The theory of electromagnetic field motion. 5. Unipolar generator with a rotating magnet

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The unipolar generator with a rotating permanent magnet is considered in the article. On the basis of the theory of electromagnetic field motion and, in particular, of the principle of superposition, the method of calculating the EMF in a closed measuring loop is schematically set forth. It is shown that the magnetic field of a permanent magnet does not rotate together with the magnet, but translates around a rotation axis of the magnetic field together with elementary magnets (electrons) of the magnet. It is also shown that the EMF at separate locations of the loop differs from that at similar locations of the unipolar generator with a metal rotor rotating in the magnetic field due to this kind of motion, but, despite it, the total EMF values of both generators are equal.

5.1. Introduction

It was noticed in article [1] that rotation of the current carrying solenoid about an intrinsic longitudinal axis should not result in any consequences because magnetic flux lines in such a rotation remain motionless. At the same time, when a cylindrical permanent magnet rotates around a longitudinal axis an electric field is generated near the magnet which can be directly measured by an electric field sensor. It is this field that causes EMF occurrence in the rotating permanent magnet version of unipolar generator [2]. It is impossible, however, to consider the magnetic field in such a unipolar generator as rotating. Let`s recollect that the magnetic field of a permanent magnet is created by electron magnetic moments. When the magnet rotates electrons may be represented to some extent as gyroscopes that can move only onward around the magnet rotation axis. There are no forces in the nature which can force the electrons and their magnetic field to rotate faster or more slowly. This is a rather obvious statement. Nevertheless, causes of such a situation will be considered hereinafter in more detail.

Rotations of the magnetic field of a rod-like permanent magnet or a magnetic dipole around the axis coinciding with the direction of the magnetic moment are extremely poorly studied theoretically. There are only few publications on the matter, in particular, earlier articles [2] and [3] we have already mentioned. The conclusions drawn in these articles concerning the magnetic field rotation are inconsistent, in our opinion, and are not quite correct from the physical point of view.

The purpose of the present work is to consider, using an example of the magnetic field, the processes of motion of electromagnetic field when a permanent magnet rotates, and also physical consequences of such a rotation. This consideration will be based on the principle of electromagnetic field motion considered in the preceding chapters.

5.2. Unipolar generator with a rotating magnet

The unipolar generator with a permanent rotating magnet is shown in fig. 5.1*a*. A cylindrical permanent magnet made of conducting material (hard-magnetic steels), rotates about the axis, as is shown in the drawing. Voltmeter V is connected to sliding contacts K_1 and K_2, contacting the lateral surface and the cylinder rotation axis respectively, to form closed electric loop L.

