DEVELOPMENT OF AN AUTOMOTIVE PARKING BRAKE ACTUATOR USING SHAPE MEMORY ALLOY (SMA) MATERIAL

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DECLARATION

"I hereby declare that the work in this report is my own except for summaries and quotations which have been duly acknowledged."

Signature: ....

Author: ....

Date: ....

To my parents, to whom
I owe my dreams and spirit.

ACKNOWLEDGMENT

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ABSTRACT

Shape Memory Alloy (SMA) is a special metal alloy that has a very unique character. Because of this unique property, SMA can be used in mechanical applications such as automotive. The unique property is its ability to remember its original shape after charging certain circumstances. The situation involving changes in temperature and because the SMA has two phases: martensite and austenite. In these two situations is the ability to produce. This special characteristic can adapt as the actuator. This project is about using SMA alloy to replace the conventional actuator for parking brake system, the parking brake pedal. By using SMA alloy, the parking brake pedal will be removed and being replace with SMA actuator. The SMA actuator needs to be design so that it can work as effective as the conventional parking brake system. Several experimental methods will be using to analyse the potential of the SMA actuator comparing the conventional parking brake. From the idea above, then emerge into the idea of applying the SMA actuator into automotive application and the study using SMA in a vehicle braking system has been carried out.

ABSTRAK

Shape Memory Alloy (SMA) adalah satu bahan besi aloi istimewa yang mempunyai satu sifat yang amat unik. Kerana sifat unik ini, SMA boleh digunakan dalam aplikasi mekanikal contohnya automotif. Sifat unik tersebut adalah kebolehannya untuk mengingati bentuk asal nya selepas dikenakan beberapa keadaan tertentu. Keadaan tersebut melibatkan perubahan suhu dan kerana SMA mempunyai dua fasa iaitu martensite dan austenite. Dalam dua keadaan inilah kebolehan ini terhasil. Projek ini adalah mengenai menggunakan actuator SMA dalam menggantikan actuator brek parking yang biasa iaitu pedal brek parking. Dengan menggunakan aloi SMA, pedal brek parking akan dibuang dan kemudian digantikan dengan aktuato SMA. Actuator SMA tersebut direka bentuk dalam projek ini supaya mempunyai kebolehan seperti system brek parking yang biasa. Beberapa kaedah eksperimen akan digunakan untuk menguji kebolehan actuator SMA berbanding dengan sistem brek parking yang biasa. Daripada idea diatas, maka tercetuslah idea untuk mengaplikasikan SMA kedalam system kenderaan dan usaha untuk menggunakan SMA dalam system brek kenderaan telah dijalankan.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Nowadays, technologies have become more advances. Every machine, mechanism, or system must be simple as it can. It must be smallest as it can because spaces are really important now. The scientists, inventors or engineers when design something, the space occupied must be reduces as small as possible. People today like something that is simple, easy and less mechanical but more to computer and electronic based product. The actuator as the example, for conventional actuator, motor was used to operate the actuator. From the early discovery of actuator there is no other mechanism that can replace the motor to operate the actuator. But as the time growing and many new discovery has been found, then another method, mechanism and system can be used to replace the motor where it will increase the efficiency of the actuator at once increase the performance of the actuator.

The new system was the title made for Projek Sarjana Muda (PSM) but in the context of the automotive braking system. SMA, the short form of Shape Memory Alloy is a very special material that can remember it origin shape even its shape has changed due to external factor such as human action bending the bar of shape memory alloy. This special property of the SMA causes the engineer to develop an actuator using SMA and because of this, the idea is to apply this actuator into the application of automotives braking system.

Automotives braking system is a very important component in a vehicle and without the system the vehicle is not safe and will face fatal accident. The system helps in stopping a vehicle or reduce it speed. The automotives braking system use friction brake as it mechanical system this kind of system has two common type of brake that automotives have used that is disc brake and drum brake. Commonly the drum brake is use for rear tire and disc brake for front tire but nowadays people like to modify their car by using disc brake for rear tire because of it elegance and sporty looked. Car manufactures also produce new car with disc brake for both front and rear tire to attract customer. For the project the application will use drum brake as the brake system.

