MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

FEA DESIGN AND IMPLEMENTATION OF DOUBLE SPRING SHAPE MEMORY ALLOYS ACTUATOR

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MASTER THESIS
Department of Mechatronic Engineering

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ABSTRACT

This study presents a finite element and analytical modelling of a shape memory spring by taking advantages of the superelastic mechanical properties of shape memory alloy based on NiTiNol (Nickel-Titanium Alloy).

Because industrial applications of shape memory alloys are constantly increasing, there is a need for good simulation models to understand whether, under what conditions, and in which ways a part could fail and what loads it can withstand. In engineering practice, analysis is largely performed with the use of finite element computer programs.

It is very important to make the simulations with correct model in Finite Element Analysis and it is believed that the model which is proposed in this study will facilitate the system design process and that these processes will be minimized.

After design process this spring is tested using an experimental setup which is capable of measuring current, load and displacement values. In experimental setup spring undergoes deformation with weight effect and it returns to original shape by heating with electrical current.

ÖZET

Bu çalışma, NiTiNol (Nikel-Titanyum) bazlı şekil hafızalı alaşımın süperelastik mekanik özelliklerinden yararlanarak bir şekil hafızalı yayının analitik ve sonlu elemanlar modelerini sunmaktadır.

Şekil hafızalı alaşımların endüstriyel uygulamaları sürekli olarak arttığından, hangi şartlar altında, hangişekilde ve hangi bölümlerde arıza yapılabileceğini ve hangi yüklerin dayanabileceğini anlamak için iyi bir simülasyon modeline ihtiyaç vardır. Mühendislik uygulamasında, analiz büyük ölçüde sonlu eleman bilgisayar programlarının kullanımı ile gerçekleştirilir.

Sonlu elemanlar analizinde doğru model simülasyonların yapılması çok önemlidir ve bu çalışmada önerilen modelin sistem tasarım sürecini kolaylaştıracağına ve bu süreçlerin minimize edeceğine inanılmaktadır.

Tasarım sürecinden sonra bu yay, akım, yük ve yer değiştirme değerlerini ölçebilen deney düzeneği kullanılarak test edilir. Deney düzeneğinde yay ağırlık ile deformasyona uğrar ve elektrik akımı ile ısınarak orijinal şekline geri döner.

SYMBOLS

A	**:** Current (amper)
°C	**:** Degree celsius
d	**:** Diameter of wire (mm)
D	**:** Diameter of spring (mm)
n	**:** Number of turns
γ	**:** Shear strain
E	**:** Modul of elasticity
P	**:** Force (N)
G	**:** Shear Modulus (MPa)
Cp	**:** Heat capacity
L	**:** Latent heat
$\mathbf{T_{avg}}$	**:** Average temperature
R	**:** Electrıcal resistance
$\boldsymbol{\rho_m}$	**:** Density
$\boldsymbol{\rho}$	**:** Resistivity
kg	**:** kilogram
m	**:** mass (kg)
mm	**:** milimeter
t	**:** second (s)
T	**:** Temperature (°C)
W	**:** Watt
Ω	**:** ohm

ABBREVIATIONS

A_f **:** Austenite Finish Temperature

A_s **:** Austenite Start Temperature

M_f **:** Martensite Finish Temperature

M_f **:** Martensite Start Temperature

NiTiNol **:** Nikel-Titanyum Alloy

Ni-Ti **:** Nikel – Titanyum

PE **:** Pseudoelasticity

SE **:** Superelasticity

SMA **:** Shape Memory Alloys

SME **:** Shape Memory Effect

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1. INTRODUCTION

Classical materials have been used as structural materials for many centuries and their development is the center of interest for many scientists and engineers also. Main goal is not only to develop new materials. Increasingly it has come to expect that new functions and capabilities will be teased out of materials themselves, for reducing system difficulty and thus system weight or volume reduction. [2]

Principle of sensing is that a mechanical input is being transmuted into a non-mechanical signal (e.g., voltage), whist in actuator system non-mechanical value is converted to mechanical exit. Active materials in general show a mechanical reception when exposed to other than a mechanical field (thermal, electrical, magnetic, and optical). Smart materials are undergroup of multifunktional materials that are able to of detect non-mechanical impuls like temperature, electric potential or light intensity from environment and give response to those in way of modificateing its mechanical properties.

Although being focused on producing new materials, their development does not automatically result in usable products. The ultimate value of materials lies in advanced mechanical systems that entirely integrate these functions. **S**hape **M**emory **A**lloys (**SMA**) with their numerous unique properties are one of the constantly upgraded smart materials. [2]

SMA are newer types of metal alloys that consist of two or more different materials of a particular chemical composition. The main characteristic of these alloys is the **S**hape **M**emory **E**ffect (**SME**), meaning that they have the ability to return to their initial shape in case that heat treatment is applied to them. The plastic deformation of such alloys begins at low temperatures, and after the alloy is exposed to high temperatures, it returns to its initial form.

Internally responsive SMA, the reversible solid-solid, diffusionless thermo elastic phase transformations between a austenitic phase and martensitic phase are causing amazing phenomenon like SME and superelasticity (SE). Adventage to recover initial shape when warmed is related to SME, and property to recuperate larger strains than other materials (up to 8%) during mechanical loading-unloading is related to SE.

After Adolf Martens disclosured martensite phase transformation in steels in the 1890s a noteworthy move toward the inevitable finding of SMA was made. The martensitic

change was maybe the most broadly examined metallurgical phenomena amid the mid 1900s. The martensitic change is as an irreversible procedure. The idea of thermoelastic martensitic change, that clarified the two-phased change of martensite, was presented in 1949 by Kurdjumov and Khandros as a result of research of the martensitic structure in alloy of CuZn. But the first serious interests for such alloys begin when the same effect is observed on NiTi. Beginning in the 1950s this phenomenon was first observed in AuCd and later in 1960s in NiTi. When the same effect was observed in CuAlNi it became clear that this behaviour was common to alloys which underwent thermoelastic martensitic transformations. Following this initiative, subsequent researchers have discovered the SME in the large number of alloys and also their implementation in different systems. [1]

2. SHAPE MEMORY ALLOYS

2.1. Martensitic Transformation

The term “martensitıc transformation” is defined as a type of phase transformation which includes shearing deformation and resulting form collective atomic movement. The number of atoms dissolved in two phases is the same. Most of alloys that goes under thermo-elastic martensitic transformation, SMA also, have superelastic structures and are body-centered-cubic (BCC). [1]

SMA can occur in two different phases, each of them have a different crystal structure and for that reason don’t have same properties. One phase is*austenite*, characteristic for hig temperatures and the other is *martensite*, *at* low temperature. Austenite (generally cubic) has a different crystal structure from martensite (tetragonal, orthorhombic or monoclinic). It is known that the austenite becomes stable at high temperature, and the martensite at lower temperatures. [4]

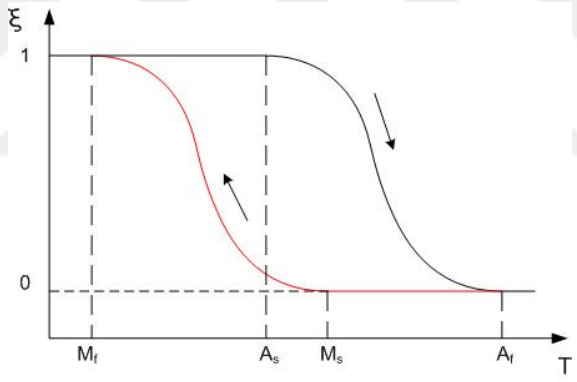


Figure 2.1. Phase transformation of SMA [2]

When a SMA is heated, transforming from martensite into the austenite phase starts. The Austenite-Start-temperature (As) is the temperature where this transformation starts and the Austenite-Finish-temperature (Af) is the temperature where this transformation is done. Once a SMA is heated over As it begins to compress and goes back to the shape before deformation. This transformation is possible even under high applied loads. After the cooling process, the transformation turns back to martensite at the Martensite-Start-temperature (Ms) and ending point is at Martensite-Finish-temperature (Mf), as showed in Figure 2.1.

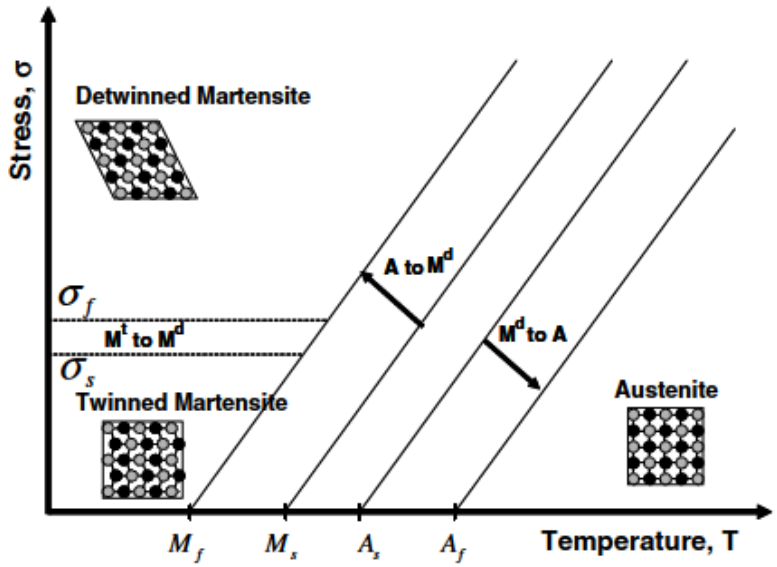


Figure 2.2. Phase transformation in SMA while loaded [4]

To start detwinning process in these alloys, high loads must be applied. Minimum stress needed to proceed the transformation is named as detwinning start stress (σs) and stress which cause the complete detwinning process is named as detwinning finish stress (σf). If material is loaded with loads greater than σs and cooled in the same time detwinned martensite will be formed and that will reflect as a change in a shape. Heating after deformation will activate SME and material will take shape that is memorized.[4]

2.2. Shape Memory Effect

SMA manifests the *SME* when deformed in twinned martensitic phase and after unloaded while still at a temperature lower than As. Heating alloy to temperature above *Af* will return it back to parent austenitic phase and result in with initial shape. [1]

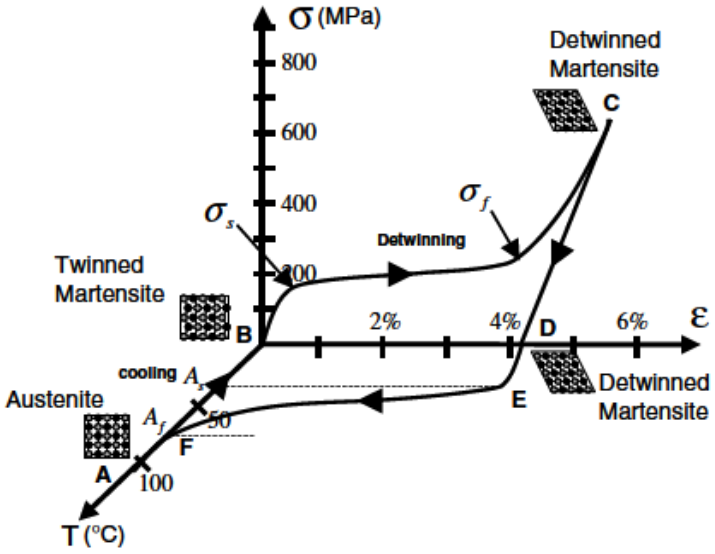


Figure 2.3. Stress-strain-temperature diagram [4]

Diagram on Fig.2.3 shows stress-strain-temperature behavior characteristics of SMA wire used as a one time actuator. SMA wire is deformed in axial direction at temperature lower than M_f. Stress is increasing until it reaches determined value and wire starts extending with a small increasment in stress and this is where detwinning process starts. This will continue till total strain is around 4% and wire has been detwinned completely. The end of this process is defined by the change in inclination in process of loading. Elastic unloading will occur in stress-free conditions and when the strain produced by to the detwinning is not recovered and wire can be used for actuation process. As temperature increases again wire goes under thermal expansion till temperature has value of A_s. At that point detwinned martensite transforms to austenite and it results in contraction. Wire will be completely in austenitic state only if temperature reaches A_f. A_f temperature depend on stress applied in deforming process. When cooled againg the wire returns to the twinned state if stress applied by the attached structure is relieved. For other actuation process structure of SMA wire has to be detwinned again unless wire is working as a two-was SMA. [4]

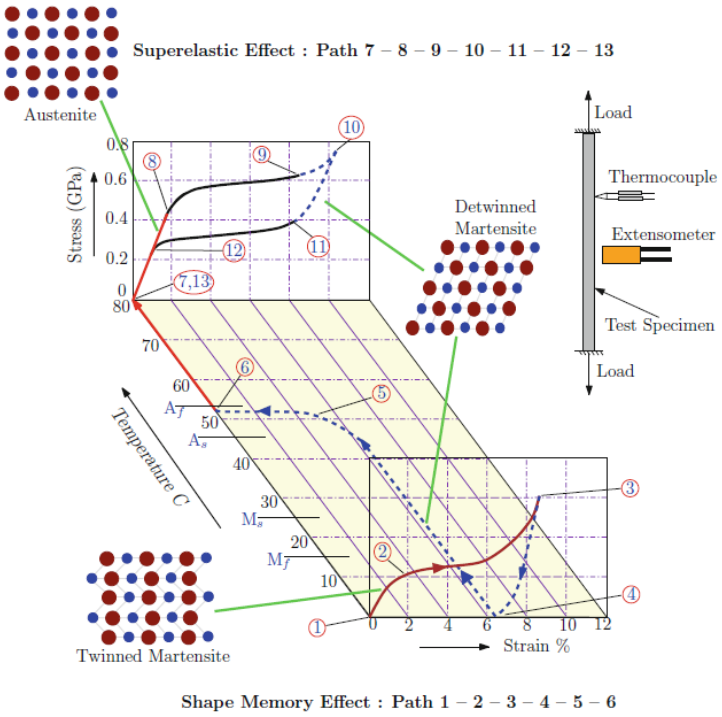


Figure 2.4. SME and PE in NiTiNol

Figure2.4. given above illustrates SME and PE and is also a good demonstration of differences between this two effects in SMA. [2]

In the one hand, path 1-2-3-4-5-6 represents SME. First two steps (1-2) show a standard elastic deformation of any metal which occurs at lower stresses as a aftermath of self accommodated martensite variants aligning themselves. As a load is increasing self accommodated martensite variants twin into stress prefer only one variant martensite named as a detwinned martensite. In point 3 when SMA is unloaded also elastic unloading of detwinned martensite occurs but not completely; there is a strain of about 6%. This strain can be connected with classic plastic strains when metals are disfigured over Yieldpoint. As it is said before, SME is being activated with heating (4-5-6). Transforming martensitic phase to stable austenitic phase recovers strain to beginning point. This transformation happens between As (Point 5) and Af (Point 6). Path 6-1 is last step; if SMA is cooled below martensite finish temperature without external loads where austenite changes to self-accommodating martensite twins.

In the other hand, path 7-8-9-10-11-12-13 represents PE in SMA which is activated by loading and unloading at temperatures greater than Af. Under some external load austenite elastically deforms (7-8). If loading continues while austenite becomes stable

in thermodynamical way to transform to a single variant martensite (8-9). This change from cubic crystal structure to monoclinic results in deformation of about 6-8% strains. In theory it is expected that all austenite is transformed. Very high load can cause plastic deformation which cannot be recovered completely so this part of response is commonly used in designing process and there is recommended strain in SMA which is limitted to 6% (9-10). Upon unloading from point 11 martensite unloads till point 10 which is still stable. Path 11-12 shows inverse transformation from self induced martensite to austenite. In ideal situation, which generally cannot be achieved, 7-8 path overlaps with 12-13. This experiment has been done withNi-Ti test specimen.

