श्रीचन्द्रशेखरेन्द्रसरस्वतीविश्वमहाविद्यालयः
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Lecture Series - 1
Sensors and Actuators – A brief review on SMA based Actuators

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AGENDA

- Introduction
- Sensor
- Transducer
- Actuator
- Principles of various sensors
- SMA based Actuators
- Shape Memory Alloy – SMA
- SMA – Introduction
- Examples
- Phases in SMA
- Shape memory effect
- Types of Shape Memory Effect
- Pseudo Elasticity
- Advantages and Disadvantages
- Applications

Introduction

Measurement devices perform a complete measuring function, from initial detection to final indication.

The important aspects of measurement system are

i) Sensor – Primary sensing element when exposed to physical phenomenon produces proportional output signal.

ii) Transducer – changes one form of energy to another form energy

iii) Actuators – Takes energy(electric current, fluid/air pressure) and converts it into motion

SENSORS

A device which provides a usable output in response to a specified measurand.

- Sensor is a device that detects and responds to some type of input from the physical environment.
- Input could be light, heat, motion, moisture, force, pressure, displacement, etc.
- It produces a proportional output signal (electrical, mechanical, magnetic, etc.).

Human beings are equipped with 5 different types of sensors.

➢ Eyes detect light energy, ears detect acoustic energy, a tongue and a nose detect certain chemicals, and skin detects pressures and temperatures.

➢The eyes, ears, tongue, nose, and skin receive these signals then send messages to the brain which outputs a response.

For example, when you touch a hot plate, it is your brain that tells you it is hot, not your skin.

BASIC SENSORS

RESISTIVE SENSOR (PRINCIPLE)

PRINCIPLE OF RESISTIVE SENSORS

- **Resistive sensors detect changes in resistance**
- The conductor length is directly proportional to resistance of the conductor and it is inversely related with area of the conductor.

FACTORS AFFECTING RESISTANCE

Electric resistance is the opposition offered by the conductor for the flow of current. S.I Unit is ohms (Ω)

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

Length of the conductor: Resistance directly proportional to the length of the conductor. Length increases, the resistance increase $R \propto l$

Area of cross section:
Resistance of a conductor is inversely proportional to the area of cross section of the conductor. Area of cross section increases, the resistance decreases. $R \propto 1/A$

Nature of material: Different materials have different concentrations of free electrons therefore different materials have different resistance. $R=\rho l/A$
Where, ρ=constant of proportionality (Resistivity)

Temperature: Resistance of a conductor is directly proportional to the temperature Temperature increases, the resistance increases. $R \propto T$

INDUCTIVE SENSOR (PRINCIPLE)

PRINCIPLE OF INDUCTIVE SENSOR

Inductive sensors works on the principle of electromagnetic induction

$$V = L.di/dt$$

- **Where 'L' is the inductance, 'V' is the voltage and 'di/dt' is the rate of change of current.**
- **'L' depends on the number of turns in a coil, magnetic flux, and the area.**
- **The magnetic flux can be changed by changing the area or reluctance and thus producing a proportional output voltage.**

FACTORS AFFECTING INDUCTANCE

Reluctance S – Magnetic resistance
The reluctance of a material is to setting up of magnetic flux lines in the material
Unit: Ampere-turns / Weber

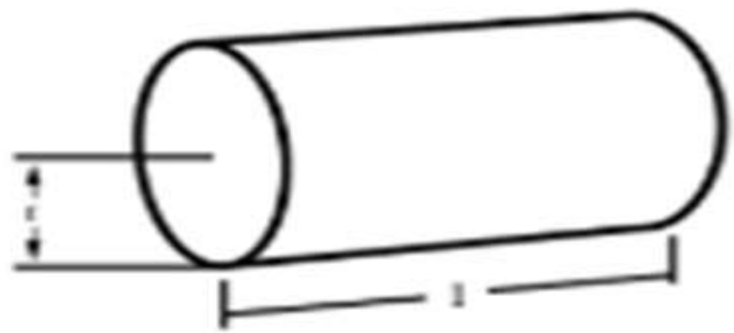
$$S = \frac{l}{\mu_0 \mu_r A}$$

where,
l = length of the magnetic path in meters
μ_0 = permeability of free space (vacuum) = $4\pi * 10^{-7}$ Henry/meter
μ_r = relative permeability of a magnetic material
A = Cross sectional area in square meters (m^2)

FACTORS AFFECTING INDUCTANCE

$$L = \frac{N^2 \mu A}{l}$$

$$\mu = \mu_0 \mu_r$$



Where,

L = Inductance of coil in Henrys

N = Number of turns in wire coil (straight wire = 1)

μ = Permeability of core material (absolute, not relative)

μ_r = Relative permeability, dimensionless (μ_r = 1 for air)

μ_o = 1.26x10^{-6} T-m/At permeability of free space

A = Area of coil in square meters = πr^2

l = Average length of coil in meters

CAPACITIVE SENSOR
(PRINCIPLE)

PRINCIPLE OF CAPACITIVE SENSOR

Capacitive sensor works on the principle of change in capacitance

The capacitance changes because of overlapping of plates, change in distance between the plates and dielectric constant.

CAPACITIVE SENSORS

The principle of operation of capacitive sensors are based on the following expression,
The capacitance C of a parallel plate capacitor is given by,

$$C = \varepsilon_r \varepsilon_o A / d$$

where,

ε_r - the relative permittivity of the dielectric between the plates,
ε_o - permittivity of free space,
A - area of overlap between two plates and
d - the plate separation.

The capacitive sensors work on the principle of change of capacitance which may be caused by :