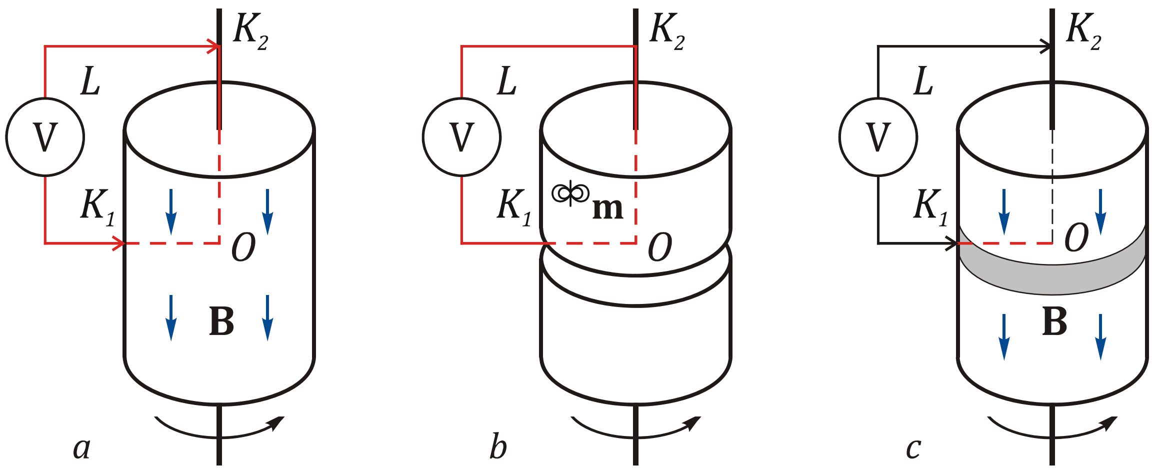

Fig. 5.1. Unipolar generator with a permanent rotating magnet

Loop L (loop OK_1VK_2O) is highlighted in fig 5.1*a* with the red color and it contains pieces in the conducting magnet indicated by a dashed line. It will be shown later that the exact position of these pieces in magnet is of no importance, the positions of contacts K_1 and K_2 is only important. Inside the magnet there is magnetic field **B** indicated by blue arrows which is caused by residual magnetization of the permanent magnet. In the space surrounding magnet, the latter forms a stray field (in fig. 5.1*a* it is not indicated, but its presence is meant).

The question is to clear whether this field moves when the magnet rotates inducing the EMF in piece K_1VK_2 of loop L, or not. This problem has been posed since Faraday times and is solved by various authors differently. So, Tamm [2] considers the idea of stray field rotation as absurd (see [1], p. 13, 14). Tamm gives, suffering certain difficulties, three methods to calculate the loop EMF: on the basis of Maxwell's equation of electromagnetic induction in the form of (4.2 [4], on the basis of the Lorentz force and on the basis of Lorentz transformations for the electromagnetic field. In all cases the magnetic field is considered to be motionless, and the problem thereby is reduced to the case of rotation of a metal disk in a magnetic field, considered in [1] where the first variant of calculation has been given. In work [3] authors, as opposed to Tamm, consider that when a solenoid is rotating about own axis the solenoid magnetic field is also rotating. The true as it often happens, lies in the middle: the magnet or solenoid magnetic field does not rotate, but near the magnet (not solenoid) the magnetic field moves. Let`s show that so it is.

5.3. To EMF calculation in measuring loop

When a magnet is rotating about the rotation axis (fig. 5.1*a*) two interconnected phenomena of electromagnetic induction occur: crossing of loop L elements by the magnetic field of the permanent magnet and crossing of the magnet field by moving element OK_1. To take into account the contributions of both phenomena in the total EMF in loop L correctly, we modify the scheme of the unipolar generator in fig. 5.1*a* into what is shown in figs 5.1*b* and 5.1*c*, to study these phenomena separately.

In fig. 5.1*b* a rotating magnet is made of two parts separated by an infinitely narrow gap not influencing the configuration of the permanent magnet field. Part of the loop L adjoining the magnet in point K_1, is prolonged to the axis at point O. In this case the presence of sliding contacts is not principal, therefore they are not indicated in the drawing.

Let's choose an elementary magnet located randomly inside magnet **m**, as shown in fig. 5.1*b*. As elementary magnets physically infinitesimal volumes with the form depending on the used coordinate system may be chosen. Magnetic properties of these elementary magnets are defined by magnetic moments of electrons, responsible for ferromagnetism, and not related to the magnet rotation by no means. A field of the elementary magnet is the field of a point magnetic dipole moving onward together with the dipole relative to the magnet rotation axis.

To calculate the electric field strength at any point of loop *L* it is necessary to calculate a magnitude of magnetic induction **B** and field velocity $\mathbf{V}_m$ equal to the velocity of dipole **m**, and then using formula (2.5) [1] to calculate the contribution of dipole **m** in the total electric field at any chosen point of loop *L*. Integrating by the whole magnet volume, according to the principle of superposition for moving fields [5], we obtain a magnitude of the electric field strength at a specified point of loop *L*. This will be rather easy to do if the magnet magnetization distribution formula is known. For example, in magnets made of rare-earth alloys for which the coercive force is very high and the shape of a magnetic hysteresis loop is almost squared, magnetization may be considered as almost homogeneous by the whole magnet volume. The calculated electric field is generally nonzero and can be measured by means of an electric field sensor (but not by a voltmeter with probes) after the loop itself has been removed.

Such a calculation method is the only possible way if the magnitude of the electric field strength at loop points is of our interest. Upon integrating the magnitude of this field along loop *L*, it is possible to obtain the EMF value in the loop. The obtained result, however, will not be general because it may change depending on the loop and magnet configuration and also on the magnet magnetization distribution, but anyway, it is valid for an electric field magnitude at each point of the loop.

