feasible orientations of locators and snaps to be examined during optimization.

3 METHOD

3.1 Overview

The method synthesizes optimal designs of the locator-snap system by solving the following optimization problem:

- **Given:** the geometry of the two mating thin-walled parts, the coordinates of the vertices of the polygon representing the mating line where locators and snaps will be placed, the feasible region for heating, and the library of locators and snaps that can be used.
- **Find:** orientations, numbers, and locations of locators and snaps, and location and size of a heating area.
- **Minimizing:** the number of locators and snaps, and the area of heating
- **Subject to:** the parts are under constrained and do not interfere with the neighbouring parts before snap engagement, the parts are not under constrained and meet the structural requirements after snap engagement, and heating induces displacement sufficient for unlocking snaps.

Figure 2 shows a simplified example of inputs 1-4. In addition to the actual geometry of feasible locators (and the associated protrusions) and snaps (and the associated catches) available for a given problem, the library contains the wrench matrix representing the motion constraints imposed by each locator and snap, with respect to its local coordinate system. The optimization problem is solved using a genetic algorithm [27] coupled with structural and thermal FEA.

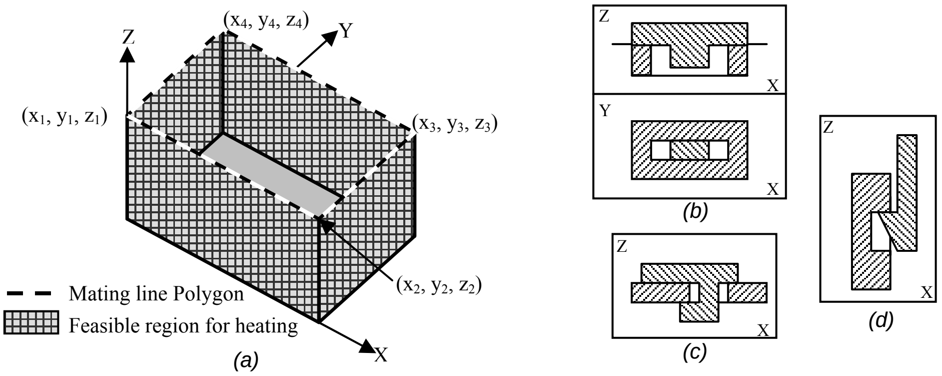


Figure 2, Example inputs. (a) part geometry (only one part shown), the coordinates of the vertices of the mating polygon, and feasible region for heating. (b)-(d) locators and snaps in the library.

3.2 Generation of feasible orientations of locators and snaps

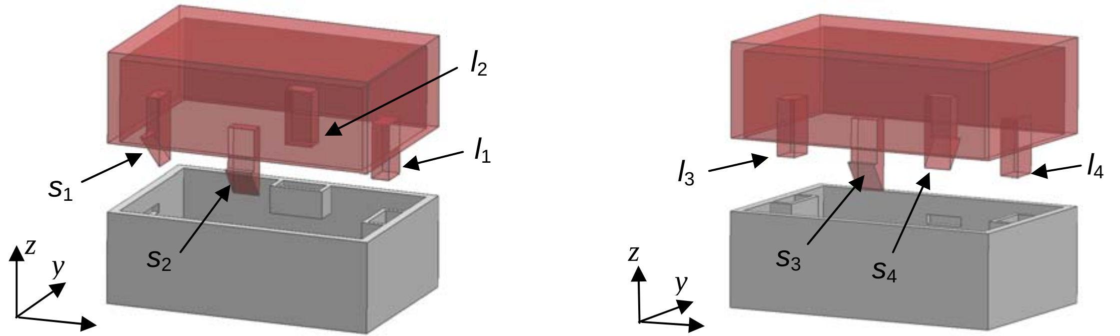
In order to avoid examining a large number of infeasible designs during optimization, a set of all orientations of locators and snaps feasible to the motion constraints of the above optimization problem is pre-calculated using Screw Theory. It is assumed that:

- locators (and the associated protrusions) and snaps (and the associated catches) can be placed on either of the two mating parts.
- locators (and the associated protrusions) and snaps (and the associated catches) can be placed

only at predefined discrete locations (*e*.g., nodes of finite elements) on the internal surfaces along the edges of the mating polygon and only in predefined discrete orientations (*eg*., a subset of 0^{o}, 90^{o}, 180^{o}, or 270^{o}) relative to the edge.

