ACTUATOR BASED IN SHAPE MEMORY ALLOY: STUDY OF SEGMENTED BINARY CONTROL

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Abstract.*A shape memory alloy (SMA) wire may present up to 4% contraction in its total length when heated. This property, caused by a metallographic phase transformation, can be used to construct actuators. However, the control of the final position of the actuator may be difficult, mainly when the actuator is supposed to have intermediate positions (not a single on-off actuator).To solve this problem, this paper presents the experimental evaluation of the segmentation of the SMA wire into pieces with lengths proportional to 1:2:4:...:2n. With a proper combination of segments activated intermediate positions can be reached. An experimental set-up was constructed, with a parallel-port based control software and a monitoring system using computational vision to measure the contraction.*

Keywords*: actuator, sma, binary, memory*

1. INTRODUCTION

Shape memory alloy is a smart material that changes its properties of elasticity when heated. In the case of wires, the heat causes the contraction of about four per cent of its total length, and this property can be used to build actuators.

Heating the material by Joule's effect (through electrical current) is efficient, but the contraction to intermediate positions is difficult to be reached with the continuous control of this current, as showed in Romano and Tannuri (2009). Several nonlinearities of the material, mainly related to a large hysteretic behavior, make the continuous control very complex and degrade the dynamic performance.

To solve this problem, this project proposes the segmentation of the wire in several pieces with lengths proportional to 1:2:4:8…, as showed in Cho and Asada (2005, 2006). The idea is to use each segment as an independent wire (without a real segmentation, but passing electrical current just through a part of the wire), and to use the binary control (on-off) to get intermediate levels of contraction. The contraction of six units, for example, corresponds the binary number 110 - contraction of the segments with length 2 and 1 units (the contraction is proportional to the wire's length).

2. OBJECTIVE

The objective of this project is to experimentally show that the segmented binary control is an efficient method to control the contraction of the wire and to achieve intermediate positions of the final actuator. A simple actuator device was built and the performance, accuracy and repeatability of it were verified.

3. METHODS

As mentioned, in order to validate the idea of binary control applied to SMA actuators, a simple device was constructed. A tower supports the wire and integrates all the systems developed to control and monitoring it:

- Drive to amplify the current:
  The control of the wire was implemented using the computer by a parallel port, and a current drive was necessary to provide up to 800mA to the SMA wire. The drive was made with ULN2003A, an array of transistors Darlington, based on Roger Com (2010).
- Control software:
  The software developed to communicate with the parallel port was made in C, based on CEFET (2010).
- Monitoring system:
  To analyze the contraction of the wire, a software in MATLAB® was developed. This software processes a video made by a webcam, registering the position in pixels of a point in the wire.
- Refrigeration system:
  The behavior of the wire is not symmetrical, since the natural cooling in the ambient temperature is slower than the heating induced by Joule's effect. So, the contraction of the wire is faster than the relaxing. To reduce such difference, two coolers were placed next to the segments to improve the heat loss when the segment is no more heated. Another cooler was placed to refrigerate the drive, because of the 10W-resistors used to equilibrate the current passing through each segment (the electrical resistance of the material is 32Ω/m).

The complete system is presented below, Fig. 1-2. Fig.3 exemplifies the principle of working of the device.