2.2.1. One-way and two-way SME

Generally, SME is one-way process and two-way effects are specifically mentioned. SMA deformed at low temperatures can be turned back to initial shape by heating at defined temperature but further cooling will not bring same SMA to the shape it had deformed at low temperatures. This effect is known as two-way SME and requires special techniques to be used in order to get repeated operations according to changes of temperatures from low to high and conversely.

There are two methods:

- a special processing to be performed to give the alloy itself two-way SME, and
- combination of one-way SMA with other springs, weights or such a parts so that a system with two-way behavior.

Processing techniques such as heating under restriction and work hardening make the control of both the high and low temperature shapes very difficult and this also makes fixing the size of displacement harder. It is also tough to control the temperature hysteresis and the forces created during reversion. This effect is not essential property to SMA, but it can be accomplished after different thermomechanical treatments. Simple explained, microscopic reason for storing the shape at low temperatures is hard deformation while specimen is in martensitic state, so that disloacations stabilize the configuration of martensitic phase. These dislocations are present also in the parent phase after reverse martensite when heated so it can be concluded that there are three microstructural forms for these alloys; austenite, martensite and third is stress-based martensite created by applying loads at temperatures below M_f or near to A_f.

In practice two-way SMA is rarely but method of combining one-way SMA (so called “Bias technique”) with other parts is used more than training method. [2]

Fig.2.5 shows SMA compression spring in which SMA wire was shaped and subjected to memory processing, and another compression coil made from ordinary stock. System is made so that two springs mutually push against each other. At low temperatures, SMA coil is pushed leftward due to bias force provided by the spring; if temperature rises SMA goes under shape recovery, pushes against the bias spring and moves to the right. When temperature falls SMA coil will again move to the left. This is simple example of two-way SME.

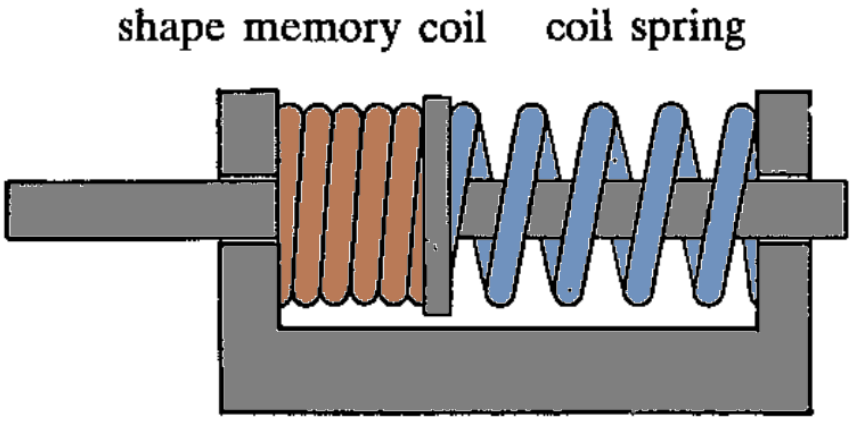


Figure 2.5. Two-way SMA system [1]

2.3. Application Of SMA

For many years, SMA have been a good choice for engineers and other designers who apply the SME to convert thermal energy into mechanical work. They have a variety of applications in aerospace, medicine and transportation. In aerospace, they have been used in the Smart Wing program and the Smart Aircraft and Marine Propulsion System demonstration, rotorcraft and the low shock release mechanism in satellites. In the field of medicine, SMA can be used in orthodontic applications, cardiovascular applications, orthopedic applications and Surgical Instrument applications. In transportation, SMA have been used for applications such as impact absorption, sensing and actuation: deployment of a protective panel; actuating blinds that cover the fog lamp to prevent damage; and SMA spring-actuated valves to adjust the oil level in gearboxes.

2.3.1. Industrial applications

The development of SMA started in early stage. After SE and SME of materials as NiTiNol were founded, practical applications of those started also. One of the examples is the satellite antenna shown in Fig. 2.6. Development was not completed but was a big step forward. Satellite is designed with NiTi sheets and rods which are twisted into volute springs and stored in the inside of satellite. Anthena is heated with electric warmer when satellite is launched and accomplishes a stable orbit and it unfolds out into space. [1]

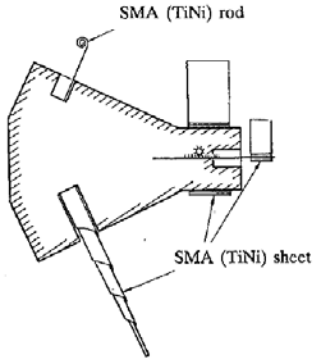


Figure 2.6. SMA satellite antenna [1]

Although SMA are used for different medical applications, they are also important component of many industrial. Before SMA were used mainly for fasteners and couplings in military sector. With the evolution of the technology there is a growth of SMA applications also and some examples are:

1. Couplings and fasteners

Pipe couplings : SMA were first used as one-way components, and the first practically developed products were pipe couplings. TiNiFe alloy with a change temperature infra than room temperature (about — 1.50°C) was framed into tubing where dimensions of inner diameter 4% smaller than the outer diameter of the pipe that will be connected. At the point when they are joined together, the coupling is first inundated in fluid nitrogen and kept up in a low temperature state; at that point a tapered plug is impelled inside the coupling so that its inner diameter expands for 7% — 8%.While the expanded pipe coupling is moved to the assembly site, it is maintained at the low temperature by some suitable handling tool which has a

high thermal inertia. Pair of pipes are put on both ends of the coupling. After removing the handling tool, temperature rises also and consequently inner diameter recovers the size before expansion and that is putting the ends of two pipes together as shown in Fig.2.7. [1]

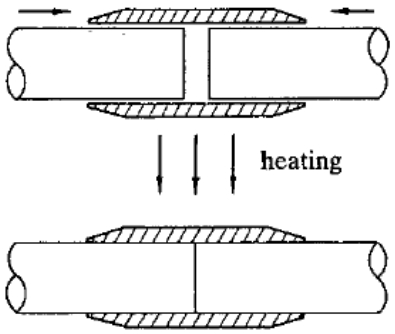


Figure 2.7. SMA as couplings[1]

The advantage of using couplings made from SMA are, aside from their high reliability, there is no thermal damage to surrounding materials due to no need of the high temperatures for conventional welding, and overhauls are streamlined since the couplings can be removed simply by freezing them once again.

Fasteners: Fasteners made from shape memory alloys and an exploiting 3D shape recovery effect which makes fasteners usable even in structures such as enclosed mid-air structure where installation of regular fasteners is not possible. [4]

For fastener applications, SMA with A_f temperature lower than room temperature are used. Fasteners have shape as showed in Fig.2.8, with both ends separated. Before they are installed, the fasteners are cooled withdry ice and the ends are disentangled. After they are inserted to hole in fastened object and subjected to room temperature, shape recovery will occur and the ends will separate anew and by that installation is completed. This is illustrated in following figure.

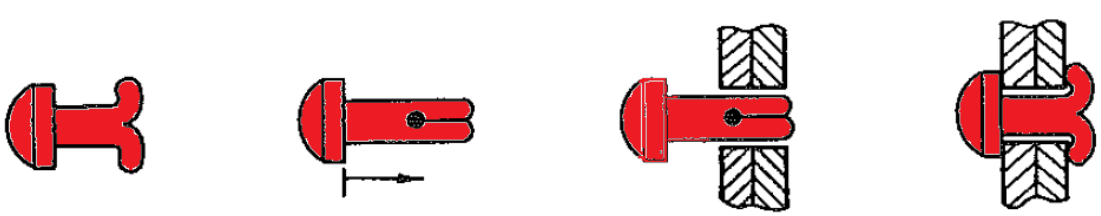


Figure 2.8. SMA as fasteners

Connectors: In a free, unobstructed position, the slit between the two tips opens wide as shown in Fig.2.9. A ring produced using NiTi with an Af of — 20°C is pulled over the sleeve to tighten two ends of sleeve at room temperature. At lower temperatures SMA reacts and ends of sleeve expand. Bias Spring in this case is sleeve.When utilized as a connector, the whole system is cooled and the male end is embedded into open slit. At the room temperature the ring experiences shape recuperation and braces down.

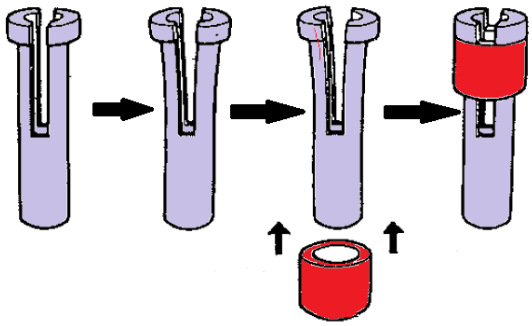


Figure 2.9. SMA as connectors

2. Actuator and robot applications :

Actuators : Since components constructed with SMA are capable of functioning both as temperature sensors and actuators, it would be efficient to employ them as combination sensor/actuators. Many applications, though, use them simply as actuator units. SMA actuators are basically similar to the two-way components described before. By heating or controlling them in suitable ways they can be moved back and forth or rotated. Electric currents are most commonly used to heat these components but a number of techniques have been used practically: currents of hot and cold water, blowing hot air, high-frequency induction heating, incident laser light, etc.

There are two basic types of application of SMA actuators; they can be used either as a thermal or electrical actuators which depends whether current or temperature change is present in process. While thermal actuators are combination of sensing and actuating functions and they can change a shape or generate a force with temperature change, electrical actuators are used simply; to move an object or perform a task on demand when currentis given to a system. [2]

The primary advantage of SMA actuators is their small size. This is understandable given that the mechanism is simple and the component is made as one unit from the

alloy. Shape memory alloy (SMA) actuators can be an ideal substitution for more traditional actuators (e.g., magnetic solenoid) due to low cost, light weight, scalable and having a high power/weight ratio, these actuators are promising in a variety of mechanical systems, particularly in the automotives.

Another advantage of SMA actuators is that the component is not influenced by environmental or atmospheric factors other than temperature. Accordingly, it is possible to install them in locations with rather severe environmental conditions, such as vacuums or underwater, without special adaptations: sealing rings such as are used in motors or oil/air hydraulic cylinders are not necessary. [4]

Control systems: From the point of view of control, the best technique for driving SMA actuators is heating induced by direct currents. While both analog and digital signals can be used in current control systems, the digital type using a pulse current in which the current is modulated with pulse width modulations (PWM) or pulse code modulation (PCM) is practical.

Generally, servo-mechanisms guided by suitable feedback signals are adopted in precision control systems. Since the operating characteristics of SMA actuators vary with the surrounding temperature, it is especially important that they will be adequately compensated. As in the ordinary actuators found in motors or oil cylinders, these feedback signals are often produced using position detection sensors such as potentiometers or encoders; in the case of SMA actuators a more efficient technique which exploits the changing characteristics of the alloy itself has been developed.

In the feedback system for SMA actuators, changes in the properties of the SMA (for example, electrical resistance) are monitored during the interval between pulses when no current is flowing. By using this information as a feedback signal to determine the size of the next pulse, the component can be adjusted. Example of such a system's block diagram is shown in following Fig 2.10.

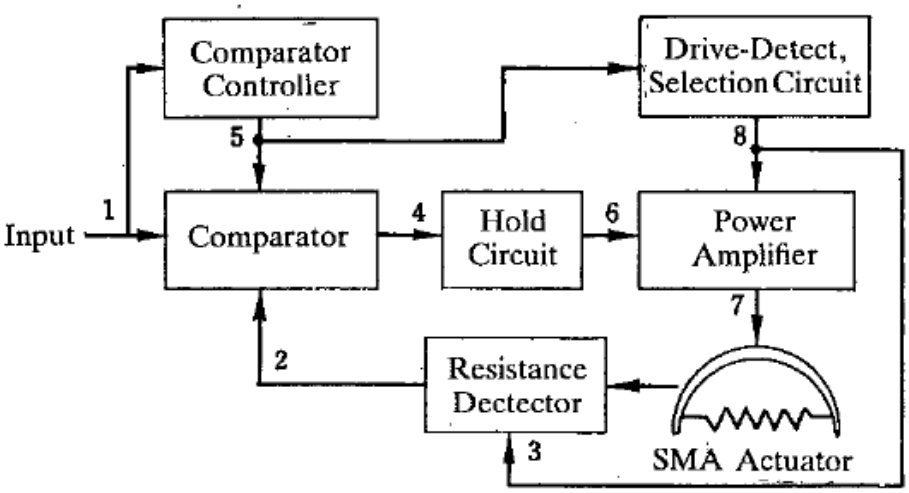


Figure 2.10. SMA system's block diagram [4]

3. Heat engines

Since SMA generate powerful forces when subjected to temperature differentials like that between hot and cold water, it can be expected they would be applied in heat engines for extracting mechanical energy from low-grade energy such as warm waste water, geothermal energy, solar thermal energy and so on.

SMA engines have 4 types: offset crank engines, turbine engines, field engines and miscellaneous engines. Most commonly used type is offset crank engine and principle of operation of this engine are similar to diesel engine. Between a wheel and a crank SMA is set, which is offset from the wheel axis. In these situations, SMA parts with contractions and expansions of the components due to temperature changes work as a cycling pistons and also turn the wheel.

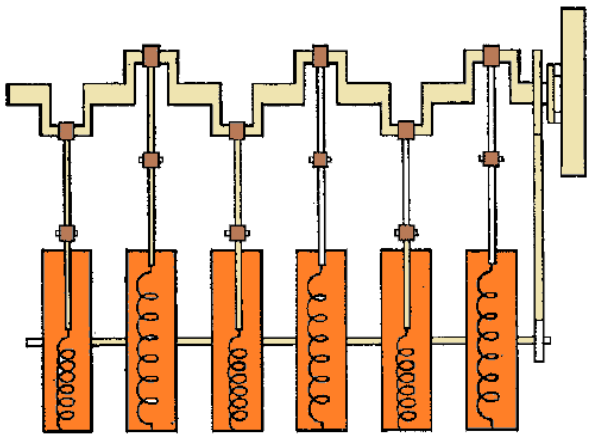


Figure 2.11. SMA heat engine

Example of first SMA heat engine with rods made of NiTiis showed in Fig.2.12. Rods are made as U-shaped curves and are held on crank which rotates around an offset center and a rotating drive ring turning around a fixed shaft. While in the hot bath, rods are in their original form and are employed for turning the ring. The rods in cold are U-shaped by the force of the rods in the hot bath. When ring turns, the rods in cold bath start moving to the hot bath which returns them to straight shape. Concurrently rods in hot bath move into the cold bath and take U shape again. This process enables the rotation continuously.

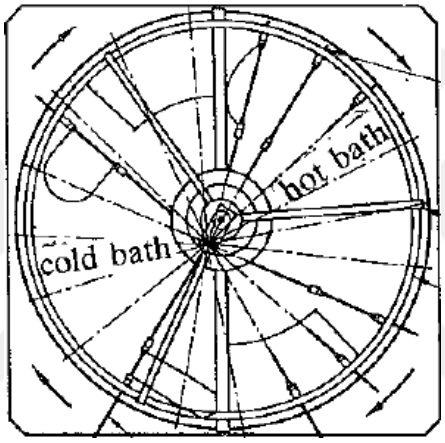


Figure 2.12. First SMA engine

4. Other automotive applications

Actuators are gadgets which are employed for operations such as moving, either on request or as a reaction to change in temperature, pressure and so on. Modem auto consists of more than 100 different actuators that are utilized to control motor, transmission and suspension, to enhance security and improve driver comfort.