- each edge of the mating polygon can have one or more locators (or the associated protrusions) or snaps (or the associated catches) only of the same type, only in the same orientation.
- each edge of the mating polygon can have either locators (or the associated protrusion) or snaps (or the associated catch), but no both.

Based on the above assumptions, all possible combinations of locators, snaps, orientations, and edges can be enumerated. Since each edge can only have locators or snaps of the same type in the same orientation, their numbers and locations along each edge can be ignored for the purpose of the analysis of motion constraints. Since relative motion constraints on an edge are independent of the choice of the part on which the locators or snaps are placed, the choice can also be ignored for the purpose of the analysis of motion constraints. Each combination of locators, snaps, orientations, and edges is tested against two motion constraints in the above optimization problem: 1) the parts are under constrained and do not interfere with neighbouring parts before snap engagement and 2) the parts are not under constrained after snap engagement. After testing, only the combinations that satisfy both conditions are stored in a set of feasible orientations to be examined during optimization. Examples in Figure 3 illustrate the two motion constrains without loss of generality. In the figure, it is assumed that a locator can constrain the normal direction (positive and negative) of the surface on which it is placed and its direction of insertion (-z in the figure), a snap can only constrain its direction of disengagement (+z in the figure), and there is no neighbouring part that might cause interferences. In the orientations shown in Figure 3a, the both conditions are satisfied. Locators L_1 and L_2 constrain the motions in the $\pm x$ and -z, and $\pm y$ and -z directions respectively, but nothing constrains the +z direction. After snapping, snap S_1 and S_2 provides the constraint in this direction, thereby fully constraining the two mating parts. In the orientations shown in Figure 3b, on the other hand, the second condition is not satisfied. Locators L_3 and L_4 constrain the motion only in the $\pm x$ and -z directions, whereas snaps S_3 and S_4 constrain the +z direction. As a result, this is under constrained as it is free to move in the ±y direction.



(a) *(b)*

Figure 3. Examples of two different locator and snap orientations

The above conditions can be more precisely expressed using Screw Theory [21]. Adopting the wrench matrix representation similar to [2, 26], for example, the locators and snaps in Figure 3 are represented as:

$$\mathbf{W}_{l_1} = \mathbf{W}_{l_3} = \mathbf{W}_{l_4} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix} \tag{1}$$

$$\mathbf{W}_{l_2} = \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix} \tag{2}$$

$$\mathbf{W}_{s_1} = \mathbf{W}_{s_2} = \mathbf{W}_{s_3} = \mathbf{W}_{s_4} = \begin{pmatrix} 0 & 0 & -1 & 0 & 0 & 0 \end{pmatrix} \tag{3}$$

where each row represents the directional (row) vectors of the force and moment in the global reference frame, which can be supported by a mating surface in a locator or a snap. For example, the 1st row in Equation 1 has -1 at the 1st column, indicating the upright surface of locator l_1 can support the force in $+x$ direction. Note moments (the 4th, 5th, and 6th columns) are ignored due to our primal concern on the translational degrees of freedom. In testing each combination of locators, snaps, orientations, and edges in the enumerated set, the wrench matrix of a locator or a snap placed on an edge in an orientation is transformed to the one with respect to the global reference frame, using the rotation matrix constructed from the directional cosines of the edge and the rotation matrix for the orientation.

