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ANALYSIS OF THEORETICAL AND EXPERIMENTAL STUDIES OF THE HUBER EFFECT

The history of theoretical and experimental researches of a physical phenomenon that emerges in moving wheel or bearing pairs, when an electric current flows through the contacts between the wheels or balls and their guides (the Huber effect) has been reviewed.

Keywords: Huber effect, Kosyrev–Milroy motor, electrodynamic laws.

1. Introduction

According to the fundamental laws of the material world, which follow from a general interconnection between its constituting elements and an unbroken link between the matter and its motion, it is reasonable to assert that, in real objects, there are no perfect linear dependences between separate physical phenomena, as well as no autonomous (isolated) objects, stationary processes, inherently physical constants, and so forth. Therefore, the success in the creation of mathematical models (MMs) describing cause-and-effect relations in a researched object (the revelation of physico-mathematical regularities) depends on a reasonable compromise between the MM accuracy and complexity. It is well known that the “system identification deals with the problem of developing the mathematical models of dynamical systems based on observed data from the system” [1]. Nevertheless, “from the time of I. Newton up to now, no one has invented another theoretical description of the mathematical machinery behind this (gravitational) law... So there is no model of the theory of gravitation today, other than the mathematical form” [2]. The same is also true for plenty of other physical phenomena.

Hence, in most cases, physics is identical to the identification theory, because it creates behavioral MMs. Therefore, only the behavioral aspects that are approximately reflected by MMs in the form of physical laws will be discussed.

In particular, for an external observer, the Huber effect consists in the following [3]. If a wheel pair rolls along rails or the shaft and the internal thrust washer in the Kosyrev–Milroy motor rotate [4], and provided that, firstly, an electric current flows through a contact between the wheels (or balls) and the rails (guides) and, secondly, as has become clear recently, the system has a moment of inertia, there appears an additional torque M. The rotational velocity Ω of the wheels or balls increases with the growth of current magnitude I, but it does not depend on the current direction and whether the current is AC or DC. The torque M equals zero, if the material is not ferromagnetic. Provided that the supply voltage of the source is invariant, the dependence of M on Ω is extreme. If $\Omega = 0$, the torque $M = 0$. As Ω grows, the magnitude of M increases to a maximum value $M_{\max}$, if the mechanical moment of counteraction does not exceed $M_{\max}$. Then the velocity Ω continues to grow, but the value of M diminishes. If the counteraction moment changes its sign, M vanishes ($M = 0$) at a certain synchronous velocity Ω_c, and if Ω grows ($\Omega > \Omega_c$), M becomes negative ($M < 0$). This behavior is similar to the moment characteristic of the single-phase asynchronous electric motor. However, the result of researches [4] testify that different processes take place here.

2. Background of the Issue

The Austrian engineer J. Huber was the first who, in 1951, discovered an effect of torque formation in a moving wheel pair, provided that there is an electric current through the contact between the wheels and the rails. J. Huber considered this phenomenon to be of the electromagnetic origin, but he did not manage to explain its essence. Nevertheless, being an engineer, he applied this effect at a railroad yard. After rolling down from a hump, railway cars continued to move not only due to their inertia, but also because there emerged a torque from the current through the contacts between the car wheels and the rails.

The Huber effect attracted attention of many scientists. Several explanations have been proposed by different scientists since the moment of its discovery [5–12]. Unfortunately, they were not confirmed by further experimental researches. In particular, the torque was assumed [6,7] to arise owing to the interaction, according to Ampere's law, between the currents in the guide and in the wheel (or in the ball) that are mutually oriented at an acute angle. However, even if this interaction had created a torque, the same torque with the opposite sign would have emerged at the other wheel of the wheel pair or on the other side of the bearing ball.

The torque was also supposed [5] to arise due to the ignition of a spark and, as a result, the air pressure growth at the front flank of the contact. In order to confirm this hypothesis, the bearings was placed inside a vacuum shroud, and the air was gradually pumped out. In the vacuum environment, the bearing motion stopped. It could be a result of the overheating of bearings and their jamming owing to a substantial reduction of the heat removal in vacuum from the balls heated by the current to a temperature of 250 °C. The absence of the spark ignition in vacuum could be an alternative reason for that. But the author of work [8] claimed that the spark is not the reason. A negative effect of sparking on the motion was discussed in work [9].

A thermodynamic explanation [6] associates the torque emergence with a thermal deformation of guides. This deformation gives rise to the alleged appearance of a hump, from which the ball or wheel rolls down. However, this expalantion does not take a considerable thermal inertia of the materials into account, so that this scenario could have taken place only at superlow velocities Ω, at which the torque does not arise.

