Measurement of SMA Drive Characteristics

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SMA (Shape Memory Alloy) drive has the behavior of the non-linear, hysteresis and dynamic system with many parameters. This system has changeable delay time and depends on initial conditions and motion direction. Transitions between inner hysteresis loops depend on the previous states – the SMA memory. Considering the complexity of conditions, failure effects and quantity of parameters, the SMA drive qualities measurements by programmable digital measuring devices with GPIB communication was automated.

Keywords: Shape Memory Alloy, Ni-Ti alloy, martensitic transformation, SMA actuator

1. Introduction

Shape Memory Alloy converts thermal energy to mechanical work by the change of lattice structure (so-called thermoelastic martensitic transformation) [1]. Drives constructed from these alloys belong to the group of thermal drives (thermal actuators). In other famous thermal actuators physical basic of the shape memory is different. SMA uses "inner molecule forces" and offers new drive technique perspectives with quite new properties as diverse forms and shapes of SMA drives and very good ratio mechanical power – mass, noiseless, no need of maintenance, anticorrosion (Ni-Ti). Measurement of electric resistance and SMA drive temperature seems to be the convenient possibility for position information reconstruction and for making feedback without using the position sensor which with its mass and dimensions overtops the SMA drive itself. For this purpose the measuring stand (place) for Ni-Ti wire loaded by constant load was made. It allows to measure electric resistance and power, position and temperature of the Ni-Ti drive sample. By means of digital source and multimeters with GPIB communication the measuring experiment was controlled.