Based on the principle of virtual work, the forces and moments represented by wrench matrix $\mathbf{W} = (\boldsymbol{w}_1,\ldots,\boldsymbol{w}_n)^{\mathrm{T}}$ constraints the motions represented by twist matrix $\mathbf{T} = (\boldsymbol{t}_1,\ldots,\boldsymbol{t}_m)^{\mathrm{T}}$ if and only if there exists a negative component in every column of the virtual coefficient matrix [24]:

$$\Delta(\mathbf{W},\mathbf{T}) = \begin{pmatrix} \delta(\boldsymbol{w}_1,\boldsymbol{t}_1) & \cdots & \delta(\boldsymbol{w}_1,\boldsymbol{t}_m) \\ \vdots & \ddots & \vdots \\ \delta(\boldsymbol{w}_n,\boldsymbol{t}_1) & \cdots & \delta(\boldsymbol{w}_n,\boldsymbol{t}_m) \end{pmatrix} \tag{4}$$

where $\sigma(\boldsymbol{w},\boldsymbol{t})$ is the virtual coefficient of wrench $\boldsymbol{w} = (\boldsymbol{f}^T, \boldsymbol{m}^T)$ and twist $\boldsymbol{t} = (\boldsymbol{\omega}^T, \boldsymbol{v}^T)$:

$$\delta(\boldsymbol{w},\boldsymbol{t}) = \boldsymbol{v} \bullet \boldsymbol{f} + \boldsymbol{\omega} \bullet \boldsymbol{m} \tag{5}$$

Equivalently, this can be written as:

$$\text{fully-constrained}(\Delta(\mathbf{W},\mathbf{T})) = \begin{cases} \mathit{true} & \text{if } \forall j, \exists i,\ \delta(\boldsymbol{w}_i,\boldsymbol{t}_j) < 0 \\ \mathit{false} & \mathit{otherwise} \end{cases} \tag{6}$$

Equation 5 gives a compact representation of the above two conditions for feasible locators and snap orientations:

$$\text{fully-constrained}(\Delta(\bigcup_{k\in L} \mathbf{W}_k, \mathbf{T}_{all})) = \mathit{false} \tag{7}$$

$$\text{fully-constrained}(\Delta(\bigcup_{k\in L\cup S} \mathbf{W}_k, \mathbf{T}_{all})) = \mathit{true} \tag{8}$$

where L and S are the sets of locators and snaps, respectively, and $\mathbf{W}_k$ is the wrench matrix of a locator (if $k \in L$) or a snap (if $k \in S$), and $\mathbf{T}_{all}$ is the twist matrix of all translational motions in $\pm x$, $\pm y$, and $\pm z$ directions:

$$\mathbf{T}_{all} = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & -1 \end{pmatrix} \tag{9}$$

Using Equations 1-2, for example, the virtual coefficients matrix for Figure 3a before snap engagement is given as:

$$\Delta(\bigcup_{k\in\{L_1,L_2\}} \mathbf{W}_k, \mathbf{T}_{all}) = \begin{pmatrix} 1 & -1 & 0 & 0 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 & 0 \end{pmatrix} \tag{10}$$

Since the 5th column has no negative entry, fully-constrained = *false*. If $\mathbf{W}_{s1}$ and/or $\mathbf{W}_{s2}$ are added, *i.e.* snaps are engaged, the virtual coefficients matrix will have at least one negative entry in each row, thus fully-constrained = *true*. On the other hand, the virtual coefficients matrix for the design in Figure 3b after snap engagement, Equation 11, does not satisfy Equation 8. The matrix does not have negative values in $+y$ or $-y$ axis; thus, the design is always under-constrained in the y direction.

$$\Delta\Big(\bigcup_{k\in\{L_1,L_2\}\cup\{S_1,S_2\}} \mathbf{W}_k, \mathbf{T}_{all}\Big) = \begin{pmatrix} 1 & -1 & 0 & 0 & 0 & 0 \\ -1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 0 & -1 & 1 \end{pmatrix} \tag{11}$$

Since Equations 7 and 8 do not prohibit over constraining of the panel, the same degree of freedom can be constrained by multiple locators and/or snaps. While this may cause undesirable tolerance stack-up, the dimensional tolerances of the panel and frame are assumed to be sufficiently small in the following case study. The issue of over constraint and tolerance stack-up, however, will be addressed as a part of future work.

3.3 Simultaneous optimization of locators/snaps and heating area

Three design variables are defined for the optimization problem in Section 3.1:

- $\boldsymbol{x} = \{x_1, x_2, \ldots, x_n\}$ where x_i is a vector of the id's of d finite element nodes on edge i on which locators or snaps are placed; $x_{ij} = nil$ if the j-th locator/snap is not placed on edge i.
- $\boldsymbol{y} = \{y_1, y_2, \ldots, y_m\}$ where y_i is a coordinate vector of the i-th vertex of the area to be heated.
- $\boldsymbol{z}$ is a combination of locators, snaps, orientations, and edges in the feasible set generated as discussed in Section 3.2.