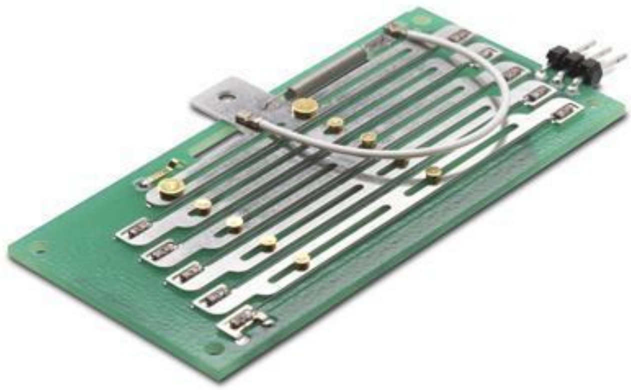


Figure 1.1: Shape Memory Alloy actuator

(Retrieved from migamotors.com, (2009))

1.2 OBJECTIVE

This project objective is to design and develop an automotive brake actuator using shape memory alloy material by replacing the conventional braking system with applied SMA actuator braking system.

1.3 PROBLEM STATEMENT

The conventional automotives braking system using cable then fluid as the mechanical actuator to allow the brake system works and this kind of actuator has been use from the early stage production of the car. By using SMA actuator to replace the old actuator, it will modernize the automotives brake system and give a new look in automotives industry. Using this actuator also can simplify the braking mechanism by make less of mechanical system in braking. Replacing the conventional actuator with the SMA actuator can reduce space and weight of the braking system because this action will cause removing of the lever compartment.

1.4 SCOPE

For this project, PSM 1 scope is to study mechanical behaviour of shape memory alloy (SMA) for actuator application. This required in studying only the theory of the SMA and how its work when apply into automotives braking system. Besides that, the conceptual design for PSM 1 will be done to show how the project is look like. For the PSM 2, the scope is cover in designing and developing a prototype of an automotive brake actuator using SMA material. The scope also included the study of performance of the engine.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION TO SHAPE MEMORY ALLOY

Shape Memory Alloy (SMA) is known because of its unique properties that it can remember its original shape when it subjected with certain temperature. SMA is lighter in its weight, solid state alternative to conventional actuators such as hydraulic, pneumatic, and motor-based systems. In industry, applications of SMA have been used including medical and aerospace. Shape memory alloy was developed because of its strong demand for high performance in recent year. SMA has five documented function that it can deliver. The five functions is (Santiago, 2002):

1. Free recovery – SMA is the only element that serves to generate transfer. Because there is no work done, this type of application most used in control devices and relay mechanism
2. Constrained recovery – SMA in this function are prevented from displacement generating large amount of stresses and being used increasingly in fittings, couplings and connectors for machinery

3. Actuator – when used as the actuator, the element of SMA produce work energy that combined with displacement. Most of the application use SMA in this way.
4. Superelasticity - this SMA behaviour make it has the spring behaviour with high elastic deformation.
5. High damping capacity in the martensite state.

2.1.1 HISTORY OF SHAPE MEMORY ALLOY

The shape memory alloy behaviour was first time being observes in 1932 by Olander in his study of "rubber like effect" in samples of gold-cadmium and Greninger and Mooradian in the study of brass alloy (copper-zinc) (Janez Dolinsek 2007). After recent years later another person, Chang and Read give the term "shape recovery" when working on gold-cadmium alloys. William J. Buchler and his co-workers at the Naval Ordinance Laboratory have discovers the shape memory effect of an alloy in nickel and titanium. Because of this, he named his discovery as NiTiNOL (nickel-titanium Naval Ordinance Laboratory)(Janez Dolinsek 2007). The discovery of the shape memory property of NiTiNOL was found accidentally. In the laboratory management meeting, a strip of NiTiNOL was presented that was bent out of shape so many times. Dr. David S. Muzzey, one of the people present heat the NiTiNOL with his pipe lighter and the strip show its behaviour when it stretched back to its original form (Janez Dolinsek 2007).

