Magnetic shape memory (MSM) Technology

“Materials that make things move”
Content

• Introduction of Adaptamat
• Fundamental properties of MSM-alloy
• MSM based applications
  • Vibration energy harvesting
  • Displacement sensor
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AdaptaMat in brief

- The pioneer of Magnetic Shape Memory (MSM) materials and devices. Established 1996 and backed by private (VC) investors.
- Inventor of the MSM-alloy, owner of basic MSM-patent families, new patents filed
- World class and international R&D team with in-depth understanding of NiMnGa based Magnetic Shape Memory alloy
- Constantly high-quality NiMnGa single-crystals produced
- Targeting multibillion application markets. Demo versions of Energy harvester, Placement Sensor, Actuator and more built
MSM Effect in action - Macro

“Materials that make things move”
Magnetic Shape Memory (MSM) Technology

“Materials that make things move”
NiMnGa as MSM material

- Magnetic Shape Memory alloy (MSM), also known as Ferromagnetic Shape Memory Alloy (FSMA):
  - Material responds to externally applied magnetic field
- Similar to magnetostriction, but with vastly greater strain
- Single-crystalline material
- MSM effect is based on magnetic anisotropy and martensitic twin variant transformation of the crystal structure
Magnetic Shape Memory Effect

- **MSM Effect:**
  - Twin variants turn (martensitic shape change) by magnetic field leading to macroscopic shape change of 5-10 % of the material
  - Perpendicular (magnetic) field elongates and parallel field contracts the MSM
  - Fast rise-time of less than 1 ms and 2.8 MPa maximum force
  - Movement proportional to the magnetic field
• Other Main properties

  – Villari effect
    • Inverse magnetostriction

  – Proportional change of resistance

  – Proportional change of permeability.

  – High Temperature Shape Memory Alloy

  – Inherent damping properties
High Temperature SMA

- MSM as a High Temperature Shape Memory Alloy

  - Transition temperature can be set anywhere between -150 ºC and +400 ºC
  - Superelastic properties
  - Strain/elongation: 6 %, Temperature hysteresis 12 ºC
Applications

Application space of MSM
Application space and markets

Current core applications

**Linear Movement**
- Actuators & Valves
- Proportional Ctrl, pumps, mobile devices

**Sensors**
- Distance, Force, pressure, Magnetic field

**Energy Harvesting**
- Powering of WSN
- Process Industry
- Automotive

**High Temp SMA**
- Car industry
- Aerospace, Oil

Other potential applications

**Magneto-calor.**
- Refrigeration
- Air Conditioning

**MSM thin-films**
- Micro devices
- MEMS

**Medical Apps.**
- Bone stretch
- Robotics

**Vibration damping**
- Aerospace
- Heavy Machines

Other potential applications
Vibration Harvester

Demo Harvester Design based on NiMnGa
MSM Vibration energy harvesters

- MSM vibration energy harvester/1st generation
  - The MSM vibration energy harvester is based on the MSM alloy’s variable permeability (magnetization) as its length is changed by external vibration.

- The main properties:
  - Element: $1 \times 5 \times 17$ mm (active length)
  - Measured: 20 mW at 44 Hz
  - Simulated: nearly 50 mW at 50 Hz
  - Size: $3.5 \times 3.5 \times 5$ cm
  - Power density measured: 330 µW/cm³
MSM Vibration energy harvesters

• MSM vibration energy harvester 2nd generation:
  – AdaptaMat’s 2nd generation harvester design is targeted for small size. Current versions are approximately the size of AA-batteries.

• The Main properties:
  – Element: Ø 3 mm × 17 mm (active length)
  – Measured: 5 mW at 60 Hz
  – Size: Ø 13.5 mm, h=38 mm
  – Power density measured: 930 µW/cm³
  – Voltage depends on coil turns, several volts possible
• High resolution MSM displacement sensor
  – Based on proportional change of permeability
  – MSM element placed inside a coil
  – Coil part of oscillating circuit
  – As the MSM length changes the frequency of oscillation changes as well
  – Sensitivity 3 kHz / mm

• Other sensors proposed
  – Force and pressure
  – Strain gauge
  – Speed sensors
  – Magnetic field
Actuator Examples
• MSM Actuator specifications:
  - Element size: 20×2.5×1.0 mm
  - Maximum stroke: 0.9 mm
  - Maximum output force: 5 N
  - “No-power” holding force: 1 N (with return spring removed)
  - Fatigue life: >200 million cycles
  - Rise time: 1 ms (see Fig)
  - Actuator dimensions: 25×25×66 mm
  - Weight: 160 g
Self-sensing MSM sensor

- MSM actuators with self-sensing capability for open/closed-loop proportional control or load-sensing applications.
- Proportional control by adjusting the magnetic field
- Position sensing by 4-point measurement of element resistance
- Open-loop operation with position indication or closed-loop microprocessor control e.g. by PID algorithm
Self-sensing MSM sensor

Sensing principle:

- Magnetic field $H$ produces movement, element’s resistance $R$ provides position information:
  - Magnetic and resistive effects are fully orthogonal with no crosstalk (no magnetoresistance observed)
  - Geometric effect on resistance is about 2x the change in length
  - Very small resistance: must compensate wire and contact resistances
  - Temperature effects on resistance must be compensated
Self-sensing, compensation

Seebeck

$\text{SMSM} \approx 23.8 \, \mu\text{V/K} \quad (\text{SCu} = 6.5 \, \mu\text{V/K})$

Temperature calibration
Closed-loop PID control of MSM actuator

- ON/OFF
- Sensing bias current
- Actuator current
- Voltage sensing
- A/D
- MCU
- Current control
- Setpoint
PID control performance in an MSM actuator

Actuator position

Drive current

500 ms

250 ms
• Micro actuators and thin film devices
  • The size of the enclosed micro actuator is 10 × 9 × 6 mm (upper right)
    – Maximum stroke length is 0.36 mm with a 0.3 × 1.5 × 6 mm element
    – Max. blocking force is 0.5 N
    – Power consumption of the first version is 0.5 W (100 % ON-mode)
  • Figure on lower right and at the middle shows actuator work done at KIT & Professor Kohl
**MSM Pump for MicroFluidics**

- **Microfluidics pump**
  - MSM element can be immersed into the fluid-channel
  - No direct contact or hard wiring or needed to the MSM element
  - Remotely controlled by the magnetic field
  - Pumps very small amounts (0.16 µl per rotation or less)
  - Dual action valve and pump (no separate valves needed)
  - *Idea presented originally by Ullakko, Mullner & Hampkian*
Local deformation in magnetic field
Operating principle

Deformed area moves as magnet turns
Operating principle
Operating principle

Inlet

Cover

N

S
Operating principle
Operating principle
Operating principle

Outlet

N
S

N
S
Operating principle
Operating principle
Operating principle
Operating principle
MSM Pumping

“Materials that make things move”
MSM Pumping

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Thank you!

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