Smart Materials

(*Magnetostriction*)

Smart Materials Structures and Systems
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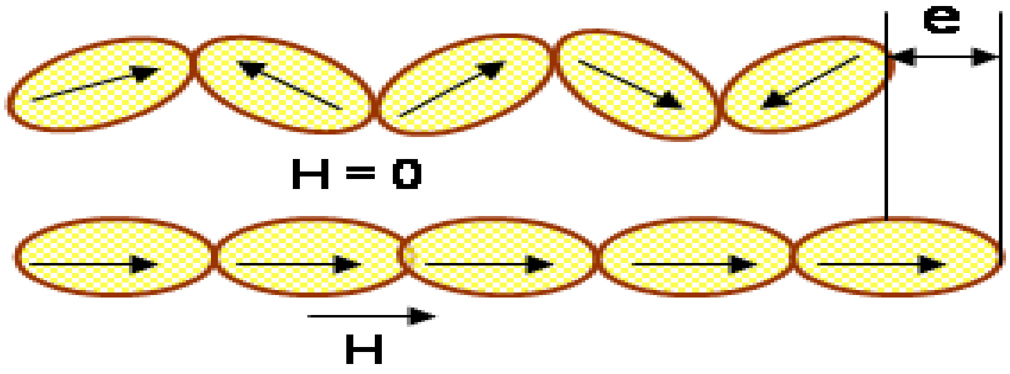
Preface

- Magical power of magnets awed people of early civilizations as a strange force from the rocks that attracts shoes and swords without revealing itself!
- In 1842, James Prescott Joule noted that a ferromagnetic sample changed its length with the application of Magnetism.

Contents

- What is Magnetostriction?
- Some Examples
- A Brief History of Magnetostrictive Materials
- What are the different effects of Magnetostriction?

What is Magnetostriction?



Magnetostriction (e) in materials due to domain migration and reorientation under applied magnetic field H

Reference: mxp.physics.umn.edu

- If a crystal of ferromagnetic material is **initially** at a **compressed state**, the effect of Magnetostriction becomes **more pronounced**.

- All ferromagnetic elements show Magnetostriction to **different degree**.

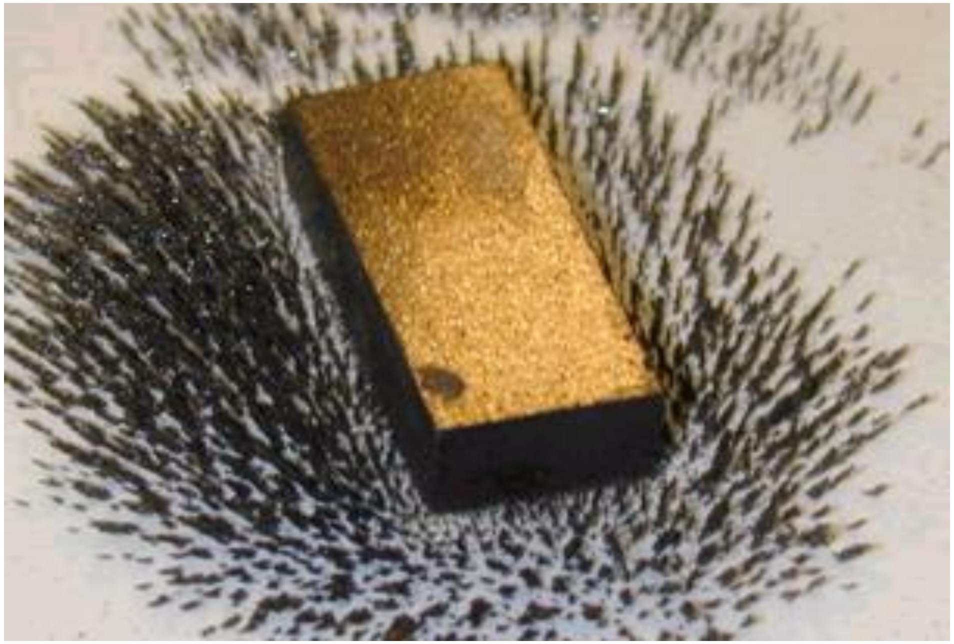
- It is observed that the maximum one can achieve is for **Cobalt** which saturates around 50 µstrain (ppm).

Material	Magnetostriction (ppm)	Curie Temp. (K)
Fe	14	633
Ni	-33	1043
Co	50	350
Permalloy	27	713
$DyFe_2$	650	635
$TbFe_2$	2630	703
$Tb_{.3}Dy_{.7}Fe_{1.9}$	2400	653

A brief Time~Line

Year	Event
1842	Magnetostriction discovered in Nickel by Joule
1865	Villari discovers inverse Joule Effect
1926	Anisotropy in single crystal iron
1965	Rare-earth metal magnetostriction in Terbium and Dysprosium by Clark
1972	$TbFe_2$ and $DyFe_2$ at 300 ^oK by Clark
1975	Terfenol-D by Clark
1994	Polymer Matrix and Terfenol-D particulate composite (Sandlund et al)
1998	Discovery of Galfenol – a more rugged MS material at NSWC (Clark)
2002	Oriented particulate Composite (Carman)

