University Of Technology- Iraq
Department of Materials Engineering
General Materials Branch
Fourth class

Smart Materials

Lecture 6 : Material Behavior and Magnetostrictive Effects Class Code on Google Classroom :2shhens

Magnetic Anisotropy

- Magnetic anisotropy refers to the dependency of magnetic properties on the direction in which they are measured.
- It can be of several kinds, including crystal, stress, shape, and exchange anisotropy. Of these, however, only crystal anisotropy is a material property.

Magnetic Anisotropy

- In many crystalline materials, the magnetic moments do not rotate freely in response to applied fields, but rather they tend to orient along preferred crystallographic directions. This phenomenon is called ***the magnetocrystalline or crystal-anisotropy***,
- the associated *anisotropy energy* is the energy required to rotate the magnetic moments away from their preferred directions

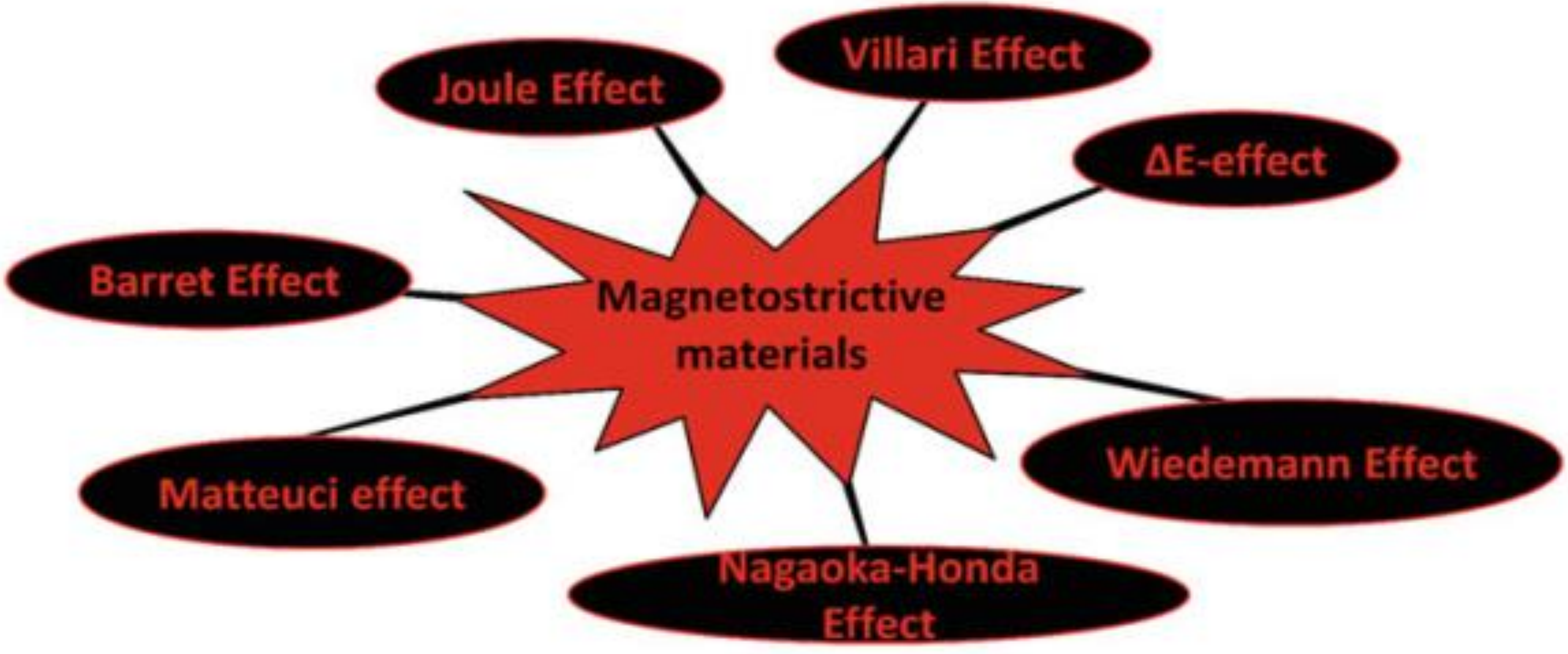
Magnetic Anisotropy

- Crystal anisotropy energy and magnetostriction are closely related effects;
- if the anisotropy was independent of the state of strain, there would be no magnetostriction.
- While accurate models for crystal anisotropy and its relation with the magnetization process exist for the simple cases of cubic and hexagonal crystals, models for complex crystal structures often rely on simplifying assumptions which reduce the analysis to the simpler cases .

