the general science journal

Resolution of the Faraday Paradox

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More than 150 years ago, Michael Faraday discovered that in a unipolar generator with a simultaneous rotation of a magnet and a disk, a voltmeter in a fixed measuring circuit shows an EMF. The question arose whether the field rotates with the magnet or remains stationary. Numerous researchers are still unsuccessfully trying to answer this question, and it is generally accepted that direct measurement of emf is impossible. Einstein begins the article "On the Electrodynamics of Moving Bodies" with the statement that "the electrodynamic interaction between a magnet and a conductor with current ... depends only on the relative motion of the conductor and magnet" [1] Supporters of the SRT still claim that unipolar induction is a relativistic Effect.

This paper presents the results of our study of the Faraday paradox. It is shown that conventional measurement methods in principle do not allow to experimentally solve the problem of field rotation. The method of measuring the emf we developed, allowed us to prove that the rotation of the magnet is not equivalent to the rotation of the conductor around the magnet, while simultaneously rotating the disk and the magnet, the field does not rotate and EMF is induced only in the disk.

Essence of the Faraday Paradox

The Faraday paradox arose from the fact that conventional measuring devices do not allow us to determine where the emf is induced in the disk of a unipolar generator or in a measuring circuit.

The problem is that to measure the induced emf, a voltmeter is connected to the disk with two wires, as a result of which the rotating disk and the fixed wires form a closed loop in which the same emf is induced both in case the field rotates and in case the field is stationary.

In the simplest case, when the disk rotates and the magnet is stationary, the emf is obviously induced only in the disk and the voltmeter connected to it by sliding contacts shows exactly this emf (Fig. 1a).

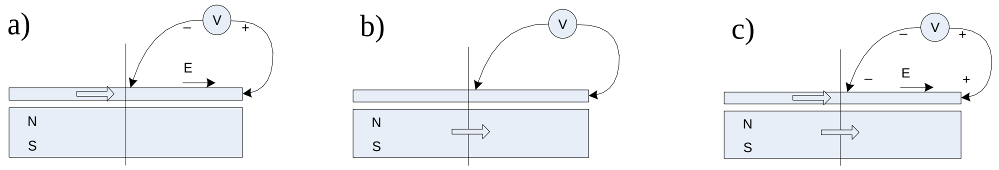


Fig.1

The problem occurs when only the magnet rotates (Fig. 1b) or when the magnet and the disk rotate together (Fig. 1c)

So, in the case of Fig. 1b, the voltmeter shows zero, but this may be because the field does not rotate and the emf is simply not induced anywhere, or because the field rotates and therefore an equal opposing emf is induced in the disk and in the measuring wires. In the case of Fig.1c, the voltmeter shows the emf, but it may be the emf that is induced in the rotating disk if the field does not rotate, or it is the emf that is induced only in the fixed wires of the measuring circuit, if the field rotates.

In both these cases, it is impossible to say for certain where the emf is induced, since the voltmeter, although it is connected to the disc, shows not only the emf of the disc, but the emf of the circuit consisting of the disc and the measuring wires.

As can be seen from Fig. 2, no attempt to somehow “remove” the wires from the magnet field can eliminate the generation of emf in them, since the same emf is induced on the section of the mn wire as on the km section of the disk.

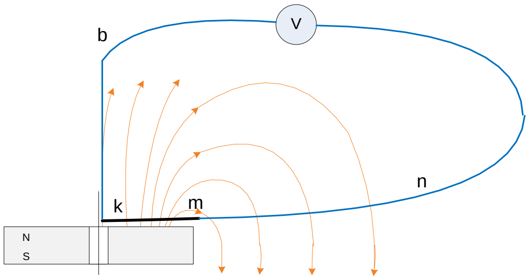


Fig.2

You can eliminate the EMF generation in one of the wires if you take it away from the disk, strictly along the axis of rotation of the magnet (segment kb). We used this fact to create the field rotation detector described below. However, it is basically impossible to exclude emf generation in both wires simultaneously.