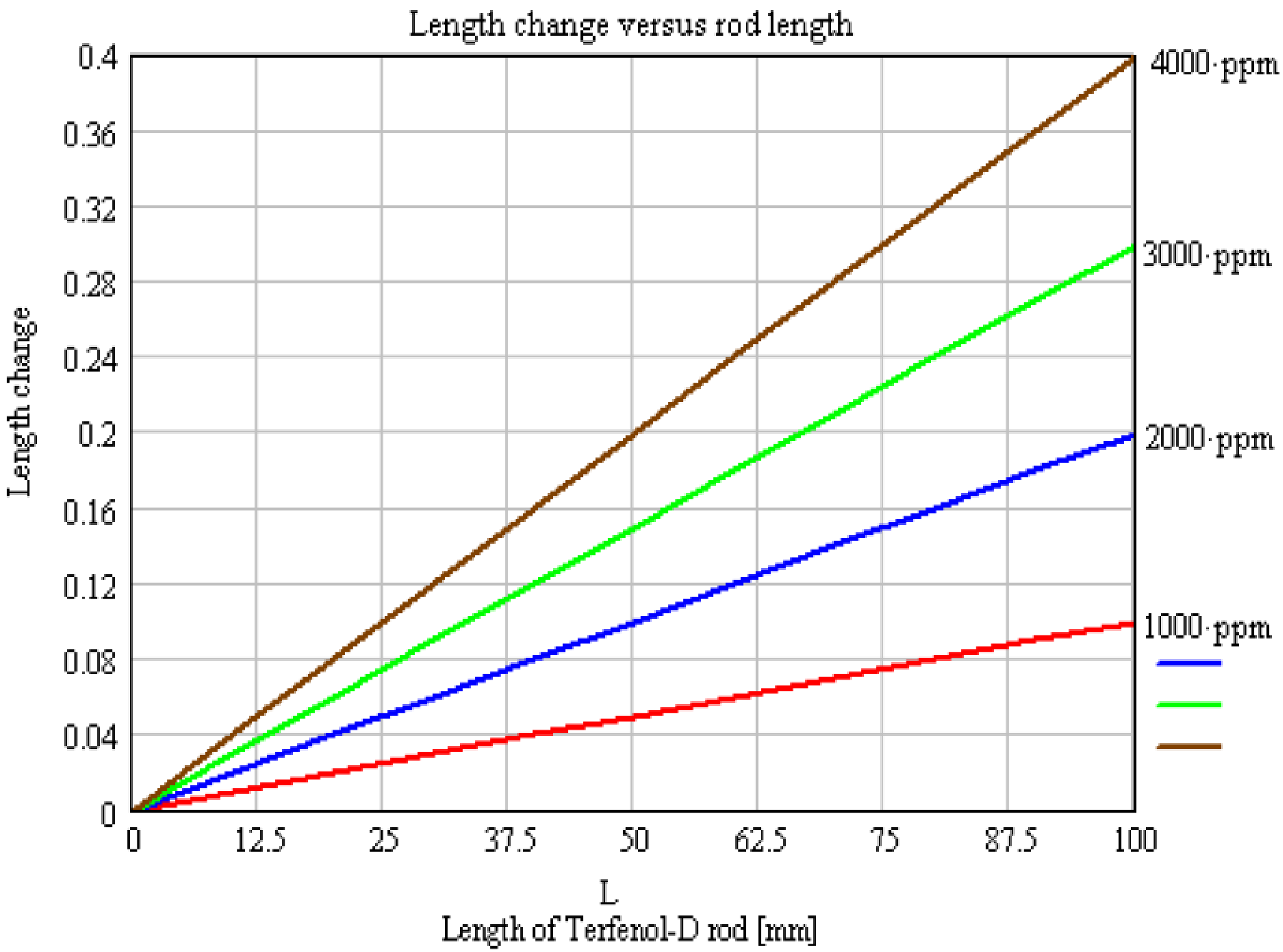
Terfenol-D: A Magnetostrictive Smart Material