Opening and closing the grill of louver in front of a car can be performed with SMA, empowering you to control the aerodynamics of a car. Springs produced using SMA can be utilized as sensor-actuators in pressure control valves or oil cooler bypass valves in automatic transmissions. Interesting application of SMA is as a "heat energy catcher" that can collect heat energy from engine exhaust gases and send that energy to batteries for hybrids or next generation cars. With continuously increasing number of researchers and designers exploring this material, SMA parts are very popular for car applications.Although two-way SMA actuators are accessible, one-way alloys are

utilized generally. [1,3]

Temperature sensitive governor valve is one fruitful application more, which is responsible for controlling the shifting pressure in automatic transmissions. The function of this type of valve is on Fig.2.13. Two springs are present: bias spring made of stainless steel and SMA spring, which is weaker when in martensitic state. Because of that bias spring is compressing the NiTiNol spring toward the closed position.When temperature becomes higher NiTiNol spring extends and pushes the piston into open position. This valve upgrades cool start performance in car and also smoother shifting at low temperatures.

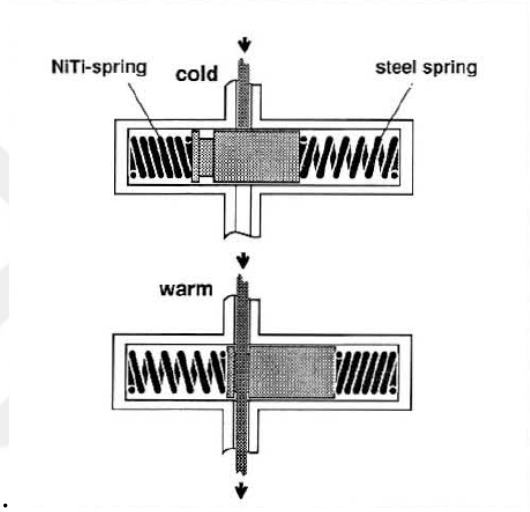


Figure 2.13. SMA pressure valve [5]

2.3.2 Other applications of SMA

Before was mentioned that SMA have many different applications, except industrial applications there are also biomedical, civil engineering, aerospace and miscellaneous applications.

Biomedical applications–Because of many advantages such as their biocompatibility, MRI compatibility, kink resistance, corrosion resistance SMA have found many biomedical applications like drug delivery systems, self-expanding stents, stent delivery systems, implantable devices, catheters or guide-wires. Biocompatibility is main requirement for these devices. It is defined as a property of the material to stay nontoxic inside of the body while doing any of processes described below and also without producing any allergic reaction to a patient.The other requirement is its biofunctionality, which is the ability to function acceptably for its

expected service life in the human body. These two requirements are the most important factors for choosing SMA as a right material for any of these applications. [3] In the most of cases, SMA are programmed so that they have $A_f$temperature below the body temperature. SMA components are cooled to their martensite temperature and deformed so that they can easily be inserted to body. After put into body it is naturally heated and gets the original form in order to perform its function.



Figure 2.14. Orthodontic application of SMA

SMA spring and wires are used also in orthodontics because they can produce constant forces over large activation strokes (Fig.2.14) and are commonly employed for space closure and tooth movement processes. Stainless steel counterparts can deliver higher forces but their forces are not constant as compared to SMA.

SMA have found applications in many “minimal invasive surgery applications” as they can easily pass through convoluted paths and reach various parts of human body or in the neurosurgical fields as a coils, stents or micro guide wires mainly to treat cerebral aneurysm by positioning coils into aneurysm to facilitate “clotting or thrombotic reaction within the aneurysm”. [2]

An early cardiovascular SMA application was the Simon Filter (Fig 2.15). This device is filtering blood from the clots. It is constrained through a catheter in a deformed shape.The filter is floating in the blood at the temperature higher than its $A_s$what is the reason for expanding to a original form. Also commonly use used SMA device is NiTi self-expanding stent. Like other customary stents, this one is utilized to help the inner

circumstances of tubular passages in the body. Before stents were mostly made of stainless steel. These stents are extended from the dimensions of catheter to dimensions ofartery walls by an inflatable balloon.

After being restricted, SMA stent is put into body and released in the artery at the temperature higher than AS. It is there expanding to bigger diameter and pushing the walls. Besides, it also can adjust to any oblong passage while steel stents are biased towards a circular shape.

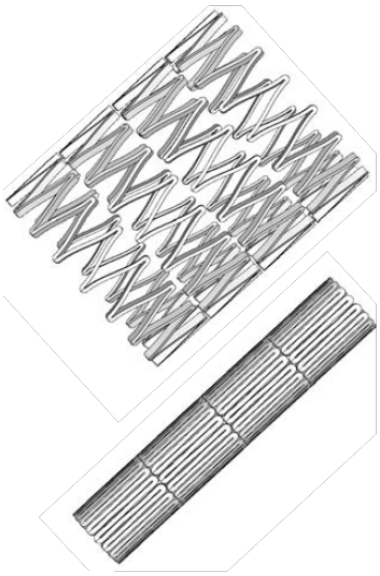


Figure 2.15. Cardiovascular SMA device

Aerospace applications- SMA applications in the airplane industry has covered the fixed-wing aircraft, rotorcraft, space shuttle zones and work in every one of these zones is still ongoing.

The Smart Wing (Fig.2.17) program and the Smart Aircraft and Marine Propulsion System exhibition (SAMPSON) are maybe two the most known of all fixed-wing programs. The motivation behind the Smart Wing was to execute smart materials, for example, SMA, to enhance the performance of lifting bodies. But unfortunately SMA torque tube was not strong enough to actuate a full-scale wing. [4]

In some flying machine applications, brilliant SMA couplings have demonstrated plausibility of substitute socket welds or compression fittings. As indicated in Fig.2.16, so that it can easily slide over the pipes to be fastened, when at temperatures underneath Mf couplings extend to a bigger diameter. Once the SMA couplings changes back to austenite temperature, which is mostly modified to be lower than room temperature, it

returns to its first shape and safely holding the pipe closes as the SMA couplings produces sufficient compressive forces.

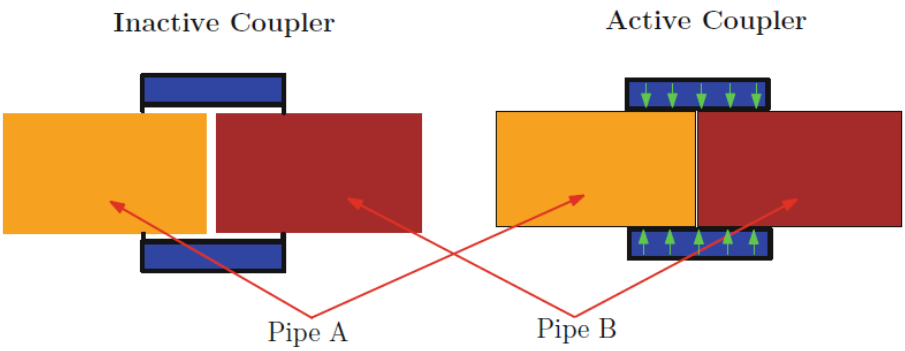


Figure 2.16. SMA coupling

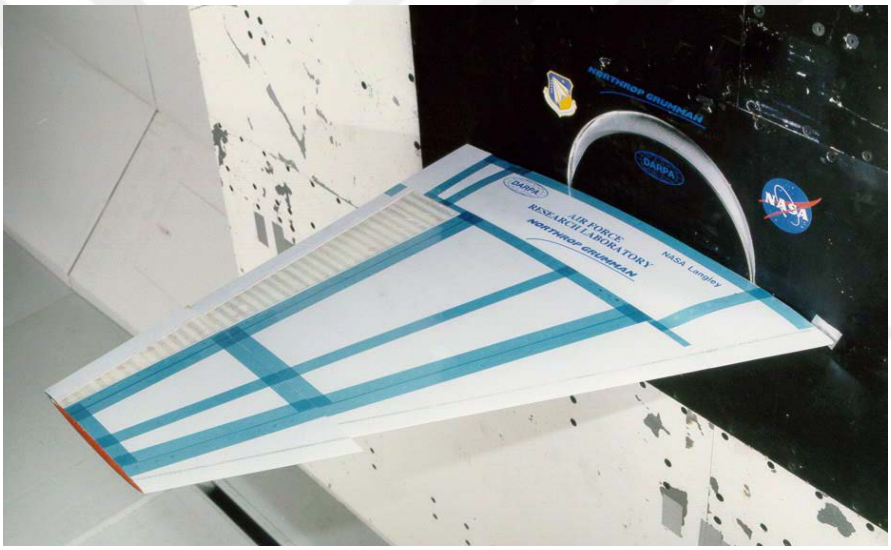


Figure 2.17.*Total view of the SMART Wing model [4]*

When about rotorcraft applications of SMA, it is centered on the main rotor. One ongoing research field is SMA cutting edge actuation. Because this alloys have high actuation energy density and also can generate needed forces in a small available volume, they are in a perfect way suited for such applications. It is believed that the utilization of SMA torque tubes to vary the twist of rotor blades, as found on tiltrotor aircraft, is also possible. These SMA torque tubes, when impelled, could encourage the arrangement of various blade configurations and in this way improve execution of such aircraft in both the hover and forward flight regimes. [2, 4]

Not only the aviation, transportation and medical applications, but also the numerous

different fields uses SMA. The oil industry has demonstrated a great enthusiasm to utilize the SMA activation capacities in discharge devices and protection frameworks for downhole drilling equipment. The high working conditions have additionally opened the road for the utilization SMA in these devices.Regular applications, for example, coffee machines and rice cookers have also been made with some SMA components. A SMA in a rice cooking machine is employed in a way that valve is being activated when the cooker achieves a specific temperature and then discharges the excess steam in the chamber. SMA activated louvers are also joined in air conditioning vents that can modify with change of the temperature of the air exiting the vents. The SME is likewise used in shower designs where a SMA spring controls the hot and cold water to keep up a wanted water temperature.

2.4. NiTi Based Shape Memory Alloys

Combining different additions and suitable materials with already existing SMA gives a 100 different alloys with this effect but in practice only NiTi and CuZnAl are used.Reasons why other alloys are not practically used lays in their price or fact that for being usable they must be in a form of single crystals.

Because of different elements they are constituted from NiTi and CuZnAl have different properties also. In Table 2.1 properties of these two alloys are listed and compared and following conclusions are made:

- NiTi alloys are used when performance of system is crucial but when costs are more important then reasonable is to use CuZnAl.
- NiTi is used almost exclusively when operations are repeated many times (actuators, electric switches and applications which demand high reliability).
- CuZnAl is good choice for safety devices such as fire alarms because they do not operate continuously and using expensive system in that case is meaningless.

In practice, selection of either alloy is decided by a systematic evaluation of the application, environment, the cost and other factors.

Table 2.1. Comparison of NiTi alloy with other alloys [1]

Item	NiTi Alloy	CuZnAl Alloy	316 Stainless Steel
Recovery Strain	max 8%	max 4%	max 2%
Recovery Stress	max 400 MPa	max 200MPa	-
Repetition Life	10^5 (ε=0.02)	10^2 (ε=0.02)	
	10^7 (ε=0.005)	10^5 (ε=0.005)	
Corrosion Resistance	Good	Problematic, especially stress corrosion cracking	Good
Workability	Poor	Fair	Good
Shape Memory Processing	Comparatively easy	Fairly difficult	-
Machinability	Difficult	Very good	Easy
Density [g/m^3]	6.4-6.5	7.54-8	7.8-8
Electrical resistivity[10^{-6} Ωm]	0.5-11	0.07-0.12	0.74

Of the known SMA structures, the NiTi has been examined most broadly and is employed as a part of big number of different applications. The exact name for this unusual material is Nitinol, alloy of equal percent of nickel and titanium generally. Its name originates from the initial two letters of every one of those components, in addition to the condensing of the US Naval Ordnance Laboratory where it was first made in 1961.

Free-recoverable strain in polycrystalline titanium-nickel can reach 8%, however is restricted to a most extreme of 6% if complete recuperation is wanted. Connected loads contradicting recovery reduce recoverable strain. Unmistakably, stronger SMA will be influenced less by contradicting stresses. Recoverable stresses mostly can achieve 80 to 90% of yield pressure.

When is under homologous conditions this alloys shows strong SME, two-way SME, and pseudoelastic behavior, which makes this material perfect for an assortment of uses. It also exhibits resistance to corrosion and is biocompatible, making it suitable for use in biomedical applications. Although it is the shape memory phenomenon for

which Nitinol is best known, the material also has other useful properties. In particular, it has excellent fatigue strength, which means it can be cycled many thousands of times without any significant change in its strength or shape.

2.4.1. Phase diagram of NiTi alloy system

NITiNol consist of of nickel and titanium, generally in equal relation. The Ni-Ti phase diagram in Fig.2.18 clearly shows how temperatures can effect both of the consistents, their formation and thermomechanical treatements. [2]

Many investigations have been made on the equilibrium phase diagram of the Ni–Ti system. Importance of phase diagram lies in their effect to heat-treatements of the SMA and improvisation of alloys. Before is mentioed that these alloys have two different phases and main difference between them is that one, martensite occurs at low temperatures and other at high temperatures.

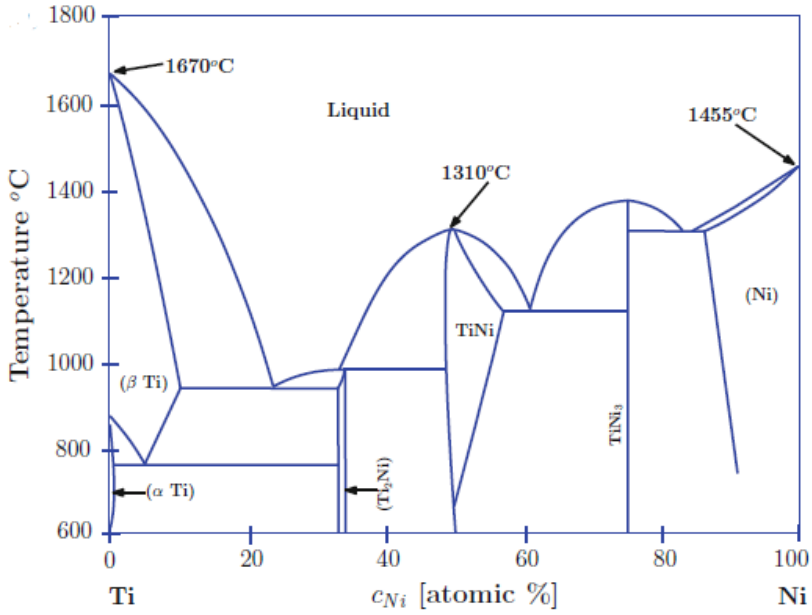


Figure 2.18. Phase diagram of NiTi alloy

The most important part of diagram is placed in the central bounded by Ti_2Ni and $TiNi_3$ phases, since the single phase 'Ti–Ni' B2 transforms into a monoclinic phase martensitically B19'. At 1090◦C indicates BCC→B2 transition, so, this diagram can be used for analyzing the heat-treatments in order to improve shape memory characteristics. The crystal structures of Ti3Ni4 and Ti2Ni3 phases were determined also. [9]

Titanium-nickel is to a great degree sensitive to the exact titanium/nickel proportion. Mostly, combinations with 49.0 to 50.7 at. % titanium are used, with superelastic alloys in the scope of 49.0 to 49.4 at.% and shape memory compounds in the scope of 19. 7 to 50.7 at. %. SMA with less than 49.4 % titanium are not considered as stable. With increment of Nickel in alloy durability falls. [10]

3. ACTUATORS

Actuators are mechanical or electro-mechanical instruments which provide positioning or movements that are operated electrically, manually, or by various fluids such as hydraulic, air etc. Actuators are basically behind story of mechatronics system that accepts a control command (most of the time in the form of an electrical signal) and produces a change in the physical system by generating motion, heat, flow, force, etc. [6]

There are two basic motions, linear and rotary. Taking in consideration the three dimensions of space, a translation motion can be defined as a movement along one or more of three axes. Rotation which has components rotating about one or more of the axes is called rotational motion. [7]

Linear actuators do convertion of energy into straight line motions, usually for positioning applications, and generally have a pull and push function. By use of a rotating knob or hand wheel some of linear actuators are unpowered and manually operated. Rotary actuators do conversion of energy to make possible rotary motion. [7]

By adjusting feedforward or feedback control or an operator actuators input variable are adjusted as well. Considering these facts, actuator acts on the system of energy flow of the process by means of information processing. Furhermore they are important link between the signal level of the information device and the technical process (Fig. 3.1.). [8]

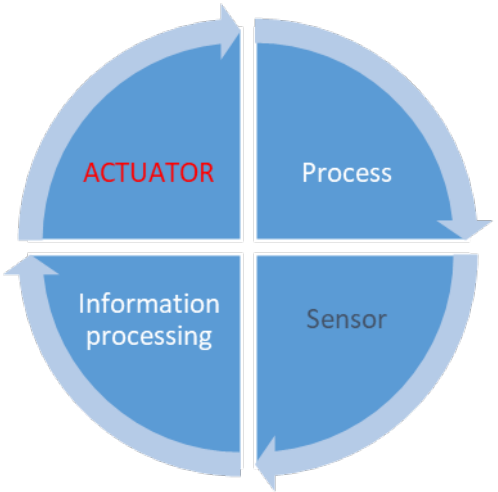


Figure 3.1. Actuator in technical process

It means that actuators normally are used in conjunction with the power supply and a

coupling mechanism. The power unit provides either AC or DC power at the rated voltage and current. The coupling mechanism (gear drive, belt drive, lead screw, piston and linkages) acts as an interface between the actuator and the physical system.

