A One-Piece Compliant Stapler

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This report describes the design of a one-piece compliant stapler, a project entry by the authors, that was placed first in the graduate division of the 1994 ASME student mechanism design competition at the 1994 ASME Design Technical Conferences, held at Minneapolis, Minnesota, September 11–14, 1994.

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Introduction and Motivation

Today's competitive market demands continued consideration of alternative designs to improve quality, economy, and safety, for the commercial success of any product, big or small. Motivated by this challenge, this project aims to improve upon the design of one of the most common pieces of stationery—a stapler. Typically, a stapler is comprised of at least four separate rigid parts and a spring assembled together to serve the various subfunctions. In general, designing a product with fewer components, and eliminating the component assembly results in a decrease of its production cost considerably. In order to economize the cost of production of a stapler, we present a novel design for a stapler that consists of only one component and performs as good as a conventional stapler. In the design proposed, the desired functionality is achieved entirely through the compliance, i.e., elastic deformation in a suitably shaped, single piece of flexible material. This feature accounts for the use of the word *compliant stapler* to describe the new design which falls under the class of *compliant mechanisms*. The principal advantage of this new design is an enormous savings in its manufacturing cost besides light weight and aesthetic looks.

The Concept of a Compliant Mechanism

A *compliant mechanism* represents a class of mechanical systems that gain all or part of their mobility from the relative mobility of deformable elements in their design, as opposed to only the rigid body members [Midha 1992]. Significant advantages offered by a compliant mechanism, such as need for fewer parts, less wear, friction, noise and backlash due to clearances, make it a superior choice of design over a rigid-body mechanism performing similar functions for a given function in many cases. Researchers in the field of compliant mechanisms believe that this field is important, and is expected to continue to grow as materials with superior properties are developed. This emerging concept of compliant mechanisms, especially the fully compliant, one-piece construction leads to a new design paradigm—***Integrated Design for Eliminating Assembly, IDEA***. The proposed design for a stapler serves as a good example of this concept.

The Design Approach

Due to lack of a systematic method, the design of compliant mechanisms continues to rely upon the intuition and experience of the designer. True to this statement, the creation of a compliant stapler too was largely a creative effort derived from the intuitive understanding of the rigid-body mechanism behavior and the elastic behavior of a continuum under specified loads and boundary conditions.

The design of compliant mechanisms are obtained, generally, by suitably replacing the rigid joints and rigid links by either a fully compliant entity of material or a structure with discrete localized compliant segments. The first logical step in the design of such mechanisms, therefore, is to identify the basic subfunctions and the parts of the mechanism that accomplish those subfunctions. The next step would be to conceptualize the distribution of compliance or the localized compliant segments which can perform similar subfunctions. The final step in the design is to obtain the suitable dimensions for all of the segments of the compliant mechanism. The next section presents the first two steps applied to the stapler design and the final design step is explained in the section following the next.

Functional Description and Conceptualization

The four main subfunctions in a stapler can be identified as: (i) holding the staples securely in a slot, (ii) loading and unloading (if necessary) of the staples, (iii) plunging a rigid member on to a staple and (iv) stapling (i.e., piercing a staple through a stack of papers and folding back of its sides). Typically, in a conventional stapler shown in Figure 1, at least four rigid parts and two springs accomplish these functions.

In order to meet the primary goal of this project—to design and fabricate a stapler out of a single piece—the design is conceptualized as a distributed compliant structure with a few discrete highly flexible segments. A solid-model rendering and a line sketch of the conceptual design are shown in Plate 1 and Figure 2 respectively. Although the design resembles a conventional stapler, it can be seen that the major ideas incorporated in the new design are: the two single-axis flexure hinges to serve the purpose of the rigid pin joint and a compliant curved beam to serve the purpose of the spring holding the staples. The flexure hinges are formed by circular cutouts on both sides of the blank to from necked-down sections as shown in figure. The compliant curved-beam, whose one end is attached to the middle part and the other connected to a slider, remains almost flat with a large radius of curvature when staples are unloaded, and bends into an arch with a smaller radius of curvature when the staples are loaded. Table 1 below, shows how the various subfunctions are accomplished in the conventional and the new designs.