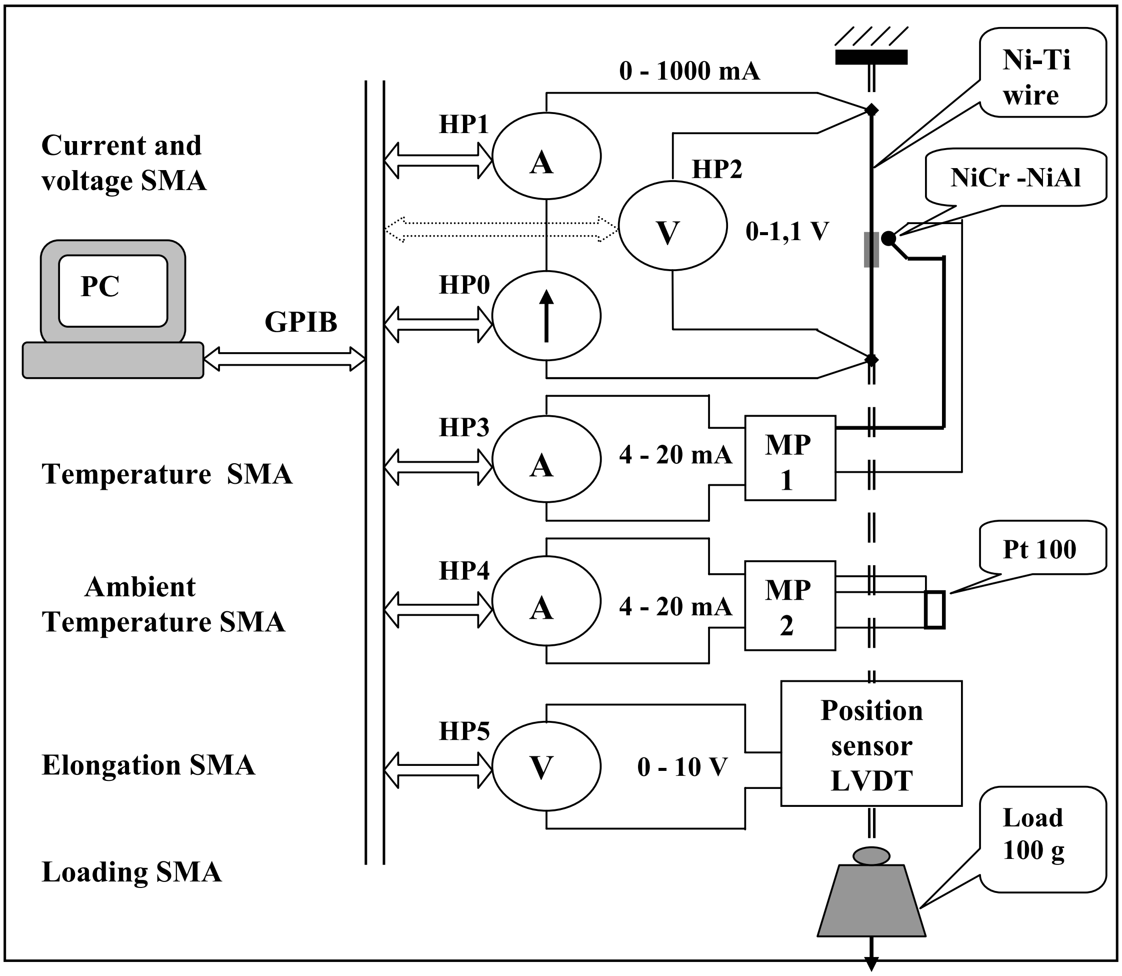
2. Subject and Methods

The subject of research is the SMA drive from Ni-Ti alloy. It is realized as the wire with the circle cross-section. It is mechanically fastened and electrically connected in the same place. SMA drive is heated through electric resistance heating, cooled by natural air-cooling and loaded by constant reverse load. This load is limited by the fatigue process of material. The SMA drive model is non-linear dynamic system with many parameters and complicated inner couplings [2],[3],[4]. This system is being discovered step-by-step by many research works about material physics, thermodynamics and empiric knowledge from practical applications. In majority of the works the certain degree of idealization of SMA drive model is considered. The proposional position control of SMA drive is not possible only on the basis of mathematic models with sufficient accuracy. Measuring of electrical resistance and temperature of SMA drive is demonstrated as the convenient possibility for motion information reconstruction. The author in [5] had deduced the general equation for SMA drive electric resistance:

$$\frac{dR}{R} = \pi_e d\sigma + K_\varepsilon d\varepsilon + \alpha_{RT} dT \qquad (1)$$

Where: T = temperature; σ = stress; ε = strain; π_e = piesoelectric coeffient

R = electric resistance; α_{RT} = coefficient; K_ε = shape sensitivity coefficient



HP0: *controlled current direct source: Agilent E3640A or by voltage controlled current direct source with Burr Brown circuit (own construction)*
HP1 až HP5: *multimeters HP 34 401A, Hewlett Packard*
MP1: *intelligent measuring temperature converter, Sitrans T, Siemens*
MP2: *intelligent measuring temperature converter, TT 301, Smar*
LVDT: *linear contactless transformer position sensor, 0- 6 mm, ZPA*

Fig. 1. SMA automated measurement scheme

Basic status quantities are: temperature T, stress σ, strain ε and martensite fraction X. Electric power P, ambient temperature To, mechanic load in form of force F_L acting in direct axis drive are input quantities of measured system. Status quantity X depends on temperature T and stress σ and in equation it influences coefficients π_e and α_{RT}. From the tensometer theory the piesoelectric coeffient $\pi_e = \delta\rho/\delta\sigma/\rho$ [Mpa^{-1}] is known. Coefficient $\alpha_{RT} = \delta\rho/\delta T/\rho$ [°C^{-1}] explains the direct influence of the temperature on the SMA specific relative resistance. Shape sensitivity coefficient K_ε for Ni-Ti is $K_\varepsilon = 1+2\mu = 1{,}66$. The experiment was oriented to the measurement of static characteristic of real SMA drive to generate feedback from temperature and SMA electric resistance. To that fact it is calibration measurement for reconstruction the position. Next aim is mapping the drive behavior at cyclic and irregular movements inside the hysteresis loops. Measured quantities at Fig.1. are: SMA exciting current, SMA voltage, SMA temperature (thermocouple K) and SMA position (sensor LVDT-ZPA), ambient temperature (Pt100). Ni-Ti wire (sizes: length 100 mm, diameter 0,32 mm, weight 52 mg) was connected in 4-wire Ohm measurement. Electric resistance (cca 1 Ohm) and electric power (to 1 W) supplying SMA drive were evaluated. To guarantee the repeatability these conditions are needed to be secured before and during the experiment:

1. Constant conditions for SMA cooling (air flow, ambient temperature).
2. "Erasing the drive memory" before the measurement by means of thermal cycling without load.
3. To measure after loading in define cycle at same input conditions.
4. Constant load during the measurement; it represents influence of parameter.

3. The Efficiency of the Measuring Methods and Results

Considering the quantity of conditions and parameters a lot of measurements is needed. We can measure e.g. number of samples per hour for every method for certain application. "Manual" measurement has low accuracy and efficiency is cca 25 samples/hour. Programmable multimeters measurement allows to increase the accuracy of the results and efficiency to 60-90 steady values/hour. Mean values and errors from 10 samples at every working point were calculated.

