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ANALISYS AND INVESTIGATION OF HIGH-FREQUENCY FERROMAGNETIC MATERIALS: A SHORT REVIEW[11]

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Abstract: *The modern development of soft magnetic leads to the design and production of highly efficient and compact electromagnetic devices. They are widely used in the fields of measuring technology, automation, electrical engineering, electronics, and etc. Soft magnetic materials are characterized by relatively high saturation magnetization, low coercive intensity, small hysteresis curve area, and respectively small over-magnetization losses. Determining the electrical and magnetic properties and characteristics of magnetic materials with high accuracy and in a wide frequency range is an important requirement for accurate modelling, design, and research of various electrical and telecommunications devices. These characteristics depend on a number of factors such as frequency, temperature, homogeneity, isotropy, and others. The losses of eddy currents in the core of the magnetic component depend on its electrical properties. In addition to conducting a magnetic field, ferromagnetic materials are used to ensure the electromagnetic compatibility (EMC) of electrical products through magnetic fields (at low frequencies) and to reduce the levels of eddy currents (at high frequencies). Shielding can be an effective means of reducing electromagnetic fields generated by a source and is often built into the design of equipment to limit electromagnetic emissions.*

Keywords: *Ferromagnetic Materials, High-Frequency, Soft Ferrite, Electromagnetic Compatibility.*

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INTRODUCTION

Magnetic material is widely used in the electrical power and electronic industry. The ferromagnetic coupling curve was discovered first time by Warburg and Ewing in 1881.

So, firstly we can say that ferromagnetism is the basic mechanism by which certain materials form permanent magnets or are attracted to magnets (Bordianu A. 2017). In daily life, we use this principle for relays, electromagnets, and many more.

When we talk about the properties of ferromagnetic materials we should understand and the concept of domain. It is generally a small locale in these materials that has a particular spin alignment because of quantum mechanical exertion. The permeability of these materials is extremely high, sometimes it can be several thousand (Codescu M., Kappel W., Chitanu E. and Manta E. 2017). After that, it will happen the reverse action when electron spin and orbital motion will not get eliminated in these materials.

There are 2 types of ferromagnetic materials: soft ferromagnetic materials and hard ferromagnetic materials (Ionita V., Covaliu C. 2011).

• The soft ones have high permeability, also they can be magnetized and demagnetized easily. Some examples are iron, nickel, aluminium, tungsten, and cobalt. These materials are used for telephones receivers, electromagnets, relays, inductors, and many more.

• The hard ones have less permeability, they can’t be magnetized and demagnetized easily. Some examples are cobalt steel, some alloys of cobalt. The properties of these let them be implemented in speakers, measuring tools, and many others.

EXPOSITION

The main parameters that characterize the magnetic field are the magnetic induction B, magnetization μ, and magnetic field intensity H (Fig. 1).

$$B=\mu 0.H \quad (1)$$

There is another important parameter called the magnetic susceptibility, χ, which is a measure of the quality of the magnetic material and is defined as the magnetization produced per unit applied magnetic field.

$$\chi = M/H \quad (2)$$

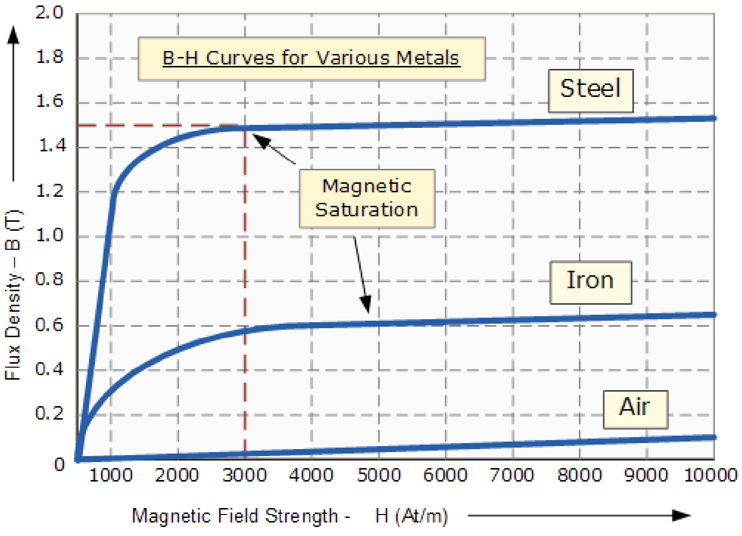

Fig. 1. The relationship between magnetic field and flux density
(Source: http://www.electronics-tutorials.ws/electromagnetism/magnetic-hysteresis.html)