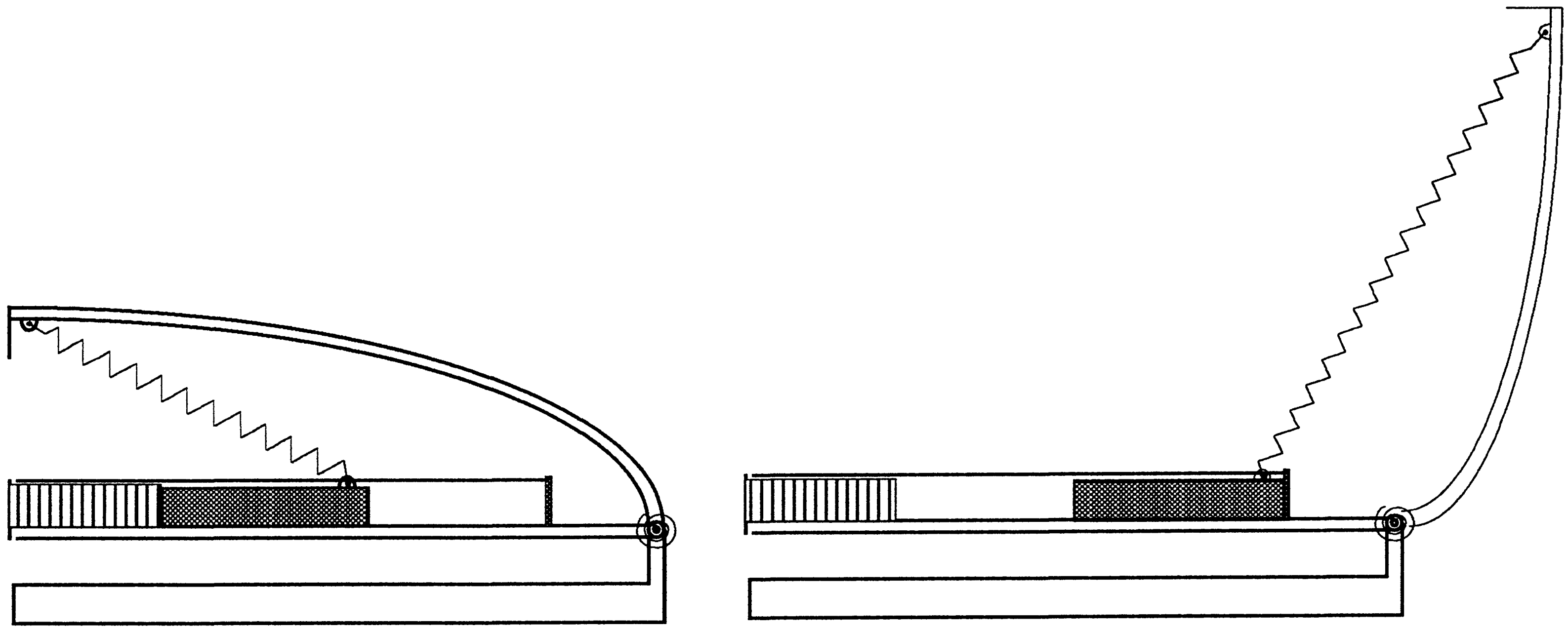


Figure 1: Schematic diagram of a conventional stapler