The concept of the circuit and the Faraday formula $E=w\frac{d\Phi}{dt}$ are not sufficient for the study of a unipolar generator. This formula works perfectly in all practical cases: when analyzing transformers, electromagnets, various sensors and all electrical machines, both direct and alternating current, but it turns out to be useless when analyzing unipolar devices. But in order to understand the physical meaning of the processes, it is necessary to consider each conductor separately in the circuit and use the formula for determining the emf, $E=BlV$, where B is the field induction, l is the conductor length, V is the linear velocity of motion. This is well illustrated by the example of a sensor with a wire loop laid in the road surface, which gives a signal to open the gate or to switch the traffic light when a car hits it. But this sensor does not feel when a bicycle enters the circuit. Because is the weight of the bike not enough to change the quality of the circuit? Of course, but this is not entirely true. The same sensor works fine if the bike doesn’t just run into the circuit, but turns out to be exactly above the groove in which the wire is laid. And this happens because it is not the circuit that actually works, but the conductors that make up this circuit. Therefore, all our studies were carried out taking into account the emf $E = BLV$, induced in each individual conductor, and not in the abstract Faraday “contour”,

Conductor Motion Sensor Development Relative to the Axial Magnet Field

In order to resolve the Faraday paradox, it was necessary to find a way to measure the induction emf separately, without contact in a rotating disk or in the measuring wires. Therefore, the main goal of our research was the development of a measuring device.

In the first stage, we investigated the possibility of creating a sensor with shielded test leads that could measure only the emf induced in the disk, but did not react to the emf induced in the measuring wires. As a result, we concluded that a sensor with shielded wires cannot be created in principle. However, in the course of these studies, we discovered an effect that was not known to us: **screens that confidently protect the conductor from induced emf with a varying magnetic field do not work when the conductor moves relative to a uniform magnetic field.**

After trying to create a sensor with shielded wires, we decided to create a field motion detector that directly responds to both the movement of the conductor relative to the field and the movement of the field relative to the conductor. We were able to create such a detector by using our idea of measuring the induction emf with the connection of a voltmeter “at one end” to an amplifier, performed on a field-effect transistor with subsequent amplification of the signal by an operational amplifier. This detector made it possible to unequivocally prove that with the rotation of an axial magnet its field does not rotate and remains stationary relative to the inertial frame.

Attempt to Shield one Test Lead

When the conductor rotates around the magnet, the emf $E=BLV$ is induced in it . If the circuit rotates with respect to the magnet, two emfs are simultaneously induced in it and the resulting emf is determined by their difference, which is always zero.

We carried out the first measurements with the use of contact current collectors, but then, in order to eliminate the influence of the emulses arising on the contacts, we proceeded to contactless circuits similar to that of Fig.3.

The idea of measuring with shielding was to use a loop for measuring emf, one branch of which is shielded from the magnetic field and does not create counter-emf.

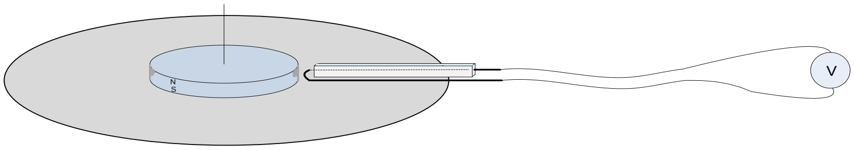


Fig.3

The half-shielded loop is mounted on a plastic disc, which can be manually rotated quickly around the axis of the magnet at some angle. When the wires going to the voltmeter are displaced, the same oppositely directed emf are induced in them. In the absence of a screen in both branches of a loop moving relative to the field, the same emf is induced and the device shows a zero. If one branch is shielded, the emf induced in the moving loop must be different and the instrument must see the difference in emf. If it turns out that such a loopback sensor reacts to movement relative to the field, it can be used to detect a rotating field: if the field rotates, the sensor located near the rotating magnet should produce an emf. The absence of emf proves that the field does not rotate. However, it was impossible to implement this idea, because in the course of research we found that no ferromagnetic shield does not protect the conductor from targeting emf in it, when the conductor rotates with respect to an axial magnet.

The most effective is the shield in which steel plates divert the field from the conductor (Fig.4). A Hall sensor placed inside such shield shows that when the magnet approaches, there is practically no field inside the shield. The reed switch placed inside this shield also does not work.

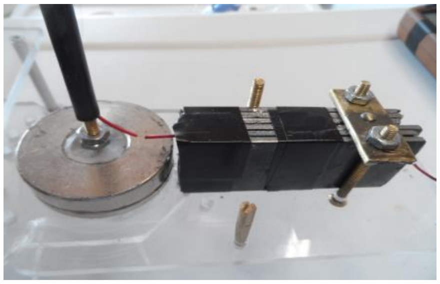


Fig.4

However, when a conductor with such shield rotates relative to an axial magnet, in both cases — when the conductor is placed in the shield or when there is no shield — the same EMF is induced in the conductor.

