ISSN 1516-392X

Theme: Shape memory alloys

HYBRID NiTi SMA/400 GRADE MARAGING SPRING ACTUATOR – CONCEPT DESIGN*

Fernando Henrique Gomes de Souza[1]
Osmar de Sousa Santos[2]
Jorge Otubo[3]

Abstract

Techniques which use a spring to supply the bias force to actuator are well adopted since they are inexpensive and simple to construct. In this work it was design an actuator concept using bias-type device technique, which comprises two coils that mutually push against each other to supply the stroke. For the coils springs, it was used a wire of NiTi shape memory alloys (SMA) and a wire of 400 grade maraging steel as construction materials.

Keywords: Actuator; NiTi SMA; 400 grade maraging steel.

[1] *Materials Engineering, BSc., student, Unifesp, ITASMART, Mechanical Engineering, Instituto Tecnológico de Aeronáutica, São José dos Campos, São Paulo, Brazil.*
[2] *Physicist, MSc., student, ITASMART, Mechanical Engineering, Instituto Tecnológico de Aeronáutica, São José dos Campos, São Paulo, Brazil.*
[3] *Physicist, PhD., professor, ITASMART, Mechanical Engineering, Instituto Tecnológico de Aeronáutica, São José dos Campos, São Paulo, Brazil.*

* *Technical contribution to the 69th ABM International Annual Congress and to the ENEMET, July 21st -25th, 2014, São Paulo, SP, Brazil.*

ISSN 1516-392X

1 INTRODUCTION

Materials that have two (or sometimes several) crystallographic phases for which reversible transformations from one to the other occur through diffusion-less transformations are known as shape memory alloys (SMAs) [1]. The SMAs exhibit two notable characteristic which are the shape memory effect (SME) and superelasticity (SE) [2].
Due to its unique SME and SE property, the NiTi alloy represent an important class of SMAs, being possible the use of this alloy in wide applications in engineering designs, such as pipe couples, seismic protectors and actuators [3-7].
Techniques which use a spring to supply the bias force to actuator are well adopted since they are inexpensive and simple to construct [6]. Many devices utilize this principle such as gripper [8-10], thermal mixing valve, thermal protection valve [6], micro-valves [8–11] and endoscope [12].
In Figure 1 is sketched a typical mechanical construction of a SMA actuator which uses a SMA spring and a Bias spring [13].

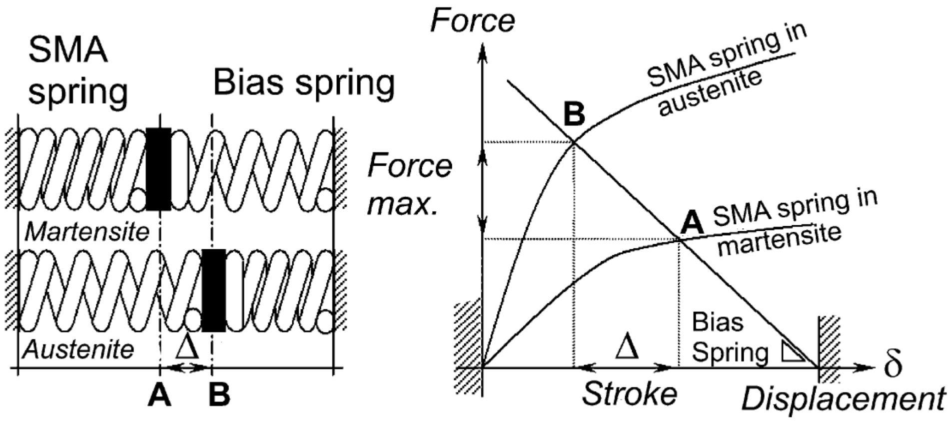

Figure 1. General principle of a spring-based design [13].

In this actuator (Figure 1), the stroke deformation of the SMA spring at low temperature is caused by the bias force of the bias spring. For the high temperature phase, the SMA spring recovers its shape (i.e., the high parent phase), and as a consequence the SMA spring push the bias spring causing a new stroke, where Δ is the total stroke.
The use of NiTi for the SMA spring is justified by applications requiring large displacements, low strength, demand of high reliability and many times repeated operations [6,7]. For the bias spring the use of 400 grade maraging steel is an alternative for the conventional bias spring due to its thermomechanical processing, high mechanical strength, weldability and toughness relationship.
Seeing the high applicability of the NiTi alloy and the 400 grade maraging steel, in this work was designed an actuator using bias-type device technique, which comprises two coils that mutually push against each other to supply the stroke, where the SMA spring was made of NiTi SMA and the Bias spring was made of 400 grade maraging steel.