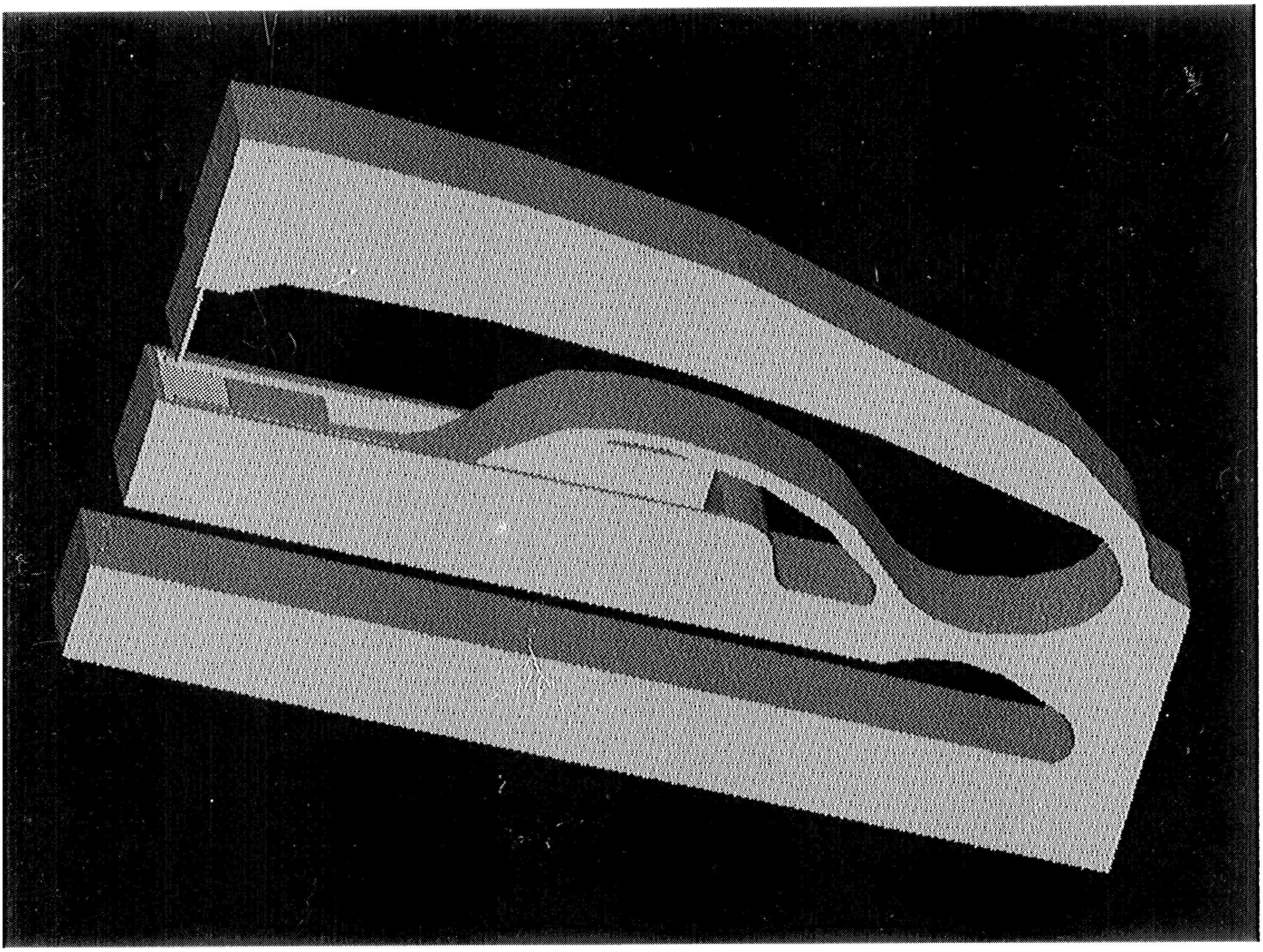
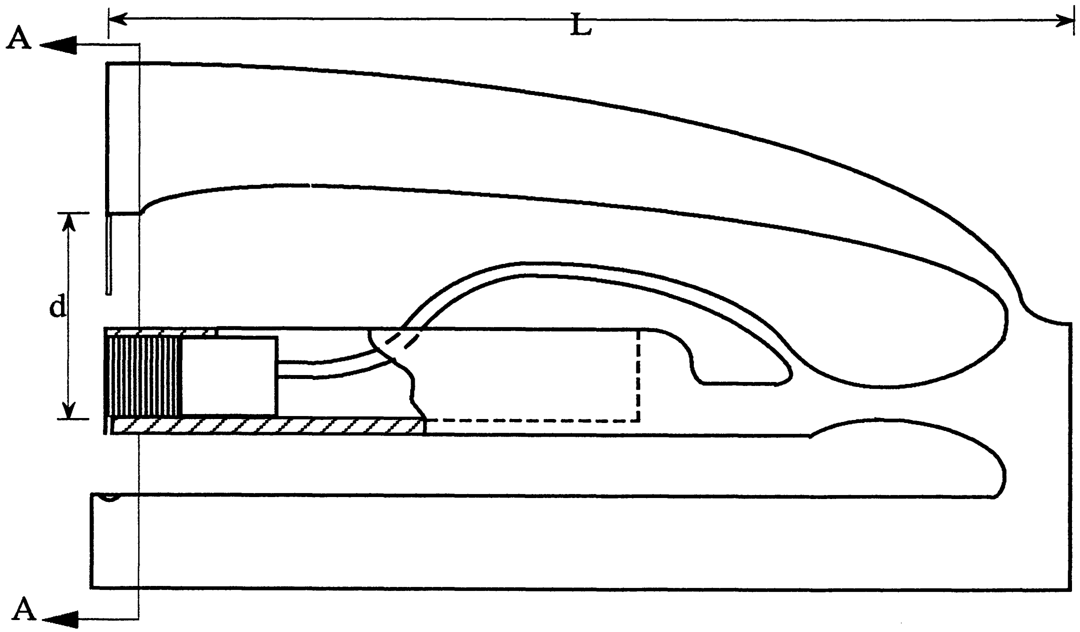
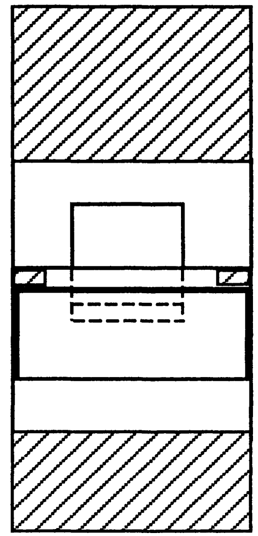