Mechanical Behaviors

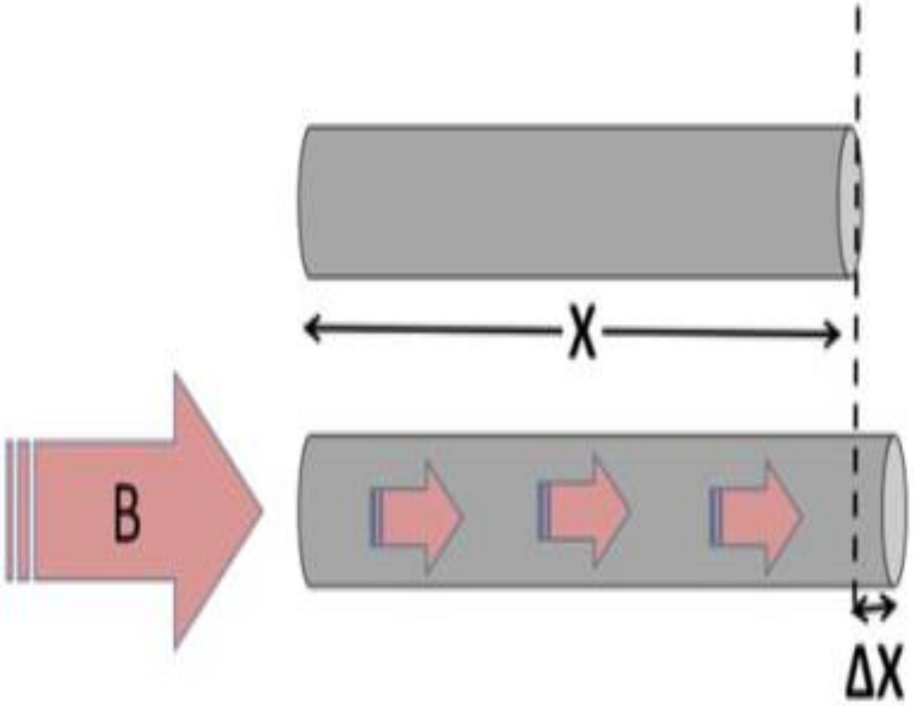
- Mechanical impedance matching of the harvester is an important property of magnetostrictive materials for kinetic energy harvesting. Materials like Terfenol or Galfenol are quite rigid with a mechanical behavior near that of bulk iron
- availability of softer magnetoelastic materials would enable vibration harvesting with lower stresses and higher strains, in the 0.1–1% range, with a rubber-like behavior.
- Metglas has been proposed for energy harvesting, has the advantage that it can be laminated to achieve a higher energy density.
- The material is a Fe-based amorphous ribbon with excellent gnetic softness and elastic response, and its production is in principle cheaper than Fe-Ga and Fe-Tb-Dy alloys

Magnetostrictive Effects



Joule effect

- The most understood effect which is related to magnetostriction is the Joule effect. As the applied magnetic field increases, magnetic domains tend to rotate toward the field direction, resulting in a dimensional change