* *Technical contribution to the 69th ABM International Annual Congress and to the ENEMET, July 21st -25th, 2014, São Paulo, SP, Brazil.*

2 MATERIAL AND METHODS

The NiTi alloy used in the production of SMA spring was melted in argon atmosphere using a vacuum arc remelting furnace (VAR) and remelted for five times subsequently, in order to homogenize the chemical composition of the alloy.
In Figure 2 (a) one can see the plates of nickel and titanium interposed each other inside the crucible of VAR for the production of NiTi SMA. The arrangement of nickel and titanium plates inside the crucible for melting was chosen in such a way that the NiTi alloy would be as homogeneous as possible.
In Figure 2 (b) one can see the ingot after five remelts.

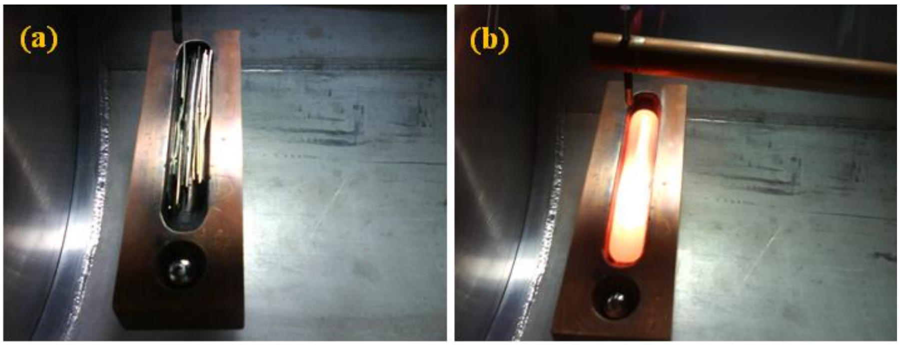

Figure 2. (a) nickel and titanium plates interposed fr melting the NiTi alloy. (b) NiTi ingot after five remelts.

To reduce the diameter of the ingot from approximately 16.0 mm in diameter down to 2.6 mm, the ingot was hot swaged at 850°C. Due to the range of reduction in diameter, the hot swaging was given as follows:
a) 1st part: diameter reduction from 16.0 mm down to 9,525 mm in a rotary swag FENN 5F – four hammers, interspersing annealing at 850°C for 15 minutes for each swaging pass;
b) 2nd part: diameter reduction from 9.5 mm down to 2.6 mm in a rotary swag FENN 3F – two hammers, interspersing annealing at 850°C for 15 minutes for each swaging pass.
Note that all heat treatment of this work was performed in the Heavy Duty furnace without internal atmosphere control, and the oxide layer formed by heat treatment was removed by grinding.
For the reduction in diameter from 2.6 mm down to 1.0 mm, the NiTi wire was cold drawn in a 5 HP single pass bullblock wire drawing machine using a tungsten carbide dies with 15° angle and MoS_2 as a lubricant. For each drawing pass the wire was annealed at 750°C for 15 min and with 1.00 mm in diameter the wire was solution treated at 850°C for 1 h, followed by a water quench.
A M14 screw was used to make the SMA spring, where the NiTi wire was rolled along the screw and memorized at 450°C for 10 min in a Heavy Duty furnace, followed by a water quench. The result was a SMA spring with 24 turns, 46 mm length and 16 mm in diameter.
For the production of the 400 grade maraging steel ingot via VAR, the mass of 100 g of the alloy was taken from a disc of 150 mm in diameter and 34 mm thick produced via arc furnace with controlled atmosphere at the Instituto de Pesquisas Tecnologicas – IPT.

* *Technical contribution to the 69th ABM International Annual Congress and to the ENEMET, July 21st -25th, 2014, São Paulo, SP, Brazil.*

After remelted, the ingot of 400 grade maraging steel was mechanically formed in the same way as the NiTi ingot was, but with one significant difference, there were no heat treatment in any stage of the mechanically forming until the wire reaches 1.00 mm in diameter.
The same M14 screw was used to make the 400 grade maraging steel bias spring, where the wire was rolled along the screw and aged at 480°C for 1 h in a Heavy Duty furnace, followed by a water quench. The result was a 400 grade maraging steel bias spring with 4 turns, 10 mm length and 16 mm in diameter.
A universal tensile testing machine (INSTRON 5500R) with environmental chamber was used for mechanical testing. The SMA spring was tested at 20 mm/min extension rate at the room temperature (25°C). After the first test, the spring was heat to 120°C to shape recovery purpose and then performed another test at 120°C with 20 mm/min extension rate. For the 400 grade maraging steel bias spring the tensile test was performed at room temperature and 2%min^{-1} strain rate. For both tests, it was not possible to make a proper spring alignment in the tensile test due to cutting of the ends of the spring. The experimental tensile test set for the SMA spring can in the Figure 3.