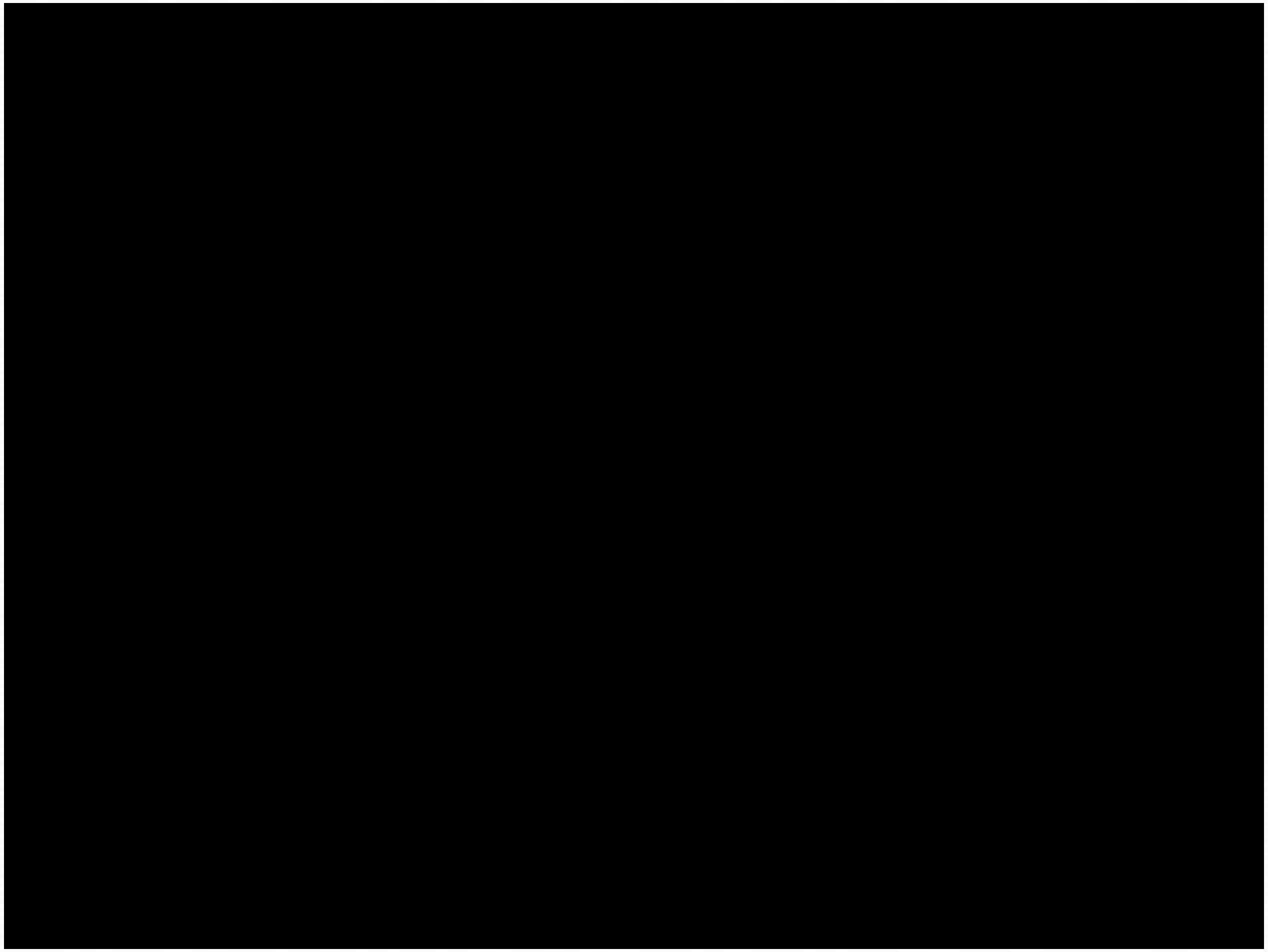
(i) change in overlapping area *A,*
(ii) change in the distance d between the plates
(iii) change in dielectric constant.

SMA-based Micro actuators

SMA-based Micro actuators

- When shape memory alloys (SMAs) are deformed under a certain critical temperature and then heated up to above this critical temperature, they will "remember" their original form and assume it again.
- This effect can be used for generating motions or forces.

Shape Memory Effect – Actuators Demo



Introduction of SMA

- A shape-memory alloy is an alloy that "remembers" its original shape
- SMA, smart metal, memory metal, memory alloy, smart alloy
- If deformed, they recover their original shape upon heating.
- Take large stresses without undergoing permanent deformation
- Formed into various shaped like bars, wires, plates and rings thus serving various functions.
- The SMA effect was discovered in various copper alloys, in which a reversible, thermal-mechanical transformation of the atomic structure of the metal takes place at certain temperatures.
- When the temperature is raised or lowered, the metallurgical structure of an SMA transforms from a martensite state (low temperatures) to the austenite state (high temperatures), or vice versa.

Shape-memory alloy (SMA)

Examples of SMAs

- SMA are intermetallic
- Compounds having super lattice structures and metallic – ionic – covalent characteristics.
- Thus , they have the properties of both metals and ceramics.
  - Cu-Zn-Al alloy
  - Cu-Al-Ni alloy
  - Au – Cd alloy
  - Ni-Ti (50 % Ni and Ti, Nitinol, which stands for Nickel Titanium Naval Ordinance Laboratory)

Shape-memory alloy (SMA)

Phases of SMA

Phases of SMA

i) Martensite
ii) Austenite

Martensite: Martensite is the soft and easily deformed phase of SMA which exist at lower temperatures.

- It has two forms: a) Twinned Martensite before loading
  b) Deformed Martensite after loading

Austenite: Austenite is the stronger phase of SMA which occurs at higher temperatures.

Triggers for martensite transformation

- Stress
- Temperature

Shape-memory alloy (SMA)