Joule Effect

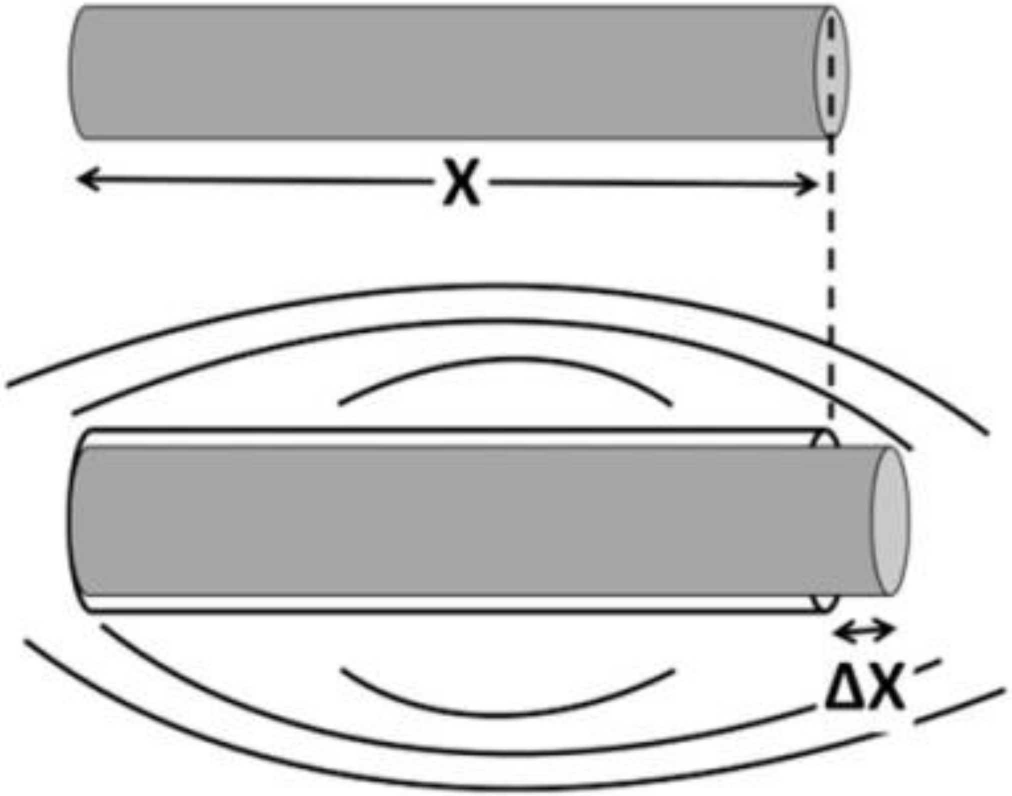
- The mechanical strain can be calculated

$$S = C^H + d_\sigma H$$

- C^H =Coefficient at constant field strength H
- d_σ is the magnetostrictive constant at constant stress.
- The magnetic field strength, H = Current (I) * Number of coil turns (N).

Villari Effect

- Another widely utilized effect related to magnetostriction is the *Villari Effect*.
- As the mechanical load on the magnetostrictive material increases, all magnetic domains tend to be aligned in the basal plane perpendicular to the load and there is a change in the magnetic flux density



Villari Effect

It can be analyzed using Equation The magnetic induction

$$B = d\sigma + \mu^{\sigma}$$

where d is magnetostrictive constant,
σ is stress change,
μ^{σ} is permeability at constant mechanical stress σ.

Wiedemann Effect

- Another effect related to magnetostriction is the Wiedemann effect. The physical background to this effect is similar to that of the Joule effect, but instead of a purely tensile or compressive strain forming as a result of the magnetic field, there is a shear strain which results in a torsional displacement of the ferromagnetic material

Matteucci Effect

- The inverse Wiedemann effect, known as the Matteucci effect, is the change in axial magnetization of a current carrying wire when it is twisted .
- It is observable in amorphous wires with helical domain structure, which can be obtained by twisting the wire, or annealing under twist. Alternating current fed to a coil creates a longitudinal magnetic field in a sample, and this, in turn, creates a magnetic flux density in the sample.

Barret Effect

- In certain extreme operational conditions, the volume of the material may change in response to a magnetic field. This effect is called Barret effect or volume magnetostriction.
- This volume change in response to a magnetic field and is so small that it can be neglected under normal operational conditions. The effect has little applicability in smart structure systems.