Using $\boldsymbol{x}$, $\boldsymbol{y}$ and $\boldsymbol{z}$, the optimization problem in Section 3.1 is written as:

$$\begin{aligned} &\text{minimize } f_1(\boldsymbol{y}) \\ &\text{subject to} \\ &\qquad \text{min\_displacement}\,(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}) > h \\ &\qquad \text{structural\_requirements}(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}) = true \\ &\qquad x_{ij} \in [L_i, U_i\,] \cup \{nil\}; \quad i = 1, \ldots, n; \quad j = 1, \ldots, d \\ &\qquad \boldsymbol{y} \in P_h^{\,m} \\ &\qquad \boldsymbol{z} \in F \end{aligned}$$

where:

- $f_1(\boldsymbol{y})$ is the area enclosed by vertices in $\boldsymbol{y}$
- min_displacement($\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}$) is the minimum outward thermal displacement of all nodes along the edges on which snap-catch pairs are placed.
- h is the height of snaps plus small tolerance
- structural_requirements($\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}$) is the structural requirements on the assembly while in use, such as minimum stiffness and resonance frequency.
- L_i and U_i are lower and upper bounds of the node numbers on edge i, respectively.
- P_h is the feasible region of the heating area.
- F is the set of feasible combination of locators, snaps, orientations, and edges generated as discussed in Section 3.2.

The evaluation of min_displacement($\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}$) requires thermo-structural FEA, whereas the evaluation of structural_requirements($\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}$) requires structural FEA only. It should be noted variables $\boldsymbol{x}$, $\boldsymbol{y}$ and $\boldsymbol{z}$ do not explicitly specify the choice of the part on which a locator or a protrusion (or similarly a snap or a catch) should be placed. Since the choice does not affect the motion constrains and structural behaviour during snap engagement, it can be arbitrary in the case of a locator-protrusion pair. In the case of a snap-catch pair, the choice is determined based on the thermal deformation upon heating. If the surface of a part bulges outwards, a catch is placed on the part. If the surface bulges inwards, a snap is placed on the part.

4 CASE STUDY

4.1 Inputs

The method is applied to the case of a DVD player made of two mating pieces of injection molded Nylon 66 with 30% glass (properties are given in Table 1) enclosure of size 250×500×150mm and wall thickness of 1.5 mm with a T-shaped mating line. Although the DVD shape is simple, the proposed method can be used on more complex problems effectively. Figure 4 shows the simplified DVD player model. To avoid breakage of the enclosure during use, the deformation at the mating line in the z direction under the product's own weight is restricted to be ≤ 0.5 mm.

Table 1: Material properties of Nylon 66-30% glass filled.

Property Name (units)	Value
Density (g/cm3)	1.36
Elasticity modulus (MPa)	8500
Poisson Ratio	0.36
Melting point (^{o}C)	260
Thermal expansion coefficient (m/m.^{o}C)	3.00
Specific heat capacity (j/kg.^{o}C)	1800
Conductivity (W/m.^{o}K)	0.40

