A Novel Concept of a Braille Device Based on Wax Paraffin Actuator

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Abstract— **The aim of this paper is to investigate and develop a novel refreshable Braille device actuated by thermal actuators based of phase change transformation material. The paper starts with a short introduction about some representative tactile devices, the importance of those devices into society, and highlighting the author's previous work in the field. Second paragraph presents the proposed design of a Braille cell, third paragraph discuss aspects regarding the thermal analysis of the proposed model along with numerical results. Forth paragraph deals with the presentation of the developed prototype along with results from the conducted test of its performances.**

Keywords— **Braille device, paraffin, actuator, Assistive Technology, design.**

I. Introduction

The recent developments in industry and technology have enhanced people's requirements for information availability. One of the challenges is to satisfy the need of information for the blind and visually impaired people in order to integrate them into society. Tactile devices are used for this purpose [1].

Numerous studies have been performed on tactile sensation of human beings and tactile information transmission methods, and a lot of devices have been proposed. A Braille display is an electronic device, that allows the visually impaired to read the contents of a display one text line at a time in the form of a line of Braille characters. Solutions based on mechanical needles actuated by electromagnetic technologies, piezoelectric crystals, shape memory alloys, pneumatic systems, and others have been proposed. Other methods, such phase change materials, and in particularly wax paraffin are under investigation [2-4]. Additionally, thermally driven actuators (including thermo-mechanical, phase change and shape memory methods) require cooling to reverse their action. This can occur through passive thermal radiation, or via active cooling systems, both electrical and mechanical. In [4], a refreshable Braille cell actuated using paraffin wax micro-actuators has been developed for Braille displays. In addition, this actuator has also been applied to micro-fluidic bulk-micro-machined micro-valves, micropipettes and micro-grippers.

Our previous works were focused on the design and development of an interface for a Braille device [7].

II. Design model of a cell

For the development of active Braille dots, the standard dimensions for an actuator are taken into consideration. This prototype has the overall dimensions doubled and all further results will be reported to this. The design of the developed Braille cell prototype and the corresponding dimensions elements are presented in figure 1 and described as follows.

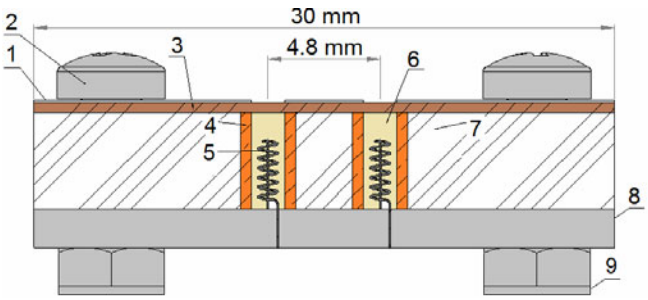

Fig. 1 Section through the Braille cell

On the support plate 8 made of aluminum, plate 5 which has 6 holes Ø3 [mm] in form of the 2x3 matrix is mounted. Thermal insulation between the Braille dots is assured because Plexiglas thermal conductivity is 0.19 [$Wm^{-1}K^{-1}$]. Inside each hole a copper bush 4 is inserted to obtain a good thermal conductivity and improving the actuation result. In this case, generated heat at the resistive mini heater can produce thermal disturbance to the other neighbor actuators. For this reason, the important roles of added case for insulate against the generated heat and to allow interoperability with other modules is fully justified. The wax paraffin 6 is melted by mini heater 5 in form of a spring made from NiCr alloy and mounted in the center of the recipient. The flexible membrane 3 is maintained on the plate with a 0.1 mm thick aluminum plate 1. All this plates are put together and fixed with four M3 screws 2 and nuts 9, to perform sealing to the entire device. The distance between Braille dots is 2.8 [mm] and a pin diameter has Ø2 [mm]. The prototype Braille cell measures 30mm×30mm×8 mm.

The reason for the huge volume expansion in paraffin when melted is that paraffin is crystal in its solid form, i.e. the molecules are packed close together. The more crystal in

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solid phase the larger volume expansion is to be expected at transition.

III. Thermal analysis

In this case, generated heat from the resistive mini-heater was imposed to rise above 64 [^{O}C]. Resistive heating wire (mini-heater) is made from a NiCr alloy. Thermal conduction problem take into consideration details regarding properties of the materials.

The actuation response time of the mini actuator is determined by the melting rate of the paraffin wax. Given the thermal properties and the measured melting time of the paraffin wax, the melting process within the actuator can be analyzed. The phase changing process is dependent on the thermal conduction, convection, diffusion and thermal properties of the material.

Thermo physical properties of the wax paraffin [8] are: latent heat capacity 206 [J g^{-1}]; specific heat 2.4 [J /g °C]; density 750 [kg m^{-3}]; thermal conductivity 0.19 [$Wm^{-1}K^{-1}$]. In accordance with the presented data, temperature and expansion behavior properties will be examined for optimization and improvement.