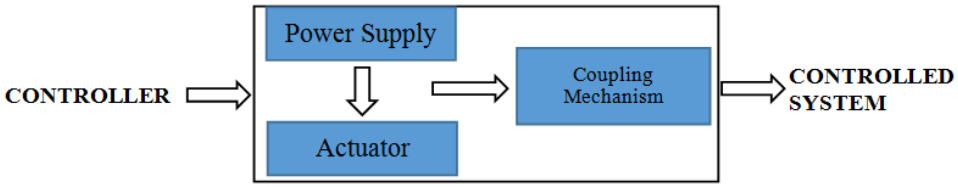


Figure 3.2. Actuator in system

Actuators are applicable in all fields of technology. Because of the numerous requirements, there exists an extraordinary assortment of designs. Actuators in mechanical system operate with an electrical input and a mechanical output, e.g., way, velocity, constrain.

3.1. Classification of Actuators

In a classification based on energy source, there are six types of actuators: electrical, electromechanical, electromagnetic, hydraulic, or pneumatic type and also new generations of actuators including smart material actuators, micro actuators, and Nanoactuators. Fig.3.3. shows different types of energy sources used for actuating and types of actuator that use mentioned sources.

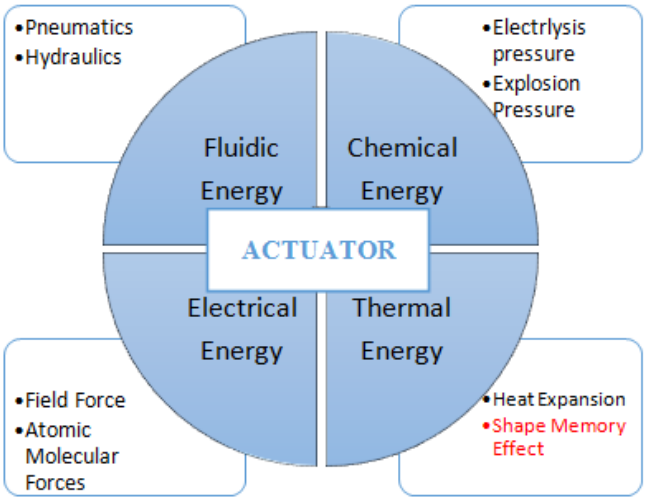


Fıgure 3.3. Main types of actuators

Table 3.1. Classification of actuators [6]

Actuators		Features
Electrical		
Diodes, thyristor, bipolar transistor, triacs, diacs, power MOSFET, solid state relay, etc.		- Electronic type - Very high frequency response - Low power consumption
Electromechanical		
DC motor	Wound field	- Separately excited - Shunt Series Compound
	Permanent magnet	- Conventional PM motor - Moving-coil PM motor - Torque motor
	Electronic Comunication (Brushless motor)	
AC motor	- AC induction motor - AC synchronous motor - Universal motor	
Stepper motor	- Hybrid - Variable reluctance	
Electromagnetic		
Solenoid type devices	Large force, short duration	
Electromagnets, relay	On/Off control	
Hydraulic and Pneumatic		
Cylinder	Suitable for lienear movement	

Hydraulic motor	- Gear type - Vane type - Piston type	Wide speed range High horsepower output High degree of reliability
Air motor	- Rotary type - Reciprocating	No electric shock hazard Low maintenance
Valves	- Directional control valves - Pressure control valves - Process control valves	
Smart Material Actuator		
Piezoelectric&Electrostructive		High frequency with small motion High voltage with low current excitation High resolution
Magnetostrictive		High frequency with small motion Low voltage with high current excitation
Shape Memory Alloy		Low voltage with high current excitation Low frequency with large motion
Electrorheological fluids		Very high voltage excitation Good resistance to mechanical shock and vibration Low frequency with large force
Microactuators		
Micromotors		Suitable for micromechanical system
Microvalves		Can use available silicon processing technology, such as electrostatic motor
Micropump		Can use any smart material

a) Electricity

Because electrical energy is almost always available and already exists and also can be stored without any problem this actuators are flexible and therefore used very commonly. Except the systems with high actuating forces or high temperatures, advantages like these and many others makes electrical energy preference over other types of energy sources.

b) Hydraulics

In these systems additional energy supply is needed for oil flow through the system. When high positioning forces are high and robust and compact actuator is needed this actuators are reasonable to be used but it is important to mention that the operation pressures are relatively high.

c) Pneumatics

Pneumatic systems are realized both with vacuum as well as with over-pressure relative to atmospheric pressure. Pneumatics provide a series of advantages such as a robust design and a reliable and safe operation, especially in a warm and explosive environment.

Depending on listed auxiliary energies, actuators can be classified as showed in Table 3.1.

3.1.1. Smart materials actuators

What makes all of these actuator types unique is that physical phenomena of SME or SE. In past years different new actuators came out of many ideas for their application. High cost of such a materials further limits the spread of these actuators.

Generally there are two main groups; first group with converters that generate force by change in atomic structure upon energisation such aspiezoelectric, and second group are SMA actuators and other smart materials actuators. They do not need power supply to operate.

In the following, concept of SMA actuators will be examined in more detail. When temperature change happens these materials change shape with effecting the environment, and they are generally called as energy converters.

Not like the conventional actuators, the smart material actuators are commonly used as a part of load bearing structures. This is accomplished by implanting the actuators in an

appropriated way and integrating into the load bearing structure that could be utilized to smother vibration, cancel the noise, and change shape.

Main factors that decide about applicability of smart materials actuators are transformation time and characteristic temperature. Range of transformation temperatures of SMA is between -100^{0}C and 100^{0}C. Most alloys are nickel-titanium or copper-zinc-aluminum alloys. Some important characteristics of SMA actuators andalso material properties of Ni-Ti are given in Table 3.2.

Table 3.2. Properties of SMA actuator [8]

Actuating principle	Change of shape during transitions from and to martensitic/austenitic crystal configuration in certain alloys
Advantages	**Disadvantages**
- Good temperature response; full transformation over temperature range as small as 10^{o}C - Can exert high forces during heating up - Shape ca be changed in different ways (expansion, contraction, bending motion…) - Large number of different SMA with change temperatures from -100^{0}C to 100^{0}C	- Very sensitive to composition variations and fabrications - Ni-Ti alloys are expensive, Cu based alloys are much cheaper - Two-way elements can only exert small forces during cooling down - Slow dynamics - Strong hysteresis
Areas of application	Actuation of safety-related devices valve and flap actuation clamping and locking
Physical properties for NiTi alloy	Melting point 1300^{0}C Density 6.4 kg/m^3 Young's modulus: Austenite 82·10 ^{9} N/m^2 Martensite 31·10 ^{9}N/m^2 Yield strength: Austenite 690·10 ^{6} N/m^2 Martensite 150·10 ^{6} N/m^2

	Ultimate strength $900 \cdot 10^{6}$ N/m^2 Temperature of transformation -200... 100^0C Max.Shape memory strain one-way 8.4% Max.Shape memory strain two-way 3%

There are different ways to achieve temperature change of SMA. Firstly, an electric warmer can be mounted on the components. Warming the component may be achieved with current passing through and also from environment, e.g. component submerged into some warm liquid. Cooling process of the component is more risky than warming up and can be done either by limiting the usage of energy when in static stage which is a decent protection of the SMA, or presentation of an active cooling component and that makes actuator more cumbersome.

Because of their behavior, these actuators are great choice for switching applications. Here, their ability of making large activation forces and their temperature reaction qualities come into support. Then again, SMA are fairly appropriate for applications where a consistent movement or quick reaction time are required. Despite the fact that the warmth up cycle can be assisted by utilizing bigger warming component, the cool down cycle stays unchanged. Likewise, strong hysteresis negates the utilization as a continuously variable actuator.

Principal practical uses of SMA as switching actuators go back to 1970s. These days, fields of use actuators for vanes that control the stream of air through jet motors and window machines that open and close automatically. Another intriguing application is as a blood clot filter. This opens up when embedded into blood vein and warmed to body temperature.

With reference to Table 3.3 the NiTi SMA actuators can be the undeniable choice for designers because of notably dislocations and actuation forces, with no necessities for a short reaction time or high effectiveness. This makes NiTi SMA an appealing possibility for using in different mechanical applications, 'smart' structures and systems. A composite air-frame with a blend of piezoelectric crystals, as the vibration sensors, and NiTi as the actuators used to balance vibration, is an astounding example of a 'smart' structure commercial application.[3]

Table 3.3. Comparison of SMA actuator and others [4]

Actuator type	***Stress [MP]***	**Strain [%]**	**Efficiency [%]**	**Bandwidth [Hz]**	**Work per Volume [J/cm3]**	**Power per Volume [W/cm3]**
NiTi SMA	200	10	3	3	10	30
Piezoceramic	35	0.2	50	5000	0.035	175
Single crystal piezoelectric	300	1.7	90	5800	2.55	15000
Human Muscle	0.007-0.8	1-100	35	2-173	0.035	0.35
Hydraulic	20	50	80	4	5	20
Pneumatic	0.7	50	90	20	0.175	3.5

The major test for some SMA actuator applications is the low operate frequency and tight bandwidth of SMA materials, which have a moderately high heat capacity and density and accordingly they may have problems with exchanging the heat quickly into and all the more vitally out of the active component. Fast warming of SMA actuators can be accomplished effortlessly with a few techniques, for example, applying electrical currents (Joule warming) to build the heating rate. But without appropriate control this may overheat and harm the actuator. Regardless, the most important matter in bandwidth constraint is the moderate cooling process, where the heat energy removal rate is restricted by the instruments of heat conduction and convection (Table 3.4.).

The size and design of the SMA actuator influences the actuator reaction time, where actuators with smaller diameter warm quicker because of their higher resistivity, and cool faster because of their higher surface area. Therefore changing the wire geometrical properties may change the application bandwidth drastically.

Higher cooling rates are achieved when cooling with a fluidic medium, however this requires an exceptional design to prevent any spillage to the earth. Active cooling may not be pragmatic in commercial applications since it adds increments in cost, weight, physical volume, also the mechanical and control complexity. [3]

Table 3.4. Effect of cooling methods to speed of SMA actuator [3]

Cooling Methods	**Improvement in Speed**
Using higher temperature wire	2:1
Increasing Stress	1.2:1
Forced air	4:1
Heat conductive grease	10:1
Oil immersion	25:1
Water with Glycol	100:1

The second test is the low related energy effectiveness. Hypothetically the most extreme energy effectiveness of SMAs is in the scope of 10-15%, which may tumble to 10%, based on the Carnot cycle efficiency in a few examinations. Thus SMA actuator applications are restricted to situations where energy efficiency is actuator efficiency (i.e. productivity of the whole framework versus effectiveness of SMA wire). Mechanically, SMA actuators come in different arrangements. The greater part of the proposed actuator designs depend on a SMA spring as the active component, where large dnot a critically outlined requirement. In any case, it should be noticed that there is a distinction between SMA efficiency and displacements can be produced from a small strain. In any case, the stress dispersion over the cross-area of the SMA spring car vary, and consequently requires more greater material volume to create the same force in a function of a linear actuator, which negatively affects effectiveness and actuator transfer speed. Hence, linear SMA actuators are profitable because of the ideal utilization of material.An outline of the highlights and potential outcomes of SMA actuators is given in Fig.3.4, which describes the SMA actuators as indicated by their important requirements and can be considered as a helpful agenda for the improvement of SMA applications.

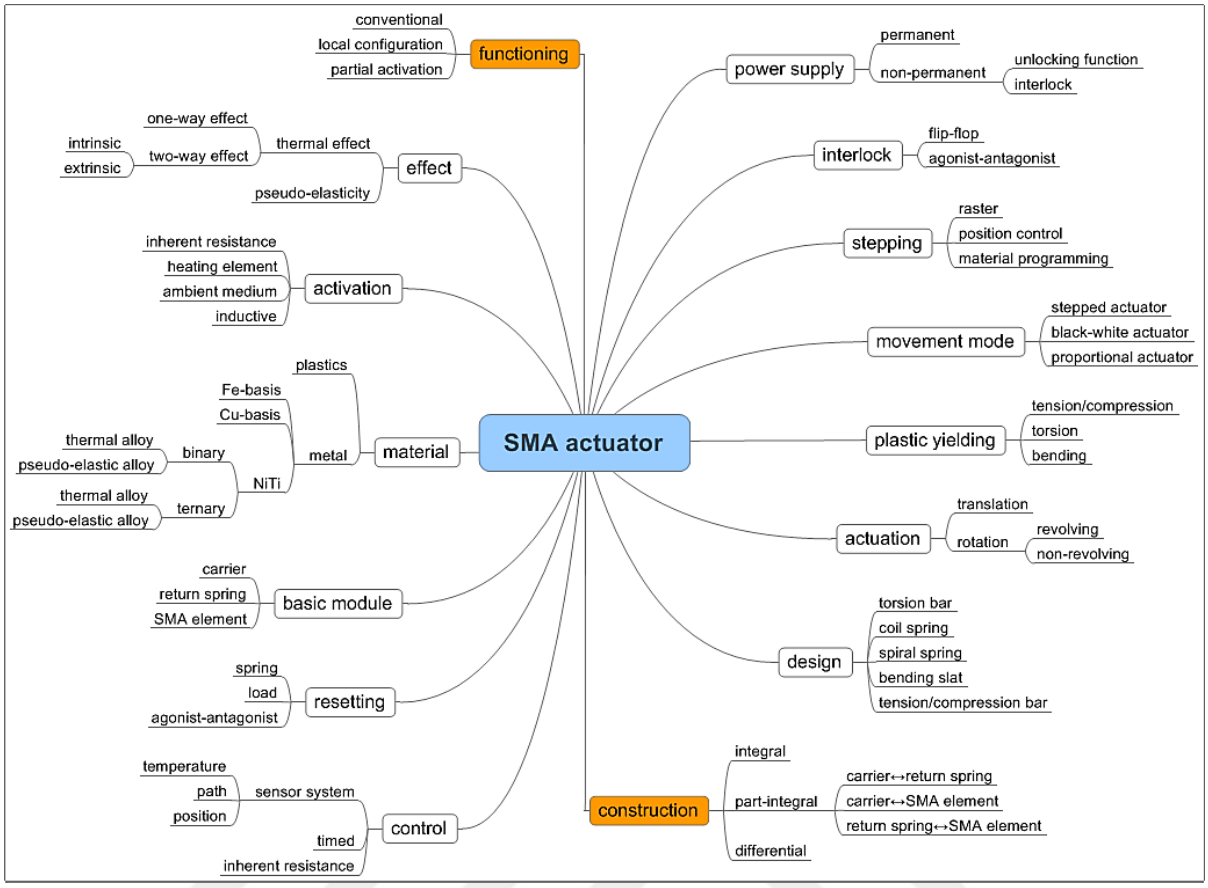


Figure 3.4. Features and possibilities of SMA actuator [3]

4. DESIGN OF SMA SPRING

4.1. Need And Functionality For SMA

A SMA actuator is used when one needs a movement with large strokes, loads in a defined area and a small footprint. SMA resembles a solid state micro scale water powered actuator. Because of its wasteful energy transformation capacities (under 5% change effectiveness) it isn't yet comparable with piezoelectric vibrators and engines for fast repeatable activity. But because of its large stroke and wire-like shape factor, it has its specialty.

