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Jacek HARAZIN, Gabriel KOST*

Institute of Engineering Processes Automation and Integrated Manufacturing Systems,
Faculty of Mechanical Engineering, Silesian University of technology, Gliwice
*gabriel.kost@polsl.pl

FLEXINOL PROPERTIES STUDY

Abstract: This article contains study concerning flexinol wire's contraction time and length. During the research, to stimulate the wire, a modulated PWM signal was used. Changes in PWM duty cycles were causing greater heat accumulation which led to faster structural transformation of the wire and in result different contraction times and lengths. The research stand and control system that were used to stimulate the flexinol wire (regulated PWM wave stimulation) and measure its contraction times, and lengths, were also described in this article.

1. Introduction

In modern technical solutions, especially in the scope of mechatronics, SMART materials are becoming more and more widely used. The most attention is concentrated on smart materials that change their properties in a controlled way (being usually stimulated by a dedicated control system). Thanks to their properties, they can be used both as actuators and sensors. The most popular and commonly used group of SMART materials contains: piezoelectric materials, magneto and electrostrictive materials and also shape memory alloys[2,3,4]. One of the materials that is included in the group of shape memory alloys is the flexinol. It is a type of nitonol alloy that contains nickel and titanium in a 54:46 proportion and is used in a form of wires with very small diameters (25μm – 510μm). The characteristic property of flexinol wires is their ability to contract after being heated to a temperature of their structural transformation. The wire's good conductance is allowing small voltages to pass through it, but its resistance (50Ω/m for 150μm diameter) is sufficient enough for relatively small currents of around 150mA to heat up 1m of the wire to 70°C in around 2 seconds time. The wire's contraction is caused by a transformation between martensitic and austenitic structure and ordering of structural bonds. After cooling down the wire's structure becomes martensitic again and is susceptible to deformation which allows it to stretch back to its former length after a strain of around 69MPa has been applied. Flexinol wire can contract to around 8% of its total length, although it is recommended that a maximum of 4 – 5% contraction should be forced on the wire during its regular and elongated work to avoid risks of permanent damage to the wire's contraction capabilities.

The wire during its contraction generates around 172MPa of strain without the risk of loosing it’s physical and material (structural) properties. The expected maximum strain that flexinol wire can hold while contracting is approximately 345MPa. In case of many duty cycles it is not recommended to surpass 2/3 of this value to avoid damage that the wire can sustain while repeatedly working under high loads. The most common flexinol wires on the market are wires with transformation temperatures of around 70°C or 90°C although it is possible to manufacture wires with transformation temperatures higher than 100°C and significantly lower than 70°C [5].

2. Aim and range of the study

The aim of this study was to designate the course of change of contraction length relative to time for the flexinol wire under standard load and in relation to changing PWM (Pulse Modulated Wave) signal that was used to stimulate the wire.

To conduct the study a research stand was made (fig. 2.1) where the flexinol wire could be put under stimulation of PWM signal that could be also modulated.

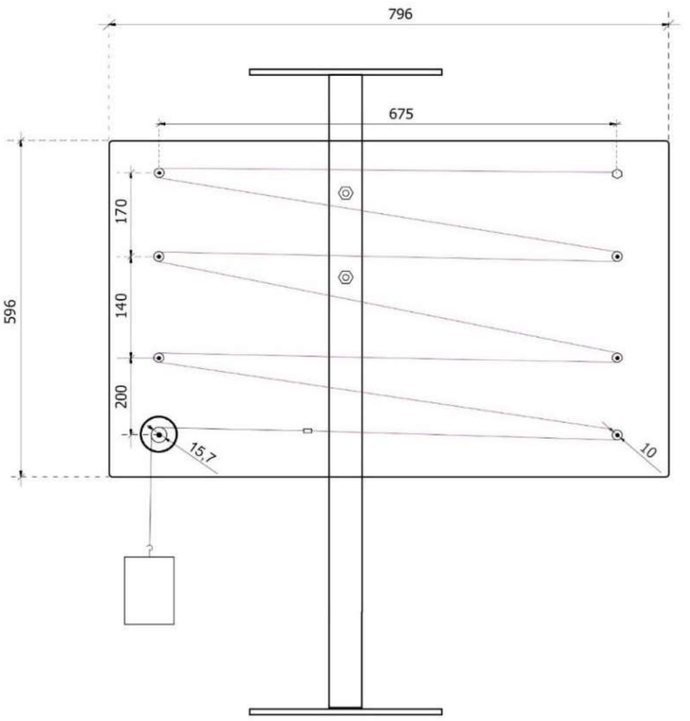


Fig. 2.1. Stand for measuring flexinol wire contraction

To achieve that, a dedicated control system was made which diagram was shown on the fig. 2.2. The research stand was also capable of registering flexinol wire’s contraction time and length in intervals of 10ms and with an accuracy of 10µm. A flexinol wire bought at Muscle Wires® [5] was used in the course of the study. Wire’s properties are represented in the table 2.1.