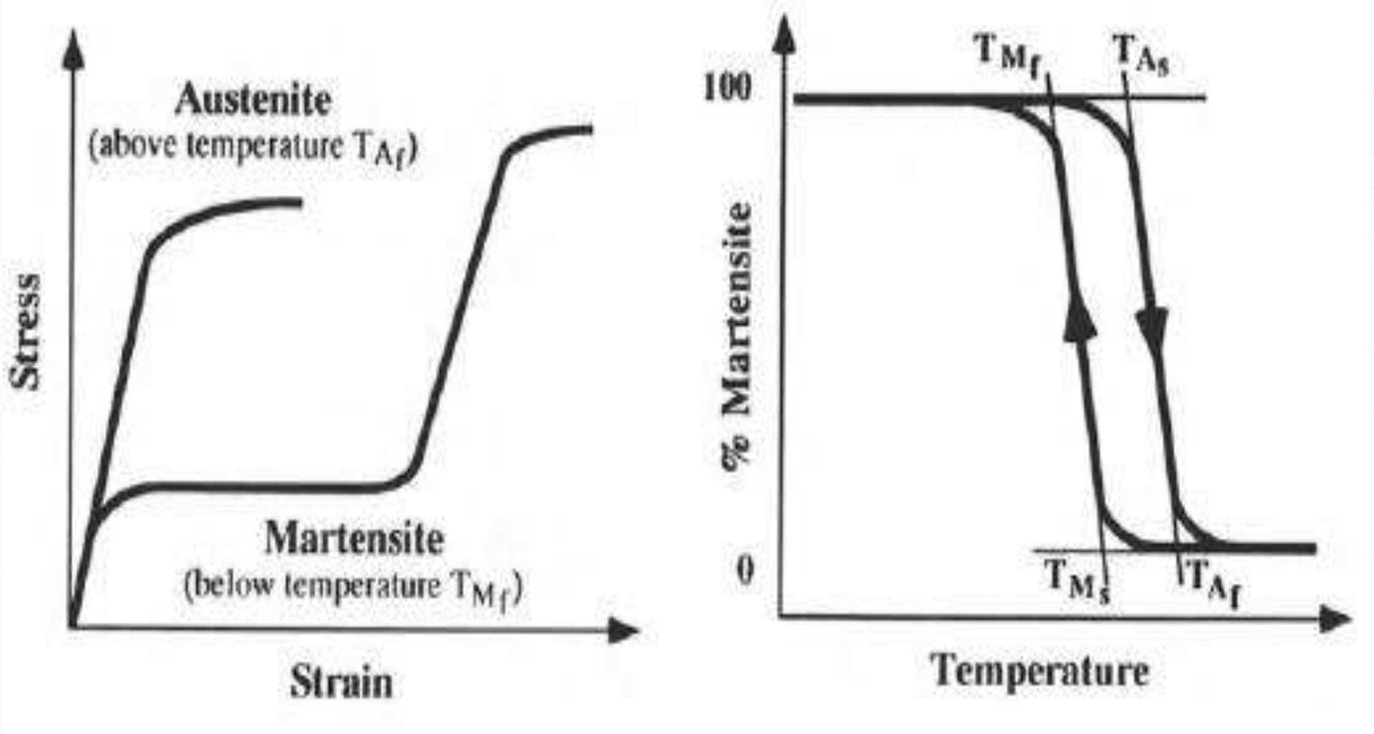


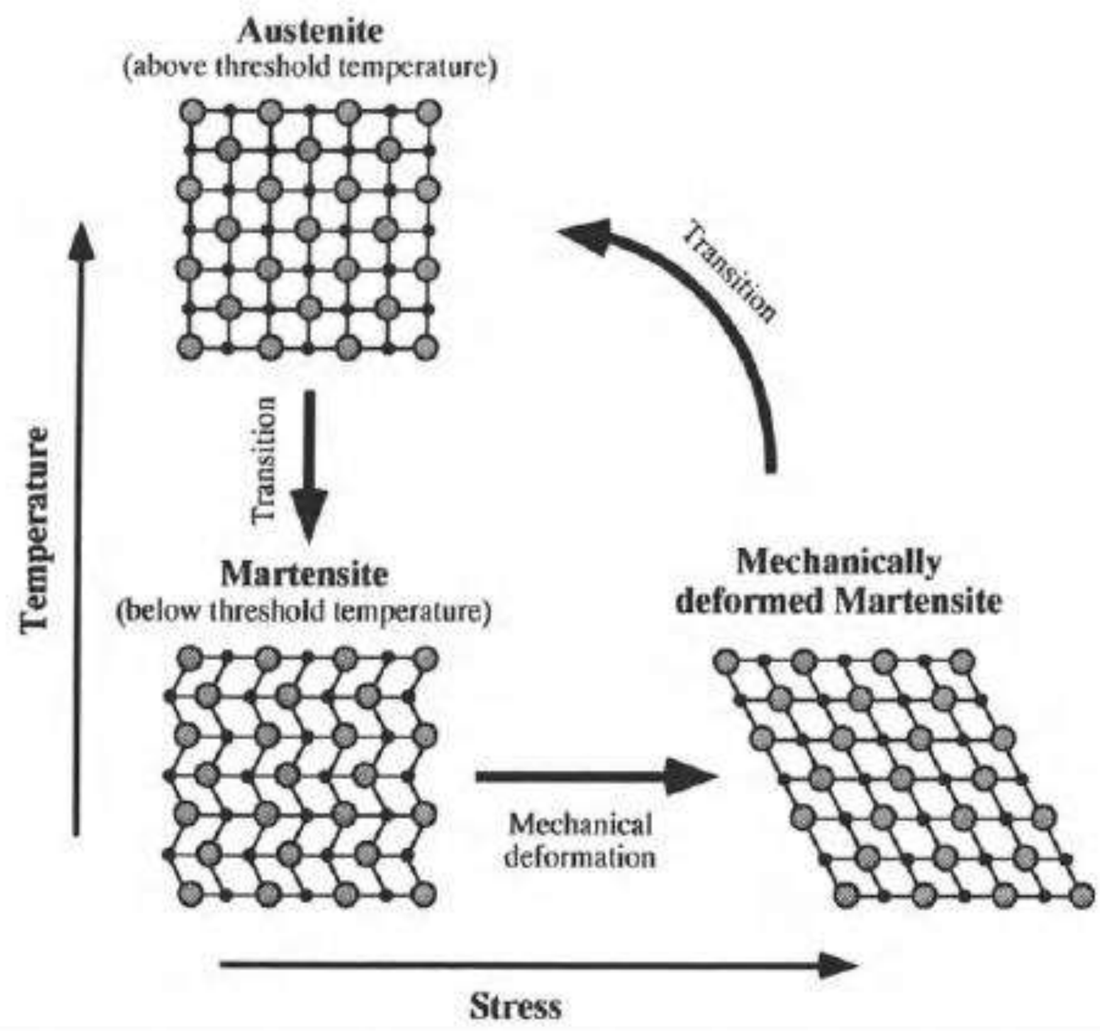
Fig. (a) Stress-Strain diagram
(b) Hysteresis curve of an SMA

Martensite transformation temperatures

- **Ms:** temperature at which austenite begins to transform to martensite upon cooling
- **Mf:** temperature at which transformation of austenite to martensite is complete upon cooling
- **As**: temperature at which martensite begins to transform to austenite upon heating
- **Af**: temperature at which transformation of martensite to austenite is complete upon heating