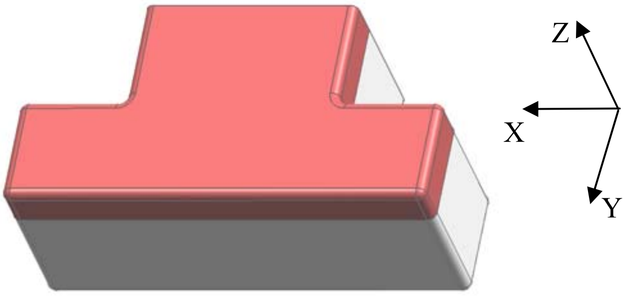


Figure 4. Simplified DVD player model

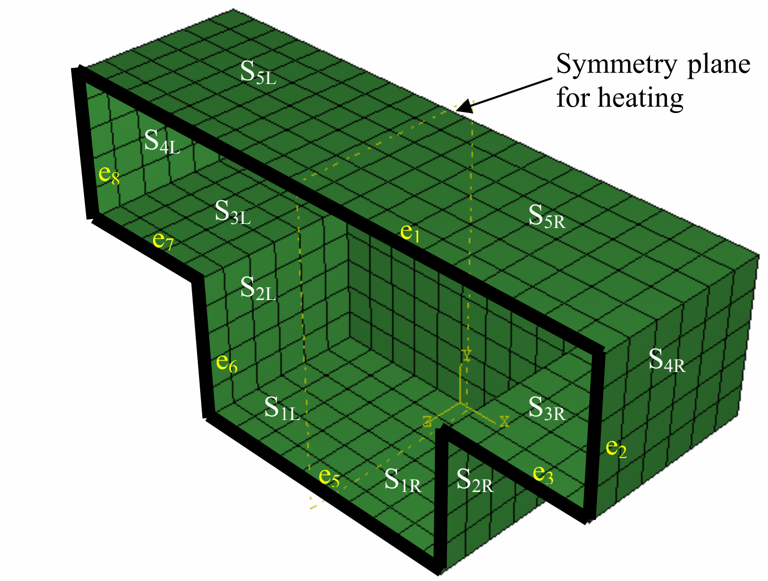


Figure 5. FE model for the lower part of assembly showing edges and heating surfaces.

Figure 5 shows the FE model of the lower part of the assembly. The mating polygon has 8 edges (n = 8), shown as thick black lines and labeled as $e_1 \dots e_8$. The feasible heating region, P_h, is considered as all the 8 surfaces of the lower part except its base surface. The heating region is subdivided into 10 sub-surfaces (labeled as $S_{1L} \dots S_{5L}$ and $S_{1R} \dots S_{5R}$), 5 on each side of the symmetry plane for heating as shown in Figure 5.

4.2 Generation of the feasible locator and snap orientations

A set of feasible orientations of locator and snaps are pre-calculated as discussed in Section 3.2. The locator and snap library used in this case study consists of those shown in Figure 2b and Figure 2d and they have the same wrench matrices as in Equations 1-3. Only orientations shown in Figure 3 are considered. After applying constraint analysis using Screw Theory on all the possible 256 orientation sets, only 224 are feasible and are included in the feasible set F. In all cases, the assembly direction is to move the two parts toward each other in the z direction in Figure 4.

4.3 Simultaneous optimization of locators and heating area

In order to avoid the usage of complex 3D polygons or 3D volumes with large infeasible regions to define the non-planar heat area, the two symmetric halves of the enclosure are first transformed to a 2D planar coordinate system creating a longer rectangular surface but having the same height, as shown in Figure 6a. The coordinates of the heated area are then applied on this transformed geometry considering the area to be rectangular (m = 4). A sample heated area is shown in Figure 6a and its equivalent area in the 3D model is shown in Figure 6b. To make use of the symmetric geometry, another design variable, t, is added to the general problem formulation to define the heated side of the enclosure (t = 0 for right side, t = 1 for left side and t = 2 for both sides). If t = 1 instead of 0 in Figure 6b, the heated area would have been on the other side (grey region). The heating temperature is 200°C in a room of 20°C. During heating, free convection to the air (convection heat transfer coefficient = 8 $W/m^2.{}^oK$) is considered as the only source of heat dissipation. It is assumed each edge can have only one locator or snap (d = 1).

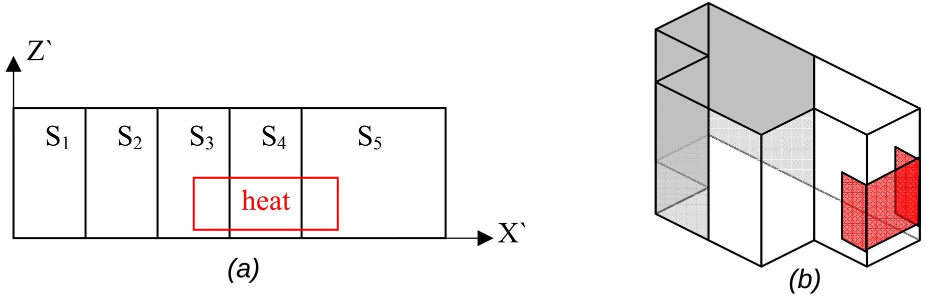


Figure 6. (a) schematic of the 2D Transformed feasible heating region, and (b) schematic of 3D DVD player with sample heating area