Explanations proposed in work [12] do not satisfy the classical laws of physics. For example, they suppose a magnetic induction created by a current and directed along the latter. Additional ambiguities were inserted in works [10,11], where the Huber effect was combined with the unclear Searle effect. An abstract mathematical variational approach developed in work [12] also did not disclose the physics of the phenomenon concerned.

The experimental researches [5–11] showed that, for the torque M to emerge, besides the requirement that the wheels (balls) must move, they, as well as guides, must be ferromagnetic, which indicates that the spark is not a driven force of motion. There must be a source of magnetization for the wheels (balls) and guides. The magnetization of objects must be stronger in the motion direction. The ferromagnetic material must be magnetically soft. The bearing lubricant, if not too dense, can also improve the parameters a little.

However, the current I in a "source-consumer" circuit cannot create a magnetic field that would generate a torque M by asymmetrically magnetizing the ferromagnets, attracting them from the front side, and, afterward, demagnetizing them. Therefore, the Huber effect remained unexplained till 2017.

3. Model that Agrees with Experimental Researches

Electrodynamics is known [13–15] to study spatially inhomogeneous systems with a non-uniform charge distribution and additional degrees of motion freedom. The force parameters depend on both the current I and the motion of system components. Let us consider a system "guides–contact area–wheel (or ball)" [4]. Let the wheels (or balls) with the radius r rotate counterclockwise with the angular velocity Ω and roll along the guides at the velocity

$$V_0 = \Omega\, r \tag{1}$$

to the left from the contact point. The transverse cross-sections of the guides, wheels (balls), and axle are substantial in comparison with the contact area. Therefore, their resistance is much lower than the resistance at the contact. As a result, almost the whole voltage is applied to a pair of wheel contacts connected in series, or to four contacts connected in series and n contacts connected in parallel in the case of two bearings, where n is the number of balls in a bearing. So, it is the processes running in the contact region that have to be analyzed.

3.1. Fixed contact

The region of a fixed contact (Fig. 1) includes section a (the electromechanical contact) surrounded by section b (the only electric contact through the air or lubricant gap δ). The interval $[-x_1, +x_1]$ (section a) is characterized by a mechanical contact with the resistance R_a and a contact through the air with the capacitance C_a. The resistance magnitude R_a depends on the area of the immediate contact between the surfaces, the specific resistance ρ_c of the contact medium, and the average thickness l_c of the mechanical contact:

$$R_a \cong \frac{\rho_c l_c}{S_c}. \tag{2}$$

The capacitance C_a of section a emerges owing to the presence of microgaps between the surfaces. This parameter is proportional to some part, S_a, of the area S_c, and the dielectric permittivity ε of the air or the lubricant; it is also reciprocal to the microgap $\delta(\alpha)$. The capacitance C_b of section b is proportional to the area S_b and reciprocal to a larger gap $\delta(\alpha)$.

The voltage U_c (the potential difference $\phi_1 - \phi_2$) across the contact is determined by resistance (2) and the current I:

$$U_c = \phi_1 - \phi_2 = I\, R_c. \tag{3}$$

Here, in the case of two contacts connected in series between the clips of a DC-voltage source, $\phi_2 = 0$. In the case of four contacts connected in series (the bearing pair), the potentials ϕ_1 and ϕ_2 are of the same sign. This is also true, if the AC voltage is applied. The total capacitance amounts to a fraction of one picofarad for bearings, and a few picofarads for wheels. The charges q_1 and q_2 at the contacting surfaces amount to a few thousandths of one coulomb,

$$q_1 = C\,\phi_1, \quad q_2 = C\,\phi_2. \tag{4}$$

3.2. Mobile contact

In the case of fixed contact (Fig. 1), the electric current I, as a flux of the electric charge q, is distributed symmetrically in sections a and b. Section b is limited by the coordinates $\pm x_2$, beyond which the phenomenon of $\delta(\alpha)$-gap breakdown disappears. However, the situation changes, if the wheel or the ball rotates at the angular velocity Ω (Fig. 2).