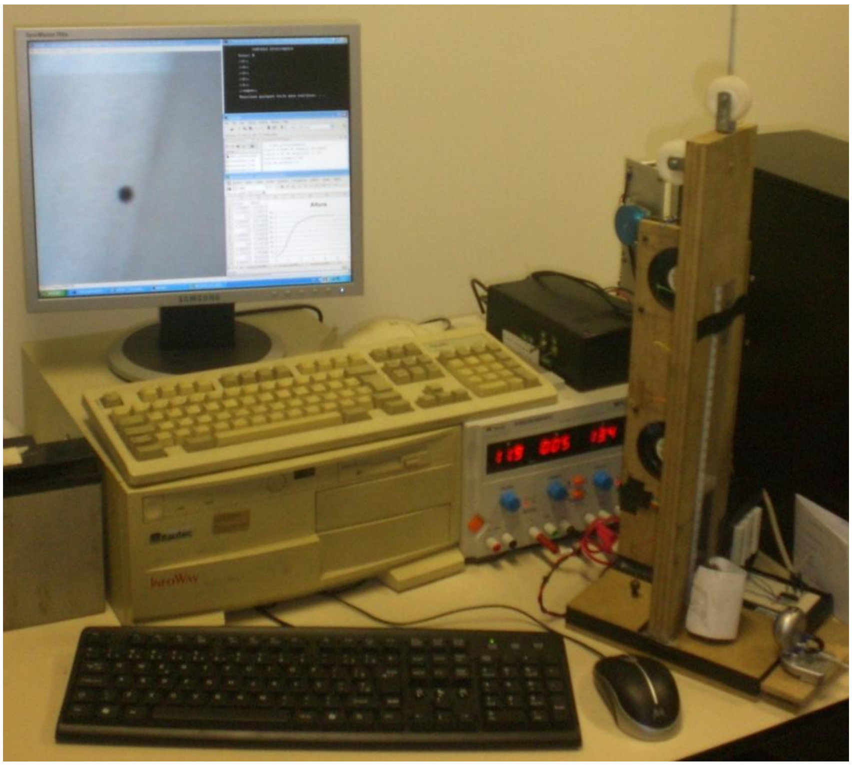


Figure 1. Complete system

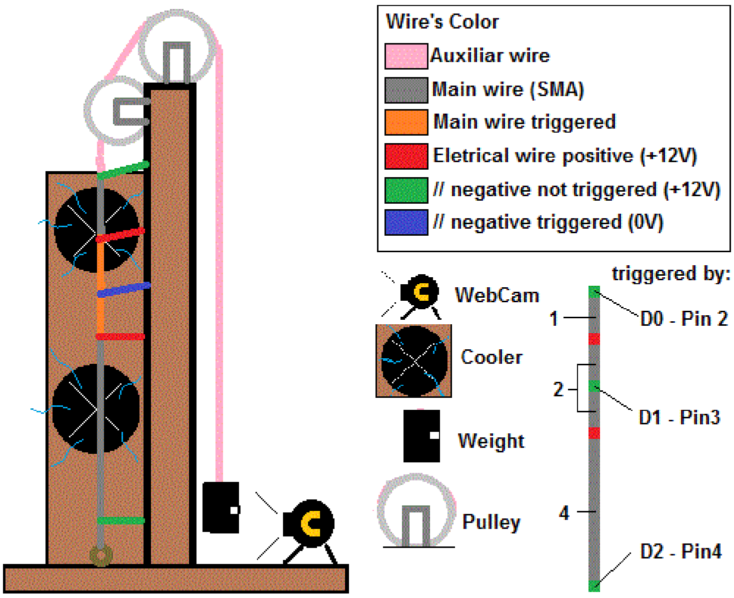


Figure 2. Simplified scheme

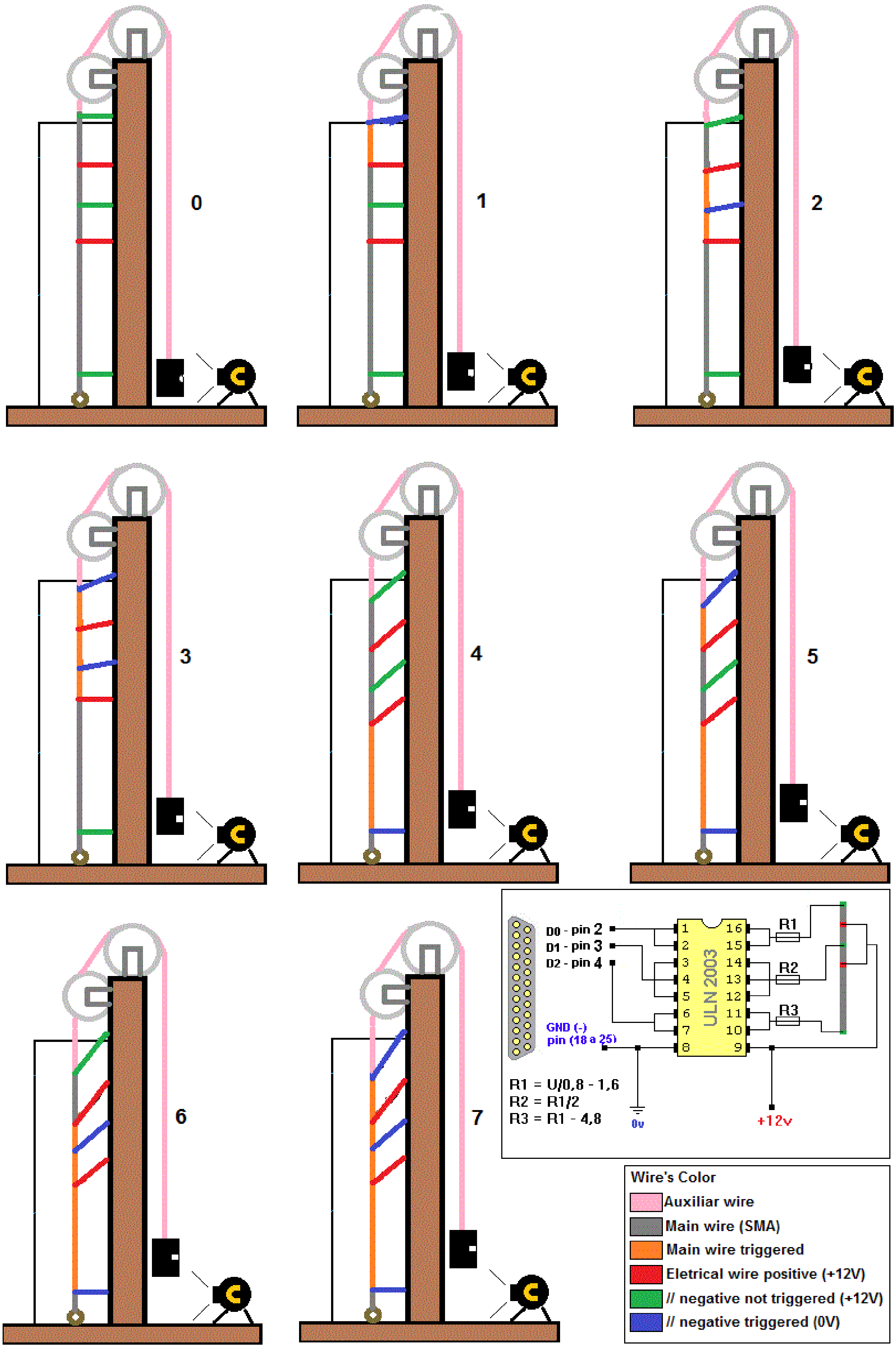


Figure3. Scheme of the complete system working

4. RESULTS AND ANALYZES

The results were presents as time-series graphics, Fig. 4 and Fig. 5-8 (all the compound states). The unit of the y-axes is a generically unit of length, the exact contraction reached is less important than the proportional contraction between states, and changes with the variation of the total length of the wire.

Fig. 4 shows the fundamental states, concerning the activation of only one segment. Several reasons may explain the inaccuracy of the results (that, in steady state, were expected to be 1, 2 and 4). The heating propagates through adjacent parts of the segments, what can cause a larger contraction than expected (a detailed discussion about this topic will be given in Fig. 8). Furthermore, the cooling is not uniformly distributed along the segments, with no fan direct to the segment 1. However, the binary control may be evaluated even with these inaccuracies in the fundamental states, by showing that intermediate positions may be achieved by the proper combination of fundamental states.