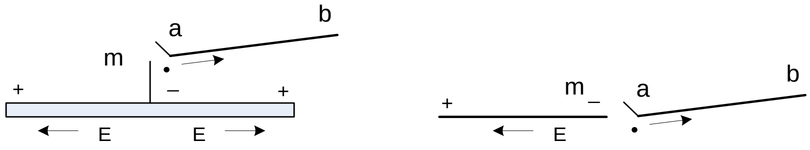
Disk or Conductor Motion Detector Relative to the Magnetic Field

To find out if a field rotates with a magnet, a detector is needed to determine if a voltage is induced in each individual element of a unipolar generator. In this case, there is no need to accurately measure the magnitude of the emf, but it is sufficient to determine the fact whether emf is induced, for example, in a rotating disk, or in a fixed disk, or in a rotating conductor, or in a fixed conductor. The possibility of such detection can be provided only by a measuring device connected to a rotating disk or conductor by one and not two conductors.

The principle of operation of such a detector is as follows.

When the disk rotates relative to a fixed axial magnet, it induces an emf E = BLV. Under the action of this emf, depending on the direction of rotation, the electrons are displaced to the axis of rotation or to the edge of the disk and a potential difference arises between the center of the disk and its edge. When the disk is rotated by the hand near the neodymium magnet, this potential difference amounts to fractions or units of millivolts.

The fact that electrons are displaced, for example, to the center of the disk (point m in Fig.5, a) or to one end of the conductor (point m in Fig. 5, b), means that at the center of the disk or at this the end of the conductor creates negative potential. This potential differs from the potential on a ball charged with static electricity only in size - it is measured not by kilovolts, but by millivolts.



a)

b)

Fig.5

If you attach an additional conductor ab to a charged point of a disk or conductor, a part of the charge will flow onto it and the conductor ab will also be charged. Here we should immediately note two circumstances:
- because of the small value of the emf and the very small electric capacity of the disk and the conductor, the potential at point m, is very small,
- due to the addition of an additional conductor, the potential of point m is greatly reduced.

Therefore, in the experiment with the measurement of potential, one should use a more massive disk, and the conductor ab should be made as short as possible.

We were able to detect the potential created in the center of the rotating drive of the induced emf by using a MIS transistor (an FET with an insulated gate), using its main property - a very large input resistance. When voltage is applied to the gate of the MIS transistor, the input current turns out to be almost zero, that is, the amplifier stage on this transistor does not load the input circuit.

If the gate of the transistor is connected to the point m with a short conductor, the gate potential will change and the current in the output circuit will change accordingly. That is, an amplifier cascade on a MDP transistor, connected to point m with only one conductor, makes it possible to detect the potential of this point.

To test the idea of detecting induced emf with "one terminal", we first used a conventional digital voltmeter - multimeter 10030S. In the extremely simplified setup shown in Fig.6, the disk rotates with a hand and the emf measured at the center of the disk by a field of a stationary magnet, is measured with a multimeter.

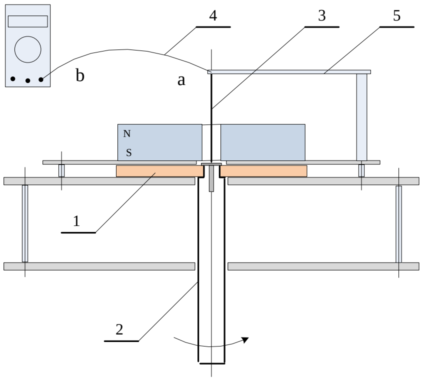


Fig.6

The aluminum disk 1 with a thickness of 5 mm is fixed on the shaft 2. A fixed neodymium magnet with a diameter of 50 mm (thickness 10 mm) is located above the disk. The potential formed in the center of the disk is transmitted by a fixed needle 3 and a short thin conductor ab (4) to the multimeter. The needle is held in a vertical position with a plastic stop 5. The appearance of the device is shown in Fig. 7.

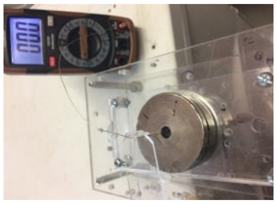


Fig.7

At the moment when the shaft begins to rotate by hand, an emf of about 0.2–0.4 millivolts arises on the disk (we can see this value of emf by connecting this or another device to the disk with two conductors). The multimeter shows the values of the emf, close to 0.2-0.4 mV only at the moment when the rotation starts and the emf appears, but then, when the charges drain from the disk, the signal becomes equal to zero. That is, due to the fact that the input impedance of the detector is not infinitely large, it actually reacts, not to the emf itself, but to its derivative - the signal at the output of this detector appears only when the induction emf changes (see attached video 1 – the signal from hand rotating disc). But this signal is quite enough to claim that the emf is induced in the disk.