Figure 3. Experimental tensile test set for the SMA spring.

The NiTi wire had its martensitic transformation temperature (MTT) determined by differential scanning calorimetry (Netzsch, model STA 404C DSC).

3 RESULTS AND DISCUSSION

The Table 1 shows the values of MTT and the overall chemical composition of the NiTi wire produced.

Table 1. Chemical composition of the alloy NiTi and its MTT.

Ni (%at)	Mi (°C)	Mp (°C)	Mf (°C)	Ai (°C)	Ap (°C)	Af (°C)
50,00	41.3	37.8	35.1	62.4	70.4	73.0

The In Figure 4 is possible to see the graph for the DSC experiment.

* *Technical contribution to the 69th ABM International Annual Congress and to the ENEMET, July 21st -25th, 2014, São Paulo, SP, Brazil.*

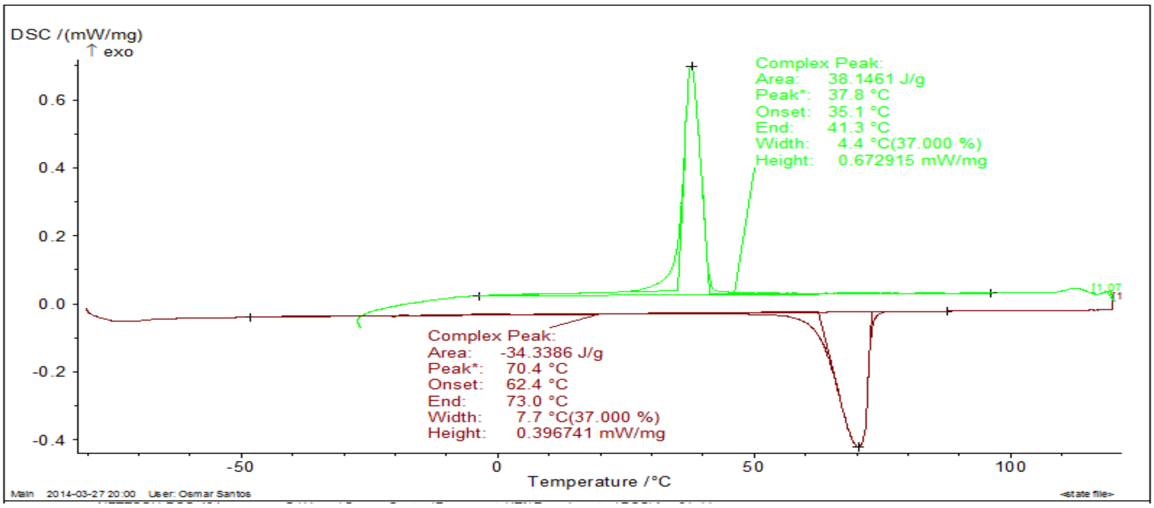

Figure 4. DSC analyses of the NiTi wire.

As we can see in Table 1 the NiTi alloy is equiatomic, therefore the martensic phase at room temperature is expected. The martensitic phase at room temperature is confirmed by the DSC analysis, where the Ms (start of temperature transformation of direct martensitic), Mp and Mf (final temperature of the direct Martensitic Transformation - MT) are above room temperature. Even temperatures of reverse MT such as As (temperature at the beginning of the reversion of martensite to austenite), Ap (peak of temperature of the reversion of martensite to austenite) and Af (final temperature of the reversion of martensite to austenite) are above room temperature. The tensile test for design the actuator is shown in Figure 5, which illustrate the results for NiTi spring and the 400 grade maraging steel bias spring.