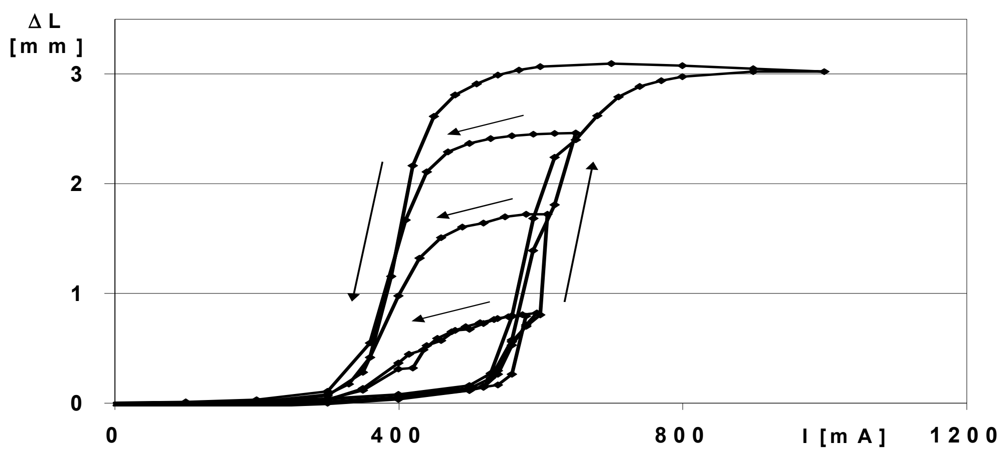


Fig.2. Fourfold "immersion" to hysteresis loops with full return to martensite

Immersion to hysteresis loop with full return to martensite is illustrated at Fig.2. The immersion is fourfold plus outside loop. In rising part maximum current of loops were selected with form spacing. Compared with this, the first two loops overlap. At third mode of the measurement the method proposed in [5] has changed in principle. By independent thermal control loop the slowly linear rising signal 1°C/32s (taking in account the drive time constant) was generated through the whole range of temperature up and down. From this quasi-steady state the static characteristic is possible to mention. Also dynamic error can be determined. Automated measurement period was 2s. The measurement efficiency is 1800 samples/hour. By this way, at least the graphic continuous characteristic behavior at Fig.3. is possible to gain.

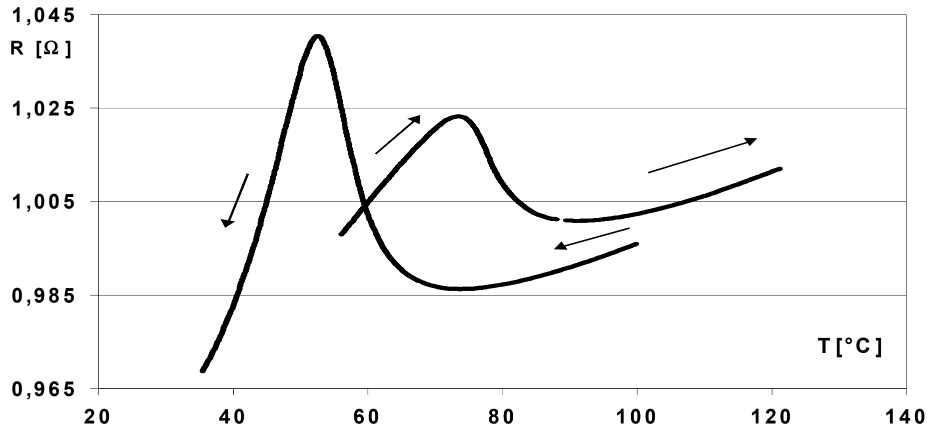


Fig.3. Temperature dependence of SMA electric resistance

The measurements were realized by 5 digital multimeters HP34401A and direct current/voltage source Agilent E3640A. These devices have interfaces GPIB and RS-232 for communication with PC. The resolution was set to 6½ digits on all multimeters. Applied programs were written in Borland C. The use of PC allows to calculate errors and uncertainties in easy way. Relative error of the measured data for current going through SMA was smaller than 0,15 %, for voltage on SMA it was smaller than 0,005 %.

4. Conclusion

Automated experimental working place allows on samples from Ni-Ti with parameters mentioned above (length,..) to measure the position, temperature, electric resistance and electric power. Automation of the measurement has brought high efficiency of measuring, sophisticated control of independent input parameters, evaluation of accuracy, security of repeatibility and digital documentation of measurements.

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