There are three ways in which materials respond to magnetic fields (Mihailescu B., Svasta P. and Vasile A. 2012). They are classified according to susceptibility χ

- Diamagnetism - small and negative χ
- Paramagnetism - small and positive χ
- Ferromagnetism - large and positive χ

Hysteresis Loop is determined from graphic dependence B (H) at cycling change of the magnetic field intensity between two of its values. The main parameters of the hysteresis loop are induction Bs, residual induction Br, coercive intensity Hc, and area of the cycle, characterizing the hysteresis losses Ph for a remagnetizing (Fig. 2).

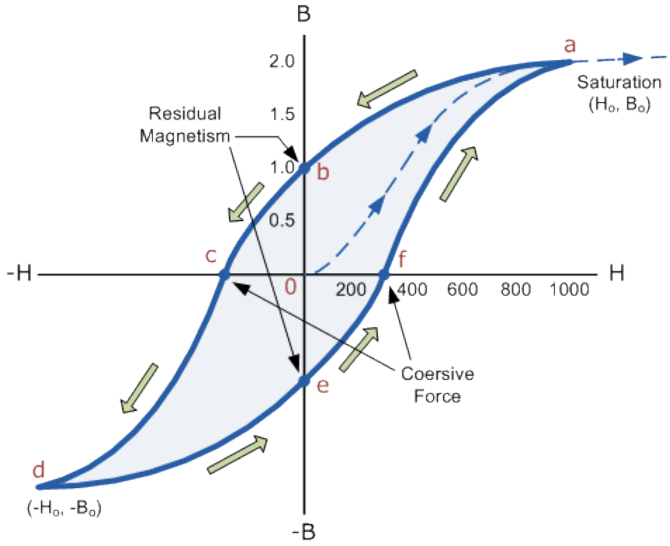

Fig. 2. About the main parameters of the hysteresis loop
(Source: http://www.electronics-tutorials.ws/electromagnetism/magnetic-hysteresis.html)

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 and their rapid magnetism reversals are useful in electrical machinery that require minimal energy dissipation (Petrescu, L.-G.; Petrescu, M.-C.; Ioniță, V.; Cazacu, E.; Constantinescu, C.-D. 2019). 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 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 ensures that memory is not easily erased.

Ferromagnetic materials are dived into 2 groups: un-magnetized ferromagnetic materials and magnetized materials (Ropoteanu C., Svasta P. and Ionescu C. 2016).

So, we begin with un-magnetized materials. The atoms inside of the materials, form different domains with different directions of the magnetic moment. Hence, the material remains un-magnetized. Let see a picture to understand better (Fig. 3a).

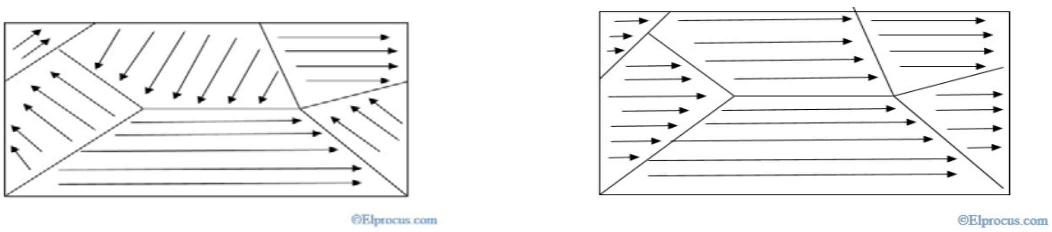

Fig. 3. Domains in un-magnetized (a) and magnetized (b) ferromagnetic materials

The interesting thing about un-magnetized materials is that if we apply an external magnetic field, domains will start to rotate and align in the direction of the magnetic field. The magnetic moments of domains are parallel to the magnetic field in ferromagnetism because these domains are also aligning in the same direction (Fig. 3b).