Similarly, this detector can measure the potential at the inner end of a conductor rotating around a magnet (at point m in Fig. 8a)

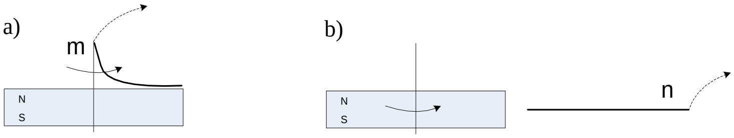


Fig.8

We carried out an additional test of the detector for the case of the motion of a prodator relative to a fixed magnet (video): the detector confidently responds to changes in the potential (see attached video 2 – detector check when moving near a magnet).

But if the magnet rotates, the detector produces no signal either during the acceleration of the magnet or at a constant rotational speed (see attached video 3 – rotation of the magnet around the detector), which unequivocally proves the motionless field. The detector signal also turns out to be zero, if in the setup of Fig.6 the disc and magnet are swapped and the magnet is rotated with a fixed disc.

Since the disk and the more so a single conductor turn out to be very low-power signal sources, we developed a detector in which the first amplification stage is performed on a MDP transistor, and the main signal amplification is performed by an operational amplifier OУ. The detector probe is connected to the gate of the MDP transistor, and the output voltage is applied to a voltmeter or an oscilloscope (Fig.9).

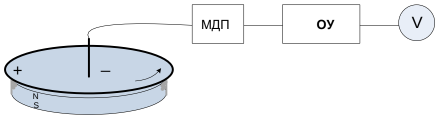


Fig.9

The amplifier has a large gain and therefore the detector is very sensitive to interference. But since we are only interested in the DC signal, the main noise, that is, the AC noise, is suppressed simply by introducing flexible negative feedback (capacitive OS).

The schematic diagram of the detector is shown in Fig.10. Input resistance R1 = (100 - 200) MOhm. The less this resistance, the faster the charge flows from the disk or conductor and the signal that appears when the disk is accelerated decreases to zero. Once again, we emphasize that with this detector we are not measuring, but only an indication of the emf.

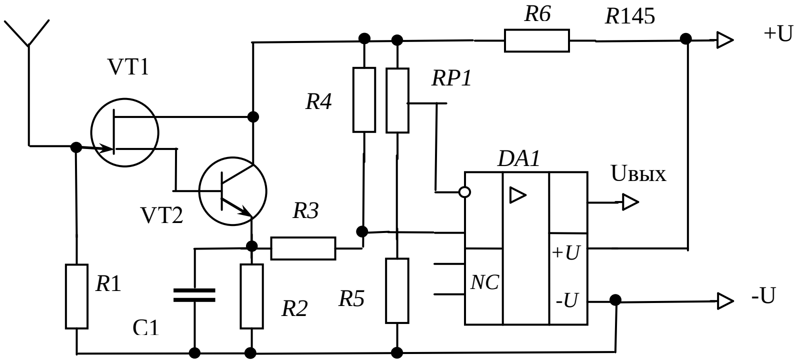


Рис.10

The value and sign of the output voltage of the detector connected to the center of the disk change when the speed and direction of disk rotation and the magnitude and direction of the emf change.

Conclusion

In the case of linear motion, the conductor or magnet moves relative to the inertial frame. In accordance with the principle of relativity, the motion of the conductor and magnet are equivalent: the same emf is induced in the conductor in both cases - when it moves relative to the magnet or when the magnet moves relative to the conductor

The situation is different with the relative rotation of the magnet and the conductor. In the case of rotation, the conductor and magnet move in a non-inertial system. Therefore, the principle of relativity does not apply to them and the rotation of the magnet is not equivalent to the rotation of the conductor.

The detector developed by us allowed us to determine that the emf is induced in the disk when it rotates relative to a stationary magnet, but is not induced either in a stationary disk or in a stationary measuring circuit when the magnet rotates. This makes it possible to unambiguously resolve the Faraday paradox: the field does not rotate together with a magnet, but remains stationary relative to the inertial frame, just as the orbits of satellites launched from the rotating Earth remain stationary rather than rotate with the Earth.

In the case of rotation, the conductor and magnet move in a non-inertial system. Therefore, the principle of relativity does not apply to them and the rotation of the magnet is not equivalent to the rotation of the conductor:

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