Shape-memory Effect

Schematic representation of SMA effect

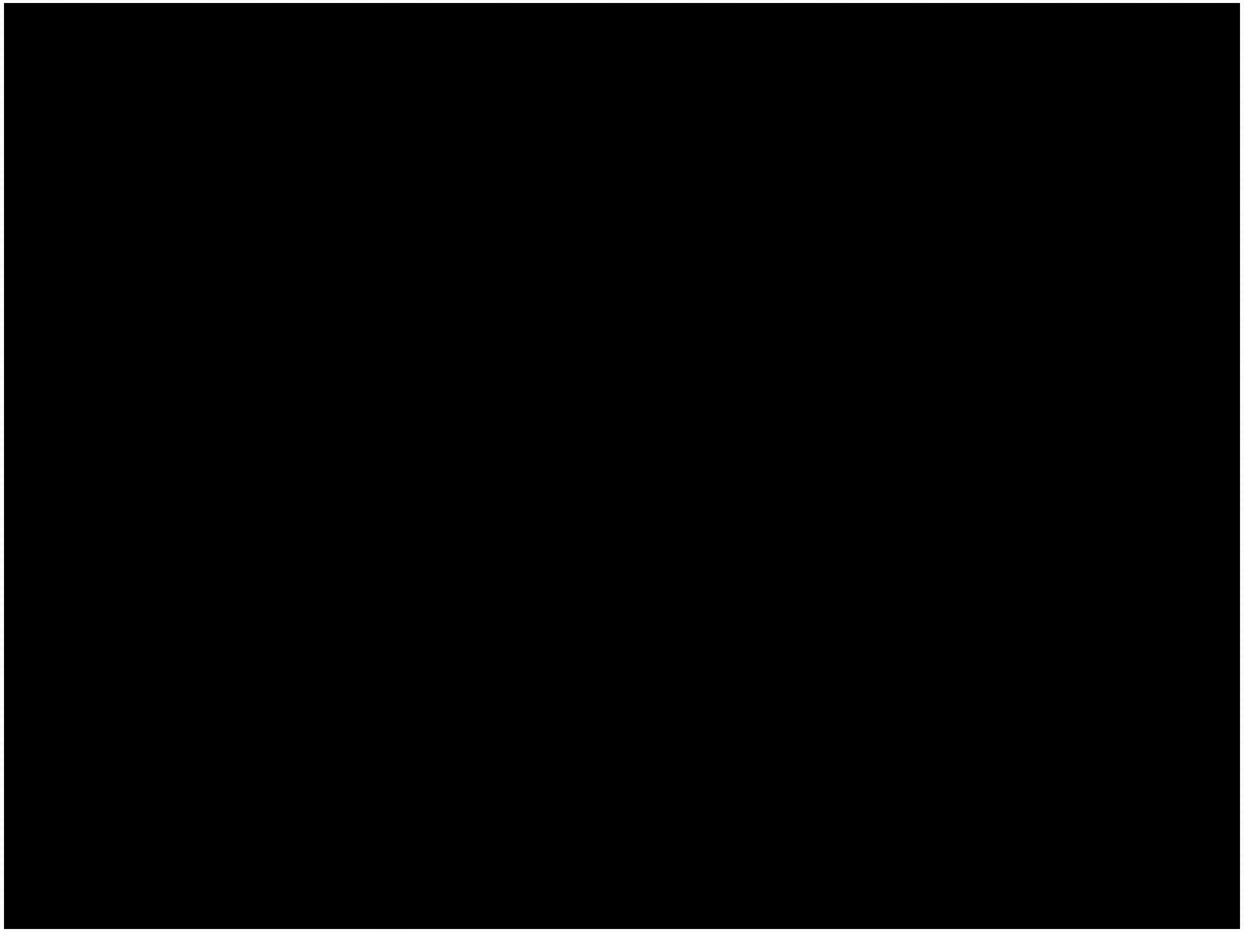


Shape-memory Effect

The basic transformation mechanism :

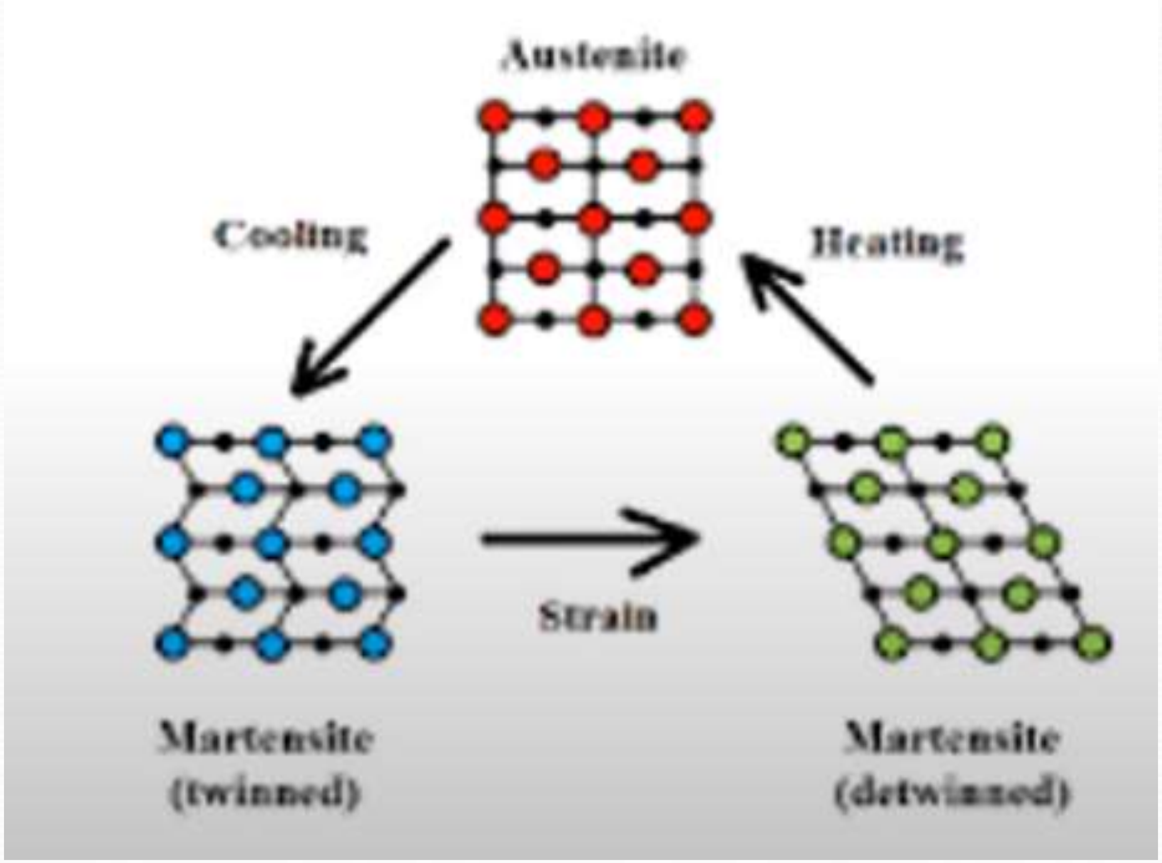
- Starting from a stable and rigid austenite state, the SMA transforms into the martensite state as the temperature sinks under the critical temperature; thereby the shape of the SMA can be deformed.
- In the low temperature state, the SMA keeps the desired deformed shape until it is exposed to a higher temperature.
- When it is warmed up above a threshold temperature, the deformed martensite is transformed back to austenite and the SMA takes on its original form (thermal shape memory).
- With this property, large displacements can be obtained compared to other actuator principles.

Shape-memory Effect - Video



Shape-memory Effect

Schematic representation of SMA effect



Shape-memory Effect

Characteristics of SMA

a) The change in shape of a material at low temperature by loading and regaining the original shape by heating it is known as shape memory effect.
b) This effect occurs in alloys due to the change in their crystalline structure with the change in temperature and stress.
c) While loading, twinned martensite becomes deformed martensite at low temperature.
d) On heating, deformed martensite becomes austenite (Shape recovery) and upon cooling it gets transformed to twinned martensite.

Shape-memory Effect

Characteristics of SMA

e) The mechanism involved in SMA is reversible (Austenite to martensite and vice versa)

f) Stress and temperature are the influence on martensite transformation

Shape-memory Effect

This animation illustrates the full shape memory effect:

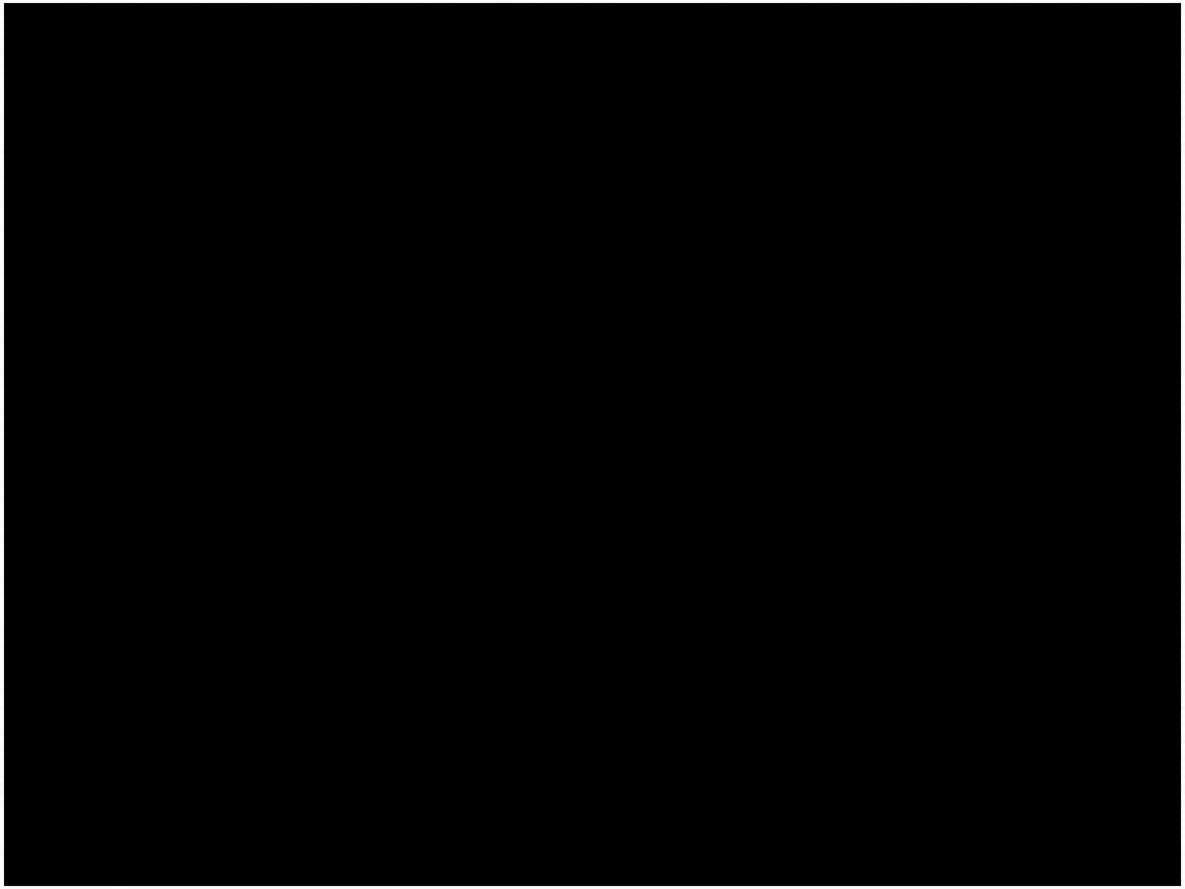
• Cooling from austenite to (twinned) martensite, which happens either at beginning of the SMA's lifetime or at the end of a thermal cycle.

• Applying a stress to detwin the martensite.

• Heating the martensite to reform austenite, restoring the original shape.

• Cooling the austenite back to twinned martensite.

Shape-memory Effect - Animation



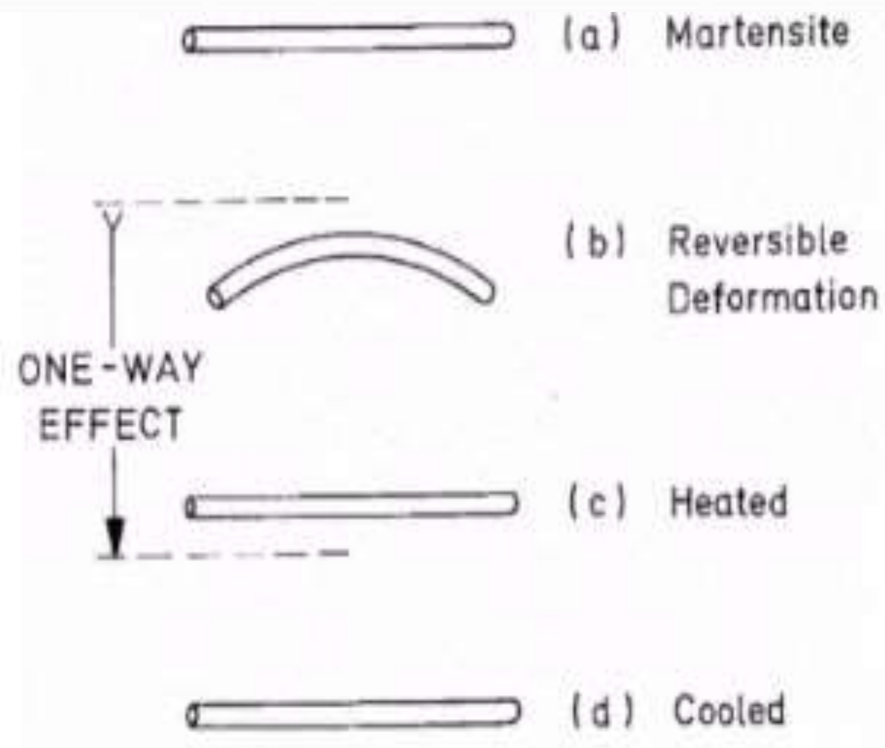
Types of Shape-memory Effect

Types

1. One way shape memory effect
2. Two way shape memory effect

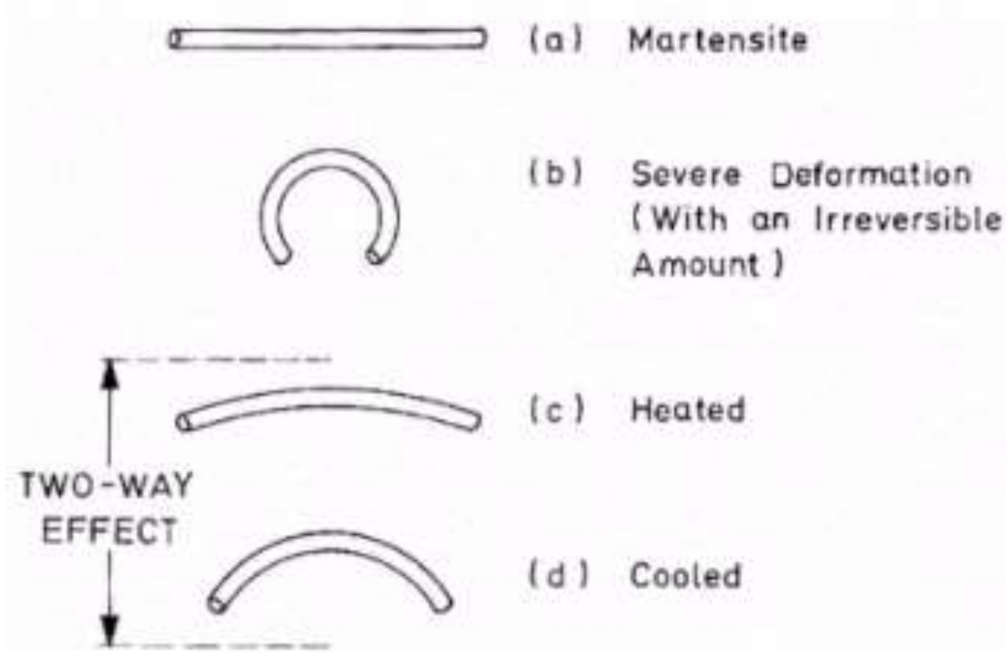
One way shape memory effect

A material which exhibits shape memory effect only upon heating is known as one way shape memory



