SMAs for Industrial applications
From first NiTiNiOL to a big success
Francesco Butera

making innovation happen, together
Shape memory alloys (SMA), if thermally stimulated by external heat or internal electrical current flow (Joule effect), exhibit a reversible thermoelastic martensite transformation with a macroscopic shape change.
SMA Superelastic alloys

Superelastic behaviour
Elastic recovery of a very large deformation (10 – 12 %)
Making small changes in the composition can change the transition temperature of the alloy significantly. For this reason, SMA may be in austenite or in martensite at room temperature, showing a superelastic or a shape memory properties.

**Histeresys cycle for Superelastic and shape memory material**

![Diagram showing the hysteresis cycle for superelastic and shape memory materials. The diagram includes temperature (T) and martensite percentage (% Martensite) axes. The cooling and heating phases are marked with arrows labeled Ms, Mf, As, and Af. The Superelastic material is shown in blue at room temperature in austenite, while the Shape memory material is shown in red at room temperature in martensite.](image-url)
# Full portfolio of Nitinol products

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Semi-finished Shapes</th>
<th>SMA wires and components</th>
<th>Nitinol Medical Components</th>
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<tr>
<td>Ingots</td>
<td>Tubes</td>
<td>Trained wires</td>
<td>Tubular Laser Cut Stents</td>
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<td>Bars</td>
<td>Wires</td>
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<td>Coils and Redraw</td>
<td>Sheets</td>
<td>Shaped components</td>
<td>Micro-coils and Shapes</td>
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<tr>
<td></td>
<td>Ribbon</td>
<td></td>
<td>Specialty Guidewire</td>
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From raw material to advanced components – an unique and integrated offer
Some pictures ....
VIM Furnace
NiTi Ingot
NiTi coils
Wire drawing line
SMARTFLEX is a 100% quality controlled SM wire for actuators

Main characteristics:

- Diameter: from 20 to 500 µm
- Transformation temperatures: 10 – 100 °C
- Maximum stroke: 5.0 %
- Force@150MPa: from 5 g to 3 Kg
- Lifetime: > 1,000,000 cycles (under controlled conditions)
- Shaping: Coil springs, torsion wires
As thermal-actuators SMA’ springs are very specific products. The combination of composition, heat treatment and operating conditions permits to cover a wide range of activation temperatures. Customized solutions may be developed to fulfill several applications.

Springs vs. Wire
- Higher Stroke
- Lower Force
- Indirect Heating
- Sensor - Actuator
- Customization

At low temperature the Martensite phase presents low force.

At high temperature the Austenite phase presents high force.

The spring moves continuously between such extreme positions in noiseless operation.

Activation temperature can be set between -50 and +100°C.
Shape Memory Effect for Actuation

\[ F_x = \sigma_x A \]

Switch-off

Switch-on

Contraction

Elongation
### Actuator configurations

<table>
<thead>
<tr>
<th>Schematic</th>
<th>Original (reference)</th>
<th>Bigger U</th>
<th>Vee</th>
<th>Single</th>
<th>U lever</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Diagram](pp bg darker - cropped to fit.png)</td>
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</table>

<table>
<thead>
<tr>
<th>Wire length</th>
<th>L1</th>
<th>L2 = 2L1</th>
<th>L2 = L1</th>
<th>L2 = L1</th>
<th>L2 = L1</th>
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</thead>
<tbody>
<tr>
<td>Actuation energy</td>
<td>1E</td>
<td>2E</td>
<td>1E</td>
<td>1E</td>
<td>1E</td>
</tr>
<tr>
<td>Displacement</td>
<td>1D</td>
<td>2D</td>
<td>&gt; 1D (depends on angle)</td>
<td>2D</td>
<td>&gt;1D (depends on lever ratio)</td>
</tr>
<tr>
<td>Force</td>
<td>1F</td>
<td>1F</td>
<td>&lt; 1F (depends on angle)</td>
<td>F/2</td>
<td>&lt; 1F (depends on lever ratio)</td>
</tr>
<tr>
<td>Response time</td>
<td>1T</td>
<td>4T</td>
<td>1T</td>
<td>1T</td>
<td>1T</td>
</tr>
</tbody>
</table>
SMARTFLEX wire performs more than 1 million of cycles if stress and strain trade off is correctly evaluated.
SMA Actuators
silent, powerfull, controllable, simple and ready for your business
Have fun !!!
SMA works as an on-off operation, I need to control it ...

... SMA wires offer an intrinsic position sensor since their electrical resistance change accordingly to the displacement during the transition from martensite to austenite (from about 100 to 80 $\mu\Omega$ cm). It is possible to control the displacement using the linear part of the curve as a feedback.

**Electrical resistance vs current during the transformation cycle**

**Example of controllable actuator from Fiat Research Centre**
NiTiNOL on the market: From discovery to full success

<table>
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<tr>
<th>Years</th>
<th>Market penetration 100%</th>
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<tbody>
<tr>
<td>'60</td>
<td></td>
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<tr>
<td>'70</td>
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<td>'80</td>
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<tr>
<td>'10</td>
<td></td>
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<tr>
<td>'20</td>
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</tbody>
</table>

Technology
- SE effect
- SE design

Applications
- Antennas
- Dental wires
- Lock rings
First applications exploited the superelastic effect for simple devices...

The first Shape Memory application was on “one shot” shrinkage to tighten connectors. This solution is still in production in the aerospace field.
NiTiNOL on the market: From discovery to full success

Market penetration 100%

Years

Medical

Industrial

first NiTiNOL

Technology

SE effect
SE design
High quality SE SMA
Large scale melting
SE modelling
Laser cutting
Tubing
Coil springs

Applications

Antennas
Dental wires
Lock rings
First actuators
Guidewires
Stents
Bone staples
Implantable dev.
‘90s – ’00s: Medical applications and market

Due to the perfect match between superelasticity in SMAs and human tissues properties, NiTi has been introduced and successfully used in several medical applications.