Tab. 2.1 Properties of the flexinol wire used in the study [4]

Diameter	Resistance	Nominal contraction force	Required current	Contraction time	Transformation temperature	Cooling time (70°C)
[mm]	[Ω/m]	[N]	[A]	[s]	[°C]	[s]
0.15	55	3.21	0.41	1	70	2

The experiment was based upon recording contraction measurements of a flexinol wire, under a fixed load to maintain its steady strain, stimulated by PWM signals with varying duty cycles. The characteristics of the stimulating signal were as follows : voltage – 18.5V, current - 410mA, frequency of PWM signal - 50Hz, PWM duty cycle – regulated in range of 20% ÷100%.

2.1. Control system and measuring stand

To measure flexinol contraction length and time, a measuring system was designed, (fig. 2.2) that incorporated an angular encoder with a resolution of 5180 impulses per revolution, that was coupled with X20CP1301 PLC controller of „B&R" company. Wire contraction was measured by using the equation 1 [1]:

$$\Delta W = \frac{i}{n} 2\pi R \tag{1}$$

where: ΔW – flexinol wire contraction length [m], i – encoder impulse count, N – encoder resolution $\left[\frac{1}{rev}\right]$, R – measuring wheel diameter [m].

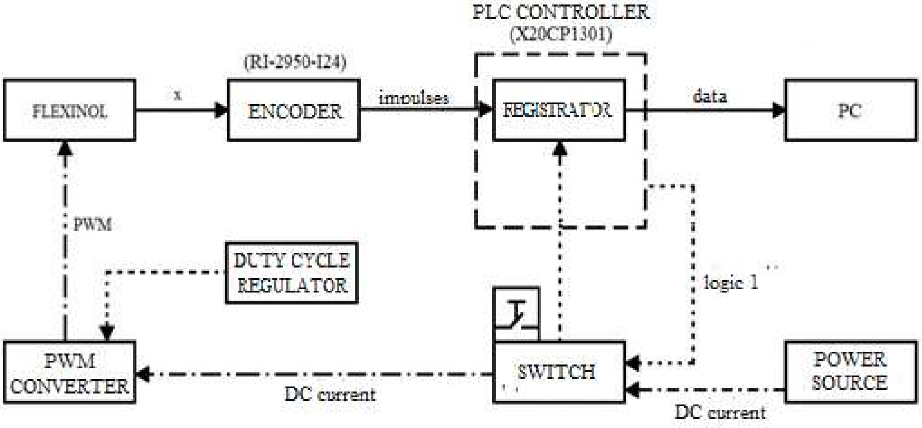


Fig. 2.2. Diagram of measuring system and power system of the research stand

Flexinol wire contraction time was measured by the PLC controller with an accuracy of 0.01s. To synchronise the simultaneous activation of PWM generator and data recorder, a button was used in a form of a gate, that was wired to the signal cable leading to data recorder and also to a power cord leading from the PWM generator to the flexinol wire. The stand consisted of a plexiglass pane with dimensions shown on fig. 2.1. On the pane, six rolling cylinders with bearings were placed to create supports for 1000mm of flexinol wire that was stretched between them. On the top right corner of the plexiglass pane, a rigid attachment was placed, to fix one end of flexinol wire. One end of the power cord was also attached to that point. The bottom left side of the plexiglass pane was prepared to mount the angular encoder with a measuring wheel of 0.0157 m diameter. The other end of flexinol wire was attached to steel cord and a thin power cord. A steel cord was moving on the measuring wheel being attached to the flexinol wire on one end and to a 321g weight on the other. The weight was responsible for generating constant optimal strain on the flexinol wire.

2.2. Flexinol wire contraction study based on PWM duty cycle

The study consisted of 9 series of measurements, each consisting of 20 measurements. Each of the measurement series was conducted for different PWM duty cycle starting with 100% and ending on 20% with 10% decrements. A reason for ending measurements on 20% PWM duty cycle was that the flexinol wire contraction was negligibly small and very slow for duty cycles below 20% (continuous stabilization of length [5]). All min, max and mean wire contraction measurements for each of duty cycles were presented in tab. 2.2. All the measurements were conducted in the ambient temperature of 36°C.

Table 2.2.Wire contraction lengths in relation to different PWM duty cycle

Contraction length after heating with PWM signal						
PWM duty cycle [%]	Contraction length [mm]			98% of max contraction [mm]		
	MIN	MEAN	MAX	MIN	MEAN	MAX
100	42.52443	42.57299	42.66726	41.67394	41.72153	41.81391
90	42.34351	42.38779	42.44825	41.49664	41.54003	41.59929
80	42.04834	42.13451	42.17212	41.20737	41.29182	41.32868
70	41.67699	41.74174	41.83886	40.84345	40.9069	41.00208
60	41.01998	41.12472	41.19137	40.19958	40.30223	40.36755
50	39.88689	40.10589	40.2868	39.08915	39.30377	39.48107
40	37.32552	37.8097	38.34435	36.57901	37.05351	37.57746
30	4.056293	4.407172	5.66548	3.975168	4.319029	5.552171
20	1.199749	1.28973	1.609187	1.175754	1.263935	1.577003