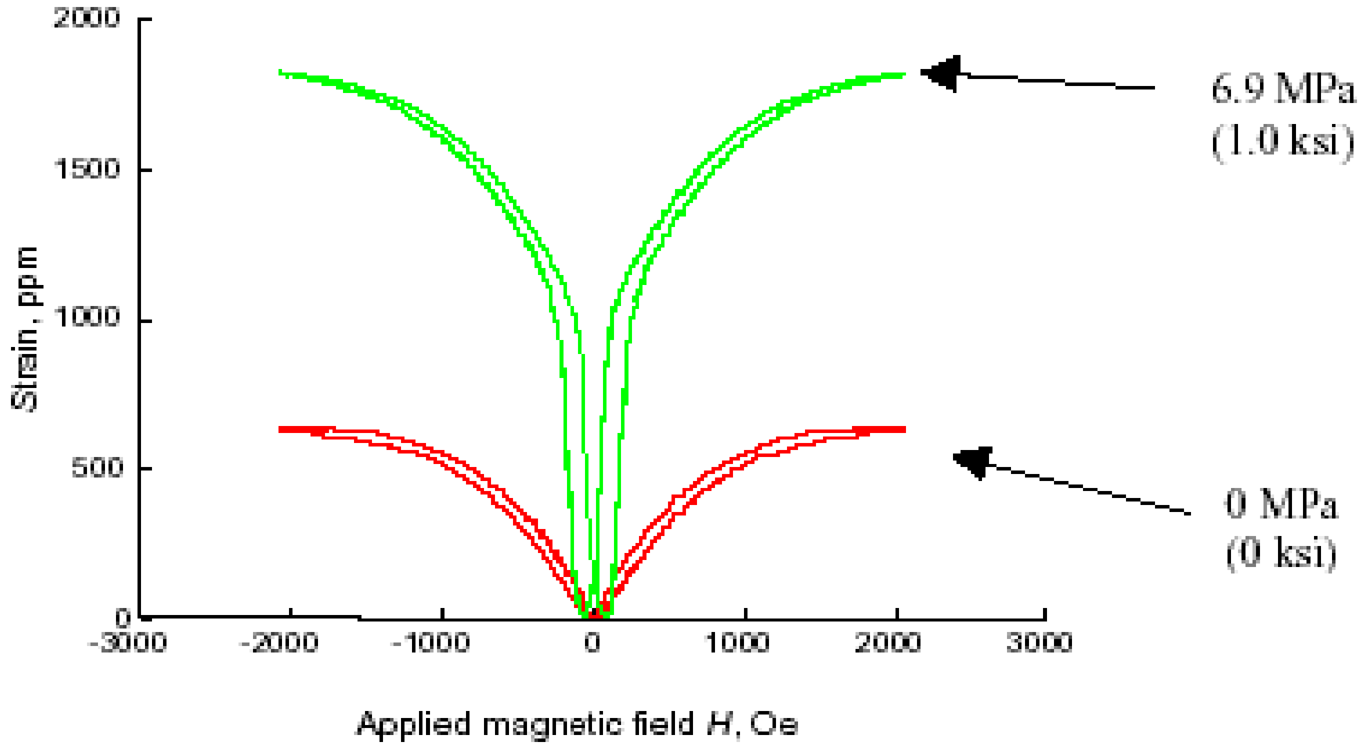
Terbium – Iron (Fe) – Naval Ordinance Laboratory – Dysprosium

(Explosive !!!)

Typical features	PZT	Terfenol-D	SMA
Actuation mechanism	Piezoelectric material	Magnetostrictive material	Shape memory alloys
Elongation	0.1%	0.2 %	5%
Energy density	2.5 kJ/m^3	20 kJ/m^3	1 J/m^3 *
Bandwidth	100 kHz	10 kHz	0.5 kHz
Hysteresis	10%	2%	30%
Costs as reference	200 \$ / cm^3	400 \$ / cm^3	200 \$ / cm^3

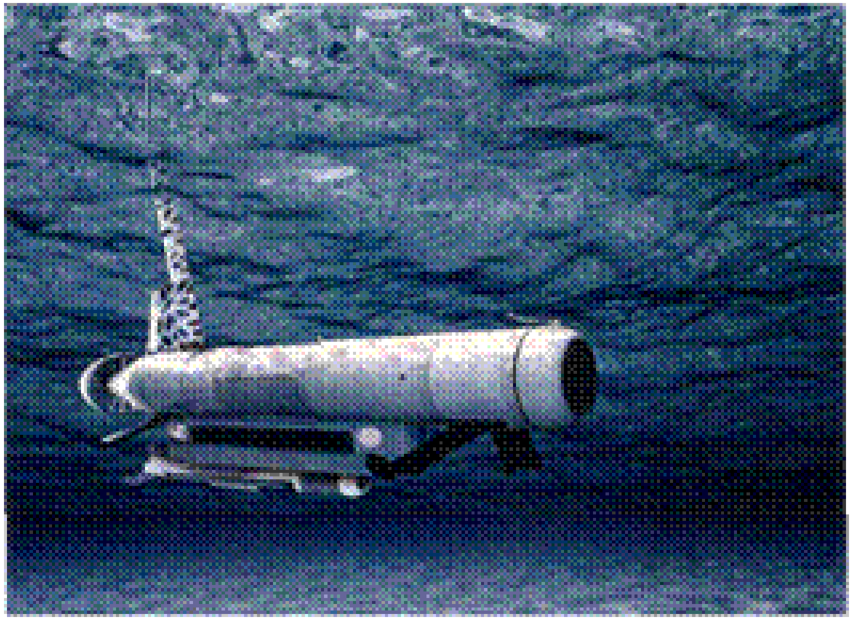

Length change versus rod length
Length change
0.4
0.36
0.32
0.28
0.24
0.2
0.16
0.12
0.08
0.04
0
0
12.5
25
37.5
50
62.5
75
87.5
100
L
Length of Terfenol-D rod [mm]
4000·ppm
3000·ppm
2000·ppm
1000·ppm

Butterfly curve for TerFeNOL~D



Attraction of Magnetostrictive Transducer

- In general: Large Force , Deflection and Energy Conversion efficiency; does not decay with time.
- **Magnetostrictive transducers** : Cost-effective in the low-frequency band and could be effectively used for deep-sea measurements due to superior mechanical properties.