Let the current I across the total contact area S_c be expressed as the sum of N currents in electric tubes, each with the current density j_k through the cross-section ΔS:

$$I = \int\limits_{S_c} \mathbf{j}(S)\, d\mathbf{S} \cong \sum_{k=1}^{N} j_k\, \Delta S. \tag{5}$$

Each k-th current tube, $I_k = j_k\, \Delta S$, is formed at the moment t_1, when a discharge emerges in the gap δ_1

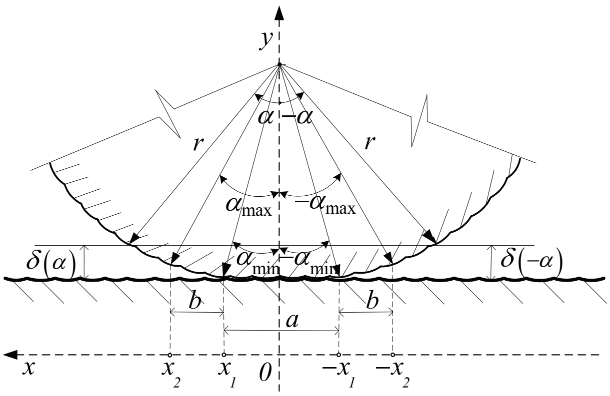

Fig. 1. Electromechanical (a) and electric (b) contact sections [3]

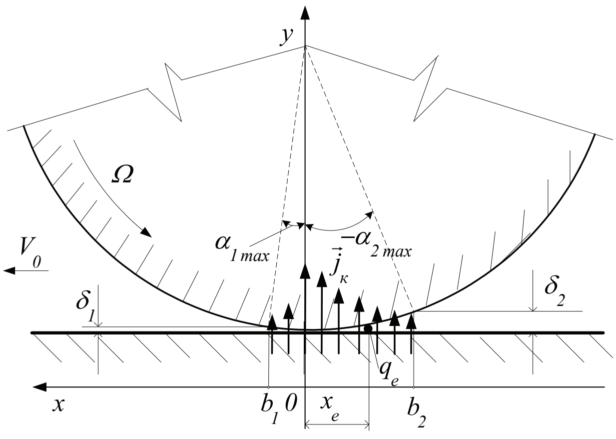

Fig. 2. Asymmetric distribution of current density j_k

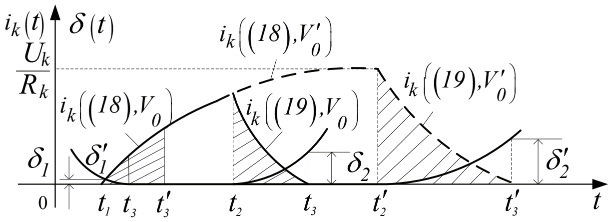

Fig. 3. Transient processes (7) and (8) in the circuit of the k-th current tube at the velocities V_0 and $V_0' > V_0$ [3]

and disappears at the moment t_3, when the discharge stops in the gap δ_2 (Fig. 3). Having a finite length and being arranged in a ferromagnetic medium, the current tube is an LR-circuit with the resistance R_k and the inductance L_k. If we adopt that the parameters R_k and L_k are constant, the instant value $i_k(t)$ of the current I_k is determined as a solution of the equation

$$L_k \frac{di_k}{dt} + R_k\, i_k = U_k; \tag{6}$$

namely, for $t_2 > t \geq t_1$,

$$i_k(t) = \frac{U_k}{R_k}\left(1 - e^{-\frac{t-t_1}{\tau_k}}\right) \cdot 1(t - t_1) \tag{7}$$

and, for $t_2 \leq t < t_3$,

$$i_k(t) = \frac{U_k}{R_k}\left(1 - e^{-\frac{t_2-t_1}{\tau_k}}\right) e^{-\frac{t-t_2}{\tau_k}} \cdot 1(t - t_2), \tag{8}$$

where $1(t - t')$ is the Heaviside step function, and $\tau_k = L_k/R_k$ is the time constant.

Within the time interval $[t_1, t_2]$, the current $i_k\,(t)$ exponentially grows and reaches either the stationary value U_k/R_k for the velocity V_0' or its fraction $i_k\,(t_2)$ for V_0. After the mechanical contact has been broken (at $t \geq t_2$ or $t \geq t_2'$), the current exponentially decreases to zero [Eq. (8)]. The field strength $\varepsilon_{br.}$,at which the gap δ from the front side is broken down, equals U_c/δ_1 (Fig. 2). At the moment t_1, there emerges current (7). The hatched area under the curve $i_k\,(t)$ is equal to the charge q' passed through the gap within the time interval $[t_1, t_3]$ for V_0 or $[t_1, t_3']$ for V_0', where t_3 is the moment, when the mechanical contact was established. The electromechanical contact is actual within the time interval $[t_3, t_2]$ or $[t_3', t_2']$. At the time moment t_2 or t_2', the mechanical contact is broken, and current (8) emerges. This current exponentially decreases until the moment t_3 or t_3', at which the ratio between the quantity $U_k + L_k \left|\frac{di_k}{dt}\right|$ and the gap δ_2 or δ_2' becomes equal to $\varepsilon_{\rm br}$. That is, $\delta_2 > \delta_1$ (Figs. 2 and 3). The hatched area under the curve $i_k(t)$ [Eq. (8)] equals to the charge q'' passed within the time interval $[t_2, t_3]$ or $[t_2', t_3']$. As one can see (Fig. 3), this charge is much larger than the charge on the front side ($q'' \gg q'$).

