Continuous rotation of a circular coil experiment

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22 June 2017

Abstract: Experiment that shows continuous rotation of a coil in its plane revealing the action of a magnetic force that is parallel to current.

There is a long standing debate about whether tangential magnetic force exists. In «Tangential magnetic force experiment with circular coil» I discussed this force and presented an experiment that showed the action of this force. But, as the rotation of the coil in that experiment was limited to a small angle, it does not show that tangential force exists all over the coil. So, I have carried out the present experiment that shows continuous rotation of the coil to make clear that tangential force has the same value around the coil.

1. Coil and current

The circuit of this experiment is shown in **Figure 1**. From an external lead a current *I* flows into a ring of bare copper which sends the current into the coil via a conductor bridge. The current flows multiple turns in the coil then get out through the central lead. The coil is circular and free to rotate about its center. If it rotates, the driving force must be parallel to its current, which will reveal the action of a tangential magnetic force on the current.

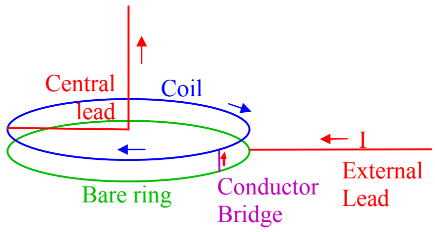

Figure 1

For the weak magnetic force to be able to rotate the coil, the assembly coil-ring is put floating on water because water opposes small resistance to the rotation of the assembly. For the coil to be able to rotate continuously, current must be connected to the peripheral wire of the coil without touching it. This is achieved by adding salt to water which makes water conductor and connects the external lead to the ring without contact. Two coils have been tested. In the case of **Figure 2**, the coil and the ring are separated so that the ring is under water to get the current while the coil is above water. In the case of **Figure 3**, the coil and the ring are joined together and both are under water.


Figure 2
The ring under water, the coil above water.


Figure 3
The ring and coil joined together, both under water.

2. Continuous rotation of the coil

In the experiment, the coil rotates immediately and continuously soon after the current is connected. The video of the experiment is on YouTube https://youtu.be/9162Qw-wNow .

Is the rotation due to Lorentz force? Being perpendicular to the coil's peripheral wire, Lorentz force on the latter makes no driving force. The only wire that bears Lorentz force in the direction of the rotation is the central lead, which in an external and vertical magnetic field would create a rotating torque. The current in the experiment being alternating, the average Lorentz force created by any constant external magnetic field such as the terrestrial field is zero.

Secondly, the magnetic field of the circuit itself is non uniform, which would create varying Lorentz force on the central lead and varying speed of rotation. Because the rotation is constant, the driving force is constant and then, cannot be Lorentz force on the central lead.

In consequence, the rotation of the coil is driven by the force on the peripheral wire which is parallel to current. The major magnetic force on the coil comes from the nearest current: the external lead. This experiment is a clear evidence that parallel-to-current magnetic force exists.

3. Creation of the tangential force

Tangential force can be created by radial force between point-like objects. For example, gravitational force is a radial force that lies on the radial vector joining 2 masses. Let us see the ball in **Figure 4** which is rolling on a slope in the gravitation field of the Earth. The force accelerating the ball F_s is a tangential force because it is parallel the motion of the ball.

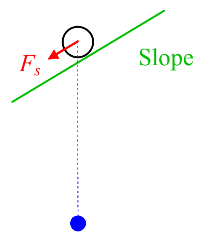

Figure 4

Tangential magnetic force between current elements is created in the same way. Let us imagine that in **Figure 4** a current element is at the place of the center of the Earth and the ball is a second current flowing in a wire represented by the slope. As the ball-current can only flow in the direction of the slope-wire, the magnetic force driving the current is the force's component parallel to the wire, that is, parallel to the current. This component is a tangential magnetic force.

Figure 5 explains the tangential magnetic forces on the coil of the experiment. The force F_1 that the current element I_0 exerts on the current element I_1 lies on the radial line joining I_0 and I_1. In the same way, the force on the opposite current element I_2 is F_2. When we add F_1 and F_2 together, we obtain the tangential magnetic force $F_1 + F_2$ that drives the coil.

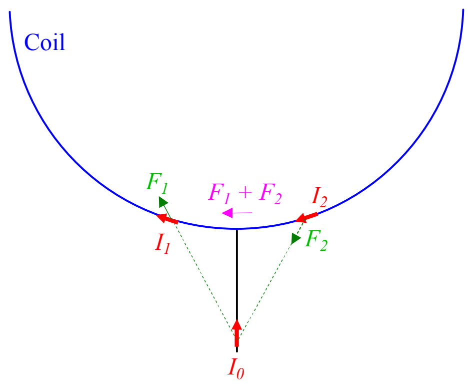

Figure 5
The tangential force $F_1 + F_2$ is created by the radial force F_1 and F_2 on currents I_1 and I_2.

So, in addition to prove the existence of tangential magnetic force, the rotation of the coil proves also that magnetic force between 2 current elements is radial.

Since the magnetic force that drives the coil in the experiment is not predicted by Lorentz force law, we have to find another law that expresses radial magnetic force. This law could be the original formula proposed by André-Marie Ampère in 1822 which is the following expression:

$$d\boldsymbol{F}_2 = -\frac{\mu_0}{4\pi}\left(2d\boldsymbol{I}_1 \cdot d\boldsymbol{I}_2 - 3(d\boldsymbol{I}_1 \cdot \boldsymbol{e}_r)(d\boldsymbol{I}_2 \cdot \boldsymbol{e}_r)\right)\frac{\boldsymbol{e}_r}{r^2} \qquad \textbf{(1)}$$

See page 29 of «Ampère's Electrodynamics» by A. K. T. Assis and J. P. M. C. Chaib).

This law can explain the magnetic force on an infinite straight current which should be parallel to the current. In fact, just imagine the radius of the coil in **Figure 5** to become infinite and the wire near the force $F_1 + F_2$ will become an infinite straight wire. In this case, the force $F_1 + F_2$ is parallel to the infinite straight current.

4. Caption for the video

Continuous rotation of a circular coil experiment
This is a homopolar motor without magnet, only electric current is involved. The coil is circular so that only parallel-to-current magnetic force can rotate it.

1) The circuit of the assembly Coil-Ring-Lead

Tests with alternating current

2) Low voltage (~30V)
3) As soon as the current is connected the coil starts to rotate
4) The coil rotates continuously showing that a tangential force exists on the entire coil
5) The coil makes several turns showing that the force is constant
6) High voltage (~80V)
7) The coil rotates faster
8) But the current is too strong and the heat generated by the coil boils water into steam
9) When the lead is connected before immersion, sparks appear

Tests with direct current. The coil is completely immersed in water.

10) The coil rotates but there is a strong electrolysis as the bubbles reveal
11) The surface of the ring becomes rapidly less conductor making the current weaker and rotation slower.
12) I switched to alternating current to solve this problem

This experiment proves that tangential magnetic force exists

The external lead making other angles with the coil

13) In comparison with horizontal external current
14) Vertical external current seems to make stronger force and the coil rotates faster
15) The external current in the same direction than the current in the coil
16) The external current in the opposite direction than the current in the coil

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21 June 2017