NiTi SMA wires are exceptionally corrosion resistant and because of that are appropriate for applications in harsh conditions or when supply isn't simple. For instance, it could be utilized for different applications in solar based plants where heat is promptly available and moderate large movement is required. Since, SMA execution can be influenced by working temperature, loading condition, loading rate, geometry, material synthesis and thermomechanical history, it is fundamental to plan a legitimate feedback control system if precise movement is required. [3]

In general, the following questions need to be asked before deciding on the use of an SMA actuator:

1. *Is the motion needed primarily linear* "*back and forth*" *rather than cyclic* "*rotary*?" Electromotor is a good option for full rotary motions.

2. *Is the intended motion fast or slow, i.e., what is the cycle duration*? In the situationwhere the frequency is in the scope of 1– 10Hz then it is understandable to utilize a SMA. Over that, there won't be adequate cooling time for the SMA to withdraw and complex multiplexing or cooling frameworks might be needed.

3. *Is it a two state system*? SMAs perform exceptionally well in such circumstances where exact area is required just at the begin and the end.

4. *Is it going to be used primarily for power conversion* (i.e. *as a heat engine*)? Assuming this is the case, other advancements might be more ambitious because of their higher productivity. SMAs could be valuable just in situations where there is restricted space.

5. *What kind of heat source is available*? Electrically warmed systems perform best because of the relative simplicity of warming; anyway cooling is dependably an issue.

In the event that immediate warming isn't conceivable, at that point circling a warmed fluid might be exceptionally successful (e.g., a SMA tube with inner warming/cooling liquid stream might be attainable). There have been outlines where an outer Nichrome wire was wrapped round the SMA to warm it by passing current to the Nichrome wire.

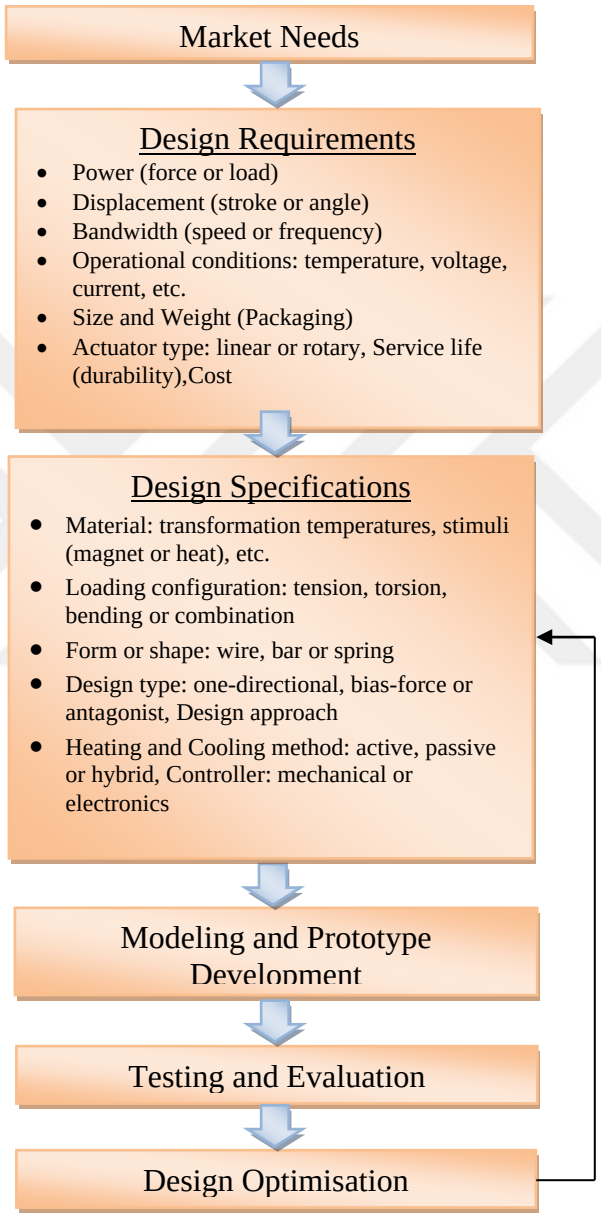


Figure 4.1. Designing algorithm for SMA actuator [3]

6. *What is the working temperature? Are there temperature variances?* Average SMAs work exceptionally well between room temperature and temperature around 150 ◦C. While there is high temperature SMAs they have a tendency to have weakness and stability problems and their costs might be exceptionally

7. *What is the recommended number of cycles?* SMA are amazingly tolerant to corrosive conditions however repeated cycling causes "memory misfortune" and debasement. Along these lines, if a big number of thermomechanical cycles are required, it is better to confine strains to around 2– 4% despite the fact it might have the capacity to be distorted and recuperated to almost 8% strains. Reccomended precent is around 4% strain.

4.2. Design Requirements

Based on extensive review of SMA actuator applications; there arethree main technical objectives that must be addressed in any commercial SMA actuator design:

1) Force (or load).
2) Displacement (stroke or angle).
3) Bandwidth (speed or frequency).

Fulfillment of these goals is challenging inside the requirements of one particular outline or application. This challenge ordinarily requires compliance between the each individual requirement; for instance: thin actuators incite more quickly than thicker actuators, yet the related actuation force is decreased; increased actuator length creates higher displacement, yet requires higher warming energy. Notwithstanding these claims, different imperatives exist in particular actuator applications including: ecological conditions; accessible packaging space; admissible size and weight; required positional control; and cost. (Figure4.1).

Generally, the SMA actuators can be categorized as providing two types of motions:

1) Linear or prismatic motion.
2) Revolute or rotary motion.

The use of specific mechanisms such as lever and pulleys to: change direction, and type of motion (e.g. from linear to rotary and vice versa); reduce required packaging space; and, to enhance the application functionality and capability are further discussed in this chapter.

4.3. Design Specifications

In response to the design requirements, a designs pacifications areconstructed to describe the details of the design and the materials used to produce the SMA application.

a) Material selection

Nitinol and its varieties are commonly utilized shape-memory composites, in spite of the fact that copper and iron based a real so accessible for certain applications. Price of NiTiNol is generally very high because process of preparing this alloy and specific transformation temperatures needs precise composition control, for example 1% Ni or 1%Ti added or removed can have a big influence to transformation temperatures. Copper based combinations are mostly utilized for clamps or fire identifier applications. In spite of the fact that copper based SMA are cheaper and are utilized for different actuator designs, these composites are not advisable for cyclic applications because of low fatiguestrength. Whether the material will be used or not directly depends on transformation temperatures, hysteresis and maximum stress to utilize either SME or SE advantagesas specified in Table4.1. Low hysteresis is wanted for quick motions (e.g.MEMS and robotics) and wide hysteresis is wanted to hold the predefined shape inside an expansive temperature range (e.g. deployable structures and pipe joining). Phase change temperatures and maximum stress are needed to distinguish the operating range.

Table 4.1. Typical SMA applications based on material properties [2]

Shape change effects	**Austenite-final temperature, *Af*[°C]**	**Description**	**Typical applications**
PE	0~10	High nickel SE Nitinol	Orthopaedic devices, surgical tools,orthodontic arches,cellular-phone antennas
	0~20	SE Nitinol	Guide wires and mandrels
	10~20	Chromium doped SE	Stents and braided wires
PE/SME	20~40	Body temperature Nitinol	Body temperature activated devices (e.g.stents and filters)
SME	45~95	Mid temperature range Nitinol	Actuators, toys and demo springs
	95~115	High temperature range Nitinol	Actuators

b) Loading configurations

Mechanically, SMAs can be connected to different loading setups. When compared to other kinds of loading, tension loading produces the greatest effectiveness and energy density for SMA actuators. Due to the related performance advantages, most SMA applications are planned in wire shape to profit from tension loading.

d) SMA geometry

As said before, SMAs can be fabricated and acquired in different shapes and structures, for example, wires, bars, tubes and strips; or as completed items, for example, helical springs and wire actuators. Table 4.2 portrays the points of interest and correlations between these structures and shapes for regular SMA linear actuators.

Table4.2. Typical SMA linear actuator form and shape

Actuator form	Properties	Remarks
Wire	▪ Actuation stroke up to ca. 5% strain. ▪ Actuation force up to 200 Mpa (full stroke) or 350 Mpa (reduced stroke) for trained NiTi. ▪ On-Offactuation	▪ Idealusage of material where minimal use of material for amount of work generated. ▪ Tension loading: produces highest efficiency compared to other load types.
Spring	▪ Recommended to apply external heat source for heating. ▪ Any kind of stroke, but typically less than 30 mm. ▪ No dynamic requirements. ▪ Actuation force up to 200 Mpa (full stroke) or 350 Mpa (reduced stroke) for trained NiTi actuators. ▪ Translational movement. ▪ Fatigue cycles up to 0.5×10^6	▪ Large macroscopic displacement out of a relatively small microscopic strain, but the stress distribution over the cross-section of the spring is not constant. ▪ Less efficient than wire because needs more material volume to produce the same force. ▪ Poor dynamic response (low bandwidth) due to the large material.

As said before, tension loading of straight wire provides the highest efficiency compared to other load types, but it also has limited stroke or strain.

4.4. Analytical Design Of SMA Spring

Generally for design of linear actuator two main properties of SMA spring are in center of interest; spring and wire diameter. While wire diameter depends on the load gain, spring diameter depends on deflection needed to be achieved. Outlining of the SMA spring for linear actuators, deflection is desired value because it shows characteristics of the actuator. Spring and wire diameters must be computed so that

spring can achieve needed deflection at a specific load. Subsequently, spring and wire diameters, number of spring turns and length of the spring must be computed.

In calculations for designing spring following symbols are used:

P- load, δ-deflection, D- spring diameter, d-wire diameter, c-spring index , R-coil radius, n-number of active turns, L-spring's length, τ-shear stress, G-shear modulus.

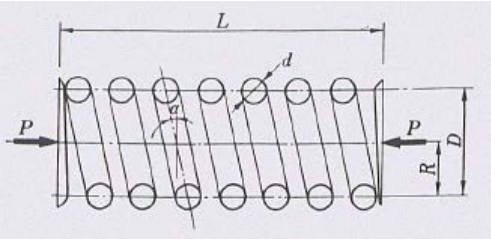


Figure 4.2 . SMA spring

In Fig.4.2 development of compression coil spring under an axial load P is showed. It is assumed that pitch angle is relatively small so bending and compressive forces are ignored. Shear stress τ occurs at the surface of the wire and can be found by the following. [3]

$$\tau = \frac{16 \cdot P \cdot R}{\pi \cdot d^3}$$

Next the deflection is calculated due to an axial load P.

$$\delta = R \cdot \varphi = \frac{64 \cdot P \cdot R^3 \cdot n}{G \cdot d^4} = \frac{8 \cdot P \cdot D^2 \cdot n}{G \cdot d^4}$$

Spring constant k is then

$$k = \frac{P}{\delta} = \frac{G \cdot d^4}{8 \cdot n \cdot D^3}$$

G represents elasticity coefficient for shearing or torsion force and depends upon the conditions as temperature or duration but it is taken to be constant. Calculations were performed using 25Gpa as a high temperature shear modulus G_H, and 2.5 GPa as a value of a low temperature shear modulus G_L. [1, 3]

In this study, desired load at low temperature and occurred deflection is;

P_L=3.3 N, deflection δ_L=1.47mm

Shear strain is factor that depends upon the number of times the operation is repeated so it is better to keep γ_{max} smaller. To ensure log lifespan γ_{max} of 1.5% is used and it is equal to shear strain at low temperatures. If γ_L=1.5% γ_H can be calculated from following relation.[3]

$$\gamma_H \cdot G_H = \gamma_L \cdot G_L$$

$$\gamma_H = 0.00162$$

Since γ_L =1.5% and G_L= 2.5GPa , $\boldsymbol{\tau_L}$= $\gamma_L \cdot G_L$= 0.015·7.5= 0.0405 GPa results.

Assuming that C=6 and k=1.28 [1], and substituting P_L and τ_L into following formula will give wire's diameter.

$$\tau = k \cdot \frac{8 \cdot P \cdot D}{\pi \cdot d^3} = k \cdot \frac{C \cdot 8 \cdot P}{d^2 \cdot \pi} \quad (*)$$

$$d = \sqrt{\frac{k \cdot C \cdot 8 \cdot P}{\pi \cdot \tau}} = 0.00165\text{m}$$

First step of dimensioning of spring is done. Substituting d=0.00165m into (*) formula gives

$$D = \frac{\tau \cdot \pi \cdot d^3}{k \cdot 8 \cdot P} = 0.0186\text{m}$$

Finding spring's diameter d and coil diameter D makes two steps in designing process done. Substituting their values and difference between shear strains at high and low temperatures,

$$\Delta\gamma = \gamma_H - \gamma_L,$$

Into relation between γ and deflection δ

$$\Delta\gamma = \frac{d \cdot \delta}{\pi \cdot n \cdot D^2}$$

The following results:

$$n = \frac{d \cdot \delta}{\Delta\gamma \cdot \pi \cdot D^2} = 14$$

Becouse spring is fixed, the total number of coils is N= n+2 [1]:

$$N = 16$$

Length of the spring is then :

$$l = D \cdot N = 0{,}26 \text{ m}$$

It is important to underline that load and displacement cannot be chosen completely arbitrarily. The following relation must be satisfied:

$$\frac{P_H}{G_H \cdot \delta_H} = \frac{P_L}{G_L \cdot \delta_L}$$

4.5. Time Needed To Heat Up And Cool Down The Spring

Time depends also on material characteristics and ambient temperature, so it is not the same if spring is heated in hot or cold environment. In most of practical usages SMA spring is heated by current, in this case with 4.5A current. Calculations of time needed to heat up or cool down are done by considering the total heat supplied by joule heating and the increase in the internal energy due to changing temperature and they

are based on the following equation. [1]

$$m \cdot C_p \cdot \Delta T + m \cdot L = [-h \cdot (T_{avg} - T_{amb}) + I^2 \cdot R] \cdot \Delta t$$

so time needed to heating/cooling is :

$$\Delta t = \frac{m \cdot Cp \cdot \Delta T + m \cdot L}{-h \cdot (Tavg - Tamb) + I^2 \cdot R}$$

Where m is mass of the spring, Cp is heat capacity per unit mass, L is latent heat per unit mass, T_{avg} is average temperature, Tamb is temperature of the environment of the spring, R is electrical resistance, ρ_m is density, h is heat transfer coefficient and ρ is resistivity.