Let us determine the distances b_1 and b_2. For b_1,

$$\varepsilon_{\rm br} = \frac{U_k}{\delta_1} = \frac{U_k}{r\,(1 - \cos\alpha_1)} \cong \frac{U_k}{r\alpha_1^2} = \\ = \frac{U_k}{r\left(\arcsin\frac{b_1}{r}\right)^2} \cong \frac{U_k}{b_1^2}\, r; \tag{9}$$

whence,

$$b_1 = \sqrt{\frac{U_k\, r}{\varepsilon_{\rm br}}}. \tag{10}$$

For b_2,

$$\varepsilon_{\rm br} = \frac{U_k + L_k\left|\frac{di_k(t_3)}{dt}\right|}{\delta_2} = \frac{U_k + L_k\left|\frac{di_k(t_3)}{dt}\right|}{b_2^2}\, r,$$

whence

$$b_2 = \sqrt{\frac{U_k + L_k\left|\frac{di_k(t_3)}{dt}\right|}{\varepsilon_{\rm br}}\, r}. \tag{11}$$

Hence, the larger is V_0, the larger is $\left|\frac{di_k(t_3)}{dt}\right|$ and, accordingly, the ratio b_2/b_1, i.e. the asymmetry. The voltage U_c across the capacitance and, accordingly, the charges q_1 and q_2 [Eq. (4)] cannot change instantly. Therefore, the charges q_1 and q_2 become shifted to the right. The current i_k in the k-th tube overpasses the air gap δ_k within the finite time interval Δt_k at the velocity V_k proportional to the field strength ε_k,

$$V_k = \beta\varepsilon_k, \tag{12}$$

where β is the mobility of charged particles in the gap δ_k. Based on the dimensionality reasons ($\mathrm{A} \times \mathrm{s} = \mathrm{C}$), we may assume that the unbalanced (since the process is dynamical) charge q_k emerges not only at the surface of the k-th current tube, but also in the gap δ_k:

$$q_k = i_k\, \Delta t_k = i_k\, \frac{\delta_k}{\beta\varepsilon_k} \cong i_k \frac{\delta_k^2}{U_k}. \tag{13}$$

The charge q_Σ can be approximated by an equivalent point charge q_e located at the distance

$$x_\mathrm{e} = \frac{\sum\limits_{k=1}^{N} q_k\, x_k}{q_\Sigma} \tag{14}$$

to the right from the contact point (Fig. 2). Generally speaking, by dimensionality (A × s = C), the total charge q_Σ can be determined, knowing the contact width l_k ($l_k = b_1 - b_2$, Fig. 2) and the time t_k of contact passage at the velocity V_0:

$$q_\Sigma = I\, t_k = I\, \frac{l_k}{V_0}. \tag{15}$$

The charges that emerged in the contact region move relatively to the wheel and guide bodies at the velocity V_0. The product of the total charge q_Σ and the velocity V_0 can be imagined as an element $I_y\, dx$ of a conditional current I_y,

$$q_\Sigma\, V_0 \cong I_y\, dx, \tag{16}$$

where

$$I_y = \frac{q_\Sigma}{dt}, \quad V_0 = \frac{dx}{dt}.$$

In accordance with the Biot–Savart–Laplace law, the current element (16) creates a magnetic field with the induction

$$dB = \frac{\mu_0}{4\pi}\, \frac{I_y\, dx\, \sin\beta}{r^2} \tag{17}$$

at a point M in the air environment (Fig. 4) The total field $\Phi(r, r_0)$ can be calculated by integrating Eq. (17) over the interval $[-r_\mathrm{max}, +r_\mathrm{max}]$. However, if ferromagnetic objects [the wheels (balls) and the guides] are arranged in this space, they will be locally magnetized and increase the magnetic induction B by a factor of μ_r (three to four orders of magnitude). In the case of an air gap $\delta(\alpha)$, in order to minimize the magnetic field losses W_M [5], they create mechanical forces

$$F_M = \frac{dW_M}{d\delta}, \tag{18}$$

which are proportional to the squared current I_y and reciprocal to the squared gap $\delta(\alpha)$. Those forces act so to reduce δ.