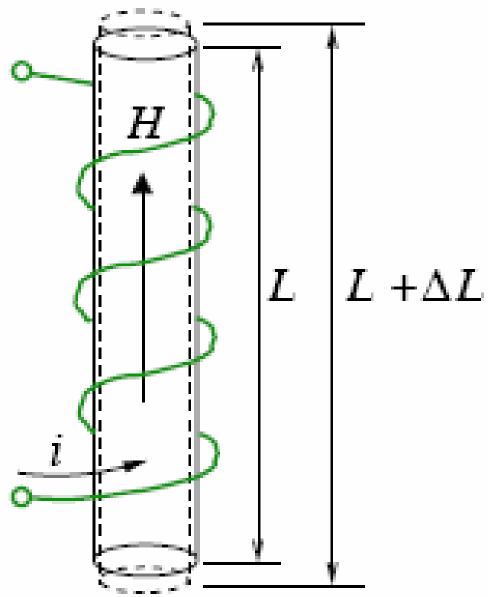


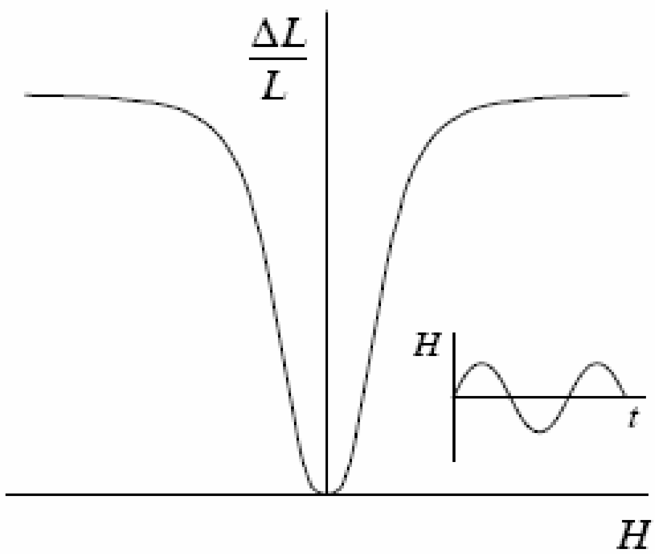
TALON (Tactical Acoustic Littoral Ocean Network) sonar system uses Magnetostrictive Terfenol-D for under-water submarine detection
Source: *Etrema Products*

Major Applications

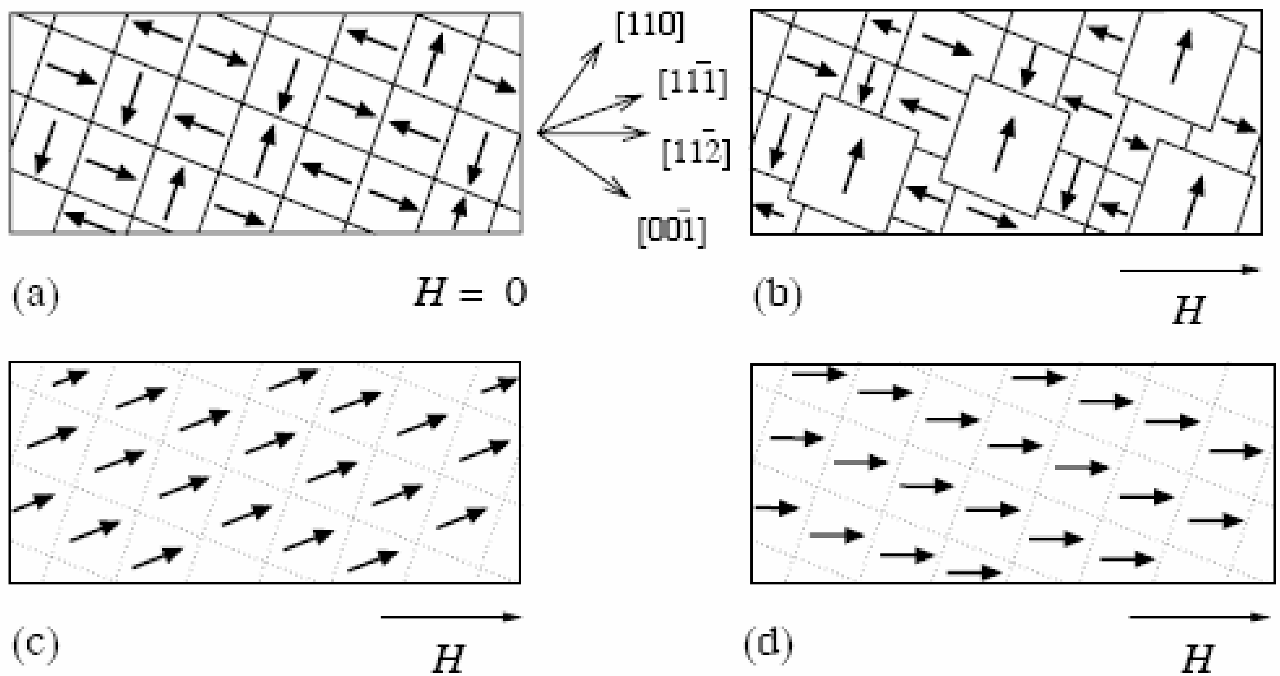
- ✓ Active Vibration and Noise Control System
- ✓ Machine Tools
- ✓ Servo Valves
- ✓ Hybrid Motors
- ✓ Sonar Devices and Tomography
- ✓ Automotive Break Systems
- ✓ Micro-positioner
- ✓ Ultrasonic Cleaning Machining and Welding