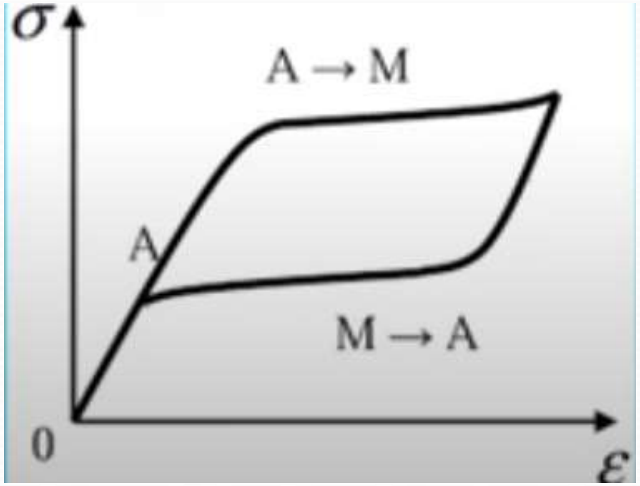
Two way shape memory effect

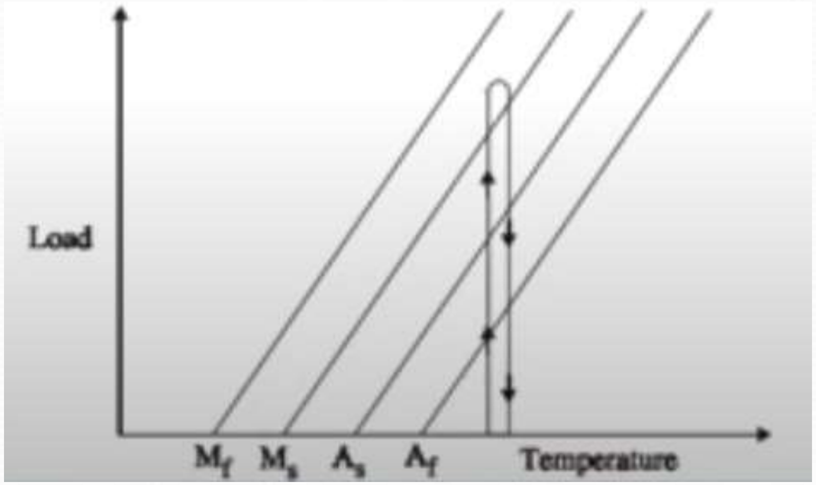
- A material which exhibits shape memory effect during both heating and cooling is called two way shape memory.
- The deformed shape is remembered during cooling, in addition to the original shape being remembered during heating, i.e., memory is with both austenite and martensite phases



Pseudo Elasticity

- It occurs in SMA when it completely in Austenite phase (temperature is greater than Af Austenite finish temperature)
- Unlike SMA, Pseudo Elasticity occurs due to stress induced phase transformation without change in temperature.
- The load on the SMA changes Austenite phase into martensite.
- As soon as the loading decreases the martensite begins to transform to Austenite results in shape recovery.





Shape-memory alloy (SMA)

Pseudo Elasticity

This phenomenon of deformation of a SMA on application of large stress and regaining of original shape on removal of the load is known as pseudo elasticity.

Also known as Super Elasticity

Hysteresis Mf < Ms < As < Af

The temperature range for the martensite to austenite transformation which takes place upon heating is somewhat higher than that for the reverse transformation upon cooling

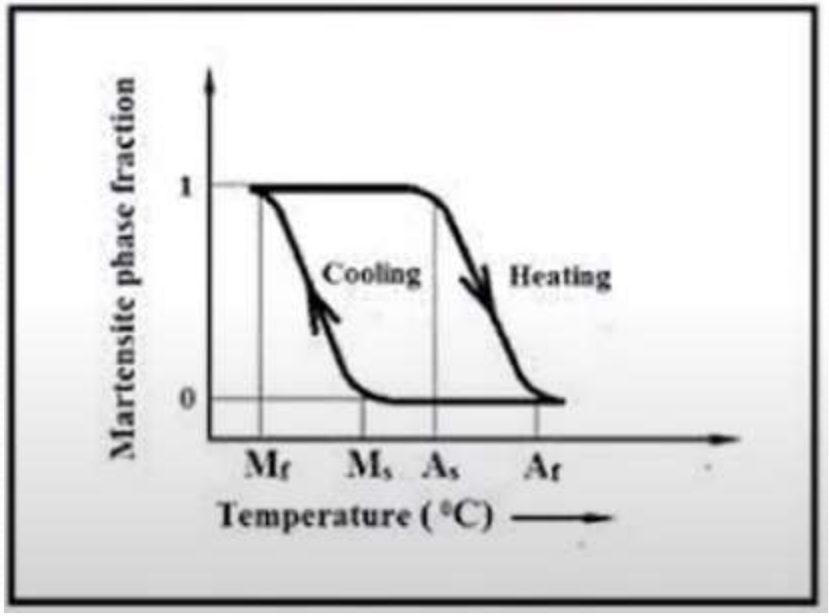
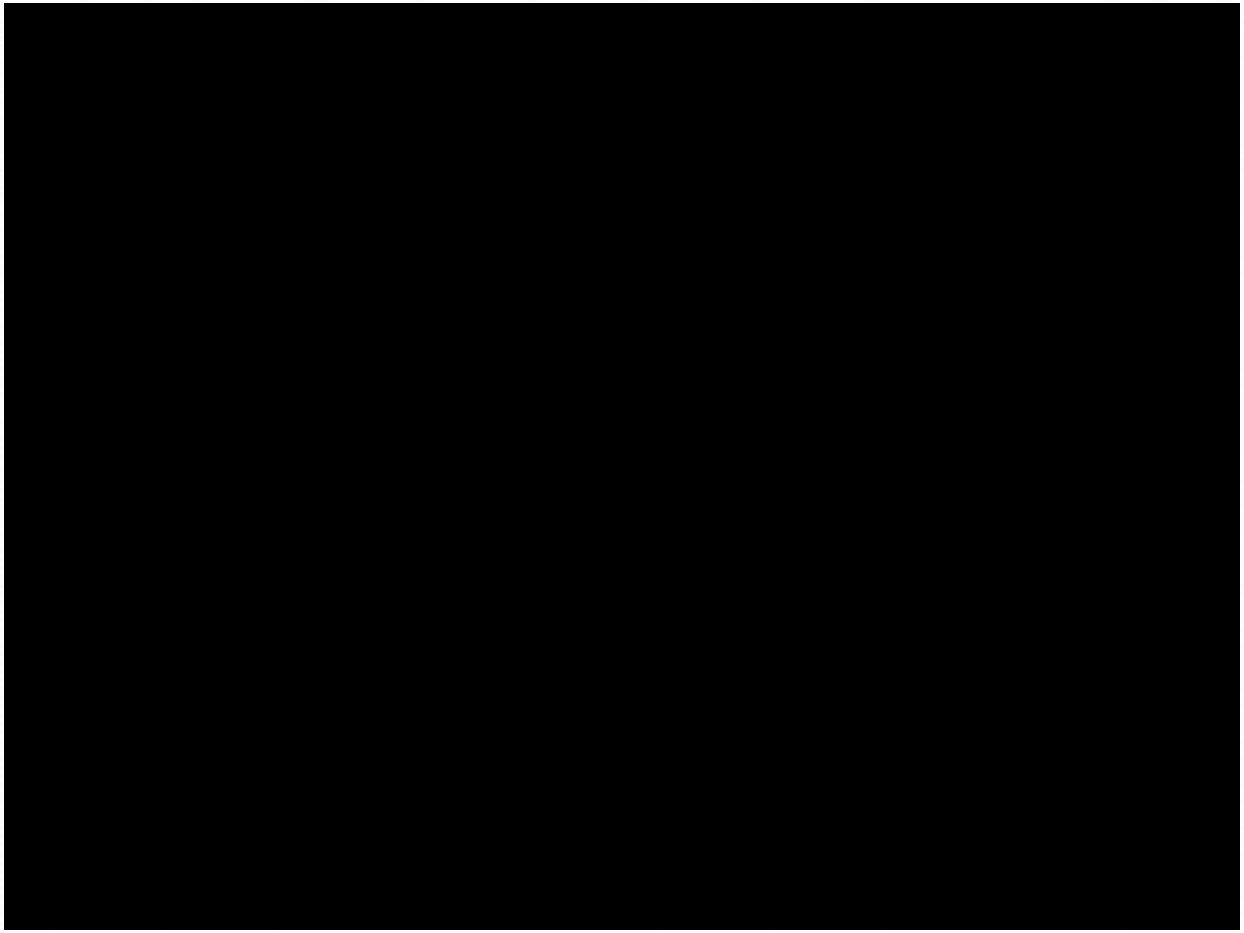