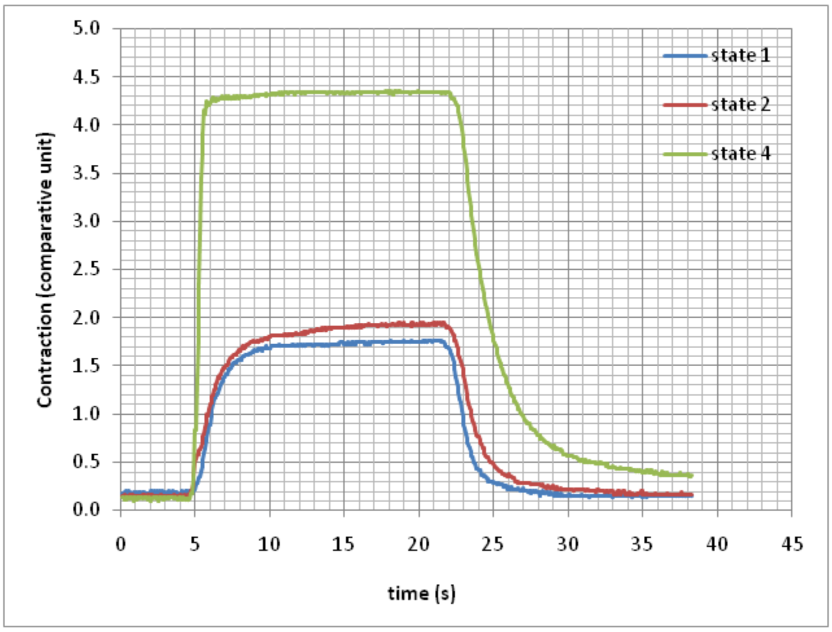


Figure 4. Fundamental states

Fig. 5-8 show the compound states and the sum of the fundamentals states are represented in the same figure for comparison. The state 3 (that is equivalent to the simultaneous activation of segments 1 and 2) presented a large difference between the summation of the fundamental states 1 and 2. A possible reason is presented in figure 8 and will be discussed latter. For all other states, a good adherence between the compound state and the summation of fundamental states were observed.

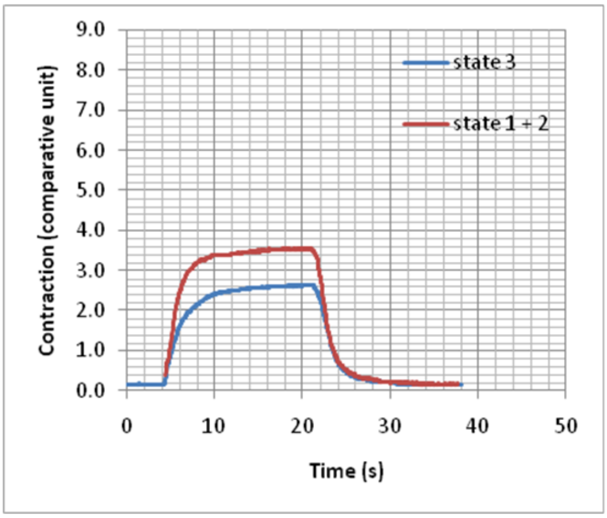


Figure5. State 3(sum of the fundamentals 1 and 2)

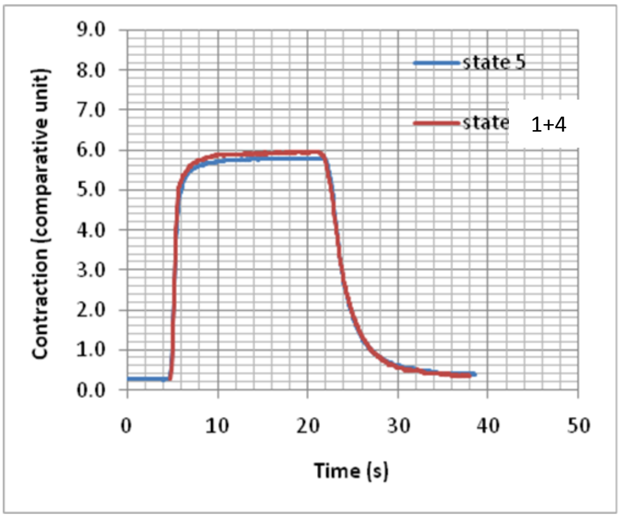
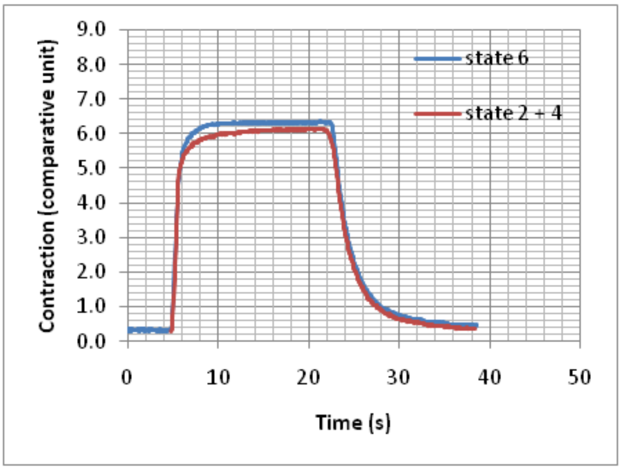


