Magnetic Hysteresis

A magnetic hysteresis, otherwise known as a hysteresis loop, is a representation of the magnetizing force (H) versus the magnetic flux density (B) of a ferromagnetic material. The curvature of the hysteresis is characteristic of the type of material being observed and can vary in size and shape (i.e. narrow or wide). The loop can be generated by using a Hall Effect sensor to measure the amount of magnetic field at various points - when in the presence of a magnetic field, when it is removed from the magnetic field, and when a force is applied to bring the magnetic flux back to zero. These loops are important in the memory capacity of devices for audio recording or magnetic storage of data on computer disks.

Introduction

Hysteresis loops are generated from the observation of ferromagnetic materials. Ferromagnetic materials are the most common of the five classes of magnetic materials: diamagnetic, paramagnetic, ferrimagnetic, ferromagnetic, and antiferromagnetic. Without a magnetic field, ferromagnetic materials exhibit paramagnetic behavior wherein their magnetic dipole moments are random and disordered as seen in Figure 1a. Once a ferromagnetic material is introduced to a magnetic field, however, their dipole moments align parallel and in the same direction resulting in a much stronger magnetic field (Figure 1b). These dipole moments are so highly ordered that when removed from the magnetic field, there is still some remnant magnetization. In order to reduce the magnetic flux back to zero, a coercive force must be

Figure 1. The magnetic dipole moments for (a) paramagnetic and (b) ferromagnetic materials.
applied wherein the dipole moments cancel each other out. This hysteresis loop therefore summarizes the pathway that a ferromagnetic material takes from the addition and removal of a magnetizing force.

**Hysteresis Loop Structure**

Hysteresis loops begin at a starting point (H=0) wherein its magnetic dipole moments are disoriented and the material portrays paramagnetism. When a magnetizing force (H) is adding to the material, it follows the pathway up to the saturation point (+Hs). At this point all the magnetic dipole moments are aligned in the direction of the magnetizing force and the magnetic flux no longer increases. When H is reduced to zero, some remnant magnetization remains; this point is known as the retentivity point (+Br). In order to remove this remnant magnetization, a coercive magnetizing force is applied in the reverse direction. The point in which there is no longer a magnetic flux (B=0) due to the cancelation of dipole moments acting in opposite directions is known as the coercivity point (-Hc). As the magnetizing force increases in the negative direction, the same saturation occurs as it did before however in the opposite direction (-Hs). The loop continues with an equal but opposite retentivity point (-Br) and coercivity point (+Hc) until its original saturation point (+Hs). Figure 2 portrays this full cycle hysteresis loop wherein points a and d are the +/- Hs, points b and e are the +/- Br, and points c and f are the +/- Hc. The magnetic dipole spins at these respective points can be seen in Figure 3 wherein the spins begin disoriented, then align with the magnetic field, and finally misalign until the moments cancel each other out to produce no net magnetic moment. Also notice that the curve does not ever go back to the origin (B and H=0). In order to get back to this point, the material will need to be demagnetized (i.e. return to having paramagnetic behavior) by hitting the material against a surface, reversing the direction of the magnetizing field, or heating it passed its Neel temperature. At this temperature, a ferromagnetic material becomes paramagnetic due to thermal fluctuations in the magnetic dipole moments that disorient the spins.

**Variations of Hysteresis Loops**

<table>
<thead>
<tr>
<th>Metal</th>
<th>Hs [A/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>$1.75 \times 10^6$</td>
</tr>
<tr>
<td>Co</td>
<td>$1.45 \times 10^6$</td>
</tr>
<tr>
<td>Metal</td>
<td>Hs [A/m]</td>
</tr>
<tr>
<td>-------</td>
<td>----------</td>
</tr>
<tr>
<td>Ni</td>
<td>$0.51 \times 10^6$</td>
</tr>
</tbody>
</table>

There is a significant amount of variation between the hysteresis loops of different materials. Table 1 shows the saturation variation of ferromagnetic Fe, Co, and Ni. Differences can also be found in the size and shape of a hysteresis loop. These variations directly relate to the properties that each material possesses. For instance, a narrow hysteresis loop implies a small amount of dissipated energy. This occurs as a result of its small area and therefore more frequently repeated reversals of applied magnetizing force. These narrower hysteresis loops also have high permeability (the slope of $B$ with respect to $H$) and low coercivity and magnetization. Soft magnetic materials used in devices that require alternating magnetic fields have these narrow hysteresis shapes. Wider hysteresis loops have high retentivity, coercivity, and saturation due to their larger hysteresis loop area. These loops are typically found in hard magnetic materials. Due to the size, these hysteresis loops have low initial permeability which leads to higher energy dissipation. For these reasons, they are utilized in permanent magnets which have high resistance to demagnetization. Demagnetization is more difficult to achieve in these wider hysteresis loops because there is a larger area to cover when reversing the hysteresis loop direction back to its original paramagnetic state. These hard and soft magnetic materials can be seen in Figure 4.

### Importance of Hysteresis Loops

Hysteresis loops are important in the construction of several electrical devices that are subject to rapid magnetism reversals or require memory storage. Soft magnetic materials (i.e. those with smaller and narrower hysteresis areas) and their rapid magnetism reversals are useful in electrical machinery that require minimal energy dissipation. Transformers and cores found in electric motors benefit from these types of materials as there is less energy wasted in the form of heat. Hard magnetic materials (i.e. loops with larger areas) have much higher retentivity and coercivity. This results in higher remnant magnetization useful in permanent magnets where demagnetization is difficult to achieve. Hard magnetic materials are also useful in memory devices such as audio recording, computer disk drives, and credit cards. The high coercivity found in these materials ensure that memory is not easily erased.

### Questions

1. Label the following hysteresis loop.
2. What are 3 ways to demagnetize a ferromagnetic material?

3. Which of these elements (Fe, Co, Cr, Ni) will not create a hysteresis loop? Why?

**Answers**

1. a) Saturation point - $H_s$
   
   b) Retentivity point - $B_r$
   
   c) Coercivity point - $H_c$

2. Hit the ferromagnetic material against a surface to disorient the magnetic dipole moments, reverse the direction of the hysteresis loop, heat the material above its critical temperature.

3. Cr will not create a hysteresis loop because it is antiferromagnetic. Fe, Co, and Ni are each ferromagnetic and will therefore create a hysteresis loop.

**Additional Links**

- Antiferromagnetism
- Coercivity (Wikipedia)
- Diamagnetism (Wikipedia)
- Ferrimagnetism
- Ferromagnetism (Wikipedia)
- Hysteresis in Magnetic Materials (Hyperphysics)
- The Hysteresis Loop and Magnetic Properties (NDT)
- Magnetic Hysteresis (Wikipedia)
- Magnetic Properties
- Magnetic Saturation (Wikipedia)
References


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