According to the value of Hc the materials are divided into:

- Soft magnets (low coercivity H_c < 1000 A·m^{-1} and large magnetic permeability)
- Medium magnets (1000 A·m^{-1} < H_c < 50000 A·m^{-1})
- hard magnets (high coercivity H_c > 50000 A·m^{-1}) and relatively small magnetic permeability.

In a separate group are included special-purpose materials - materials with a rectangular hysteresis loop, UHF ferrites, magnetostrictive, thermomagnetic, etc.

Advanced soft and hard ferrites and application

And last, but not least, we have ferrites. We can say that this classification of ferromagnetic materials is special because they contain proprieties between ferromagnetic and non-ferromagnetic materials. These contain very small particles of ferromagnetic materials that have a very high permeability nature. Also, ferrites are classified into 2 categories, soft and hard ferrites (Spatariu E., Popescu M. and Naaji A. 2015).

Soft ferrites have high resistance and have a square shape of hysteresis. The resistivity is in the range of 109ohm-cm. This range is because of eddy current resulting from the alternating fields are so decreased and the properties exhibited by these materials allow them to be used in high frequencies like microwaves. The main soft ferrites that are used in applications are Mn-Zn (Manganese-Zinc) and Ni-Zn (Nickel-Zinc).

One of the applications of soft ferrites is where the field it is on high permeability and low power loose are required as represented by Mn-Zn and Ni-Zn ferrites with less than 300MHz. Despite of this, the other region tends to be up to 300MHz, the border of microwaves, where magnetic resonance is involved. Mn-Zn ferrites are mainly used flyback transformers for television. On the other hand, Ni-Zn ferrites are used in rotary transformers at high frequencies than Mn-Zn. Scientists discovered that one of the soft ferrites applications as developers with electronic copying machines for office usage, electromagnetic noise shield, lasers where high-frequency and high-current pulses are used.

The advantages are high resistivity, a wide range of operating frequencies can be supported, with high permeability low loss can be achieved, different types of material according to applications can be selected, flexibility in the choice of core shape, low cost can be achieved. The disadvantages are that they are fragile material, the saturation flux density is low, thermal conductivity is poor and tensile strength is low.

There are main differences between Mn-Zn and Ni-Zn. First of all, Manganese-Zinc is the most common type of soft ferrite that is used in many applications, compare to nickel-zinc ferrites. Mn-Zn materials usually support a temperature range of more than 200°C. Ni-Zn ferrites have low permeability, compare to Mn-Zn materials who have high permeability. The Mn-Zn ferrite materials are usually used up to frequencies <10MHz. About Ni-Zn ferrites we can say that is high material resistivity. It’s very high, compare to Mn-Zn ferrites.

Applications of Mn-Zn ferrites are very vast and they are very useful for our lives. We can say that Mn-Zn ferrites have a broad area of application due to high saturation magnetization, low power loss, and high initial permeability. Also, these are used for microwave devices, magnetic fluid, radar-absorbing systems, bio-medical, water purification, and so on. Nowadays, we are fighting electromagnetic radiation pollution in the environment. These radiations reduce the efficiency and performance of electronic instruments and thus decrease their lifetime and safety. So, as we said before, Mn-Zn ferrites are soft ferrites and have high electrochemical stability, high permeability, and low power losses. Basically, the nanoparticles of ferrites can be used to absorb the excess radiations. Also, another major application of Mn-Zn is in the battle of COVID-19 pandemics. Nanoparticles of Mn-Zn have unique physical and chemical proprieties that have associated benefits in the development of potentially therapeutic drugs.

• Hard ferrites have a hexagonal shape and have a high-density nature. They are used for relays, employed motors, and so on. Even they are used for toys, door closer systems, latches, and many more.

Usage of ferromagnetic materials

The uses of ferromagnetic materials are so vast. First about permanent magnets (Fig. 4). The ideal material of this process should possess high retentivity and high coercivity so the magnetization can last a long time. Examples of this type of material are steel and alnico (an alloy of Al, Co, and Ni). The most important thing about ferromagnetic usage is that materials can store memory. They are used for modern computers, telephones, credit cards. Also, ferromagnetic materials are used for cars parts like a starter of the engine, relays (who are more like switches), and alternators.