Figure6. State 5(sum of the fundamentals 1 and 4)



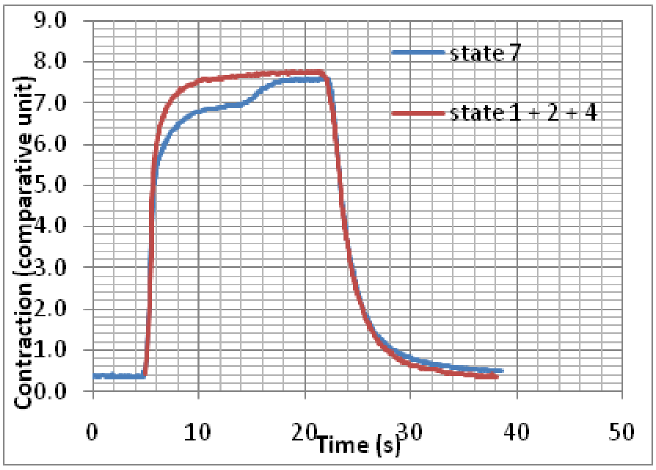


Figure7. State 6 (sum of the fundamentals 2 and 4)

Figure8. State 7 (sum of the fundamentals 1, 2 and 4)

The maximum contractions were summarized in the graphic bellow, Fig.9. The r-square of 0.96, of the linear approximation, indicates that the method is efficient in the stationary perspective, because the proportion between the contractions is quite linear (as was explained before, the errors happen in the states which use the first state).

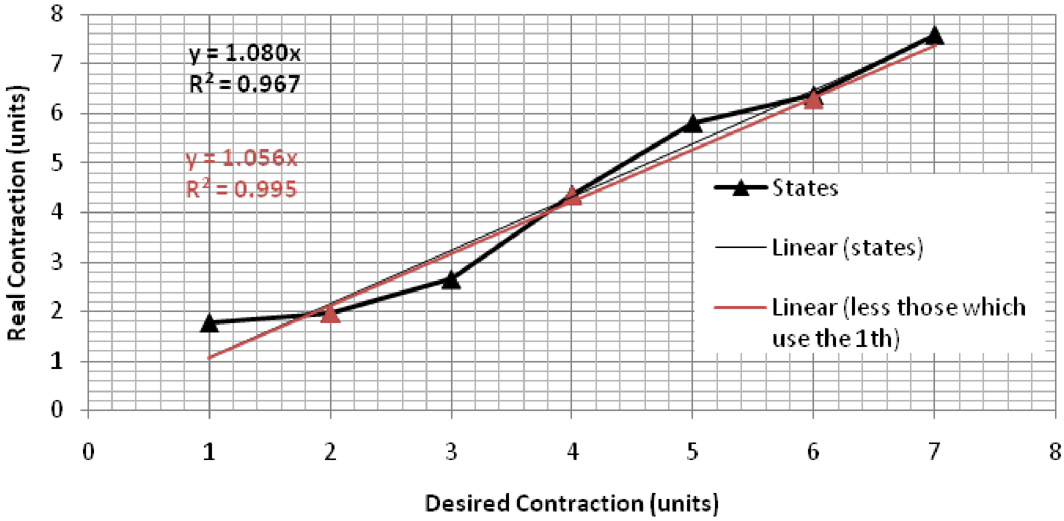


Figure 9. Maximum contractions

The difference between the expected (sum of the fundamentals) and the experimental states, mainly in the case of the first state, can be explained by the thermal conduction. If we analyze the graphic of the difference in the state 3 (which presents the biggest difference), Fig. 10, we notice that is quite similar to the graphics of contractions, which evidence that the difference is caused by an unexpected contraction.

