VISUAL BASIC APPLICATIONS FOR SHAPE MEMORY ELEMENTS DESIGN USED IN INTELLIGENT SYSTEMS

Sonia Degeratu, Petre Rotaru, Horia Octavian Manolea
Faculty of Electromechanical Engineering and Faculty of Physics, University of Craiova, Romania
Faculty of Dentistry, University of Medicine and Pharmacy, Craiova, Romania
sdegeratu@em.ucv.ro, protaru@central.ucv.ro, manoleahoria@gmail.com

Gheorghe Manolea, Anca Petrisor, Bizdoaca Nicu George
Faculty of Electromechanical Engineering and Faculty of Automation, University of Craiova, Romania
ghmanolea@gmail.com, apetrisor@em.ucv.ro nicu@robotics.ucv.ro

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Abstract: The paper presents the design strategies for two typical configurations of intelligent systems, using as active elements the Shape Memory Alloy (SMA) cantilever strip and the SMA helical spring. Based on the advantages and unique properties of shape memory alloys the authors defined the operating mode, the mechanical considerations and the design assumptions for these two examples. It also includes the experimental results of thermal analysis in order to determine the transformation temperatures for studied SMA elements. A comprehensive graphical interface, which runs under Visual Basic environment, has been developed for each design strategy. Each one provides a user friendly environment that allows intelligent system parameters configuration as well as the choice of the most adapted analysis methods and data displaying. At this moment, these two Visual Basic applications are used for engineering purposes as well as didactical ones.

1 INTRODUCTION

The shape memory alloys (SMA's) possess the ability to undergo shape change at low temperature and retain this deformation until they are heated, at which point they return to their original shape (Van Humbeeck, 2001), (Waram, 1993).

The unique behavior of SMA’s (e.g. shape memory effect, pseudo-elasticity) is based on the temperature-dependent austenite-to-martensite phase transformation on an atomic scale, which is also called thermoelastic martensitic transformation.

The SMA’s can exist in two different temperature-dependent crystal structures (phases) called martensite (lower temperature) and austenite or parent phase (higher temperature).

When martensite is heated, it begins to change into austenite and the temperatures at which this phenomenon starts and finishes are called austenite start temperature (As) and respectively austenite finish temperature (Af). When austenite is cooled, it begins to change into martensite and the temperatures at which this phenomenon starts and finishes are called martensite start temperature (Ms) and respectively martensite finish temperature (Mf).

SMA’s have been extensively studied as functional materials for a wide range of applications: robotics, actuators, automobiles, aerospace, military field, medicine, toys, electronics, optical industry, constructions, agroalimentary sector (Degeratu, 2003), (Dolce, 2001), (Van Humbeeck, 1999).

The use of SMA’s can sometimes simplify a mechanism or device, reducing the overall number of parts, increasing reliability and therefore reducing associated quality costs. Moreover, their functioning can be scheduled and controlled by establishing an adequate strategy in respect to the operating mode (Bizdoaca, 2006), (Petrisor, 2007).

2 CHARACTERISTICS OF SMA’S

The thermoelastic martensitic transformation causes the folowing main properties of SMA’s: one-way and two-way shape memory effect, hysteresis behavior, superelasticity, vibration damping capacity (Dolce, 2006), (Waram, 1993), (Van Humbeeck, 2001). The two applications presented in this paper are mainly using the two-way shape memory effect representing the ability of SMA's to recover a preset shape upon heating above the transformation temperatures and to return to a certain alternate shape upon cooling.

3 DESIGN STRATEGIES FOR SMA ELEMENTS

The first step an engineer should take when undertaking a design involving shape memory material is to clearly define the design requirements.

This article includes the design strategies for the SMA cantilever strip and for a SMA spring working against a conventional steel spring (referred to in this case as the “biasing” spring). In both design models the friction effect is neglected and a linear stress-strain behavior is assumed (Nasser, 2005).

3.1 Operating Modes of SMA’s

The most used operating modes of SMA's are: free recovery, constrained recovery and work production.

The two Visual Basic applications presented in this paper use a work production operating mode. In this kind of operating mode a shape memory element (SME), such as a strip or a helical springs, works against a constant or varying force to perform work. The element therefore generates force and motion upon heating.

3.2 Transformation Temperatures

SMA’s exhibit a large temperature dependence on the material shear modulus, which increases from low to high temperature. Therefore, as the temperature is increased the force exerted by a SME increases dramatically (Dolce, 2001), (Nasser, 2005).

This section presents the transformation temperatures obtained for the studied SMA elements (strip and helical spring) using Thermal Analysis Methods. Ni-Ti-Cu (Raychem proprietary alloy) is the material used for the two SMA elements.

Thermogravimetric Analysis (TGA), Differential Thermal Analysis (DTA) and Differential Scanning Calorimetry (DSC) methods were used to determine the required parameters. The measurements were carried out on a Perkin Elmer Thermobalance in dynamic air atmosphere, showing that the sample’s mass does not undergo any changes at heating and cooling. In consequence, the TGA curves are ignored.