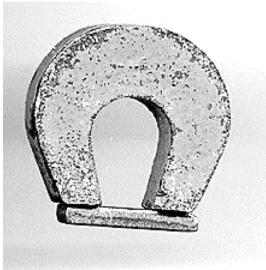

Fig. 4. Alnico magnet

Starter engine

This device is used to rotate an internal-combustion engine. There are 3 types of starters: electric, pneumatic and hydraulic. The electric one is the most used (Fig. 5). The mechanics on it is based on permanent magnets. The components of electric starter are main housing, freewheel and pinion gear, armature, field coils with brushes, brush-carrier, and solenoid. When DC power from the starting battery is applied to the solenoid, usually through a key-operated switch, the solenoid engages a lever that pushes out the drive pinion on the starter driveshaft and meshes the pinion with the starter ring gear on the flywheel of the engine.

Fig. 5. Common view of a starter engine

Relays

The relays are kind of switches that turn on or turn off a circuit. The type most commonly used in the automotive industry is an electro-mechanically operated switch. They are found in all vehicles, boats, trucks, vans, and many more. Relays are used to switch high current to small current. One relay consists of the electromagnet coil, the switch, and a spring (Fig. 6). The spring holds the switch in position until a current gets passed through the coil. The coil then generates the magnetic field which moves the switch on and off.

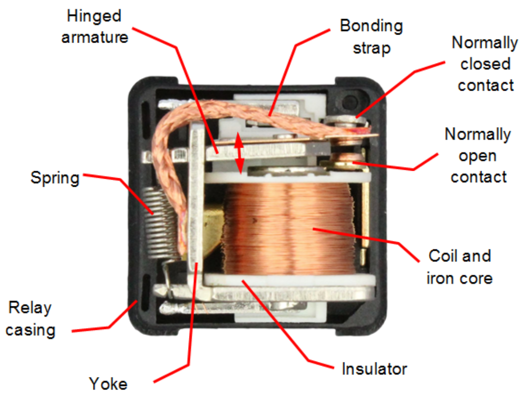

Fig. 6. Main parts of an electromagnetic relay
(source: https://www.truckelectrics.com/blogs/news/automotive-relay-guide-what-is-a-relay)

When the coil is supplied with voltage a magnetic field is generated around it which pulls the hinged armature down onto the contact. This completes the 'high' current circuit between the terminals and the relay is said to be energized. When voltage is removed from the coil terminal the spring pulls the armature back into it is 'at rest' position and breaks the circuit between the terminals. So, by applying or removing power to the coil (the low current circuit) we switch the high current circuit on or off.

Alternator

An alternator is an electrical generator who converts mechanical energy to electrical energy in the form of alternating current. Many of alternators used rotating magnetic field with a stationary armature (Fig. 7).

The battery provides electricity needed for the starter motor to start the car. When the car is running, the alternator generates energy to feed the electrical system and charge the battery. The alternator used to be called a generator, and it works in a similar way. An alternator works together with the battery to supply power for the electrical components of the vehicle. The output of an alternator is direct current (DC). When the alternator pulley is rotated, alternating current (AC) passes through a magnetic field and an electrical current is generated. This is then converted to DC via the rectifier.

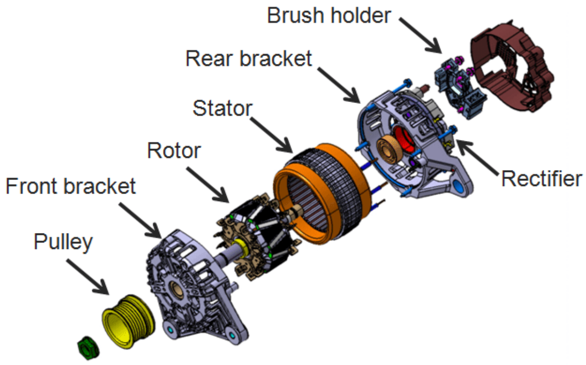

Fig. 7. Main components of an alternator (source: https://www.autoelectro.co.uk/alternators)

CONCLUSION

The report provides a brief overview of the main properties and applications of ferromagnetic materials. Particular attention is paid to soft magnetic materials. Ferromagnetic materials have been found to be very important for the proper maintenance of our devices. Their applications are everywhere in the modern world - cars, engines, computers, airplanes, radars, satellites, communications, lighting, electrical networks, etc. Ferromagnetic materials are constantly evolving and finding applications in more and more fields of technology.

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