Magnetostriction in Solid Rod



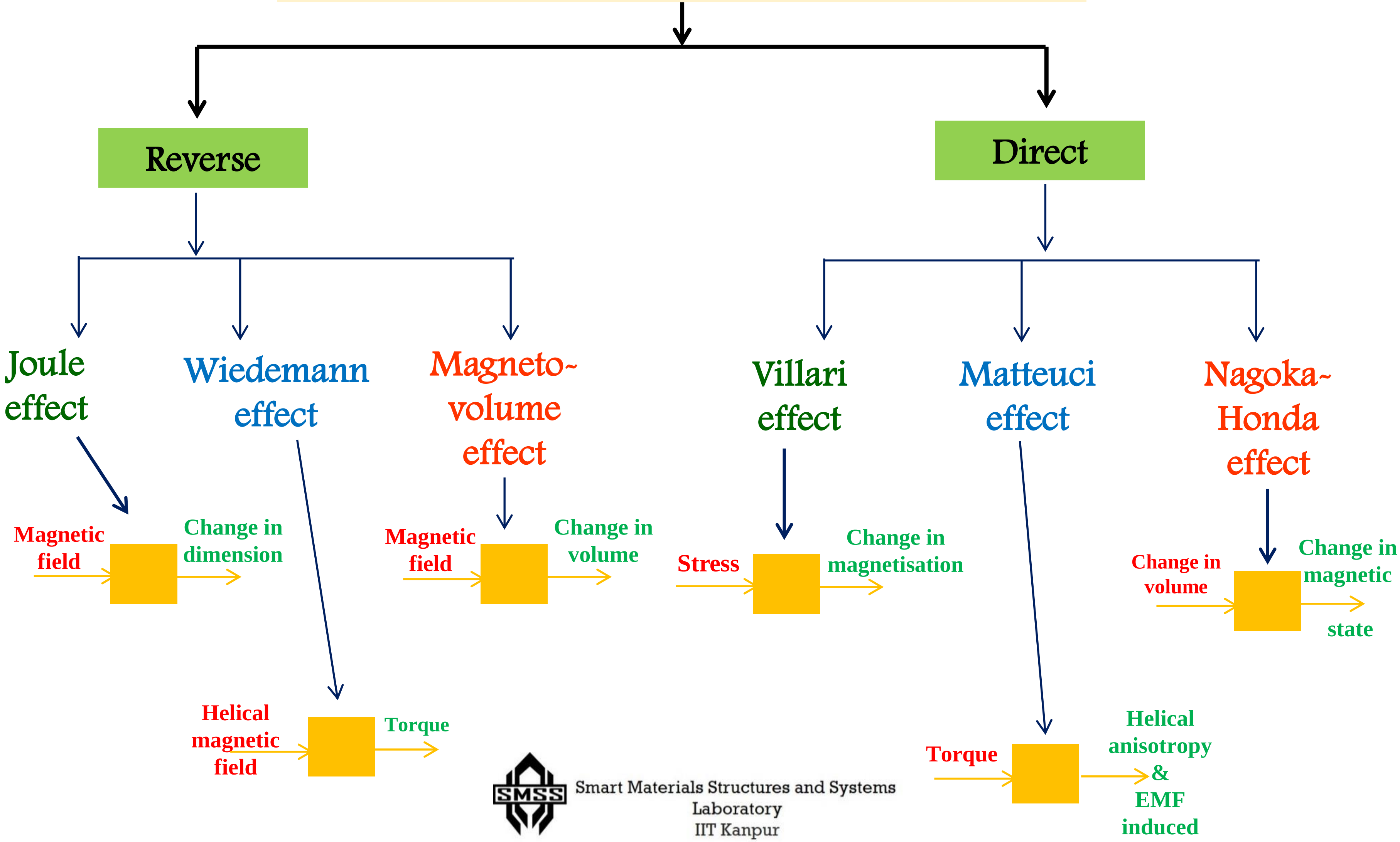


H – Magnetic field intensity (A/m)



(a) Demagnetized State (b) Partial Magnetization
(c) Irreversible Domain Magnetization (d) Technical Saturation