SMA strip transformation temperature

The temperature control program used for SMA strip measurements contains the following sequences:

- heating from 30°C to 160°C at 5°C/min;
- holding for 10min at 160°C;
- cooling from 160°C to 20°C at 5 °C/min.

The DTA and DSC curves are presented in Figure 1. By analyzing this figure we can observe two phase transitions. The first occurs during the heating while the second one appears during the cooling process. The details of these thermal effects are presented in figures 2 and 3 (reported from the DSC curve).

Figure 2 shows that the determined transformation temperatures at heating are A_s=80°C and A_f=111°C. The enthalpy of the endothermal transition process is ΔH_h=36.8858J/g. The temperature corresponding to maximum transformation speed is 98.79°C.

The transformation temperatures at cooling result from Figure 3: M_s=69°C and M_f=48.25°C. The enthalpy of the exothermal transition process is ΔH_c=-28.7792J/g and the temperature corresponding to maximum transformation speed is 59.75°C.

SMA helical spring transformation temperature

The transformation temperatures of SMA helical spring are obtained by similar measurements as in the case of SMA strip, using the following temperature-control sequences:

- heating from 30°C to 100°C at 5°C/min;
- holding for 10 min at 100°C;
- cooling from 100°C to 20°C at 5 °C/min.

The form of DTA and DSC curves is similar to the ones represented in Figure 1, for 6.849mg SMA spring sample. The experimental transformation temperatures at heating are A_s=58.89°C and A_f=67.93°C. The enthalpy of the endothermal transition process is ΔH_h=9.2J/g and the temperature corresponding to maximum transformation speed is 60.42°C. The transformation temperatures at cooling are M_s=45°C and M_f=33°C, the enthalpy of the exothermal transition process is ΔH_c = -5.03J/g and the temperature corresponding to maximum transformation speed is 39.07°C.

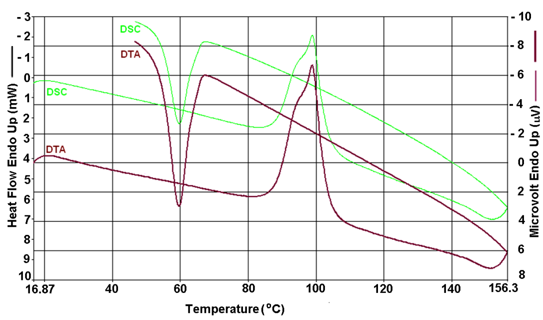

Figure 1: DTA and DSC curves for 18.275mg SMA strip.

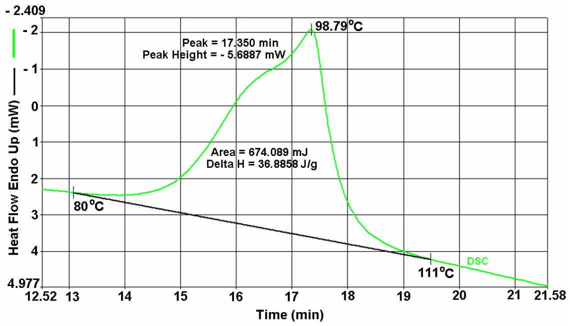

Figure 2: Detail of DSC curve for computation transition at heating of SMA strip.

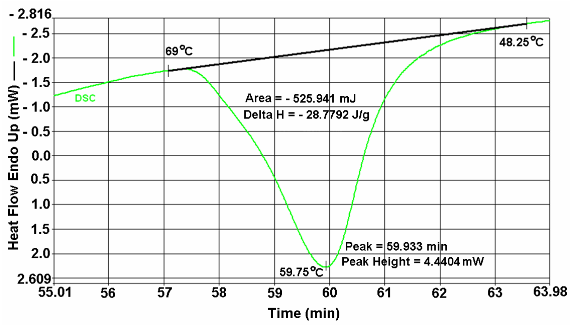

Figure 3: Detail of DSC curve for computation transition at cooling of SMA strip.

4 VISUAL BASIC APPLICATIONS

Two Visual Basic applications were implemented for SMA cantilever and SMA helical spring with biasing spring. This section details these applications.

Visual Basic application for SMA cantilever strip

Cantilevers made from SMA strip can be used to provide a lifting force and a nominal amount of motion by heating.

For the design example, assume that a cantilever is required to lift a force F=2N (at electrically energized) for a distance of 5mm (required motion) and that the maximum allowable width is 3.8mm. The high temperature stress is σ=140MPa. The operational temperatures, at heating and cooling, are those determined at section 3.2, that are 111°C and respectively 48.25°C. For these temperatures the experimental determined values of Young's modulus are E_h=59000MPa and respectively E_l=6900MPa.

A Visual Basic project SMA cantilever strip was implemented. The application background computations are entirely presented in (Degeratu, 2003).

After providing the initial parameters in the dialogue boxes of the user interface (Figure 4), by pressing the compute button the designed parameters are being displayed in the upper part of the window: cantilever length, thickness and width, reset force, high and low temperature deflections. The middle of the window displays the typical SMA cantilever configuration as well as all design parameters.