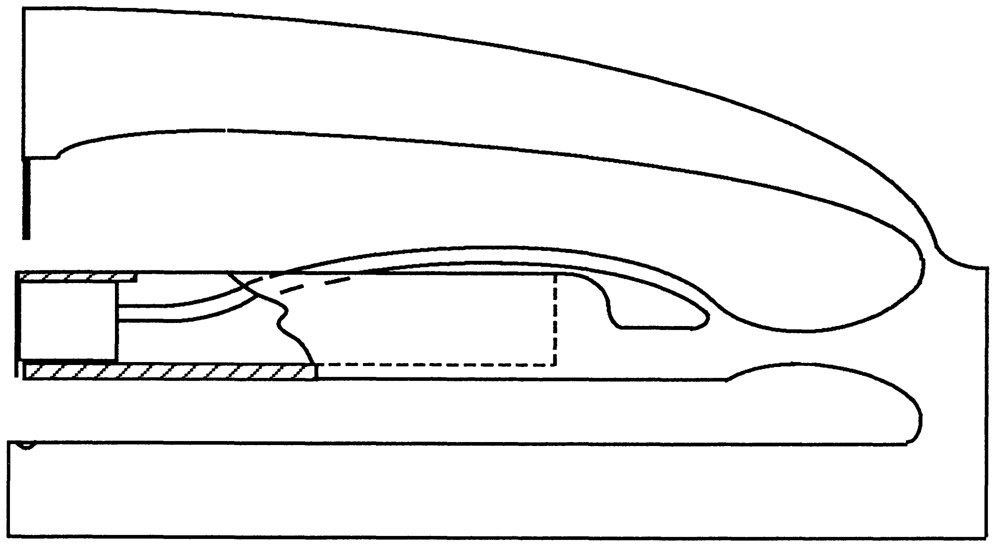
Plate 1: Solid-model of the one-piece compliant stapler.



The compliant stapler with staples loaded



Section A-A



The compliant stapler with staples unloaded

Figure 2: Line Drawing of the one-piece compliant stapler

Table 1: Functional descriptions of conventional and compliant staplers

Subfunctions of a Stapler	*Means through which the subfunction is accomplished in a Conventional Stapler*	*Means through which the subfunction is accomplished in a Compliant Stapler*
Holding the staples in a slot	A slider attached to a spring firmly presses the staples towards the front wall of the staple slot.	The deformation energy stored in a compliant beam spring provides for the spring energy for keeping the staples in place.
Loading and unloading the staples	Staples can be loaded or unloaded as shown in Figure 1 wherein the top piece is rotated through a large angle and thus pulling the slider to the right.	This is done just as in a conventional stapler by moving a slider (connected to the compliant curved beam) in the staple slot.
Plunging the staple	The top part aided by a spring force pivots about the rigid pin joint and plunges on a staple downwards.	A relatively thick beam (top part) connected to a flexural pivot provides for the pivoting and the spring force necessary for plunging a staple.
Stapling	A rigid sharp edge pushes a staple down piercing it through a stack of papers, and bends the staple ends by forming them into shape on the bottom part while the middle part pivots about the rigid pin-joint.	The sharp edge and the forming shape on the bottom part remain the same; however, the middle part pivots about an independent flexure hinge connecting its end to the base.