The out of plane displacement of all nodes with snaps is obtained from FEA and a penalty is applied if the displacement is less than the snap height plus a small tolerance. Since GA does not handle constraints explicitly, the minimum displacement constraint is written as a penalty function as shown in Equation 10 with h = 1 mm.

$$f_2(\mathbf{x}, \mathbf{y}, \mathbf{z}) = \max(0, h - \text{min\_displacement}(\mathbf{x}, \mathbf{y}, \mathbf{z})) \tag{10}$$

The structural requirement of the DVD enclosure assembly is to guarantee that the deformation at the mating line under the product's own weight (2 kg) is restricted to be ≤ 0.5 mm; thus ensure that snaps are stiff enough to avoid breakage of the enclosure during use as shown in Equation 11.

$$f_3(\mathbf{x}, \mathbf{y}, \mathbf{z}) = \max(0, \text{max\_displacement}(\mathbf{x}, \mathbf{y}, \mathbf{z}) - 0.5) \tag{11}$$

where max_displacement($\mathbf{x}$, $\mathbf{y}$, $\mathbf{z}$) is the maximum displacement of the mating line nodes obtained from FEA due to the application of uniform force of 20 N to the base of the part in the $-z$ direction. Heuristic and arithmetic crossovers are used for all the variables. Table 2 shows the GA parameters.

Table 2: GA parameters used in this case study

Parameter	**Value**
Population size	80
Number of generations	80
Crossover probability	0.95
Mutation probability	0.05

4.4 Optimization Results

Figure 7 shows the optimal placement of locators and snaps with the 25mm x 50mm heating area. The deformation of the part under its own weight (pressure load in –z direction) is shown in Figure 8. The maximum deformation at the mating line is (0.02 mm) at middle right corner as shown in Figure 8. Table 3 and Figure 9 summarise the response of the part to heating. The table gives the out of plane displacement value at each snap and whether it is bulging outward or inward. If the bulging is outward, a catch should be placed on the shown part. If the bulging is downward, a snap should be placed on the shown part. As a general rule, having snaps placed on the two mating parts is recommended as it adds to the complexity of the unlocking process; thus, prevents easy unauthorized disassembly. Figures 10a-d show CAD drawings of top cover, base part, exploded view, and assembled view of the final optimized DVD player model, respectively.