Since then, intensive research has been done to clarify the basic mechanisms of behaviour. The first effort to exploit the potential of NitiNOL as implants was made by Johnson and Alicandri in 1968. Global NitiNOL for medical applications were first reported in 1970. In the early 1980s the idea achieving more support, and some orthodontic and orthopaedic especially experimental was released. It was only the mid 1990s that the area of the first commercial stent applications made their breakthrough in the treatment. Global NitiNOL as a biomaterial become interest because of its superelasticity and shape memory effect which completely a new property compared with conventional alloys (Janez Dolinsek 2007).

2.2 GENERAL PRINCIPLES OF SHAPE MEMORY ALLOY

The principles of SMA consists two different temperature-dependant crystal structures or phase that play important role for its special behaviour that called martensite (named after German metallographer Adolf Martens) phase and austenite (named after English metallurgist William Chandler Austen) phase. Martensite phase is the phase when SMA in lower temperature condition and austenite phase is the SMA in the higher phase condition (Janez Dolinsek 2007).

2.2.1 Martensitic Transformations

In general, the memory of the event based on the ability of the material change the crystal structure, in other words change from one crystal structure to others. This transformation of the shape memory alloys is usually referred to as a martensitic transformation. The term martensite takes its name from Adolf Martens (1850-1914) a German metallurgical structure which was first discovered in the steel. Then this transformation between austenite and martensite phase was discovered was not limited to steel (Santiago ,2002). When the material changes phase reordering of atoms that occurs is referred to as transformation. In solids there are two types of transformation known as displacive and diffusional. Diffusional transformation in rearranging atoms occurs across long distance. The chemical composition for the new phase formed by a diffusional transformation is different than that of the parent phase.

The dispalacive transformation happens when the atoms move as a unit that each of it contribute a small portion of the overall displacement. The bonds between the atoms are not broken rather than arranged in a displacive transformation, thus leaving the parent phase chemical composition matrix intact. Martensitic transformation in shape memory combined type of transformation is displacive and also usually occurs between Austenite referred to as the parent phase and Martensitic. The Austenite to Martensite transformation categorizes into two parts that is Bain Strain and lattice-invariant shear.

The Bain Strain takes its name from Bain who in 1924 proposed it and refer to the necessary deformation needed to obtain the new atomic structure (Santiago ,2002).

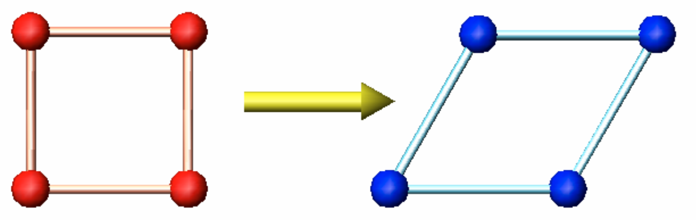


Figure 2.1 Lattice deformation required for changing crystal structure (Source: Santiago, (2002))