Fig. Hysteresis Curve

Pseudo Elasticity - Video



Advantages and Disadvantages

Advantages:

- Simple, Compact and highly safe
- Good bio Compatibility
- Have diverse applications and offer clean, silent and spark free working conditions
- Good mechanical properties and strong corrosion resistance

Disadvantages:

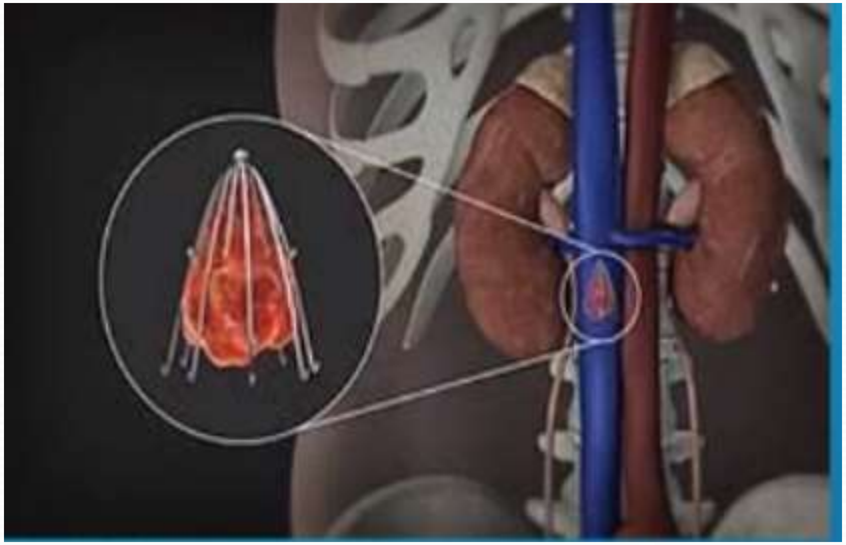
- Poor fatigue properties
- Expensive
- Low energy efficiency

Applications

- Micro valves
- Toys and novelties

Medical field

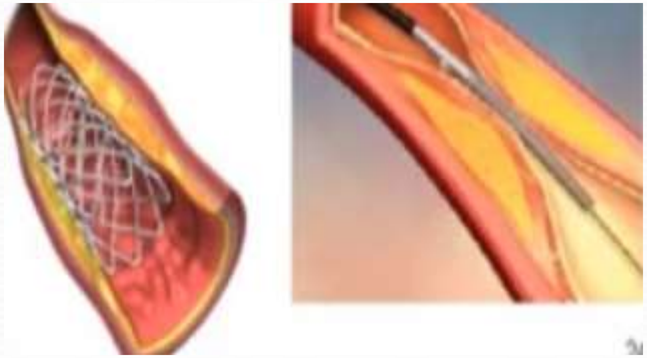
- Blood clot filters – properly shaped and inserted into veins to stop the passing blood clots
- Used in Artificial hearts



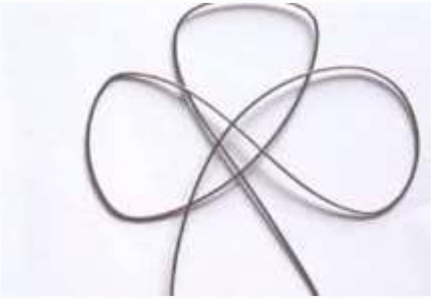
Medical Application – Stent procedure Video

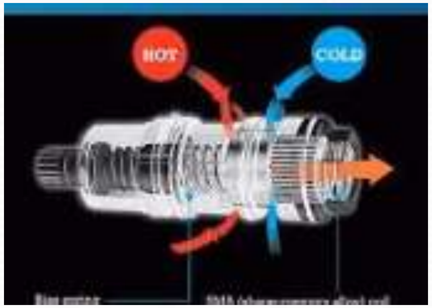
Orthodontic applications

- Ni-Ti wire holds the teeth tight with a constant stress irrespective of the strain produced by teeth movement
- It resists permanent deformation even if it is bent. NiTi is non toxic and non Corrosive with body fluid.