Magnetostrictive Effects for ACTUATION & SENSING



Const. Eqn. of Magnetostrictive Material

Joule Effect: $\varepsilon = S^H\sigma + dH$ (Actuator equation)

Villary Effect: $B = d\sigma + \mu^\sigma H$ (Sensor equation)

σ – Stress (N/m^2),

ε - Strain,

B - magnetic flux density (Tesla or N/A-m or Volt-sec/m^2)

μ^σ- Permeability of the material at constant stress (T-m/A)

H – Magnetic field intensity (A/m)

S^H - Compliance matrix of the material at constant magnetic field (m^2/N)

d - Magnetostrictive constant (m/A or Tm^2/N)

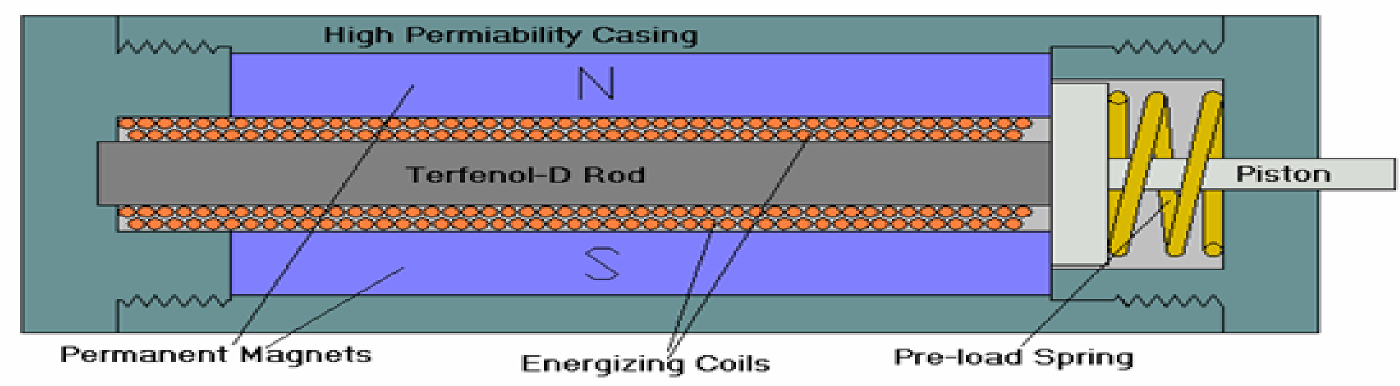
Vibration Sensing

Two approaches are taken to develop such sensors:

(a) Development of particulate composite: Terfenol-D particles of micron to sub-micron size are dispersed in a suitable resin and cured to form sensors.

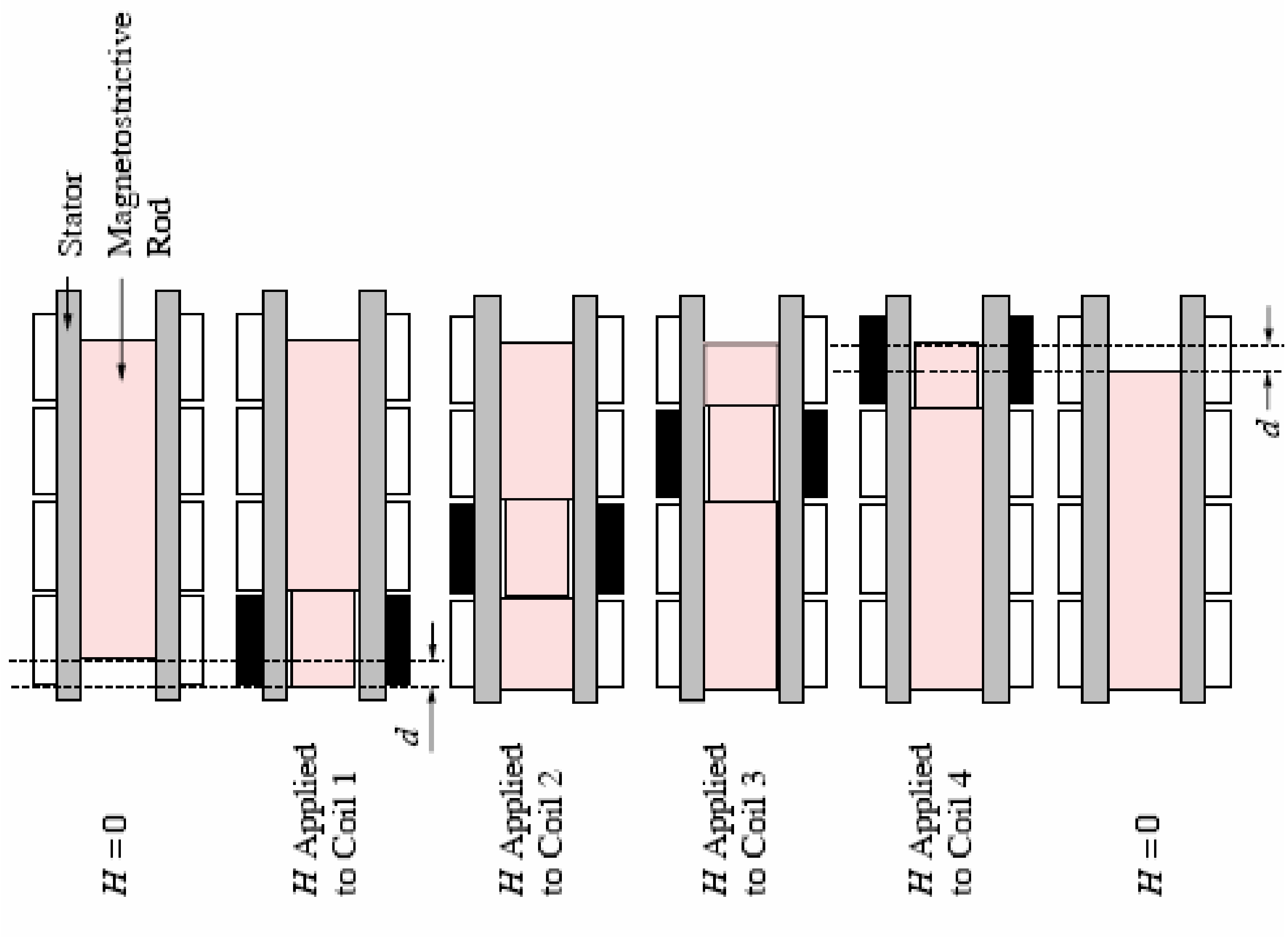
(b) Development of thin-film metallic glasses as magnetostrictive (MS) sensors.

