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Precision, low-cost braille labelling using flexural embossers and elastic averaging

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Abstract

For 49 million people globally with blindness, braille labels in their homes, workplaces and schools could enable independence. Yet, labels are not widespread. A review of existing braille label making technology shows that the key technological gap is a personal, precise (+/- $100\ \mu m$), low-cost (<$10), and language independent (130 braille scripts) braille dot embossing machine.

This paper presents the design of an embossing mechanism comprised of six, radially oriented, spherically tipped, flexural beams on a ring which are actuated by a flexural "keyboard" to deform cellophane tape into an anvil die. An elastic averaging interface connects the ring and anvil, providing planar and axial constraint, aligning the embossing arms with the anvil-die cups in *x, y,* and θ. The embossing arms are monolithically molded and comprise a connector ring, a stiff cantilevered beam to transmit 9.8N embossing force and a compliant hinge with a stress ratio less than 0.2. The tapered beams provide planar stiffness in x and y, while the flexural hinge provides normal compliance in z. The elastic averaging connector provides an estimated $15\ \mu m$ of repeatability, based on 28 points of contact. Radial error is elastically averaged and minimized at the central point of interest. The system was prototyped using multi-jet fusion additive manufacturing and designed for two part injection molding, quoted to cost $1.44 per device at scale.

An error budget was used to guide the mechanism design with the average of the linear sum and root square sum of errors calculated at the point of interest to compare with the allowable error. Error from manufacturing, elastic averaging, and load-induced Abbe and cosine errors were calculated to be $69\ \mu m$ in x and $16\ \mu m$ in y, less than the bugeted $100 \mu m$ of allowable error.

Keywords: Accuracy, Constraint, Design, Error

1. Introduction

For an estimated 49 million people globally with blindness, braille labels in their homes, workplaces and schools could enable independence. Yet, there is no label maker that meets the requirements of users, in particular, the accuracy and price point required to make widespread adoption affordable and accessible. A review of existing braille label making technology shows that the key technological gap is achieving personal, precise (+/- $100\ \mu m$), low-cost (<$10), and language independent (130 braille scripts) braille dot embossing. Current state of the art is either expensive, only in a few languages, or non-intuitive to use.

This paper presents the design of a new braille embossing mechanism meets accuracy and price point requirements by utilizing flexural beams and an elastic averaging connector, all designed to be simply injection moldable for cost requirements.

The design methodology utilized error budgets to select and integrate components in the structural loop, based on $100\ \mu m$ allowable planar error in x and y. Stiffness and compliance are addressed through design choices in the embossing beams. The embossing beams and the anvil die are separate pieces for moldability, thus risk of error in the connection is mitigated by using elastic averaging techniques. Calculated error for the structural loop and manufacturing quotes show the design presented meets the key functional requirements.

2. Design Methodology

In order to design a precise actuator, sources of error must be identified and reduced throughout the structural loop. This analysis focuses on geometric and load induced errors between the embossing beams and anvil die. Deflections, forces, stiffness, and compliance are considered in the beam design. Repeatability is considered for the elastic averaging connector.

Accuracy and repeatability of the size and spacing of the dots and characters are essential for reading comprehension.

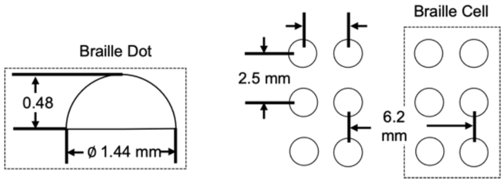

Figure 1: Braille dot and cell specifications

2.1. Embossing Beams

In this model, a short flexural segment allows for deflection, while the forward part of the beam acts as a stiff stage to transmit the force from the snap dome to the embossing tip.

Fig. 1 shows the embossed dots are 2.5 mm apart while buttons for the user's fingers to push need to be more than 18 mm apart based on human factors [1]. Initially for simplicity we sought to push direction raised features along the beams lengths, but variations in how users push on the buttons creates parasitic forces that cause unacceptable errors at the embossing tips. Hence the buttons were moved to their own flexural mounts which then provide a more pure motion to apply force to the embossing beam as shown in Fig. 2. This point of force application is still removed from the tip of the embossing beam, and hence with the embossing force creates a moment near the end of the beam. Either a uniform thickness cantilever beam or a flexural hinged beam can be molded. The latter was found to give better control of the tip contact angle. A model for large deflection, beam-based flexure joints, using a semi-analytical model [2] shown to closely match non-linear solutions, was used to calculate the bending force F_b in Eq. 1. Eq. 2 is derived from the classical model for a simply supported beam with an intermediate load.

$$F_b = \frac{EI\,\theta/l}{\left(l_v + \frac{\rho\, l}{2\omega}\right) \sin\left(\frac{\pi}{2} - \theta\right)} \qquad (1)$$

$$F_e = \frac{F_t(L + l)}{l_v + l} \qquad (2)$$

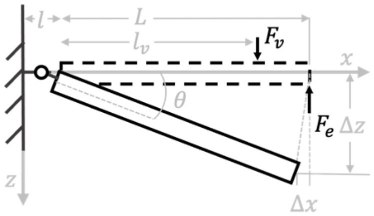

Figure 2. Free body diagrams for the flexure-joint and embossing models.