Columns described as „98% of max contraction" were created to determine wire contraction times in further calculations. Wire contraction time was designated as the time of the most dynamical wire contraction period up to the point of its final contraction length, that is the state when wire stabilized its contraction length.. To designate the wire's contraction time a value of 98% of maximum wire contraction length was taken to compensate for wire's very long time of contracting the last 2% of its length (follow-up stabilization also occurring for PWM wave duty cycles below 20%). Wire contraction times were calculated based upon table 2.2 and shown in table 2.3. Acquired data shows that when a 100% PWM duty cycle was used the wire's maximal contraction length reached 42.67 mm, which accounted for 4.27 % of the total wire's length. The approximate wire contraction time was 2s. The table 2.4 shows flexinol wire contraction times depending on used PWM duty cycles.

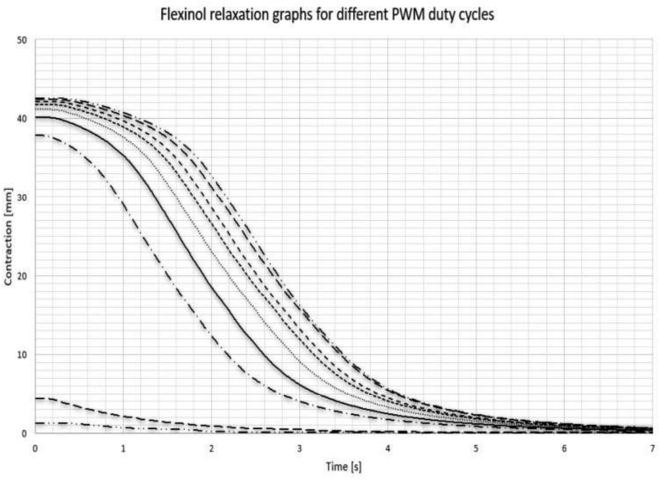
Table 2.3. Wire relaxation time in relation to PWM duty cycle

98% contraction time	
PWM duty cycle [%]	Time [s]
	MEAN
100	2.01
90	2.25
80	2.63
70	3.21
60	4.11
50	6.05
40	16.42
30	12.81
20	5.56

Table 2.4. Wire contraction time in relation to PWM duty cycle

98% relaxation time	
PWM duty cycle [%]	Time [s]
	MEAN
100	6.42
90	6.39
80	6.17
70	6.12
60	5.87
50	5.5
40	5.08
30	3.76
20	4.07

Fig. 2.3 and fig. 2.4 show the courses of flexinol wire's relaxation and contraction periods from where the data in tables 2.3 and 2.4 was calculated.



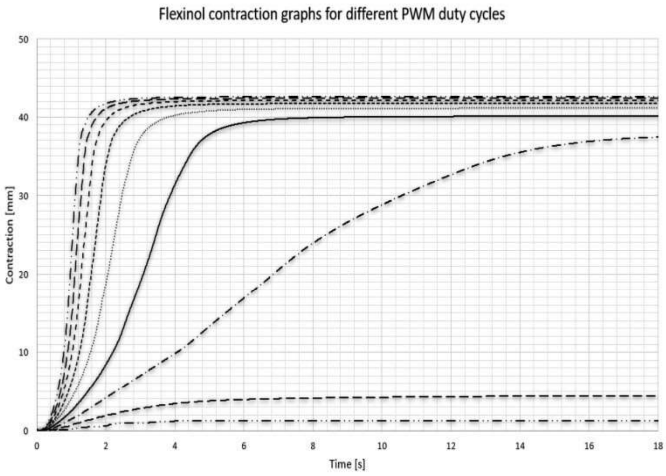


Fig. 2.3. Courses of flexinol wire's relaxation cycles in relation to PWM duty cycle used

Fig. 2.4. Courses of flexinol wire's contraction cycles in relation to PWM duty cycle used

In case of measuring and calculating flexinol wire's relaxation time, 98% of maximal wire's relaxation length was also used to compensate for very long periods of wire's relaxation up to its final length. Mean relaxation time of flexinol wire reached 6.42 seconds. That is six times more time for full relaxation than specified in wire's documentation. That result could be explained by very high ambient temperatures during the study which caused lower heat exchange between flexinol wire and surrounding air and thus contributing to its slower cooling and relaxation.

3. Conclusions

The first and most noticeable change in flexinol wire's behavior when changing the PWM duty cycle was its slow decrease in maximal contraction length following the decrease in PWM duty cycle. The most noticeable drop in wire's contraction length occurs between 40% and 30% of PWM duty cycles. Accordingly to decrease in flexinol wire's contraction length an increase in its contraction time also occurs. This increase is also the most noticeable between 30% and 40% of PWM duty cycles.

The fastest contraction time and the longest contraction length of flexinol wire occurs when stimulating it with a PWM wave with 100% duty cycle which is basically a DC current. In this case mean contraction length was 42.57 mm and accounted for 0.043% of the overall wire's length. The time to contract 98% of this length was taking averagely around 2 seconds.

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