Magnetostrictive Mini Actuator (MMA)

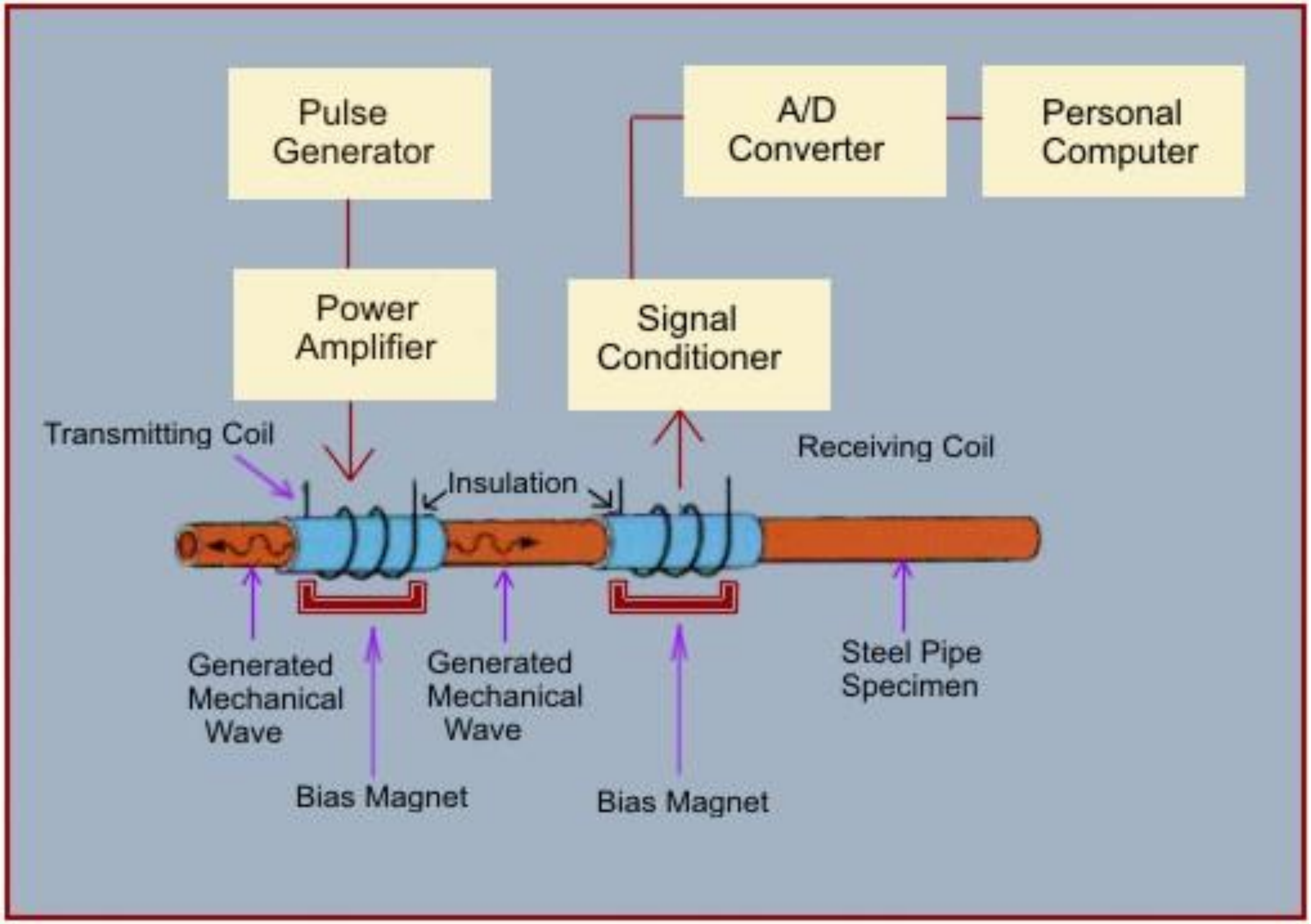


Pre-load springs and permanent magnets are used to put the piston in the zero-position and also to reduce hysteresis. The energizing coil around the rod is used to activate the Terfenol-D rod for dynamic application.