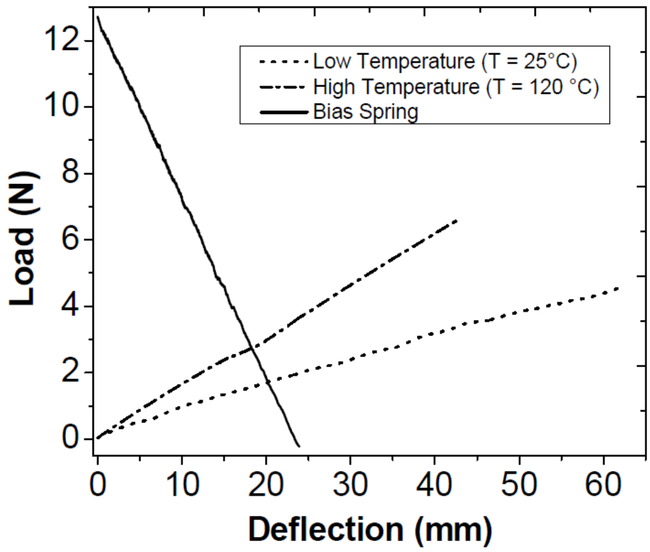

Figure 5. Load *vs* deflection for the tested springs.

The bias spring and the SMA spring are arranged so that they oppose each other's motion. Since the two springs work in opposition, the slopes of the curves have opposite signs.

At the 120°C the springs are balanced at 18.26 mm and at the room temperature (25°C) the springs are balanced at 20.16 mm, were the total stroke (Δ) installed in this actuator is 1.9 mm (Δ = 20.16 mm – 18.26 mm).

** Technical contribution to the 69th ABM International Annual Congress and to the ENEMET, July 21st -25th, 2014, São Paulo, SP, Brazil.*

ISSN 1516-392X

Analysis for the 400 grade maraging steel bias spring in Figure 5 shows that the spring constant is 541.5 $N.m^{-1}$.
The temperatures chosen for the actuator were based in the DSC analysis, ensuring that for the temperature of 25°C the SMA spring was in the martensitic phase and to the temperature of 120°C in the bias spring was fully in austenite phase.

4 CONCLUSION

As shown in this work, it is possible to make an actuator made by 400 grade maraging steel bias spring which has a high mechanical strength with a NiTi SMA spring.
Despite the fact of the total stroke for this actuator is 1.9 mm, which is small depending on application, we can infer that is possible to enhance the total stroke by changing the 400 grade maraging steel bias spring configuration or changing the martensitic transformation temperature of the SMA spring.
As a consequence of changing the configuration of the actuator's springs in order to enhance its total stroke, by the Figure 5 is possible to note that one should correct the parameters of the 400 grade maraging steel bias spring, since it presented a high spring constant to the configuration of experiment.
Viable changes in the 400 grade maraging steel bias spring can be done in the wire diameter or in the number of spring's turns.

Acknowledgments

To FAPESP for the infrastructure and equipment (grant 00/09730-1), to Universal CNPq (grant 473612/2006-2), to FINEP, PRO-INFRA and to AEB to supporting this project.

REFERENCES

1 Delaey L. In: R.W. Cahn, P. Haasen, E.J. Kramer (Eds.), Material Science and Technology, vol. 5, “Phase transformations in Materials”, VCH, Weinheim, 1991.
2 Otsuka K, Ren X. Prog. Mater. Sci., 2005; 50: 511–678.
3 Miller DA, Lagoudas DC. Smart Mater. Struct., 2000; 9: 640 – 652.
4 Buehler WJ, Wang FE. Ocean Eng., 1968;1:105-120.
5 Meng Q, Yang H, Liu Y, Nam T, Favier D. Journal of Alloys and Comp. 2013;577S:245-250.
6 Oliveira CAN, Gonzaleza CH, Araújo CJ, Araújo Filho OO, Urtiga Filho SL. Materials Research, 2010; 13(2): 219-223.
7 Otsuka K, Wayman CM (Eds.). Shape Memory Materials, Cambridge University Press, Cambridge, UK, 1998.
8 Ikuta K, Proc. IEEE Int. Conf. Robotics Autom., Cincinatti, 1990, pp.215–216.
9 Johnson AD, Martynov VV. Proc. 2nd Int. Conf. Shape Memory Superelastic Technol., Pacific Grove, CA, 1997, pp. 149–154.
10 Busch JD, Johnson AD. Shape-Memory Alloys Micro-Actuator, US Patent 5,061,914, June 27 (1989).
11 Kohl M, Dittmann D, Quandt E, Winzek B, Miyazaki S, Allen DM. Mater. Sci. Eng. A, 1999; 273–275: 784–788.
12 Kaneko S, Aramaki S, Arai K, Takahashi Y, Adachim H, Yanagisawa K. J. Intell. Mater. Syst. Struct., 1996; 7: 331–335.
13 Bellouard Y. Mat. Sci. Eng. A, 2008; 481 -482: 582 – 589.