Nagaoka–Honda Effect

- The Nagaoka–Honda effect is the inverse of the Barret effect. This effect is the change of magnetic state caused by a change in the volume of a sample because of hydrostatic pressure.
- Due to the extreme operational conditions required to make it possible to detect these effects connected with the volume change, they have not found wide use in the industry

ΔE Effect

- The ΔE-effect is another effect related to magnetostriction. It is the change of the Young's Modulus E due to a change in the magnetic field. Due to the change of Young's modulus, there is a change in the velocity of sound inside magnetostrictive materials, and this can be observed in tuneable vibration and broadband sonar systems.
- The Young's modulus of magnetostrictive material is the inverse of the slope of the strain versus stress curve, which is estimated by piecewise linearization. The elasticity of magnetostrictive materials is composed of two separate but related attributes, namely the conventional stress-strain elasticity arising from interatomic forces and the magnetoelastic contribution due to the rotation of magnetic moments and ensuing strain which occur when stress is applied.

ΔE Effect

- his is known as the ΔE effect and is quantified by Equation
- $\Delta E = \frac{E_S - E_0}{E_0}$
- where E_0 is the minimum elastic modulus
- E_S is the elastic modulus at magnetic saturation.

ΔE Effect

- Because the strain produced by magnetic moment rotation adds to the non-magnetic strain, the material becomes softer when the moments are free to rotate.
- Note that the material becomes increasingly stiffer as saturation is approached and magnetic moment mobility decreases.
- The ΔE effect is small in nickel (ΔE = 0.06), but is quite large in Terfenol-D (ΔE up to 5) and certain transverse-field annealed Fe81B13.5Si3.5C2metglas ribbons (ΔE = 10)

Advantages of MS Materials

- 1. Noncontact easy installation: Due to the involvement of magnetic setup, there is no need for additional actuation circuit connection (electric set up). Exterior magnet is enough to operate the materials.
- 2. High reliability: The magnetostrictive is based on the waveguide theory and without mechanical parts, so it has no friction and wears. The entire transducer was placed in a stainless steel tube without contact with the measuring medium. Therefore, it is reliable and durable.
- 3. More stability: The magnetostrictive structure has more stability, multi-output mode, and has overvoltage/high frequency interference prevention.

Advantages of MS Materials

- 6. No insulation and maintenance: No regular insulation and maintenance that requires an input power protection function that is available with opposite polarity.
- 5. High accuracy: The magnetostrictive fluid meter is based on a waveguide pulse, it measures the replacement time of the start and end pulses, so its accuracy is very high.
- 6. Better resolution: Resolution better than 0.01% full scale, higher than the resolution of other sensors.

Advantages of MS Materials

- 7. Safety: The function is satisfactory without any precaution. In addition, with internally safe explosion protection the function of the magnetostrictive liquid meter is satisfactory.
- 8. Suitable for system automation: The output signal of the magnetostrictive measuring device (e.g., liquid meter) is standard, so the microcomputer is very suitable for information processing and easy entry into the network, which improves the automation of the measuring system.
- 9. Can be operated with low impedance amplifiers: The advantage of magnetostrictive sensors over other types of transducers is that they can be operated with conventional low impedance amplifiers, especially at frequencies well below resonance

Disadvantages of MS Materials

- 1. Eddy currents formation: at high frequency, there is a chance of eddy currents formation in the material that prevents the excitation of the core of the material. Such problems can be eliminated by using laminated materials.
- 2. Current leakage and demagnetization: Some of the challenges associated with the use of magnetostrictive materials are related to the effects of current leakage and demagnetization, which require the efficient design of the sensor’s magnetic circuit.

Disadvantages of MS Materials

- 3. Higher product cost: The production of advanced magnetostrictive joints is expensive because the conductors of advanced crystal converters must be fabricated using crystal growth techniques that provide directional hardening along the drive axis, combined with precision lamination, end diameter, and parallel machining of cut pieces.
- 4. Significant nonlinearity and hysteresis: In terms of device implementation, magnetostrictive materials have significant nonlinearity and hysteresis to the same extent as other intelligent materials, such as electrostrictive materials, in the case of a magnetostrictive fluid-level sensor.