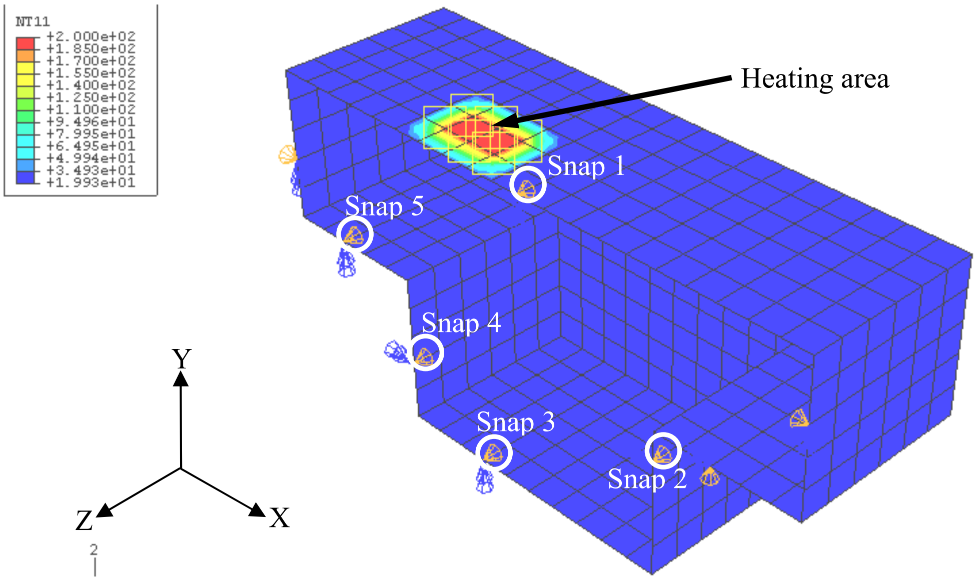


Figure 7. Optimum placement of locators and snaps and heating area

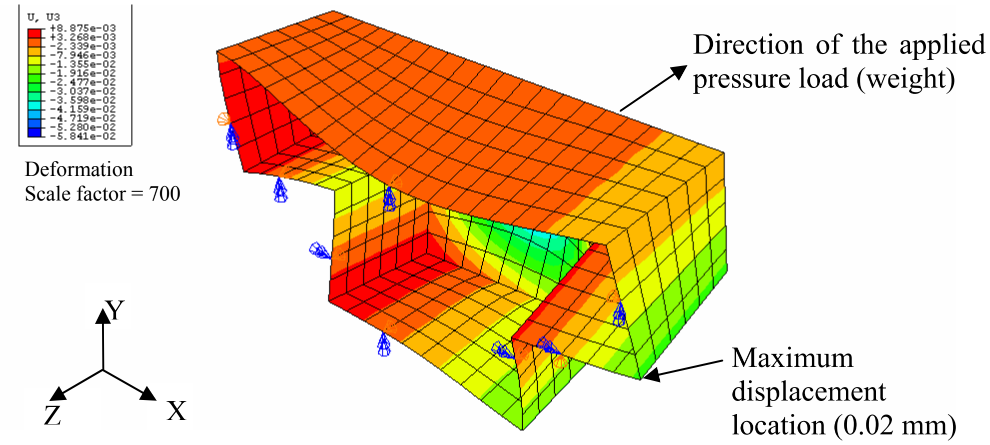


Figure 8. Deformation of the DVD case under the DVD player's own weight

Table 3: GA parameters used in this case study

Snap number	**displacement**	**Bulge side**
Snap 1	1.912	inward
Snap 2	1.211	outward
Snap 3	2.916	outward
Snap 4	1.692	inward
Snap 5	4.301	outward

