Magnetic field of a non-circular toroidal magnet

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1. Magnetic field leakage of a toroidal magnet

A round toroidal magnet does not radiate magnetic field in space because all the field lines are confined in the magnet. For non-circular toroidal magnet, it is thought that magnetic field leaks out only slightly. But rigorous theoretical and experimental studies that verify this hypothesis are rare.

I have done a simple experiment to show how magnetic field leaks out from a non-circular toroidal magnet. Here is the video of my experiment:
http://youtu.be/A8Zcb0g13e8

An iron wire suspended to a thread is immersed in magnetic field to visualize its strength. Attracted, the iron wire makes the thread to incline and its angle is a good indication of the force of the field. In the following figures, I have given estimated ratios between the forces in the cross section of the horseshoe and that in the tested field of different situations.

a) Field in the cross section of the horseshoe and near its shoulder

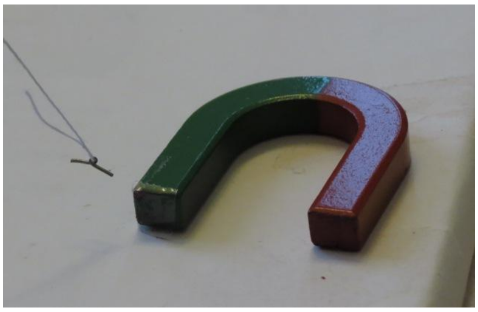

Figure 1 100% magnetic force

Figure 2 50%

b) Field parallel to the surface of the toroid

Figure 3 5%

Figure 4 10%

c) Fields near the shoulders of the toroid

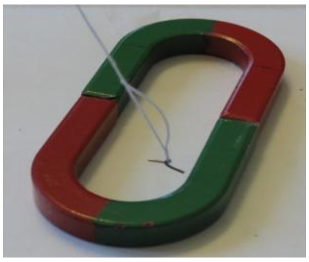

Figure 5 50%

Figure 6 40%

Figure 7 50%

Figure 8 40%

2. Analyze of the experiment

First, the magnetic force in the cross section of one horseshoe is tested. Then, 2 horseshoes are brought together to form a closed toroid. The iron wire tests the variation of the force over the gap as it is being closed. Effectively the force disappears when the tips of the 2 horseshoes joint together.

However, as the Figure 3 shows, the force does not disappear completely. It remains a small attraction in this region. I estimate this force to be about 5% of that in the cross section. This force is an important discovery because of the particular characteristic of this attraction: the iron wire is parallel to the surface of the magnet. At the round top of the toroid too, the iron wire is parallel to the surface (see the Figure 4).

This attraction is special because magnetic equilibrium is unstable. The nearer to the surface the iron is, the stronger the force becomes. As the pull on one tip is stronger than the other, iron wire always tilts completely and points to the magnet. But why is this one parallel to the surface? This phenomenon is never studied before and classical electromagnetism cannot explain it. I find out this phenomenon because my theory predicts this. I call this kind of field non-Lorentzian field. See **Non-Lorentzian Magnetic force and Aharonov-Bohm effect in CRT (PDF), (Word).**

The Figure 5, Figure 6, Figure 7 and Figure 8 show that magnetic field leaks out strongly near the shoulders of the horseshoe. The force is stronger inside the toroid than outside. I estimate that the force is about 40% to 50% of that in the cross section.

This makes me to think about why field lines leak out from a non-circular toroidal magnet. The shoulders of the horseshoe are conjunctions between straight sections and round sections where the curvature of the surface changes. So, the field lines do not bend as the surfaces do.

In magnetic circuit design, magnetic field is thought to "flow" in the iron core like electric current. My experiment shows that this is not a valid analogy. In fact, electric current is a flow of electrons that are matter particles whereas magnetic fields are not. There is no reason that magnetic field lines are held by the surface.

In comparison, electric fields are perpendicular to the surface of conductor and do cross it. This is because electric charges rearrange themselves to stay immobile. Magnetic field in iron core is created by bound currents that do not move freely and whose pattern creates magnetic field component perpendicular to the surface that leaks out. This condition is expressed by the following equation using the normal vector **n**, field intensity vectors in the air $\mathbf{B}_1$ and in the iron core $\mathbf{B}_2$:

$$\boldsymbol{n}(\mathbf{B_1} - \mathbf{B_2}) = 0 \qquad (1)$$

See “Introduction to Electromagnetic Fields” Clayton R. Paul, Keith W. White, Syed A. Nasar . Page 235.

3. Comments

This experiment is a by-product of my search for showing my theory experimentally. I thought the magnetic field around a toroidal magnet is non-Lorentzian and exert weak force on iron. But the force I find is quite strong. As it turned out, the magnetic field in the vicinity of a toroidal magnet is not a leakage but a normal out flow.

I have drawn 3 conclusions with this study:

1. The analogy between electric current and magnetic field inside a magnetic circuit is wrong.
2. Magnetic field flows out a non-circular toroid magnet from the regions where the curvature of the surface changes.
3. In the region where the curvature is constant, there exists a new kind of magnetic field of parallel nature.

This study gives a way to determine the magnetic field flux in the iron core using the field intensity measured in the air and the field conservation law. The conclusion 2 gives a theoretical base for making the surface of the iron core of high performance transformers to fit the field lines. As the field vectors are parallel to the surface, the loss of magnetic energy will be minimized and the impact on the environment limited.