Design Calculations

The dimensions for the new design were chosen to suit one of the standard sizes of the staples available in market. The important dimensions to be calculated were the cross-sections of the flexural pivots and the compliant curved beam that serves as a spring.

The proper dimensions of these flexural pivots is critical because they must be long and thin enough to travel through the required angle of rotation without becoming over stressed and must also be thick enough to withstand the required amount of fatigue loading. In order to estimate the cross-section of the flexural pivot for the top portion, it was assumed to bend through an angle $\emptyset$ in a circular arc of radius L under a force F required to staple through a few papers, which is applied at the end of the top portion.

$$\emptyset = L/d$$

where L is the length of the stapler and d is the distance through which the top part moves through to push a staple down. The force required for stapling was estimated to be about 50 N. The corresponding moment M on the flexural pivot will be:

$$M = F \times L$$

Using the values of moment and the angle of deflection, the arc radius R for the necking of the flexure was obtained by using the expressions derived by Paros and Weisbord [1965]:

$$\frac{\phi}{M_z} \approx \frac{9\pi R^{1/2}}{2Ebt^{5/2}}$$

Adopting the following values for the design parameters (see Figure 3) t = 5 mm, b = 13 mm, d = 37 mm, L = 115 mm, E = 700 MPa, R was computed to be 20 cm.

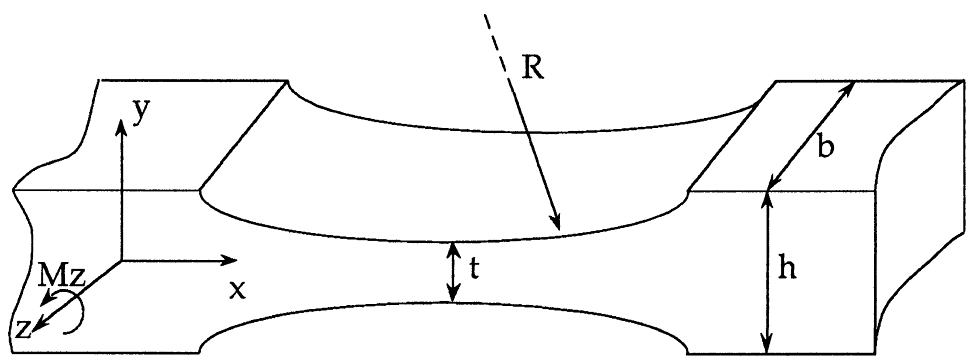


FIgure 3: The Flexural Hinge

The compliant curved beam was so dimensioned to have a spring constant equal to that of the linear spring used in a conventional stapler of an equivalent size. For the prototype size the required spring constant was estimated to be 0.5 N/cm. The corresponding cross-section dimensions calculated using the formula in (Roark and Young, 1975) was determined to be 13 mm X 1 mm. The details are given in the Appendix .

The dimensions of the sharp edge that pushes staples and the shape of the indentation on the base were selected to suit the standard size of staples chosen. All other dimensions of the stapler were selected to coordinate the motions of the edge, and the staple stack for accomplishing the desired functionality of stapling, and also to enable the stapler fabrication out of a single-piece.

Manufacturability and the Prototype

The concept of one-piece *IDEA* results in a considerable decrease in its production cost when compared with the production cost of a rigid-body mechanism for similar function in several ways. It eliminates the need for manual labor or automation equipment in component assembly, reduces the inventory and the variety of manufacturing equipment required, decreases the amount of material handling involved, decreases the number of manufacturing operations, reduces the overall turn-out time, and maintains a cleaner factory environment. The suitable manufacturing processes for such designs are molding, casting, extruding, and the like. For such one-piece designs, any plastics based flexible material with adequate fatigue strength to withstand the required elastic deformations of its members, is suitable . A plastics based material enhances the *look-and-feel* characteristic, and increases the commercial viability of the product as well. If necessary (in cases where various parts of the design require different properties not possessed by a single material), some parts of the design could be made of different materials and be used as inserts in the molding or casting process.