A. Thermal Actuator Conduction Problem

Conduction refers to that mode of heat transfer ΔQ that occurs when exists a temperature gradient in a medium. The energy is transported from the high-temperature region to the low-temperature region by molecular activities. The steady-state thermal behavior of the element can be modeled using Fourier's law. Heat changed by a system (a body) with the environment, in a basic thermodynamic process, during which the temperature of the system suffers an infinitely small variation is expressed according [9, 10] as follows:

$$\Delta Q = c \cdot m \cdot \Delta T \tag{1}$$

In accordance with it, specific heat c = 2.4 [J /g °C] depends on the nature of the body, and its thermodynamic state. Numerical determination was made to increase the temperature of a 5 grams paraffin rod which is inside the Braille dot container from figure 3 with presented dimensions. The working process is done between ambient (initial) T_a=20 [^{o}C] and melted (final) T_f=68 [^{o}C].

$$\Delta T = (T_f - T_a) \tag{2}$$

The amount of heat needed to raise the temperature is:

$$\Delta Q = 696[J] \tag{3}$$

B. Melting Process

Based on presented thermal properties of paraffin wax, the thermal diffusivity k [m^2/s] represents the heat conductivity of the material λ = 0.19 [$Wm^{-1}K^{-1}$] reported at specific heat capacity c = 2.4 [J/g ^{o}C] and paraffin density depend of its phase. The density values of material in solid and liquid phase are tacking from "*Densities of a microcrystalline paraffin wax in the solid and liquid phase*" table presented in [11].

At temperature of 26.9 [^{o}C] the material is in solid phase whit density ρ_{solid} = 923600 [g m^{-3}] and at temperature of 93.3 [^{o}C] the material is in liquid phase whit density ρ_{liquid} = 793500 [g m^{-3}]. In [10] the equation for the calculus of the thermal diffusivities is mentioned as follows:

$$k = \frac{\lambda}{c\rho} \tag{4}$$

After the equation was applied for the proposed Braille cell model, the thermal diffusivities for the *phase change material* are k_{solid} = 9.97e-8 and k_{liquid} = 1.05e-7. The melting interface moves from the centre to the surface by means of heating (Fig. 2).

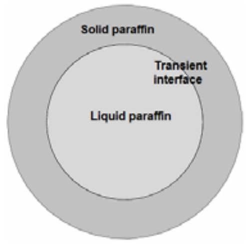


Fig. 2 Melting process of the paraffin rod

For the wax paraffin rod in 1 second, mini heater sizing calculation was made using equation (1) and phase change material data presented in previous paragraph. The power applied for mini heater to be able to melt 5 grams of wax paraffin in 1 second need to be at 580 [W].

C. Steady-State Thermal Analysis Inside of Paraffin Rod

A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis; performed after all transient effects have diminished.

We use this analysis system to determinate temperature variation and heat flux inside of the paraffin rod. The model was developed in Solid Works software and imported in

ANSYS Workbench module for performing the thermal analysis.

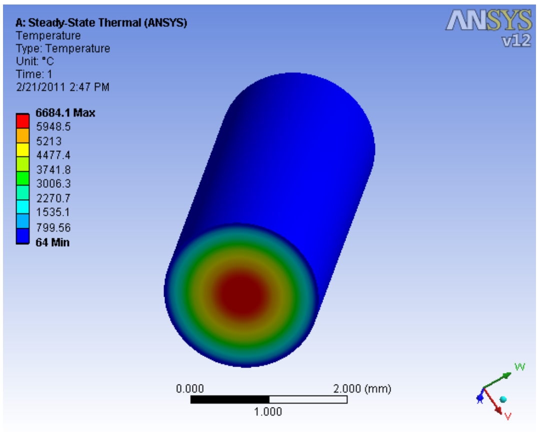


Fig. 3 Steady-State Thermal analysis of the paraffin rod

Figure 3 provide us data about the heat dispersion in the paraffin wax from the interior of the recipe. In 1 second, at an applied heat from the mini-heater of 580 [W] the paraffin wax from the recipe reaches the liquid phase; therefore the pin reaches the height of 1.04 [mm].

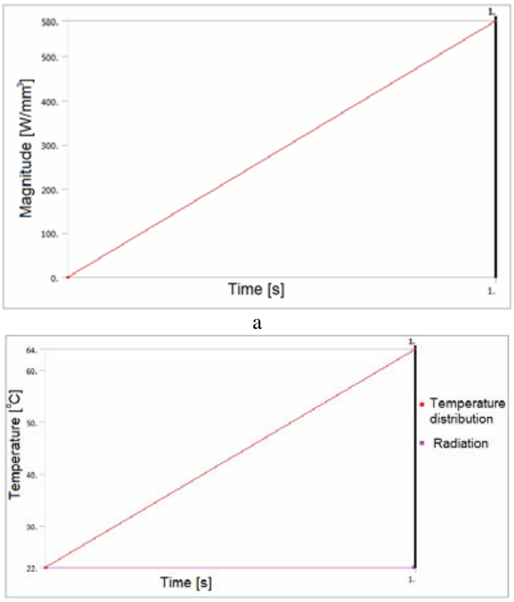


Fig. 4 a) Internal heat generation; b) Temperature distribution and radiation from environment

On the graphs from figure 4 the rising magnitude and heating temperature are presented. At 1 second the magnitude reached a value of 580 [W] and the minimum temperature reached a value of 64 [°C].