If formulas for m and R is entered,

$$m = V \cdot \rho_m = A \cdot l \cdot \rho_m$$

$$R = \frac{\rho \cdot l}{A}$$

Following equation results:

$$\Delta t = \frac{A \cdot l \cdot \rho_m \cdot Cp \cdot \Delta T + A \cdot l \cdot \rho_m \cdot L}{\frac{h \cdot (Tavg - Tamb) \cdot A \cdot l}{A \cdot l} + I^2 \cdot \frac{\rho \cdot l \cdot A}{A^2}}$$

$$\Delta t = \frac{\rho_m (\cdot Cp \cdot \Delta T + L)}{\frac{4 \cdot h \cdot (Tavg - Tamb)}{d^2 \cdot \pi \cdot l} + I^2 \cdot \frac{16 \cdot \rho}{\pi^2 \cdot d^4}}$$

If diameter of wire and its length were calculated before, and ρ_m= 6540 kg/m^3, Cp= 832 J/kgC, L= 24200 J/kg, h= 42 W/m^{2}C , I=4.5A, ρ=μΩmm then time taken to heat up the spring is t= 3.3 s.

Analytical design of SMA spring

Symbols :
P- Load
δ - Deflection
D- Coil diameter
d- Wire Diameter
c - Spring index
α - Pitch angle
n - Number of active turns
L - Spring's lenght
τ - Shear stress
G - Shear modulus
γmax- Max.Shear Strain
γmin - Min.Shear Strain
GH- G at high temp.
GL- G at low temp.

Input:	
P [N]=	0.3
δ [m] =	0.1
γL=	0.015
GH [GPa] =	25000000000
GL [Gpa] =	2700000000
C=	10.2
k=	1.28

Output:		
γH=	0.00162	
τL [Gpa]=	40500000	0.0405
d [m] =	0.000496259	
D [m] =	0.00506184	
Δγ =	0.01338	
n=	46.07713067	
N=		

Figure 4.3. Microsoft Excel calculator for SMA spring

Calculator created in Microsoft Excel (Fig.4.3) is using formulas for designing process and directly gives diameter of wire and spring also, number of coils and length of spring.

4.6. Finite Element Modelling Of SMA Spring

In this thesis, a multidisciplinary model is used to get on to complete structural, thermal and electrical model of shape memory metals. Modelling is based on following steps:

- Step 1: Creating the geometry of the model
- Step 2: Meshing
- Step 3: Defining materials properties
- Step 4: Defining boundary conditions
- Step 5: Solving
- Step 6: Commenting the results.

Key of ability to recover defined shape lies in martensitic phase transformation with four relevant temperatures that define the different stages of actuation, and that provides a method for control [5]. With other words, these four temperatures define the start and finish transformations for martensite and austenite:

- Martensite Finish (Mf)
- Martensite Start (Ms)
- Austenite Start (As)
- Austenite Finish (Af)

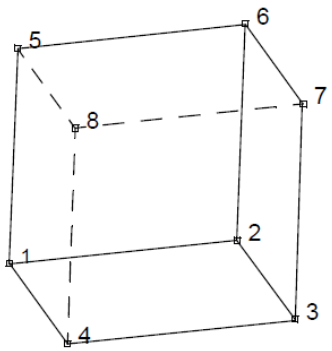


Figure 4.4. Element 7

A commercial software MSC Marc has been used for modelling and the mesh has been created with Mentat. Geometric properties of spring are given in Table 4.3. After defining geometry spring is meshed with Element number 7. This element is 3-D

isoperimetric continuum element with straight edges and trilinear interpolation and used for stress analysis. It is basically 8-noded element with three DOF's per node. The node numbering is counter-clockwise, first for the bottom face and then for the top face. The element has an eight-point Gaussian integration scheme.

Table 4.3. Geometrical properties of spring

No.	Parameters	Values	Unit
1	Wire diameter	0.6	mm
2	Turns	1	
3	Coil diameter	6	mm
4	Displacement	5.6	mm

Material used in modelling is SMA NiTiNol which is the most commonly used SMA, with characteristics given in Table 4.4. Young's modulus and Poisson's ratio is chosen to be same for austenite and martensite.

Table 4.4. Mechanical properties of NiTiNol

Sr No.	Parameters	Values	Unit
1	Elastic Modulus – E	50000	MPa
2	Poisson's ration – ν	0.3	
3	Maximum transformation strain	4	
4	Ms	-45	◦C
5	Mf	-902	◦C
6	As	5	◦C
7	Af	20	◦C
8	Working temperature - T	20	◦C
9	Twinning stress	100	MPa
10	Yield Point	120	MPa

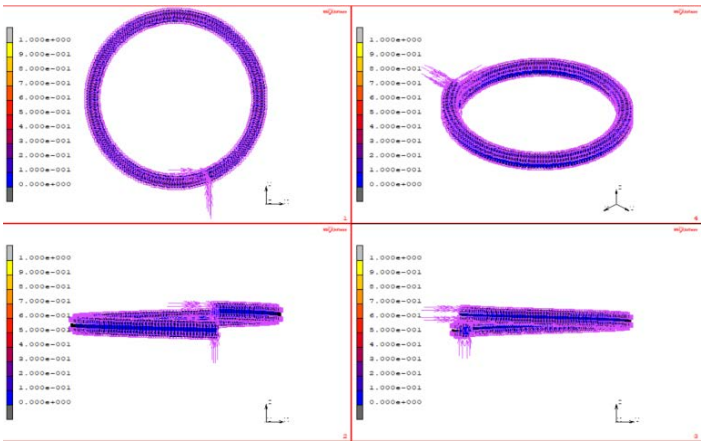


Figure 4.5. FEM model

Fig.4.5 shows 4 views of model of spring which consists of only one turn. Characteristics of model are presented in Table 4.5. When it is about boundary conditions two applies occur; while Apply1 is fixing upper end of spring, Apply 2 is extending spring in –z direction. Applies are chosen with taking Yield Point into account (Fig.4.6.)

Table 4.5. Modelling characteristics

No.		
1	Software	MSC MARC
2	OS	Microsoft Windows
3	Platform	PC
4	Analysis type	Superelastic thermo- mechanical
5	Element type	MARC-7
6	Number of nodes	1656
7	Number of elements	618
8	Number of applied boundary conditions	2
9	Apply1 (Forward Spring)	x=0; y=0; z=0
10	Apply2 (Backward Spring)	x=0; z=-1

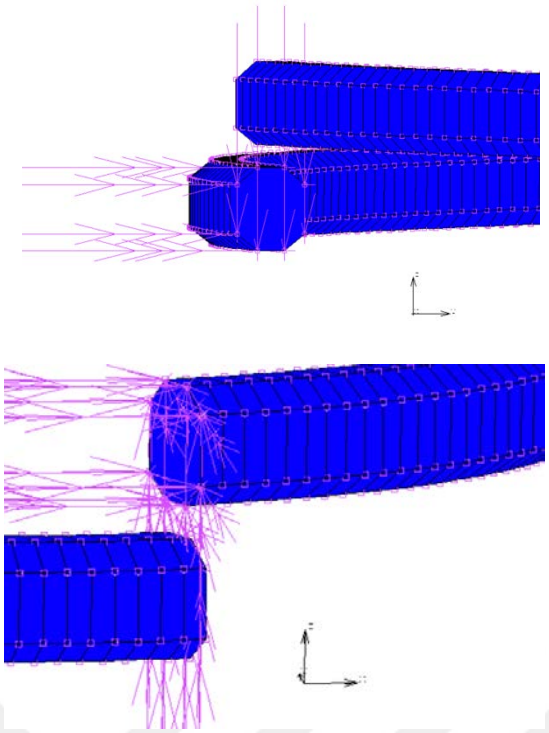


Figure 4.6. Boundary conditionsfor modelling the SMA spring

This model is created to analyse behaviour of SMA spring when opening and closing before conducting experiments.

In this research, the FEA model for analysis is based on following assumptions:

- Material properties are linear
- The martensite transformation and stress are linearly proportional to the displacement. If the displacement is doubled, the transformation and stress double.
- Spring is fully fixed in upper side.

5. EXPERIMENTAL ANALYZE

5.1. Shape Setting Of NiTiNol Spring

5.1.1. Manufacturing techniques

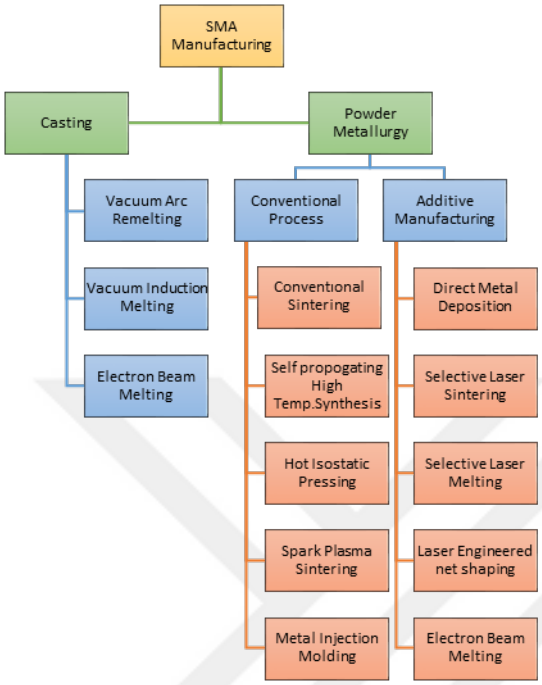


Figure 5.1. Manufacturing techniques

Two primary classes of SMA manufacturing techniques are casting and powder metallurgy techniques (Fig.5.1.).

Casting is a manufacturing process in which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify and is popular in production of SMA that generally involves melting followed, by hot working and final machining.

There are three the most popular types of these techniques:

1. ***VacuumInduction Remelting (VIR)***: Procedure involves melting of metals/alloys in inert gas or vacuum conditions and is generally used for metals that oxidize. The metallic charge filled with Ni pellets and Ti rods housed in graphite crucible are melted and homogenously mixed. Because Ni and Ti have different melting points, Ni pellets that have lower melting temperature are melted first and Ti rods follows. This type of manufacturing allows excellent control on the chemical composition, easy process control and degassing options on the final alloy.

2. ***Vacuum Arc Remelting (VAR):*** This procedure utilizes consumable or on-consumable electrodes made of materials wanted to be softened. In case of consumable electrodes, they can be made of draw materials that are utilized both as warmer a draw material which result in higher yields. When utilizing non-consumable electrodes raw materials are utilized as a part of a copper form. Utilizing an argon arc, the electrode is warmed and the liquid substance is gathered in tube shaped ingot. Consequence of this innovation procedure is purer NiTi SMA if melting cycles, material polluting, ingot homogenity and oxidation issues are precisely chosen.

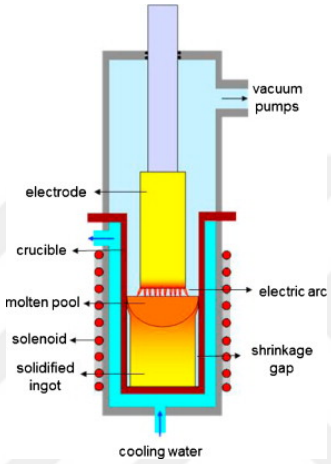


Figure 5.2. Vacuum **A**rc **R**emelting (**VAR)**

3. ***Electronic Beam Melting (EBM):*** This customary casting technique has been utilized for creating SMA since their fruitful use in refining refractory metals, for example, Mo, Ta, Nb and W. In such methods, the utilization of high vacuum conditions and water cooled Cooper crucibles result in nearly zero carbon defilement or oxidation.

Powder metallurgy technique is a technology that involves converting the starting material to the required powder form and then “sticking” the material back together again to produce a more or less solid object and the most commonly used types are :

1. *Conventional Sintering Technique*: SMA have been produced either by traditional sintering or combustion sintering. In traditional sintering, the solid state interdiffusion of the two ingredients is in charge of them to create intermetallic stages at interface. In situation of combustion sintering, the initial compacted blend is combusted which in violent combustion of the ingredients to result in SMA.

2. ***Hot Isostatic Pressing (HIP):*** This is an manufacturing procedure, used to lessen the porosity of metals which enhances the material's mechanical properties and usefulness. The elemental powders in required extent are stuffed in tube shaped gas-tight hardened steel compartments subjected to water hydraulic pressures at high temperatures. Sintering temperatures must be picked with respect to the phase diagram. After the HIP procedure, the compartments are evacuated by machining.
3. *Metal Injection Molding:* Injection shaping has been a famous procedure in plastic industry that infuses materials into pre-outlined models. Such an infusion forming strategy has been utilized for assembling some "near net shape NiTi items". Process begins with authoritative of NiTi feedstock, trailed by infusion molding, at that point deboning and than sintering process. Such procedures are for the most part utilized for creation of smaller parts for miniaturized fabricating industries as there must be a high level of geometric exactness.

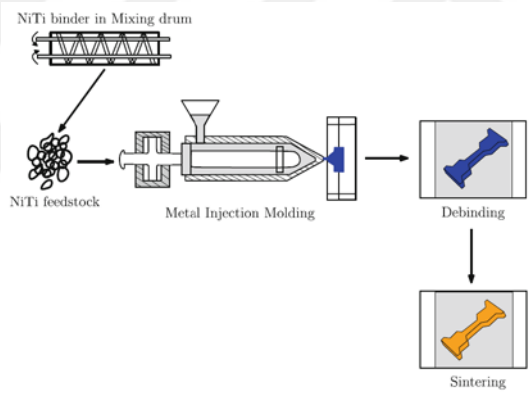


Figure 5.3. Metal Injection Molding [11]

5.1.2. Shape memory processing of NiTiNol spring

In order to get a usable product from SMA, desired shape must be stored in the alloy, and some fixed heat processing is performed to this end. This processing varies with the type of alloy and the application. This is defined after considering many factors such as shape or dimensions of the component. [1]

There are two different processes, respectively used for one-way and two-ways SMA. Because two-ways SMA are not successfully processed they are not yet ready for practical applications. Process described is used for one-way SMA.