The proposed design can be manufactured in a single stage by injection molding of a suitable plastic material. Injection molding process is suitable for a large scale production. The sharp edge and the forming base could be made of steel and used as inserts in the injection mold. However, for a prototype of the proposed design, it is economically not viable to make a mold. Hence, it was decided to fabricate a low-budget prototype by cutting process using a milling tool. Since the proposed design is meant for molding process rather than cutting process, it was decided to make the prototype in two pieces by slightly modifying the one-piece design. The modified design (**only for the purpose of making a prototype**) is shown in Figure 4. As can be seen from the Figure 4, the only modification was making the middle part (along with its flexural pivot) detachable and attachable from the

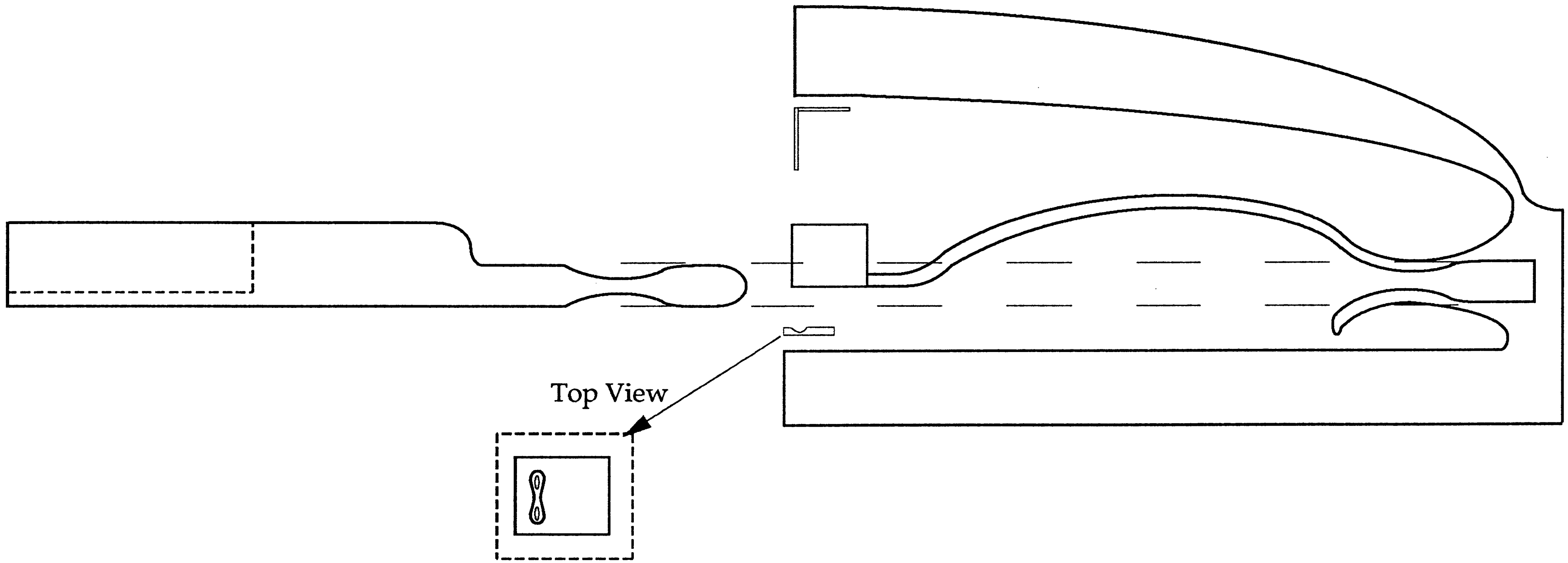


Figure 4: Schematic diagram of the manufactured prototype

main body by a snap fit into a corresponding slot in the main body. The two parts shown in the Figure 4, were cut from a half-inch thick rectangular sheet of polyethylene (whose trade name is PAXON). The two metallic parts, the sharp edge and the indentation required to bend the staple (that were to go as inserts in the molding) were fastened to the top and the bottom parts as can be seen in the plate 2. The prototype satisfactorily demonstrates the feasibility of the concept. It should be emphasized that the best performance and the cost advantage can be realized only by injection molding the one-piece design.