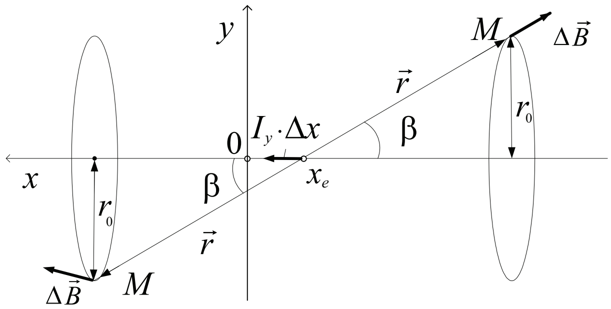

Fig. 4. Illustration to the Biot–Savart–Laplace law [3]

However, the right shift of the coordinate x_e (Figs. 2 and 4) at identical gaps $\delta(\alpha)$ on the left and right sides (at the zero time moment) creates better conditions for the body magnetization and attraction on the back (right) side from the contact point. If the moving system had a zero mass, its motion to the left would stop at once, and the asymmetry (Fig. 2) would turn into the symmetry (Fig. 1). However, there are four torques that interact at the time moment t_0: the torque M_1 that reduces the gap $\delta(\alpha(t))$ to the left from the contact point, the torque M_2 that reduces the gap $\delta(\alpha(t))$ to the right from the contact point, the dynamic torque M_3 that emerges owing to the motion of a mobile part of the system with the mass m at the velocity V_0, and the loading torque M_4. If the velocity $V_0 > 0$, the following inequality is satisfied:

$$M_1 + M_3 \geqslant M_2 + M_4. \tag{19}$$

The larger are the mass m and the velocity V_0, the larger is the torque M_3. However, larger V_0 correspond to larger x_e- and, accordingly, M_2-values. For every current value I, there is a maximum velocity V_max, at which the action of the torques $M_1 + M_3$ and the counteraction of the torques $M_2 + M_4$, the both sums being averaged over the time interval Δt, come into balance. Let us consider a time interval Δt, at the end of which inequality (19) is satisfied owing to a motion at the velocity V_0. For the system passed the path Δx, the torque M_1 averaged over the time Δt increases, because $\delta(\alpha(t))$ decreases. On the contrary, the averaged torque M_2 decreases, since $\delta(\alpha(t))$ increases. As a result, the system moves.

The force and torque asymmetry gives rise to the motion acceleration. But if the time constant τ_k is almost invariable, the asymmetry grows. The coordinate x_e [Eq. (14)] of the charge q_e shifts to the right from the contact point (0,0). As a result, the force action becomes more asymmetric, and the total torque decreases. If the angular velocity Ω is stimulated to grow further, the torque will diminish down to zero and change its sign, similarly to the torque in a single-phase asynchronous motor.

4. Conclusions

The explanation of the Huber effect given in work [11] completely describes the results of experimental researches. This effect is a result of the charge formation in the contact region. The emerged charges, when moving relatively to ferromagnetic objects, magnetize the wheels (balls) and the guides locally and asymmetrically. As a result, the attraction between the wheels (balls) and the guides is stronger on the front side and, in addition to the dynamical momentum M_3, creates an additional torque. The growth of the current I increases the charges and the torque. The growth of the velocity increases the shift of the coordinate x_e of the charge q_e to the right from the contact point and, accordingly, decreases the torque. In other words, the system is characterized by the self-balancing, unlike the Searl motor [8].

Magnetization can be induced by both the AC and DC currents, because the force F_M [Eq. (18)] depends on the squared current value. Motion is a necessary condition for the asymmetry to take place, because it provides the fulfilment of condition (19). Beyond section b on the back side of contact (Fig. 1), ferromagnets are demagnetized, and extra surface charges gradually disappear. The effect becomes stronger, if the gap is filled with a lubricant with $\varepsilon \gg \varepsilon_0$.

The authors are sincerely grateful to scientists who study the Huber effect. Owing to the results of their experiments, a physico-mathematical model of this effect was developed. Further experimental researches of the effect concerned at high velocities Ω are of interest in order to test if a recuperation regime is possible and to optimize the design of the Huber and Kosyrev–Milroy motors.

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Р е з ю м е

Розглянуто історію теоретико-експериментальні дослідження фізичного явища, яке виникає в рухомих колісних чи підшипникових парах за наявності електричного струму в контактах коліс чи кульок з направляючими (ефект Ж. Губера).