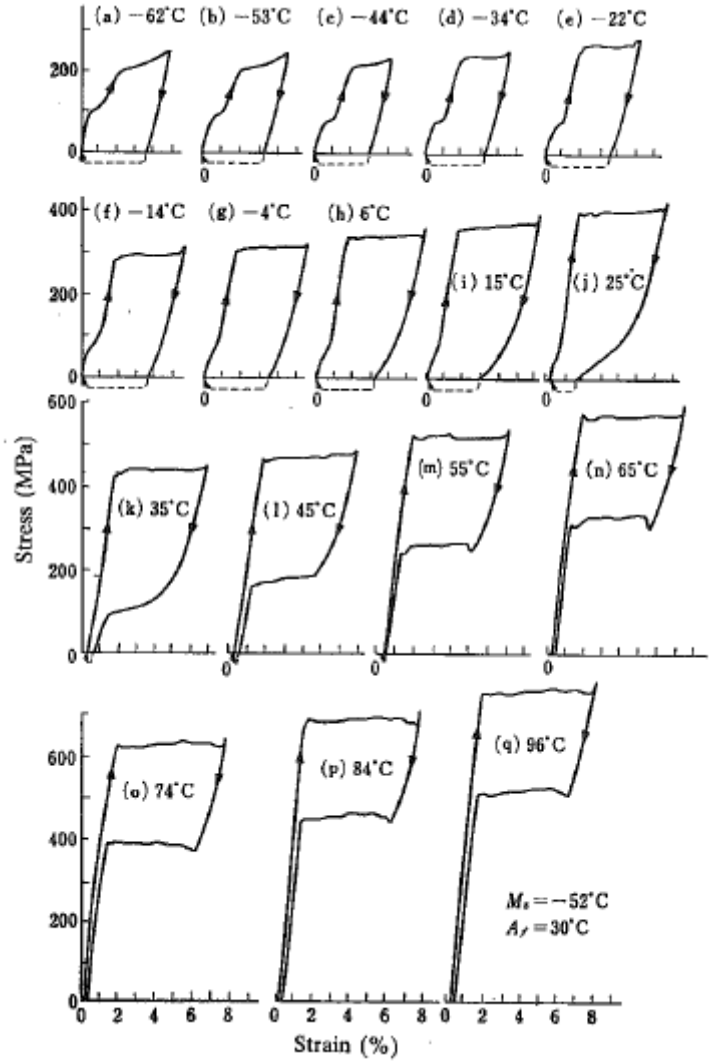


Figure 5.4. Stress- Strain curves for NiTiNol with 400^0C heat treatment

Fig.5.4. indicates stress-strain curvess at 400^0C. Preparing at this temperature has solid shape recuperation force at high temperatures, while processing at 500^0C has low yield stress at temperatures in the region of Ms.Process is basic, commonplace jigs ranges from mandrels for winding SMA springs from wires to stick and plate structures and other such thoughts for the shape. The jig is put in a heater whose settled temperature is around 400– 500 ◦C for time from a few minutes to hours, at that point evacuate and cool it with water or air. Fixtures are intended to limit SMA wires into wanted shapes. It is vital to compel the ends of wires (particularly actuator wires that are martensitic at room temperature) as they tend to return back to their austenitic state.

For the most part the temperature run for shape setting/warm treatment is picked in the vicinity of 400 and 550 ◦C [2]. The absorbing times differ in the vicinity of 5 and 30 min. longer absorbing circumstances increases transformation temperatures

(particularly Af). The writings prescribe steels, for example, 304, 440, D2, H13, and 17-4PH for the shape setting. Likewise bolting the wire ends without a doubt is critical.It is discovered that the utilization of overwhelming metal clamps for locking the springs functions admirably. Temperatures and times required with the temperature treatment/shape setting conditions fundamentally impact the last microstructure of the shape set item and its mechanical reaction, change temperatures, vitality dispersal abilities and level strains. The selection of times and temperature vary contingent on the wire diameter and the mass of the jig being used for shape setting. There are unfortunately no reliable directions for picking perfect shape setting treatment convention to guarantee the shape set item's reproducible and unsurprising repeatable mechanical execution.

At the point when the NitiNol is shape set, oxide layers might be framed at first glance. To dispose of this, vacuum heaters (flushed with latent gases as important) must be utilized particularly when cooling. In such manner, water extinguishing might be a reasonable alternative. As indicated by these guidelines following experiments are done.Following table consist of properties of wire showed in Fig.5.5 which is used for spring processing.

Table 5.1. Properties of SMA wire

Properties				
Material	NiTiNol			
Wire diameter [mm]	0.25,	0.5	0.7	1.0
Corresponding Force [N]	16	65	125	250
Length	1 m for each			

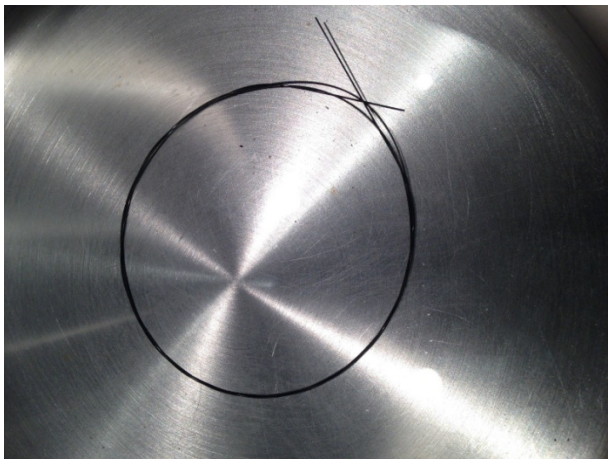


Figure 5.5. SMA wire

Different types of screws are used for fixing the wire in shape of spring. Wires prepared for temperature processing are presented in Fig.5.6. Wires with 0.25 and 0.5 mm diameters are then heated to 400^0C and held for 30 minutes. Furnace used in this experiment is Instron SFL's advanced high temperature and environmental system with max.temperature of 1300^0C (Fig.5.7.).



Figure 5.6. Fixed SMA wired



Figure 5.7. SFL advanced high temperature and environmental system

Springs showed in following figure are the results of shape memory processing. First experiment is done with 0.24 and 0.5mm diameters. Spring 1 is made of wire with 0.25mm diameter and springs 2 and 3 are made of wire with 0.5mm diameter. As it can be seen, wires with very small diameter are hard to control and number of cycles is very low so they are not usable for this application.

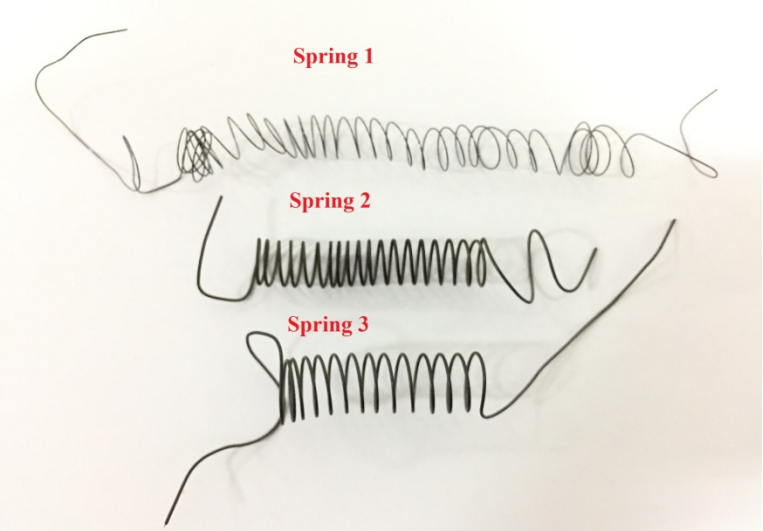


Figure 5.8. Experiment no.1

Second experiment is done with wires with diameter of 0.7 and 1.0mm and also wires are held in furnace for 60minutes. Results are showed in following figure.



Figure 5.9. Experiment no.2

Fig.5.9.shows 3 springs from Experiment no.2. Locking the wires with bigger diameter was more difficult but also results are more usable and can find their application in corresponging systems. From this experiment it is seen that locking is very important factor. If wire is locked correctly shape of spring will be more proper, otherwise spring will be loose and in that shape is not usable for a long period, as happend with first spring in Fig.5.9. Second spring will be used for further experiments. Time and temperature used in this case are accepted as correct.

5.2. Experimental Test Of Spring

The designed shape memory spring's mechanical behaviour was tested using an experimental setup, made as a thesis project in department of Mechatronics Engineering in Marmara University. Table 5.2. shows the mechanical properties of the spring , which was analytically designed before.

Table 5.2. Mechanical properties of spring

Definitions	**Analytical Value**
Load (P, N)	3.3N
Deflection (δ, mm)	1.47
Spring Diameter (D, m)	0.00165
Wire Diameter (d, m)	0.0168
Number of Active Turns (n)	14
Spring's Length (L, m)	0.46

The designed shape memory spring's mechanical behaviour was tested using an experimental setup, made as a thesis project in department of Mechatronics Engineering in Marmara University.

First, the SMA spring is connected to the experimental set up to 1 kg, 1.1 kg, 1.2 kg, 1.3 kg, 1.4 kg, 1.5 kg, 1.6 kg, 1.7 kg, 1.8 kg 1.9 kg and 2 kg weights. The SMA spring, activated with current of 2.5A is than showing its shape memory effect and going back to first position.

Second test was done by changing current used to heat SMA spring with characteristics from Table 5.2.

5.2.1. Properties of experimental set up

The schematic of the experimental setup designed and developed for position control of the SMA wire actuator is shown in Fig.5.4. It consists of the SMA spring with load cell against a weight load along with Balluf linear transducer, programmable power supply and Parallax Data Acquisition tool (PLX-DAQ). The dimension and properties of the SMA spring are given in Table. The load cell is used to measure the generated load during phase transformation. The output of the load cell is conditioned using the load cell signal conditioner to provide output in the range of 0- 10 V to the data acquisition system. The displacement sensor measures the displacement due to SMA contraction. The programmable power supply delivers power to the SMA in the

constant current mode.

Weight connected to the test device causes extension in spring and this deformation is measured by the displacement sensor. The force that opens the spring is also measured by the load sensor and the deformation force - displacement curves are plotted using Parallax Data Acquisition tool (PLX-DAQ) software add-in for Microsoft Excel which collects data from microcontrollers and puts the numbers into columns. PLX-DAQ provides analysis of collected numbers from sensors.

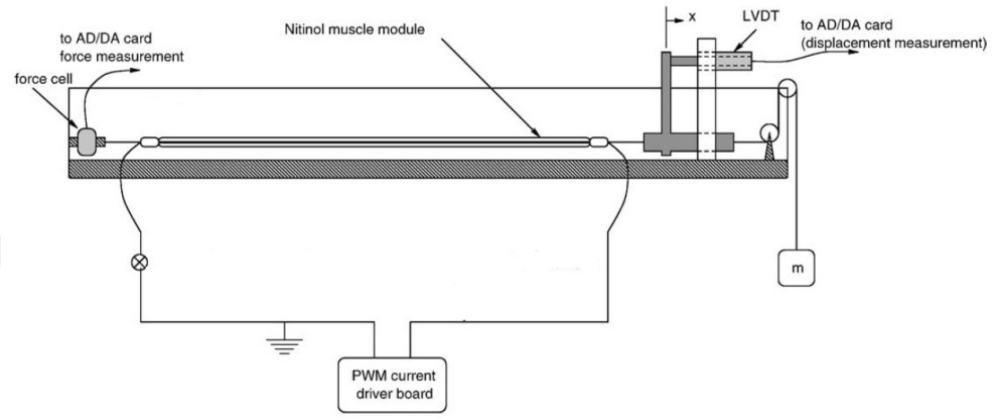


Figure 5.10. The Schematic of the Experimental Set Up

Table 5.3. Properties of linear transducer

Properties	
1. Input Current Range	Maximum of 70 mA
2. Output Range	0 → 10 V, Maximum of 5 mA
3. Overall Width	60mm
4. Stroke	150 mm
5. Brand	BALLUF
6. Minimum Operating Temperature	0°C
7. Maximum Operating Temperature	70°C
8. IP Rating	IP67
9. Overall Height	37 mm
10. Supply Voltage	20 → 28 V dc
11. Housing Material	Anodised Aluminium
12. Overall Depth	296mm

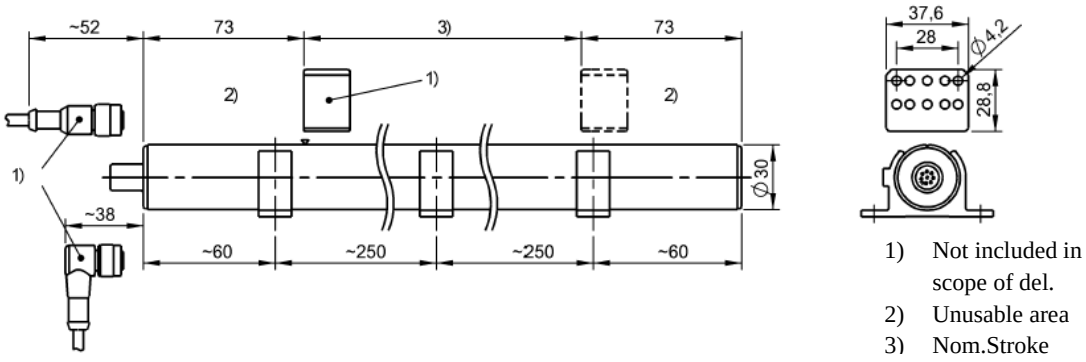


Figure 5.11. The BTL6 Micropulse transducer

Properties of linear transducer- The BTL6 Micropulse transducer is used in different systems or any kind of machine where change in a position is needed to be measured. In a system it is used with any kind of microcontroler, PLC or Arduino. It consists of waveguide and aluminum housing.Moving part is made with magnet and it is moving along the housing and constantly measuring the position. The most important characteristics of this sensor are listed in following table.

Properties of Load Cell-This load cell sensor is used for change up to 5 kg of weight (force) into an electrical signal. Electrical resistance which is directly proportional to strain is also measurable with this load cell.Aluminum-alloy is used in straight bar load cell and is also accomplished to read a capacity of 10kg. Four strain gauges are combined in a Wheatstone formation. Detailed properties are showed in Table 5.4.

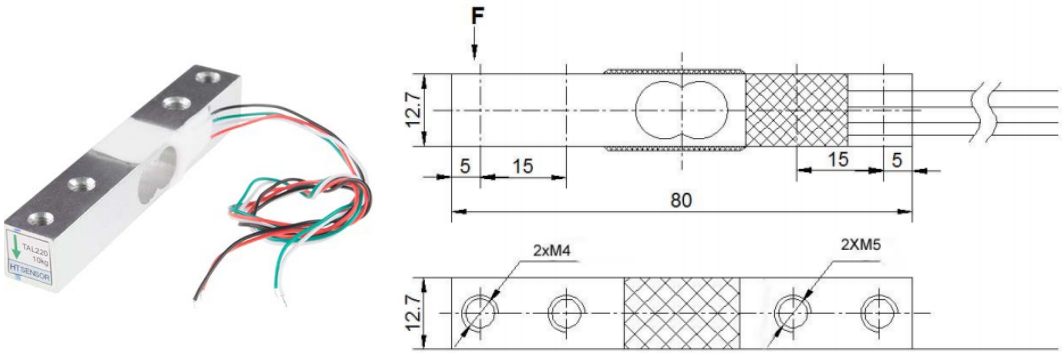


Figure 5.12. Load cell

Table 5.4. Properties of Load Cell

Properties of Load Cell	
1. Type	TAL 220- PARALLEL BEAM LOAD CELL
2. Capacity	5 kg
3. Excitation Voltage	5-10 V dc
4. Operating temperature range	From -10°C to +55°C
5. Compensated temperature range	From -10^{0}C to +40°C
6. Electrical connection	4 color wire
7. Material	Aluminum Alloy
8. Defend grade	IP 65
9. Applications	Palm scale, kitchen scale, electronic balance, fishing scale, electronic platform scale and other electronic weighing devices

6. RESULTS AND DISCUSSION

6.1. Finite Element Modeling Results

Mechanical analyse was performed to determine the stress and strain results, displacement and also martensite transformation from the model. Model loading consist of two applied displacement.

The yield stress of a material is a measured stress level that separates the elastic and inelastic behaviour of the material. Although many forms of yield conditions are available, the von Mises criterion is the most widely used. The von Mises criterion states that yield occurs when the effective (or equivalent) stress (σ) equals the yield stress (σy). In this case, because maximum value of von Mises stress is less than the Yield point value of NiTiNol(Fig.6.1.) the design can be found safe.

In design of spring it is important to keep the maximum value of von Mises stress induced less than its strength. From the analysis, the inner side of the coil is found to experience the largest stresses. The displacement distribution way of the coil spring is also shown in Fig. 6. Maximum value of displacement in z-axis is 5.606.