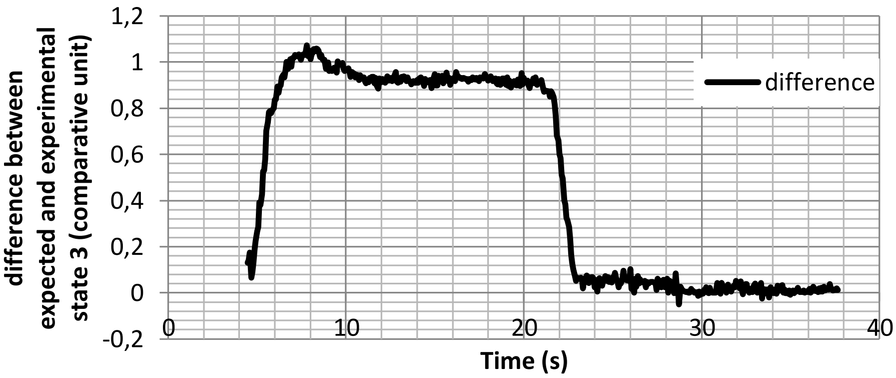


Figure 10. Difference in the 3th state

Figure 11 explains what happened. When each segmented is heated, part of the adjacent segments is also heated, by thermal conduction. When two adjacent segments are heated, some of these parts unintentionally heated become to be heated intentionally, what causes a negative difference between the theoretical and experimental states. Of course, the longer the segment, the smaller will be the proportional error.

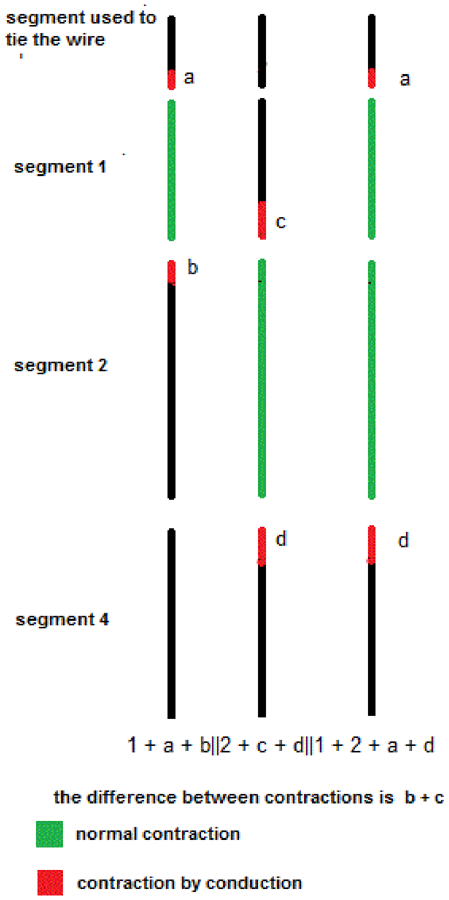


Figure 11. Explanation of the difference

Tests to analyze the transient perspective of the method's efficiency were also done, Fig. 12. A series of contractions were planned to study all possible change between the states. The time of the transitions was estimated by the fundamental states behavior, Fig. 4, as 5s to contract and 15s to relax, totalizing 20s of transition, supposed enough to reach the level of each state. The numbers below indicate which state of contraction was activated.