Discussion and Closure

A novel one-piece design for a stapler has been presented. The new design is representative of *compliant mechanisms*, an emerging class of mechanisms which derive their mobility through elastic deformations in a flexible material as opposed to the rigid-body motion of the conventional mechanisms. The proposed design can be manufactured in a single stage by injection molding a suitable plastic material with appropriate properties. The new design with performance quality as good as a conventional one can result in a significant decrease in its production cost when produced on a mass scale. It also makes a stapler lighter and more amenable to improve upon ergonomic and aesthetic aspects than a conventional stapler. A proof of the concept prototype has been fabricated. Plate 3 shows a comparision of disassembled parts of a conventional stapler and the prototype of the *one-piece compliant stapler*. The conventional stapler shown in the Plate has 20 separate parts whereas the new design has only one part.

Acknowledgments

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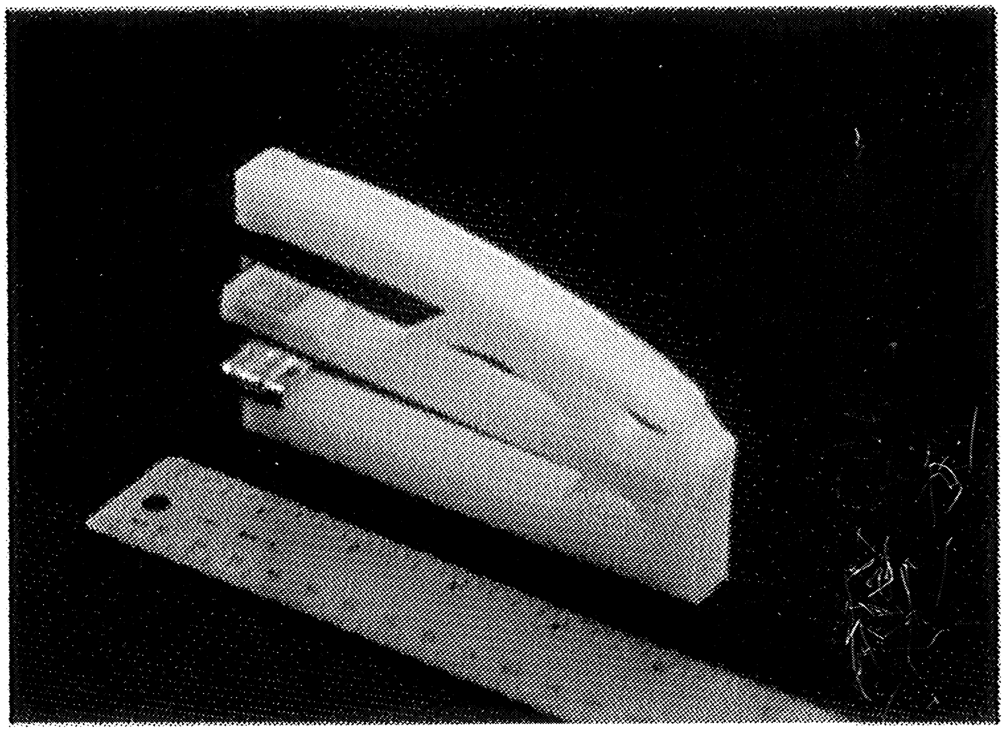


Plate 2: Prototype of the compliant stapler.