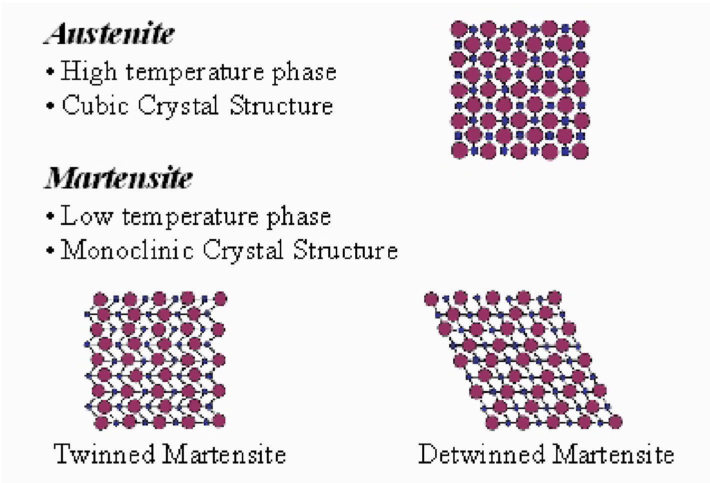
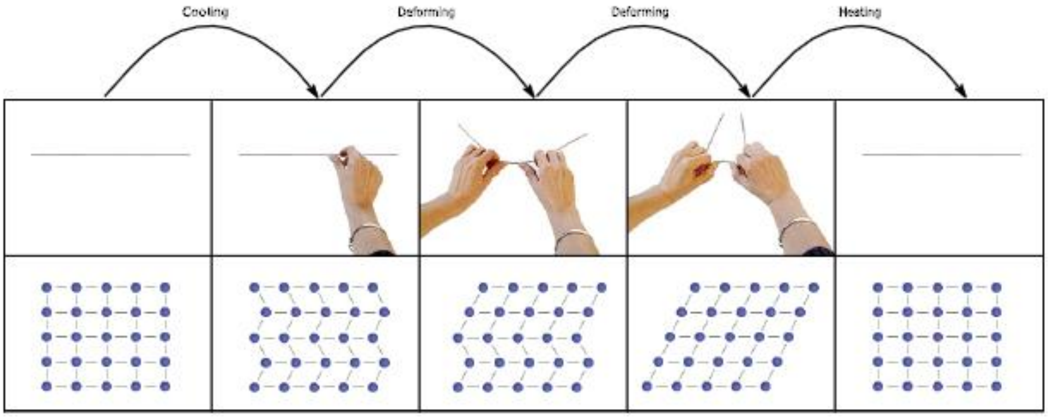


Figure 2.2: Different phases of a shape memory alloy (Source: Cimpric Darjan (2007))



Austenite (memorized shape) | MArtensite (twinned) | MArtensite (detwinned) Deformed shape 1 | MArtensite (fully twinned) Deformed shape 2 | Austenite (memorized shape)

Figure 2.3: The SME in SMAs at macroscopic and crystallographic levels.
(Source: A Four-Fingered Robot Hand with Shape Memory Alloys (2009))

Austenite phase consists of a memorized or standard material. When austenite cooled to martensite the material present a very low stiffness and yield strength. It is very malleable and can easily be changed into a new form, which is fixed. After undergoes heating process, the material phase is reverse back to austenitic phase and the original pre-defect form. At the microscopic level, the crystal structure of SMA's austenitic very symmetrical and well ordered. After cooling, crystal structure collapsed lean in the opposite direction of the next layer to accommodate themselves (or twin) so that no macroscopic deformation resulted. Applying external pressure on the SMA will caused the twinned martensite layers to begin to lean in the same direction. When all the layers lean in the same ways, SMA is oriented (or twinned). After heating processes, the crystal line layer restore to the original symmetry (A Four-Fingered Robot Hand with Shape Memory Alloys).

2.2.2 The Shape Memory Effect

In order for the alloys to show the shape memory behaviour certain circumstances must be met. Weight percentage of each type of elements must be properly combined to produce a decent shape memory material. Additional process improving the materials properties and determine the procedure of shape characteristics. Depending on the processing techniques using shape memory element, it can display one of five different shape memory behaviours (Santiago ,2002).

2.2.2.1 One-Way Memory

When a combination of his memory in cold conditions (under Al), metal can be bent or extended and will continue until they are heated above a transition temperature. After heating, the shape changes to its original shape. When the metal cooled down again it will be fixed in the form of heat, until disabled again. With effect one way, cooling from high temperatures does not cause macroscopic deformation. Deformation is necessary to create a low temperature. On heating, transformation starts at the A_s and A_f completed (usually 2 to 20 ° C or hotter, depending on the combination or the loading). As determined by the type of combination and composition. This can vary between -150 ° C and 200 ° C.