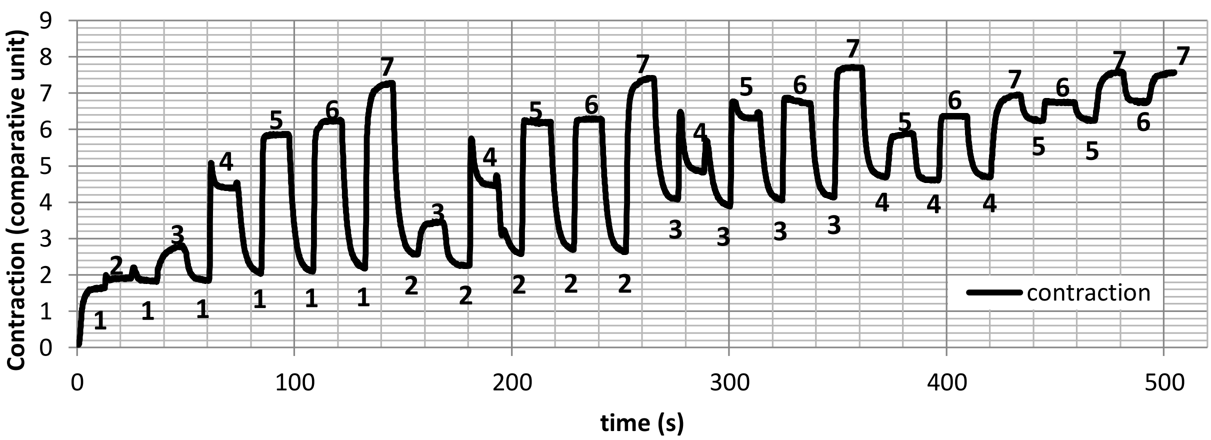


Figure 12. Transient test

The Fig.13 shows if each state remains the same after a series of contraction. The differences can be explained by the change of the time required for each transition, after a series of contractions the wire tends to be hotter (it also changes according the previous fundamental states triggered).The main situations are the 7th state in the 4th contraction and the progressive contraction of the 3th state, all can be explain by the change of the time spend to be triggered.

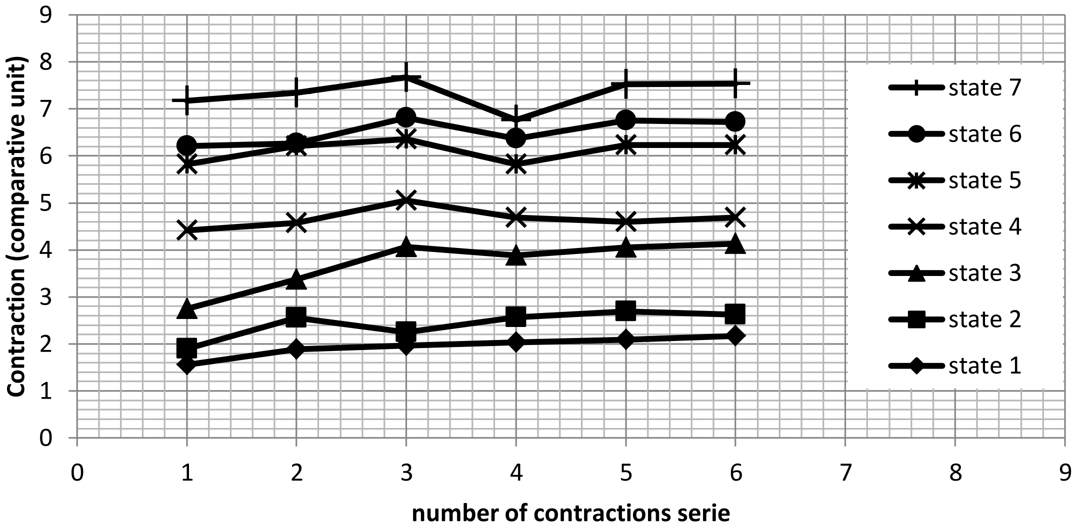


Figure13. Series of contraction

Another anomalous that happens is sudden length variations just before or after a contraction in some cases. It happens because the relaxing's time of the previous fundamentals states triggered are longer than the contraction's time of the new fundamentals states triggered. In figure 14, for example, when the fundamental state 4 starts to be triggered the fundamental states 1 and 2 are still partially trigger too and the result of the contraction is bigger than the level of the 4th contraction.

Improving the refrigeration system and, consequently, the action time of the relaxing, this problem will become smaller. The optimum behavior is when the time for contraction and the relaxing are the same.

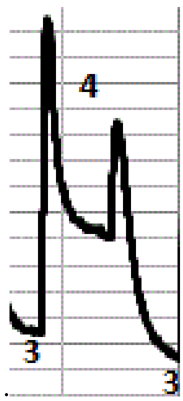


Figure 14. "Ears" in the 4th level

5. CONCLUSIONS AND COMENTARYS

The method of binary control of SMA actuators was experimentally evaluated in the present paper. Some technical problems were identified, mainly related to undesired heating propagation along the adjacent segments and unequal time for cooling and heating. Those problems can be solved by a more efficient and uniformly distributed cooling system and by the utilization of thermal isolators between the segments.

However, the general concept was validated, since intermediate positions of the final actuator could be achieved without using continuous control.

6. ACKNOWLEDGMENTS

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8. RESPONSIBILITY NOTICE

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