2.2. Elastic Averaging Connector

The embossing arms are molded as a single unit, as are the finger pushing buttons and the anvil, and all must be accurately located with respect to each other. Achieveable pin-in-slot molding tolerances were not sufficient so we created an elastic averaging connector, using Lego™-like features. The relative accuracy obtainable was calculated using Eq. 3: $r = \delta/\sqrt[2]{n}$, where r is the obtained accuracy, δ is the typical positional error of the elastic features, and *n* is the number of elastic features in contact. [3,4].

3. Results

The embossing mechanism is comprised of six, radially oriented, spherically tipped, flexural beams on a ring which are actuated by a flexural "keyboard" to deform cellophane tape into an anvil die, shown in Fig. 3. An elastic averaging interface connects the ring and anvil, providing planar and axial constraint, aligning the embossing arms with the anvil-die cups in *x, y,* and θ. A similar interface connects the human interface flexures with the ring. The embossing arms are monolithically molded and comprise a connector ring, a stiff cantilevered beam to transmit 9.8N embossing force and a compliant hinge with a stress ratio less than 0.2. The tapered beams provide stiffness in x and y, while the flexural hinge provides compliance in z. The elastic averaging connector provides an estimated $15.1\ \mu m$ based on n=28 points of contact and $\delta = 80\ \mu m$ manufacturing tolerance. This seems reasonable compared to experimental results for similar geometry in [3]. Radial error is elastically averaged and minimized at the central point of interest. Minimizing the embossing arm Δz deflection reduced cosine error and beam stress. Sources of error are tabulated in Table 1.

The mechanisms are prototyped using multi jet fusion additive manufacturing and are also designed for manufacturing by two part ABS injection molding, which has been quoted to cost $1.44 per device at scale.

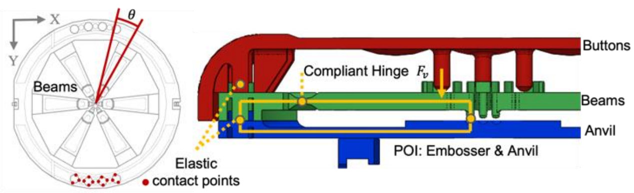

Figure 3. Top view of 6 flexural beams connected by a ring with elastic contact points shown by red dots. Cross-sectional view of the embossing structural loop comprising the beams, anvil and interface buttons.

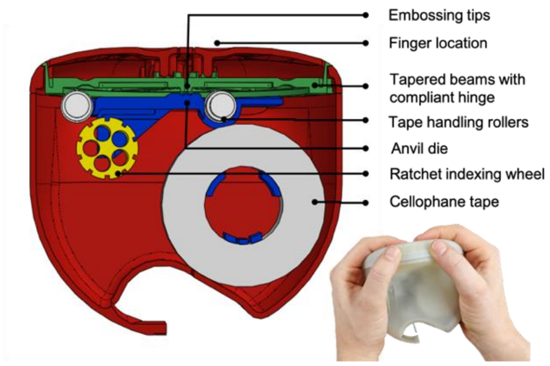

Figure 4. Cross sectional view of the prototype labeller and a photo of the handheld device showing human interface and the embossing loop connected to the tape handling rollers.

Table 1 Error budget for the embossing structural loop

Sources of Error	Sensitive Directions	
	X (μm)	**Y** (μm)
Geometric	**16.00**	**16.12**
Beams molding tolerance	8.00	8.00
Anvil molding tolerance	8.00	8.00
Elastic averaging connection	10^{-6}	0.12
Load Induced	**60.00**	parasitic
Tip abbe error from bending	39.99	
Cosing error from bending Δx	20.01	
Linear sum of errors	76.01	16.12
Root square sum of errors	62.10	16.12
Average of linear and RSS	69.06	16.12
Allowable error	100	100

4. Conclusion

This paper demonstrates the use of an error budget to select and integrate components in the structural loop of a braille dot embossing mechanism. The design utilizes flexural beams and elastic averaging connectors which are simply injection moldable and snap together for assembly. Calculated error for the structural loop and manufacturing quotes show the design presented meets accuracy and price point requirements, thus enabling development of an easily assemblable device to emboss braille labels by and for people with blindness.

Future work would experimentally measure accuracy of the device and labels created to compare with calculated results, and ultimately result in a mass produced low cost device that could be readily accessable for use by blind people around the world to make braille labels for their own use.

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