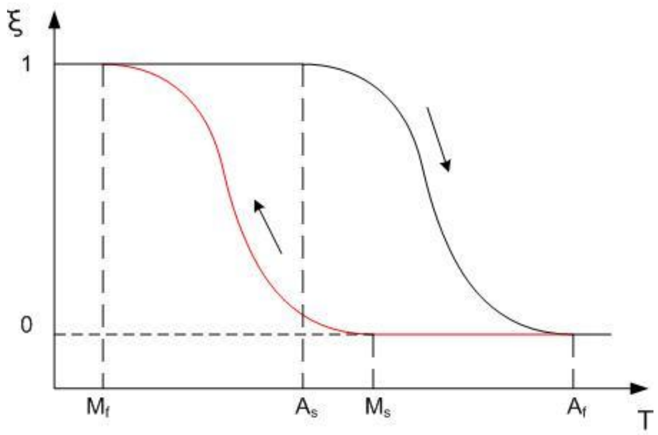


Figure 2.4: One-Way memory transformation curve

(Source: Shape Memory Alloys, (2007))

2.2.2.2 Two-way memory effect

Two-way shape memory effect is the impact of the material remembers two different shapes: one at low temperatures, and one in the form of a high temperature. A material that shows the shape memory effect for both heating and cooling is called two-way shape memory. This can also be obtained without the application of external force (intrinsic effects of two directions). The reason the material behaves so differently in this situation lies in the training. Implies that the memory of training can "learn" in behave a certain way. Under normal circumstances, a combination of memory "remembers" the form of high temperature, but after heating to recover a high temperature, will "forget" a low temperature. However, it can be "trained" to "remember" to leave some low-temperature warning defect in the high temperature phase. There are several ways to do this (Janez Dolinsek ,2007). An object, shaped trained heated above a certain point will lose the two way memory effect, known as "amnesia."

2.2.2.3 Pseudoelasticity or superelastic effect

One commercial use the combined form of memory involves the use of pseudo-elastic properties of metals for high temperature (austenitic) phase. Frame reading glasses were made from a combination of thought forms because they can undergo large deformation in high temperature and then directly back to its original shape when the stress is removed. This is the result of pseudoelasticity; martensite produced by stressing of the metal in the martensite and austenite state is able to large strain. With the removal of the load, the change of martensite back to austenite phase and resumes its original shape. This allows the metal to be bent, and exciting to play, before the reform of its shape when released. This means that the combined shape memory eyeglass frames prosecuted as "virtually indestructible" because it seems no amount of bending to produce plastic deformation remained (Janez Dolinsek ,2007).

2.3 AUTOMOTIVES BRAKING SYSTEM

To stop a moving car, braking system is needed. A vehicle without braking system is too dangerous because to fully control a machine, the power to move, accelerate, decelerate and stop the machine. A car with a braking system that is not working properly is a candidate for the wrecking yard and may be a cause of injury to the driver and passengers as well as to others. The users normally not use the maximum capability of their brakes but the brakes is very necessary when in an emergency situation that involve life. They will try not to use brake frequently because when the brakes are applied, there will energy loss to the vehicle. A vehicle is most efficient when the brakes are not used.

The ideal braking system is one that for the driver to bring a vehicle to a standstill in the shortest possible distance. be able to do this, they should have enough power to lock and slide all four tires simultaneously stopping to clean, dry pavement. Tires should be controlled in a trailer, so that no more without brake lockup can occur are made. also stop, should a moderate amount of pedal preesure occur, so that even weaker driver hangs Archive tires. Brake lockup is not desirable because they result in a longer stopping distance, probably the loss of vehicle control and excessive tire wear. Brake lockup point out that one or more brake assemblies are stronger than necessary. a brake, cannot reach the detention room is possible not as strong as it should be.