IV. Experimental results

For testing of the proposed actuator performances an experimental setup was developed. The proposed actuator prototype was designed, and based on the assembly drawings the prototype was obtained as presented in figure 5.

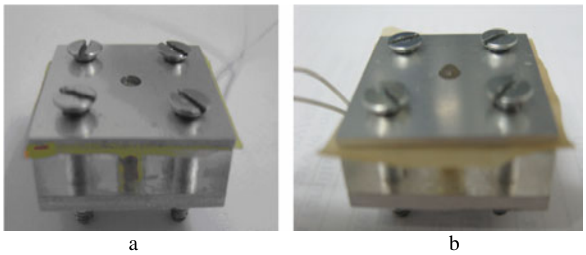


Fig. 5 Picture of the developed actuator: a) actuator in position 0; b) actuator in position 1

Based on the model, the response time of the actuator for the necessary imposed displacement was measured using dial indicator and the time using a chronometer. The measurements of the response time were conducted for the displacement of the actuator from 0 - 0.5 [mm]. In figure 6 the experimental setup for the conducted measurements is presented.

At a supply voltage of 2 [V] applied to the mini-heater and a variation of the current between 1.3 ÷ 2 [A], the time of the actuator's displacement between 0 ÷ 0.5 [mm] was measured along with the time of the free cooling process.

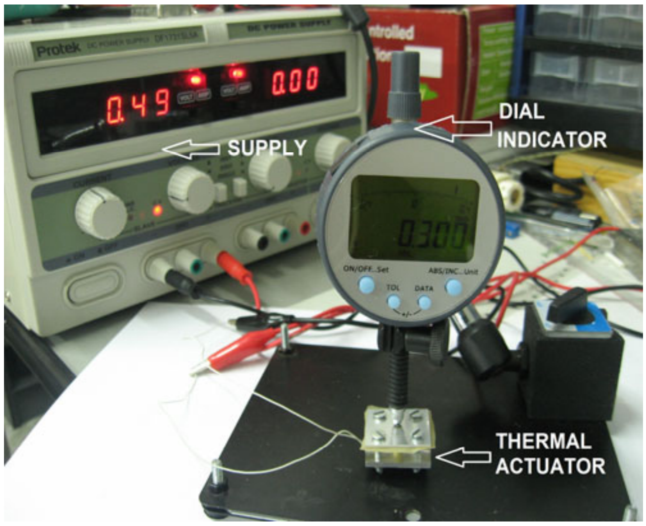
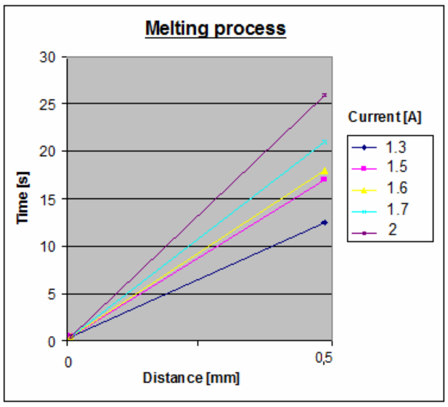
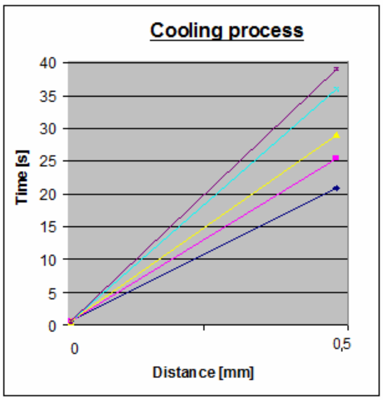


Fig. 6 The experimental stand

The obtained results from the measurements are presented on the graphs in figure 7.



a



b

Fig. 7 Actuation and return to initial position process depending of some parameters: a) Melting process; b) Free cooling process

The obtained experimental results show that the developed actuator prototype can provide a sufficient displacement caused by the thermal expansion of the active material, in a short time and at good performances, and also proves that the presented theoretical analysis is correct.

V. Conclusions

The results of this paper are included in the steps for development of future Assistive Technologies applications and represent the development and test of thermal actuators integrated in such systems. One of the most relevant applications of thermal actuators in the field of Assistive Technologies is represented by the Braille devices.

This paper represents proof-of-concept demonstration of a novel active based phase-change Braille dots, which exploits changes in volume, pressure, temperature and the different chemical properties of paraffin during its solid-liquid-solid phase transitions, and does not require a large consumption of power.

The experimental prototype was made and tested so far with a single recipient who represents a Braille dot. Overall, the materials and methods used in this work allow for cost-effective and rapid fabrication of the future prototypes. For the developed experimental setup the authors focused on a simple design.

In our future work we intend to optimize de actuator and incorporate him in a miniaturized Braille module attachable to a large variety of visually impaired aid devices. Furthermore, the cooling improvement process will be investigated with a cooler and a Peltier module.

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