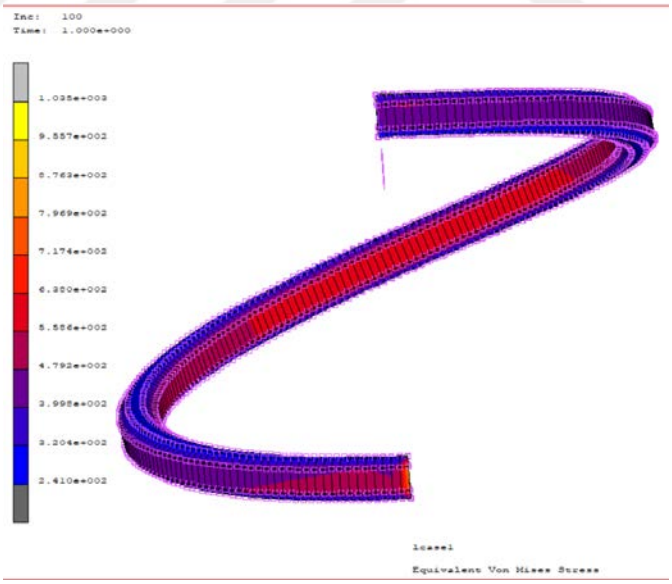


Figure 6.1. von Misses Stress distribution

In general, larger wire diameter will make the spring stronger and this is because making the wire diameter larger also makes the spring's coils tighter which reduces the spring index. The opposite effect is done when making diameter smaller, the spring index increases so it isn't as tight and it is under less stress. This adjustment will not only affect spring's force but it will also affect its elastic limit like it does when

adjusting the outer or inner diameter. When it is needed the outer diameter to be stronger it must be made smaller. Tighter coils have a smaller index, which gives more force. The way this affects the elasticity of spring design is because springs with reduced spring indexes are under more stress than springs with average or large indexes.

From the following figure it can be noticed that firstly inner side in the middle start to martensite transformation and spring didn't go under plastic deformation is seen here also. Martensite transformation is key for SME.

Because upper end of spring is fixed transformation is lower, and the highest change occurs in the middle and also in the cross section of lower end of spring. It is also certain that geometry is in relation with transformation distribution and change of geometry properties such as diameter, length of coil or number of turns of spring presented may have huge effects to transformation on Fig.6.2.

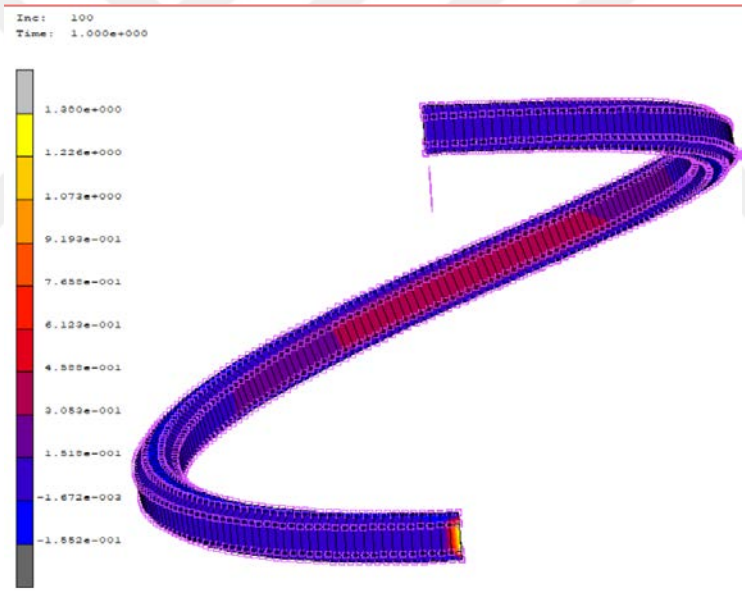


Figure 6.2. Martensite transformation

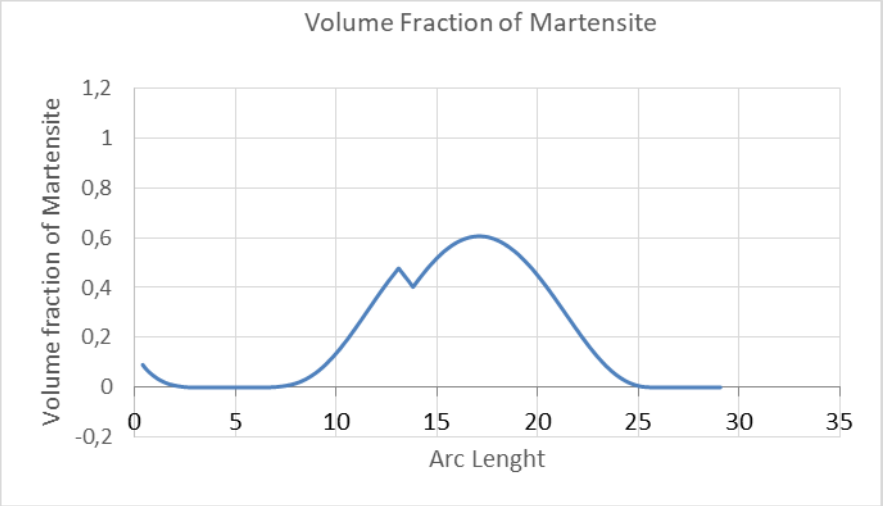


Figure 6.3. Volume Fraction of Martensite in inner side

Transformation of inner and outer side is not the same, in outer side of spring value of martensitic transformation is almost close to zero (Fig.6.3.). With higher loads transformation will be more intensive but in that case strain will be more than recommended

This analyse is done at constant temperature and spring is not extremely loaded so plastic deformation area is not reached.

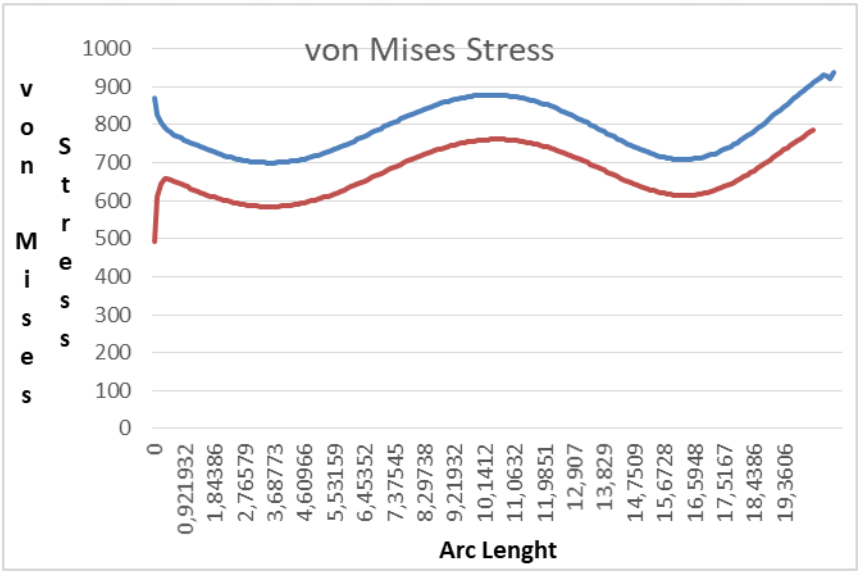


Figure 6.4. Distribution of von Misses Stress in both sides

Results are be based on Fig.6.3. 6.4., 6.5. From those it is seen that highest value of stress occurs where martensite transformation is the highest. With increase of the stress applied in the analysis, phase transformation begins and ends at critical values.

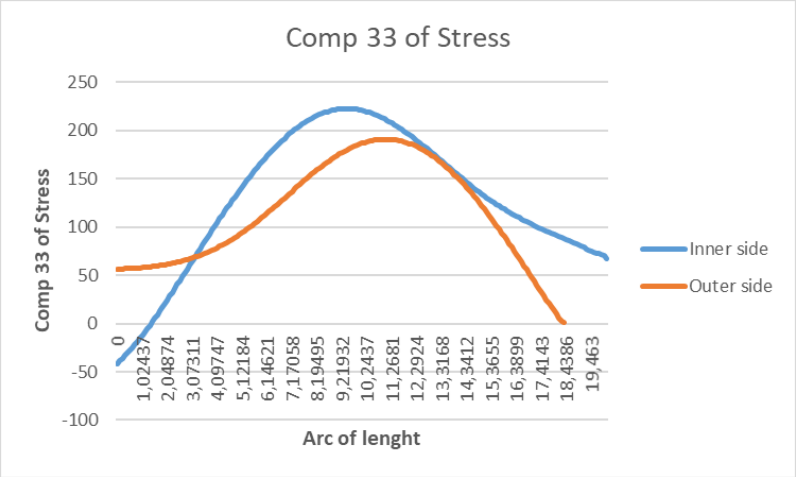


Figure 6.5. Comp 33 of Stress in both of sides

6.2. Experimental Results

Spring with most successful properties is chosen for further experiments.

First experiment aimed to compare analytical results with same variables taken from experiment.

Displacement measured with micropulse transducer and displacement calculated analytically was compared. Micropulse transducer has maximal stroke of 150 mm. Compared data are presented in Table 6.1.

Table 6.1. Change of deflection depending on load

Load (P, N)	**Deflection (δ (mm)**	
	Experimental Results	**Analytical Results**
9.81	1.25	1.22
10.79	1.38	1.34
11.7	1.51	1.47
12.7	1.63	1.58
13.7	1.75	1.71
14.7	1.88	1.83
15.6	2.01	1.94
16.7	2.14	2.08
17.6	2.25	2.19
18.6	2.38	2.32
19.62	2.51	2.44

Fig.6.6. demonstrates change of deflection depending on load and is graphical demonstration of Table 13. It is showed that there is a linear increase in deflection with change of load. Also it was observed that there was a difference of 3% between the two data. This difference is due to the resolution and repeat accuracy characteristics of the micropulse transducer (Resolution ≤10μm, repeat accuracy ≤10μm) and changes in the internal structure of the SMA spring during heating and cooling operations.

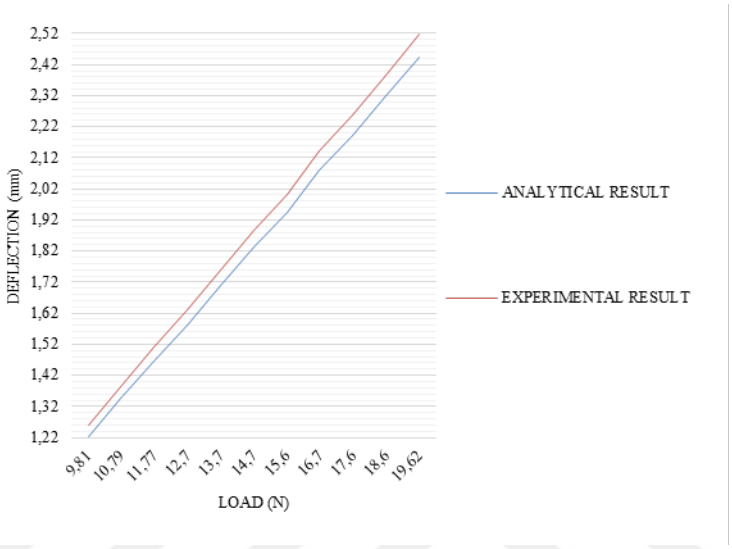


Figure 6.6. Change of Deflection Depends on Load

In second experiment effect of current to SMA spring behaviour is tested. Currents of 2, 2.5 and 3A are used and result is showed in following diagram. Spring is extended with 330gr weight. Measured displacement is 42mm. Heating cause compression in spring (spring is going back to its first position), but because weight is not removed complete recovery does not occur. Displacement of spring after heating while loaded with weight is 15 mm. After removing weight spring recover completely. Effect of current in this case is reflected to speed of recovering. As it can be seen from Fig.6.7.speed of recovering is directly proportional with intense of current; with higher current recovering process happen faster and is also almost linear in this case. SMA spring needs time to heat up and with higher current time is lower.

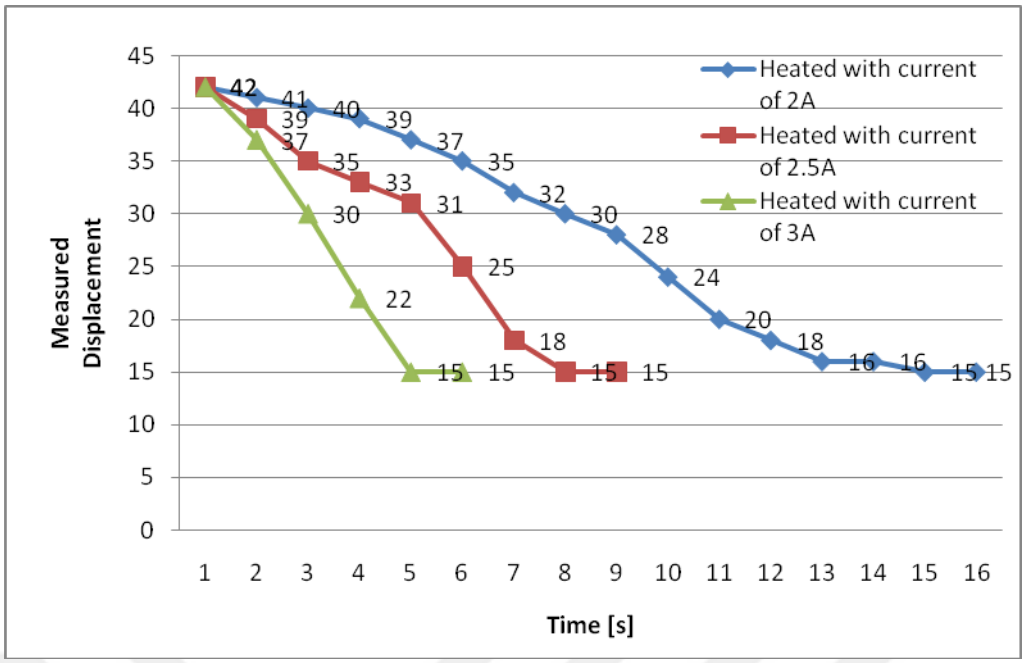


Figure 6.7. Time-Displacement Diagram

7. CONCLUSIONS

In this study, using all the advantages of superelastic mechanical properties of NiTiNol (Nickel-Titanium Alloy), Shape Memory Alloy spring is designed for linear actuators. The difference between spring's first position and position it takes when is subjected to a specified load is measured by a micropulse transducer. The experimental data obtained and the analytical data were compared. Results are found to be mutually complementary. This analytical method will guide engineers in design of linear actuators using shape memory springs.

NiTiNol based SMAs are used in a wide range of applications. A multidisciplinary model is created in MSC Marc software to analyze the behavior of SMA and because maximum value of von Mises stress is less than Yield point of NiTiNol this design is found safe. From the analysis, the inner side of the coil experiences the largest stresses and also martensite transformation is the highest, so it is important to pay attention to stress and strain distribution in that part. If design is done according to outer side, inner side can change over to plastic deformation. Neglecting that would lead toirrelevant model and wrong conclusions.

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BIOGRAPHY

Born at 28th of July 1992 in Bosnia and Hercegovina where finished first half of Primary school and than second half in Istanbul in Turkey. After that went back to Bosnia and Hercegovina and finished Gimnasium “Ismet Mujezinovic” in Tuzla. In year 2005 graduated from Mechanical Engineering Faculty, department of Mechatronics and was accepted by Turkey Scholarships for Master Studies in Marmara University in Istanbul.In 2016/2017 academic year had a functionof Student Assistant in department of Mechanical Engineering