SMA cantilever strip can be used to provide thermal control of a microswitch or automatic control of a cooling fan (Waram, 1993, Bizdoaca, 2006).

Visual Basic application for SMA spring with biasing spring. In the work production operation mode the SMA helical spring can work against varying forces such as a steel spring, fluid presure or a magnetic force. In this application the varying force is produced by a steel spring.

For the design example, assume the following requirements: a Ni-Ti-Cu spring/biasing spring combination is required which provides a net force F_n=3N with a 8mm stroke; the maximum cavity length and diameter are 38mm and respectively 5.5mm.

Assume that the force exerted by the biasing spring F_h=2N, the maximum corrected shear stress T_c=175MPa, the SMA spring index c=6 and the low temperature shear strain γ_l=0.015 (in order to ensure a good cyclic life of 50000 cycles). The operational temperatures, at heating and cooling, are those determined at section 3.2, that are 67.93°C and respectively 33°C. For these temperatures the experimental determined values of shear modulus are G_h=16890MPa and respectively G_l=3759MPa. Also assume that the two springs are separated by a plug of thickness 2.5mm.

A Visual Basic project SMA spring with biasing spring was implemented. The application background computations are entirely presented in (Degeratu, 2003) and (Degeratu, 2007).

Using standard steel spring design procedure, assume that the maximum shear stress for the wire T = 675MPa and the shear modulus G = 79300MPa.

When the VISUAL BASIC project for SMA spring with biasing spring design is run, a user interface is displayed, Figure 5.

First the user has to provide the initial parameters in the dialogue boxes in the lower part of the interface. By clicking on the Compute button, the designed parameters are being displayed for both SMA spring and biasing spring in the upper part of the interface. The total actuator system comprised of SMA spring and biasing spring is shown in the middle part of the interface.

This configuration is frequently used for SMA Controlled Valves (Bizdoaca, 2006) and SMA Latching Mechanisms and SMA Bell Crank Mechanisms (Nesser, 2005, Waram, 1993).

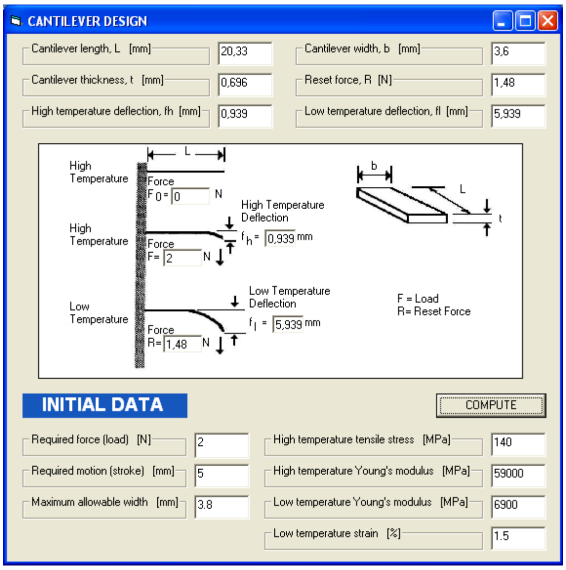

Figure 4: Dialog interface for SMA cantilever design.

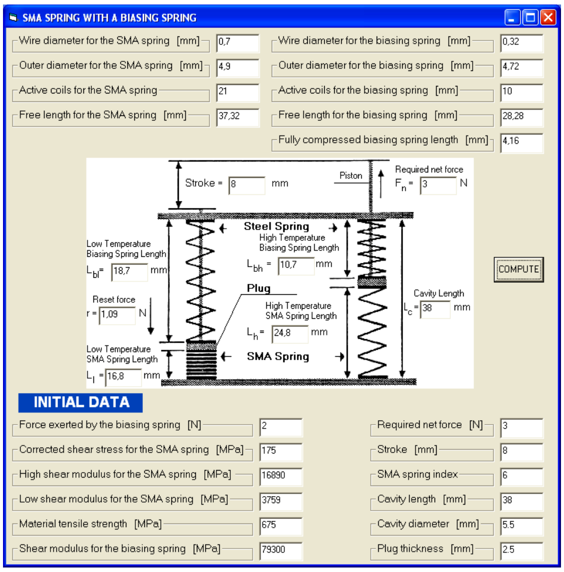

Figure 5: Dialog interface for SMA spring with biasing spring

5 CONCLUSIONS

The paper presents two design strategies for SMA cantilever and SMA spring with biasing spring. For these two design strategies the authors defined: the operating mode, the mechanical considerations and the design assumptions.

Using Thermal Analysis Methods the authors determined the experimental transformation temperatures for the studied SMA elements. These temperatures were necessary to precisely establish the shear modulus values for a high-quality design. In addition, for each design strategy, a Visual Basic application was developed, providing:

- adequate dialogue boxes for fast and easy initial parameters configuration;
- fast computation and display of all required information for a complete SMA element design;
- remarkable facilities to analyze results and choose an optimal solution.

These two Visual Basic applications are already used by ICMET Craiova for engineering purposes and by the Faculty of Electromechanical Engineering of Craiova for didactical ones.

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