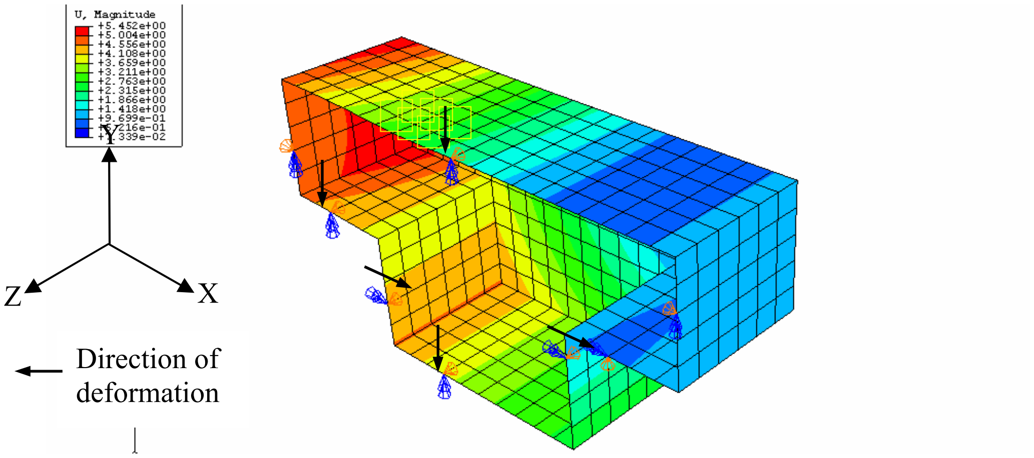


Figure 9. Deformation of the DVD case due to heating for disassembly

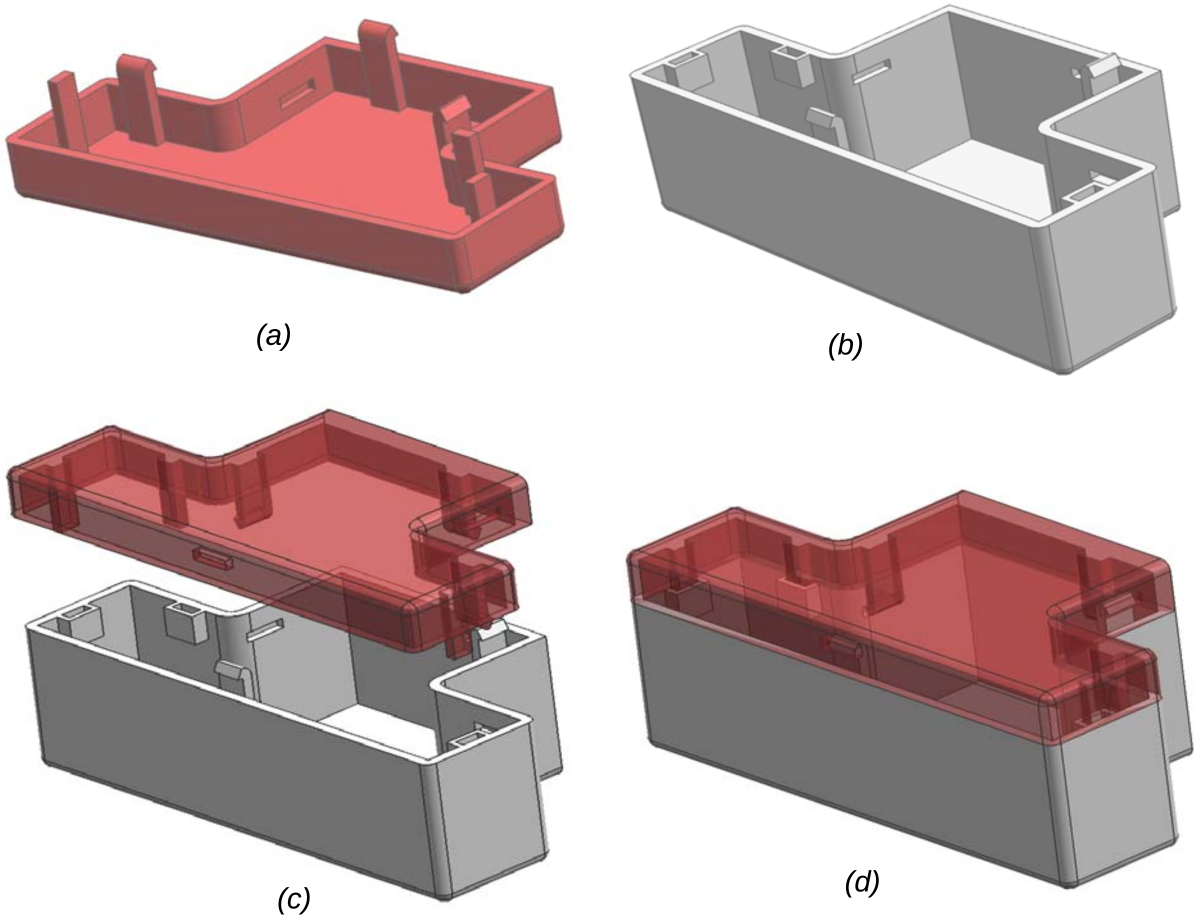


Figure 10. CAD drawing for the optimized DVD player model, (a) top part, (b) base part, (c) exploded view and (d) assembled view.

5 CONCLUSION AND FUTURE WORK

This paper presented a unified method for designing a high-stiffness reversible locator-snap system that can be disengaged non-destructively with localized heat. The method was applied to a case study of a DVD player of size 250×500×150mm and wall thickness 1.5 mm with a T-shaped mating line. The optimization results exhibit a stiff enough design to meet the structural requirements that limit the out of plane deformation at the mating line under the product's own weight to be ≤ 0.5 mm, and at the same time having small heating area, thus save energy, necessary for snap disengagement.

Future work includes accounting for fail safe design requirements against other undesired forces and environmental temperature changes, addressing the issue of undesired tolerance stack-up, and extending the problem to more complex 3D geometries with more freedom on the numbers and types of locators used.

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