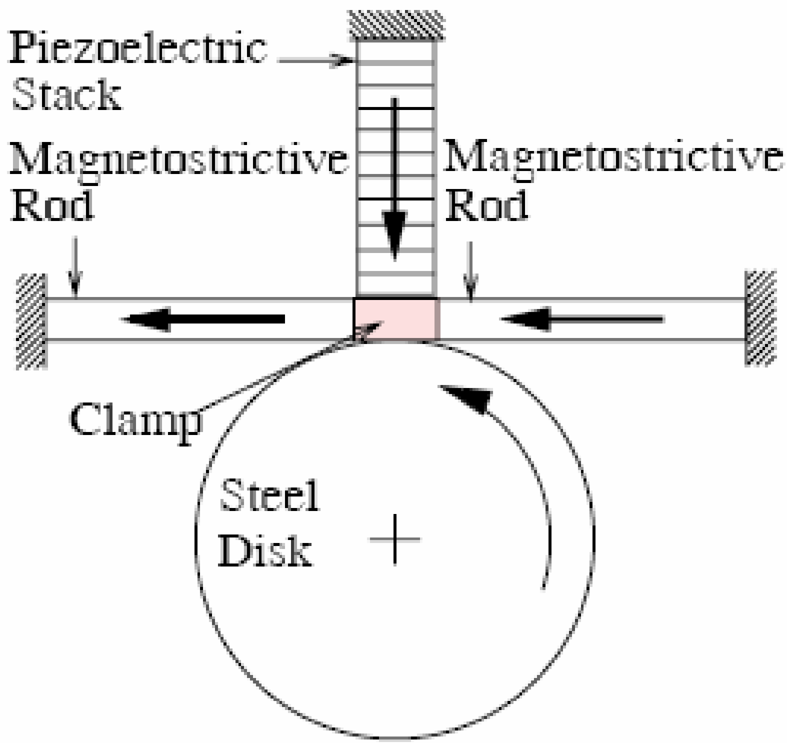
A Kiesewetter Inchworm Motor



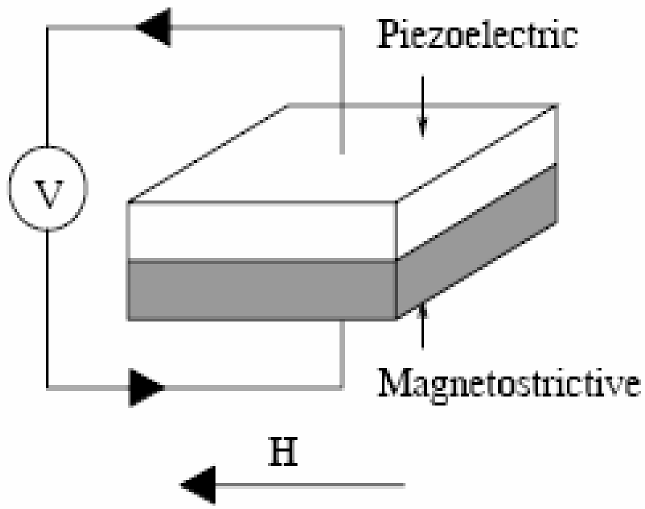
Magnetostrictive Delay Line (MDL) Sensor

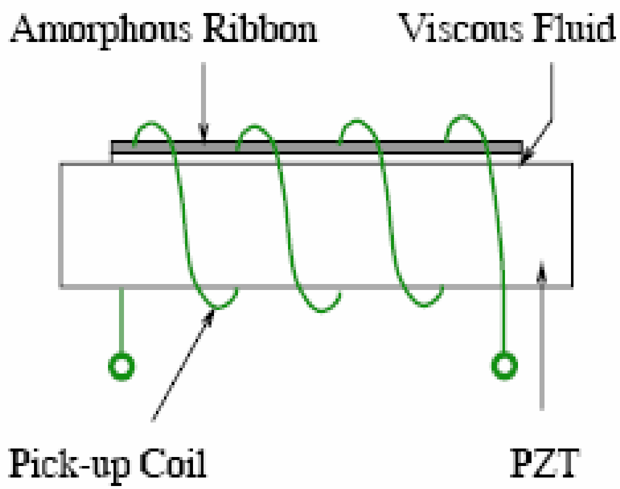


Hybrid Transducers



Hybrid Sensors





References

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