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ELECTROMAGNETIC RESONANT PRESSURE AND MOMENT FORCE

The ponderomotive effect of the electromagnetic field still remains a topic of heated debate and experimental research (1-5]. Discussions are caused by the lack of the ability to uniquely determine the density of the ponderomotive force and the energy-pulse tensor of the electromagnetic field in macroscopic electrodynamics [2], related relation

$$f_i = -\frac{\partial T_{ik}^{эм}}{\partial x_k} = -\nabla_k T_{ik}^{эм}. \qquad (1)$$

Such an ambiguity of definition is related to the difficulty of splitting the total energy-momentum tensor of a closed system (substance and field) into two parts, obeying the equation [1]

$$\nabla_k (T_{ik}^{вещ} + T_{ik}^{эм}) = 0. \qquad (2)$$

The discussion also arose about the correctness of the expressions for $\hat{T}^{эм}$ and the corresponding nm ponderomotive forces in the framework of the theory of Abraham and Minkowski. These expressions, as noted in [2], are related only to the Maxwell equations and are valid for all Ohm's laws, polarization, and magnetization. In the absence of polarization $\vec{P}$ and the magnetization of the $\vec{M}$ medium, but in the presence of currents and charges, the ponderomotive force, both in the Abraham theory and in the Minkowski theory, gives simply Lorenz. In the case when $\vec{P}$ and $\vec{M}$ are not zero, the expressions for the density of the ponderomotive force are different and

$$\Delta\vec{f} = \vec{f}_A - \vec{f}_M = -\frac{1}{2}\,\mathrm{rot}\,\vec{N} + \frac{\partial}{\partial t}(\vec{g}_M - \vec{g}_A). \qquad (3)$$

Where $\vec{N} = [\vec{M}\times\vec{H}] + [\vec{P}\times\vec{E}]$ — ponderomotive torque; $\vec{g}_M = [\vec{D}\times\vec{B}]/4\pi c$, $\vec{g}_A = [\vec{E}\times\vec{H}]/4\pi c$ — the amount of motion of the electromagnetic field in the framework of the theories of Minkowski and Abraham; $\vec{B} = \vec{H} + 4\pi\vec{M}$, $\vec{D} = \vec{E} + 4\pi\vec{P}$ — induction vectors; $\vec{H}$, $\vec{E}$ — magnetic and electric fields.

Under conditions of magnetic resonance, as will be shown below, the possibility of registering Δf due to the precession of the vector $\vec{M}$ in the phase with variable components on $\vec{H}$, $\vec{E}$.

Consider an isotropic single-domain sample of ferrite in the form of a sphere. Place it in a weakly inhomogeneous external magnetic field $\vec{H}_2(\vec{r}) = (H_1\cos\omega t + H_{0x}, H_1\sin\omega t + H_{0y}, H_{0z})$ $|H_{0z} \gg H_{0x,0y} \approx 0,\ \partial H_{0z,1}/\partial x_i \gg 2\Delta H/d$, где $2\Delta H$- , where $2\Delta H$ — magnetic resonance line width, d — sample diameter. The field inside the sample in the magnetostatic approximation and without taking into account the exchange nonlinear interaction is determined by the expression $H = H_2 - 4\pi M/3$ [6].

For simplicity, we assume $P = 0$, then

$$\vec{\Delta f} = -\frac{1}{2}\,\mathrm{rot}\,[\vec M\times\vec H] + \frac{1}{c}\frac{\partial}{\partial t}[\vec E\times\vec M]. \qquad (4)$$

Let us place the sample at the antinode of the magnetic field of the resonator (E = 0). Given the solution of the Bloch equation for magnetization [7]

$$\frac{\partial \vec M}{\partial t} = -\gamma[\vec M\times\vec H] - \omega_r(\vec M - \vec M_0), \qquad (5)$$

available

$$\langle \vec N\rangle|_{t=2\pi/\omega} = \frac{1}{\gamma}\left\langle\frac{\partial\vec M}{\partial t}\right\rangle - \frac{\omega_r}{\gamma}\langle\vec M-\vec M_0\rangle. \qquad (6)$$

$$\langle\vec N\rangle = -\frac{\omega_r}{\gamma}(M_z - M_0)\vec i_z = \frac{\gamma^2 H_1^2 \vec i_z}{\omega_r^2+\gamma^2H_1^2+(\omega-\gamma H_{0z})^2}\left(\frac{M_0\omega_r}{\gamma}\right), \qquad (7)$$

Where y — gyromagnetic ratio, Mo — static equilibrium magnetization, $\omega_r/\gamma = \Delta H$. Accordingly, for the density of the ponderomotive force (3), (4), taking into account the dependence $\vec M(\vec H(\vec r))$ write down

$$\langle\vec{\Delta f}\rangle = -\frac{1}{2}\,\mathrm{rot}\,\langle\vec N\rangle = \frac{1}{2}[\mathrm{grad}\,(M_z\Delta H)\times\vec i_z]. \qquad (8)$$

As a result of the assessment of the maximum value of the ponderomotive moment of forces and ponderomotive force within the framework of this model, we obtain

$$\langle N\rangle_{max}\approx M_0\Delta H,\ \langle\Delta f\rangle_{max}\approx M_0\nabla_i H_{0z,i}. \qquad (9)$$

For iron yttrium garnet $\left(M_0 = 10^2\,\text{Гс},\ \Delta H = 1\,\text{Э},\ \frac{\partial H_{0z,i}}{\partial x_i} = 0{,}2,\ \frac{\Delta H}{\Delta d} = 2\,\text{Э/см}\right)$ $\langle N\rangle_{max}\approx 10^2$ (дин·см)/см^3, $\langle\Delta f\rangle_{max}\approx 10^2$ дин/см^3.

Thus, the difference between ponderomotive forces within the framework of the theories of Abrahamn and Minkowski is not small, as was previously thought [one, 2], and can be detected under conditions of magnetic resonance.

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