In the case where the magnet has a strict axial symmetry relative to the rotation axis it is possible to obtain the solution in general view, but it should be remembered that the obtained common solution is valid only for a special case of the magnet axial symmetry. It would be noted that loop *L* in fig. 5.1*b* remains invariable in time and does not contain moving parts. In this case, as it was noted in [4], the Stokes theorem can be applied, which allows in calculating the EMF to replace electric field calculation at each point of the loop and its integration along the loop to the calculation of the rate of magnetic flux change through the surface limited by loop *L*. As it is known such a work was done in XIX century by Maxwell and his followers, which resulted in the law of electromagnetic induction in the form of (4.2 [4]. Let`s use it.

As can be seen from fig. 5.1*b*, the symmetric form of the magnet gives rise to a zero magnetic flux through loop *L*. If the loop is deformed so that it did not lie in one plane with magnetic flux lines, the flux becomes nonzero, but will be constant in time. Anyway, the voltmeter will not register the EMF in the loop, and the loop current will be zero. The electric field, which may be registered by the sensor after removing metal loop elements, becomes equal to zero in the presence of a metal loop at the expense of electric charge redistribution in metal elements of the loop. This result does not depend on a particular loop configuration both inside and outside the magnet. If symmetry of a permanent magnet is disturbed, for example, by soft magnetic material overlay pad at its top end face, field imbalance takes place at different points of the loop, and the voltmeter will show a variable EMF in the loop.

Thus, in the ideal unipolar generator, which is justly of our interest, contribution of a moving magnetic field due to magnet rotation in the total EMF in loop *L* is equal to zero.

Now let's consider the second electromagnetic induction component in the unipolar generator with a rotating magnet, which is generated when moving element OK_1 crosses a field created by the magnet. For this purpose we place in the gap of the rotating magnet (fig. 5.1*c*), made of two parts, a metal nonmagnetic disk (in the drawing it is highlighted with the grey color) and secure it to the rotation axis, whereas the magnet halves, on the contrary, we disconnect from the rotation axis. So long as we have already taken into account completely the movement of the magnetic field in calculating the electromagnetic induction component due to this motion (fig. 5.1*b*) the influence of the motion can be excluded by stopping the magnet rotation whereas maintaining the rotation of the metal disk. This variant of a unipolar generator modification (fig. 5.1*c*) leads us to a scheme of the unipolar generator with a motionless field created by an external source and rotating nonmagnetic disk, which takes place in the generator circuit in fig. 2.1 [1]. The EMF value on length OK_1 of loop L can be easily calculated by means of expression (4.6) [4], with the EMF in other parts of the loop is equal to zero.

The generator in fig. 5.1*c* can be easily converted into generators represented in drawings of figures 5.1*a* and 5.1*b*. In fact, having stopped the rotation of a metal disk and having renewed the magnet rotation, we obtain the generator in fig. 5.1*b*, because it does not matter what particular configuration of piece OK_1 may be, as has already been noted. The EMF in the loop will be equal to zero. If the metal disk is rotating again the EMF in the loop will appear. To obtain finally the generator in fig. 5.1*a*, let`s remove the metal disk because its thickness is infinitesimal, and the magnet itself has a conductivity in accordance with the initial conditions.

Thus, both the generators, with a magnet rotating in the external magnetic field and the one with a rotating magnet, result in the identical EMF in loops, with other conditions being equal, however, these EMF are different at separate pieces of loops. The same results are also obtained by calculations in [2] and in other numerous articles, despite inadequacy of the starting propositions stated in them.

Conclusions

1. It is shown that when a rod-like permanent magnet rotates about its longitudinal axis its own magnetic field does not rotate together with the magnet. At the same time, flux lines move near the magnet and inside it. This motion of the magnetic field is caused by translation motion about the rotation axis of the magnetic field closely related to elementary magnets or electrons inside the magnet, which define its permanent magnetization.

2. The method is schematically shown to calculate the EMF in a closed measuring loop, based on the theory of electromagnetic field motion and using the principle of superposition.

3. It is shown that due to the motion of the magnetic field near the magnet and inside it the EMF at separate pieces of the loop differs from that at similar locations of the unipolar generator with a metal rotor rotating in the magnetic field. Despite it, the total EMF of both the generators are equal. This is explained by the fact that the translation motion of magnetic flux

lines causes the EMF equal in magnitude but opposite in sign in external and internal parts of the loop.

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