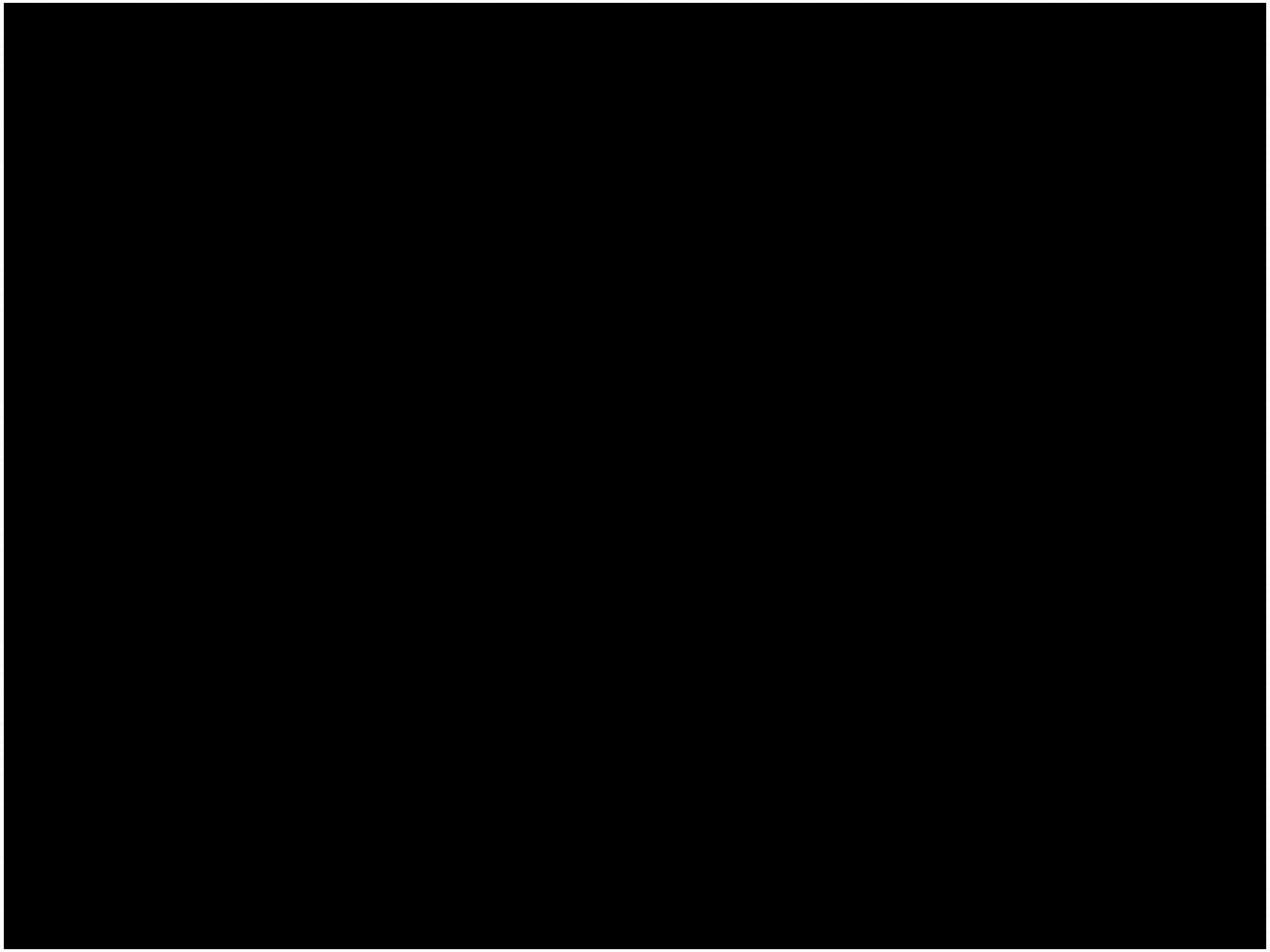


- SMAs are used to make eye glass frames and medical tools. Sun glasses made from superelastic NiTi frames provide good comfort and durability
- Antenna wires –The flexibility of super elastic NiTi wire makes it ideal for use as retractable antennas
- Thermostats – SMAs are used as thermostat to open and close the valves at required temperature.

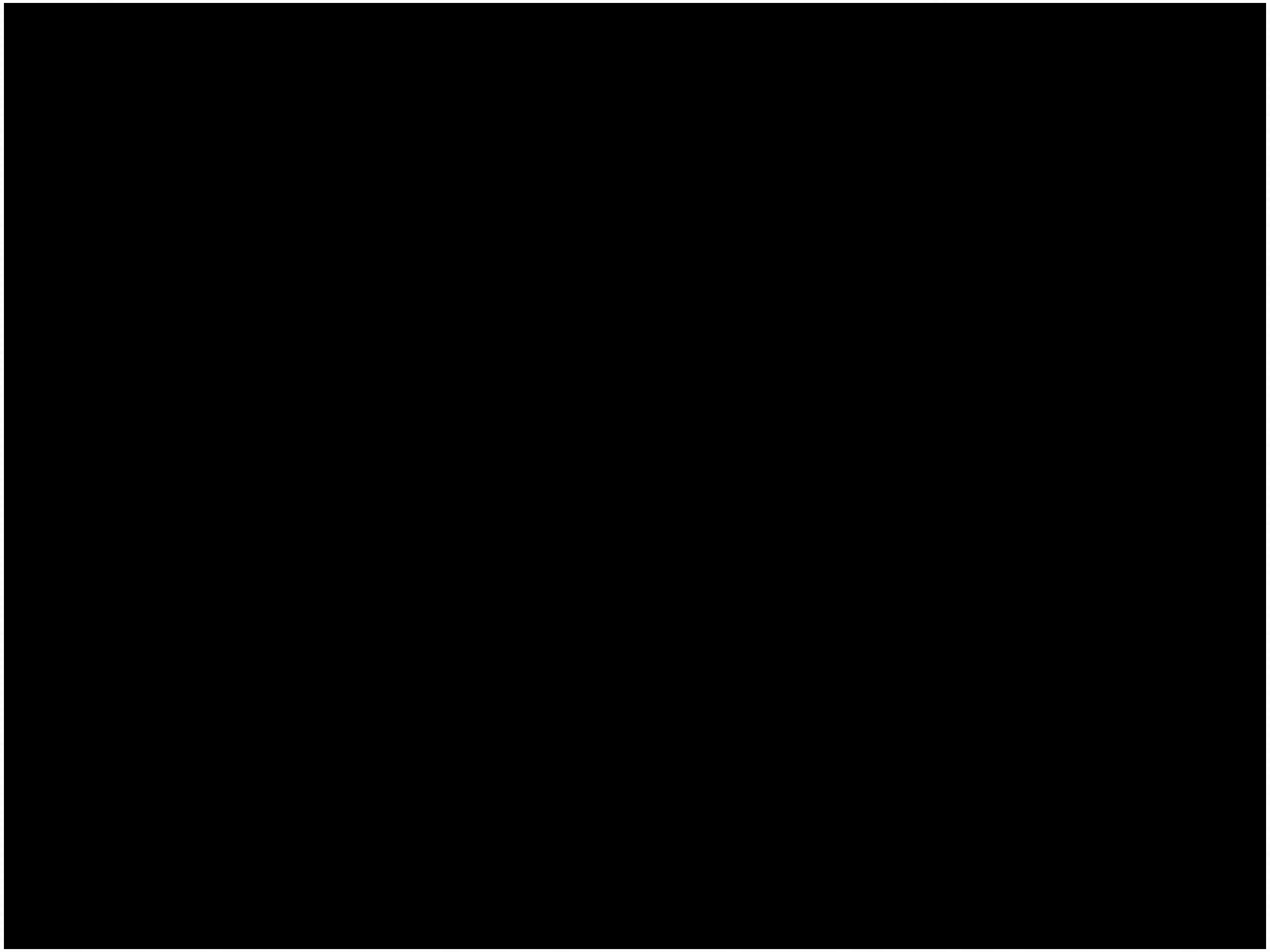


SMA Application – Specs – Optical frames Video



- Cryofit hydraulic couplings – SMAs are used as couplings for metal pipes.
- Springs, shock absorbers abd valves – Due to excellent elastic property of SMAs, springs can be made which have varied industrial applications
- Fire safety valves
- Aerospace applications
- Flaps that change direction of airflow depending upon temperature (for air conditioners)
- Stepping motors

SMA in Space- Mars Video



Conclusion

- Day by day, there has been a sharp rise in demand for SMAs alloy.
- Many new inventions are being brought to society, particularly in the bio-medical field.
- New SMA alloys are also being introduced in the biological domains, in addition to manufacturing uses like aerospace and automotive.
- Designing any application should take into account the most recent advancements in the area of fabrication and treatment of SMAs.

THANK YOU