This market started in the 90’s and now is a well established business.

Almost every implantable device is NiTi based today. This was a real revolution on surgical intervention.
‘90s – ’00s: JP pioneering the industrial application

...At the same time, only in JP, University and Companies started first real applications using shape memory elements as thermal or electrical actuators

Some of them are still successfully in production

...In EU and USA automotive companies like FIAT and GM started interesting research on new devices generating new interest on this technology for industrial application
CNR and CRF ini started...

PROGETTO FINALIZZATO
MATERIALI SPECIALI PER TECNOLOGIE AVANZATE II
MSTA II (1998-2000)

TITOLO DELLA RICERCA: LEGHE A MEMORIA DI FORMA

Partners:
CNR-TEMPE (Lecco) - Coordinatore: Dr. Ausonio Tuissi
CNR-CEFSA (Trento)
CNR-LAMEL (Bologna)
Centro Ricerche Fiat (Orbassano TO)
Scuola Superiore S.Anna (Pisa)
Università di Pavia
Università di Perugia
Università di Pisa

The very first SMA actuator for automotive industry

But at that time there was no material supplier for industrial grade NiTi Alloys.

CNR and CRF contacted SAES to promote this strategic project and a 3 parties partnership started
First automotive prototypes...

From concept design...

- Mechanical opening from the outside
- Internal electrical and mechanical opening
  Based on SMA bowden
- Rigid flaps
- Mirror support
- Shape memory wires
- Shape memory wire

...To prototypes:

[Images of prototypes with labels: Mirror support, Shape memory wires, Rigid flaps, Mechanical opening from the outside, Internal electrical and mechanical opening]
NiTiNOL on the market: From discovery to full success

Applications:
- Antennas
- Dental wires
- Lock rings
- First actuators
- Guidewires
- Stents
- Bone staples
- Implantable dev.
- Thermostatic actuators
- Electrically Controlled actuators

Technology:
- SE effect
- SE design
- High quality SE SMA
- Large scale melting
- SE modelling
- Laser cutting
- Tubing
- Coil springs
- High quality SMA
- SMA control
- SMA design
- SMA modelling

Market penetration 100%

First NiTiNOL
Today: Omnipod – the SMA insuline pump

The OmniPod Insulin Pump portable delivery system provides a “freedom of lifestyle” change for diabetics requiring Insulin use.

The unique product was made possible with the use of a Shape Memory Alloy wire actuator jointly developed with Insulet and manufactured by Autossplice.

Standard motors are too costly, too heavy, generate too much heat, and require far too much power to provide a portable solution.

The SMA actuator makes this assembly possible from both a technical and cost effective standpoint.
Today: First high volumes automotive application

SMA pneumatic valves for lumbar support in Car’s seats from ALFMEIER

Actual production in
ACTUATOR SOLUTIONS GMBH:
10 million actuators/year

Pneumatic valve to inflate and deflate cushions in car’s seats.
Installed in all main vehicle’s platform of:

- Daimler
- BMW
- GM
- Hyundai
- Ford
- Porsche/VW
Today: A very large mass production is coming

SMA Optical Image Stabilizer + AF for mobile phones from ACTUATOR SOLUTIONS GmbH

SMA OIS is placed underneath the SMA AF module. ASG already has a fully working module integrated with a sensor under evaluation by major camera modules makers.

The lens and sensor are tilted together with SMA wire on all 4 sides of the camera.

Both pitch & yaw tilt are measured by a gyroscope moving mechanically attached to the camera and compensated to a ZERO output by the OIS actuator.

With OIS enabled, the lens and sensor tilt inside the camera but remain still to the image subject – giving a sharp image.

ACTUATOR SOLUTIONS

making innovation happen, together
NiTiNOL on the market: From discovery to full success

Applications
- Antennas
- Dental wires
- Lock rings
- First actuators
- Guidewires
- Stents
- Bone staples
- Implantable dev.
- Thermostatic
- Actuators
- Electrical
- Actuators
- MEMS
- Textiles

Technology
- SE effect
- SE design
- High quality SE SMA
- Large scale melting
- SE modelling
- Laser cutting
- High quality SMA
- SMA control
- SMA design
- SMA modelling
- Thin films
- Tubing
- Coil springs
The future... Smart composites

Multifunctional composite structure
- Active material with integrated fibers → Surface morphing and stiffness adaptation
- Distributed deformable sensor layer → Detection of deformation feedback
- Smart composite structure → Adaptive noise reduction

SMA fibers for actuation
Distributed sensors for position feedback
polimeric matrix or fabric

Active flaps based on SMA composite (CRF)

SMA active textile
The future... SMA MEMS

Dosing of a shape memory and a micro-valve flow sensor
Functional Films: PD Dr. Manfred Kohl
KIT - University of the State of Baden

Microgripper of NiTi

Wafer-level integration of niti shape memory alloy wires
KTH – Royal Institute of Technology, Stockholm, Sweden

Heterogeneous Integration of Shape Memory Alloys for High-Performance Microvalves (2012)
Henrik Gradin, KTH Electrical Engineering
The future... Thin Films and programmable matter

Programmable matter by folding (2010)
Harvard University
Massachusetts Institute of Technology

TiNi shape memory alloy thin films for microactuator application
Nanyang Technological University, Singapore-MIT Alliance
Let’s start projects together

Thank for your attention

making innovation happen, together