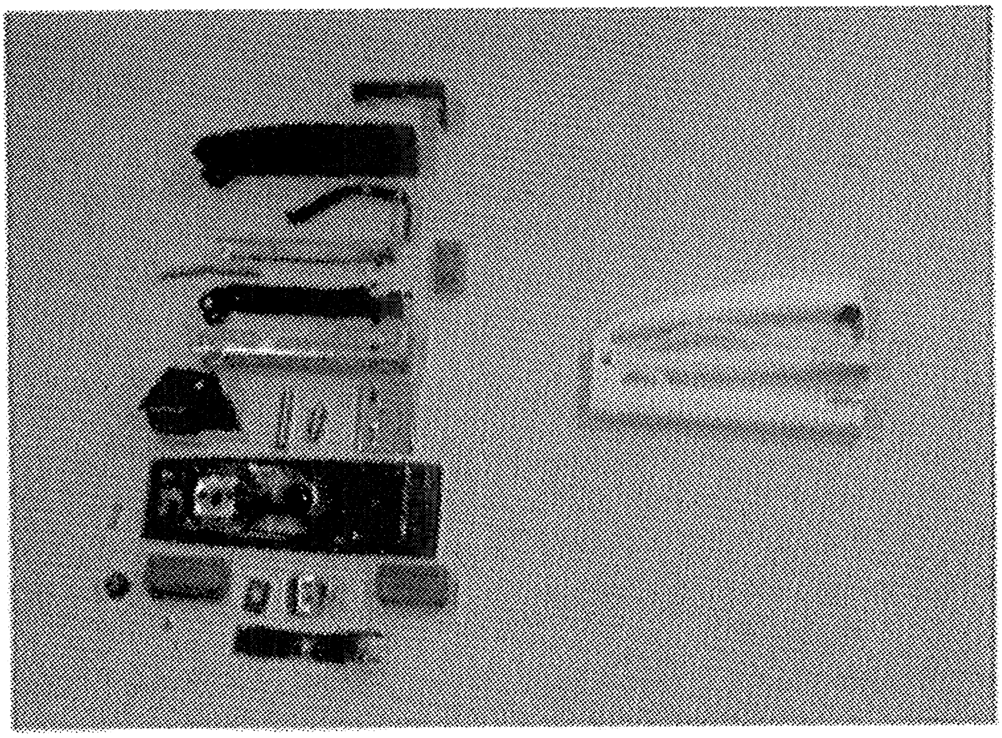
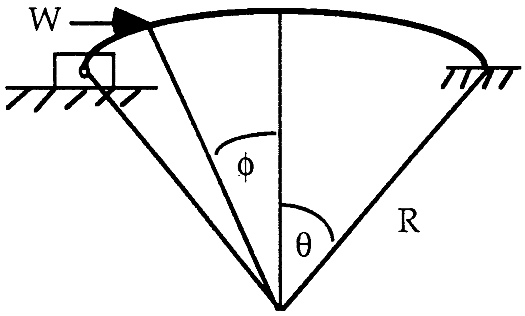


Plate 3: Comparision of a conventional stapler and the compliant stapler
Left: Diassembled parts of a conventional stapler.
Right: One-piece compliant stapler with inserts.

APPENDIX

Formulas for the Design of Compliant beam Spring

(Roark and Young, 1975)



Y = Young's modulus
G = Rigidity modulus
ν = Poisson's ratio
J = Area moment of inertia
A = Area of cross-section

$$\delta := \frac{R^3\,(LFh - Bhv\,Va)}{Y\,J}$$

$$Va := \frac{LFv}{Bvv}$$

$$LFh := W\left(\frac{1}{2}(\theta+\phi)(1+2\,m\,c) - \frac{1}{2}\,s\,c - \frac{1}{2}\,m\,n - m\,s - n\,c + \frac{1}{2}(\alpha+\beta)(\theta+\phi) + \frac{1}{2}(\alpha-\beta)(m\,n+s\,c)\right)$$

$$LFv := W\left(1 - \frac{3}{2}c^2 + s\,n + m\,c - \frac{1}{2}m^2 - (\theta+\phi)\,m\,s + \frac{1}{2}(\alpha-\beta)(m^2 - c^2)\right)$$

$$Bhv := 2\,s^2 - 2\,\theta\,s\,c$$

$$Bvv := \theta + 2\,\theta\,s^2 - s\,c + \alpha(\theta - s\,c) + \beta(\theta + s\,c)$$

$$\alpha := \frac{J}{A\,R^2}$$

$$\beta := 1.2\,\frac{Y\,J}{G\,A\,R^2}$$

$$s := \sin(\theta)$$

$$c := \cos(\theta)$$

$$n := \sin(\phi)$$

$$m := \cos(\phi)$$

$$G := \frac{Y}{2+2\,\nu}$$

$$R := \frac{1}{2}\,\frac{\frac{1}{4}h^2 + v^2}{v}$$

$$\theta := \arcsin\left(\frac{h\,v}{\frac{1}{4}h^2 + v^2}\right)$$

$$\phi := \arcsin\left(\frac{h\,v}{\frac{1}{4}h^2 + v^2}\right)$$

$$A := b\,t$$

$$J := \frac{1}{12}\,b\,t^3$$

Y = 700 MPa

G = 280 MPa

h = 6.5 cm

v = 0.75 cm

W = 10 N

t = 1 mm b = 0.6 cm

R = 7.42 cm

θ = ϕ = 0.4536 rad ≈ 26 º

δ = 2.08 cm
