УДК 530.12+537.86

01.00.00 Физико-математические науки

ТЕОРИЯ ОТНОСИТЕЛЬНОСТИ И ДИНАМИЧЕСКАЯ МОДЕЛЬ ДВИЖИТЕЛЯ ЭЛЕКТРОМАГНИТНОГО ТИПА

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В работе обсуждается динамическая модель ракетного движителя электромагнитного типа, состоящего из источника электромагнитных колебаний радиочастотного диапазона и конического резонатора, в котором возбуждаются электромагнитные колебания. Исследованы процессы возбуждения электромагнитных колебаний в полости с проводящими стенками, а также волн в поле Янга-Миллса. Создана численная многомерная нестационарная модель, описывающая процессы установления электромагнитных колебаний в резонаторе с учетом конечной проводимости стенок. Отдельно рассмотрен случай стоячих волн в резонаторе с проводящими стенками. Показано, что моды колебаний в проводящем резонаторе отличаются от таковых в идеальном резонаторе, как в установившихся, так и в неустановившихся процессах. Предложен механизм образования силы тяги с учетом изменения метрики пространства-времени, вклада токов элементарных частиц, поля Янга-Миллса и электромагнитного поля. Показано, что влияние поле Янга-Миллса взывает изменение диэлектрической проницаемости, что ведет к изменению емкости резонатора. Таким образом, в системе возникает параметрический резонанс, что приводит к усилению поля Янга-Миллса и к возникновению силы тяги. Развитая динамическая модель, которая позволяет осуществить оптимизацию силы тяги по значительному числу параметров. Установлено, что сила тяги возрастает в поле Янга-Миллса вблизи основной резонансной частоты. Предложена модель, описывающая возбуждение и излучение нелинейных волн поля Янга-Миллса. Показано, что нелинейные волны поля Янга-Миллса более эффективно уносят импульс из системы по сравнению с электромагнитными волнами, чем объясняется значительное на несколько порядков увеличение силы тяги в двигателях электромагнитного типа по сравнению с фотонными двигателями

Ключевые слова: ПРИНЦИП ОТНОСИТЕЛЬНОСТИ, СИЛА АБРАГАМА, ТЕОРИЯ МАКСВЕЛЛА, ТЕОРИЯ ЯНГА-МИЛЛСА, ЭЛЕКТРОМАГНИТНЫЕ ВОЛНЫ

UDC 530.12+537.86

Physics and mathematics

GENERAL RELATIVITY AND DYNAMICAL MODEL OF ELECTROMAGNETIC DRIVE

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The article discusses the dynamic model of the rocket motor electromagnetic type, consisting of a source of electromagnetic waves of radio frequency band and a conical cavity in which electromagnetic waves are excited. The processes of excitation of electromagnetic oscillations in a cavity with conducting walls, as well as the waves of the Yang-Mills field are investigated. The multi-dimensional transient numerical model describing the processes of electromagnetic oscillations in a cavity with conducting wall created. Separately, the case of standing waves in the cavity with conducting walls considered. It is shown that the oscillations mode in the conducting resonator different from that in an ideal resonator, both in steady and unsteady processes. The mechanism of formation of traction for the changes in the space-time metric, the contribution of particle currents, the Yang-Mills and electromagnetic field proposed. It is shown that the Yang-Mills field calls the change of the dielectric constant, which leads to a change in the capacitance of the resonator. Thus, the parametric resonance occurs in the system, which leads to a strengthening of the Yang-Mills amplitude, and to the emergence of traction. We have developed a dynamic model, which enables optimal traction on a significant number of parameters. It was found that the thrust increases in the Yang-Mills field near the main resonance frequency. A model describing the excitation and emission of nonlinear waves of the Yang-Mills field was proposed. It is shown that nonlinear waves of the Yang-Mills field more effectively carry the momentum from the system in comparison with electromagnetic waves, and it explains the significant increase by several orders of thrust in the engines of the electromagnetic type, compared with the photon rocket

Keywords: GENERAL RELATIVITY, ABRAHAM FORCE, MAXWELL'S THEORY, YANG-MILLS THEORY, ELECTROMAGNETIC WAVES

Introduction

For the exploration of the solar system and Galaxy, a new generation of engine must be created that would develop a constant traction force over a long period of time calculated in years, without significant loss of the spacecraft mass [1-5]. One of the devices with the needed parameters might be electromagnetic drive described in [6-16].

In [17-18] considered a dynamic model of the electromagnetic drive in which the thrust force arises as a consequence of changes in time of the Poynting vector that is known to lead to the emergence of the Abraham force [19-20]. It was established that the average value of the thrust force, as the Abraham force component gone be nonzero for any system comprising an oscillatory circuit (resonator) and a nonlinear resistance dependent on temperature. The mechanism of formation of traction taking into account changing the space-time metric and the contribution of the Yang-Mills and electromagnetic fields in the energy-momentum tensor was proposed. It is shown that electromagnetic drive system agrees with the laws of conservation of momentum and energy in view of the gravity field, in full compliance with the general relativity.

The physical problem of thrust force upon excitation of oscillations in the cavity with conducting walls was considered in [18]. The contribution of the vacuum polarization and elementary particle currents in the displacement current in Maxwell's theory in connection with the Yang-Mills theory has been estimated.

In this paper we investigate the effect of the Yang-Mills on the traction force occurring in a conical cavity due to the excitation of electromagnetic waves of radio frequency. The estimation of the contribution of the Yang-Mills field waves and the thermal vibrations in the thrust developed by the electromagnetic drive is given. It is shown that nonlinear waves of the Yang-Mills field more effectively carry the momentum from the system in comparison with electromagnetic waves, and it explains the significant increase by several orders of magnitude of thrust in the electromagnetic drive, compared with the photon rocket.

A dynamical model of the electromagnetic field in a cavity with conducting walls

Electromagnetic drive such as [6-9] consists of a source of radio frequency electromagnetic waves and a conical cavity - Fig. 1. Excitation of electromagnetic waves in the cavity is getting through the side surface or the end surface of the smaller diameter. In our paper [17] the mode field oscillations have been studied in a conical cavity when excited by an end surface on the assumption that the solution is independent of the polar angle. In [18], the excitation source in the form of loops arranged parallel to the end walls of the cavity and symmetrically with respect to its axis considered.

For the simulation of electromagnetic oscillation in the cavity the Maxwell's theory was applied. As is known, in the case of axial symmetry can be distinguished vibration mode with the transverse electric field - the TE mode and the transverse magnetic field - TM modes. In the case of the TE modes can be assumed that the solution of Maxwell's equations in a cavity in a cylindrical coordinate system is reduced to the wave equation for a vector potential. For a description of the electromagnetic field in the cavity and in the walls it is necessary to take into account in the dynamics equations of the electromagnetic field electric currents induced in the wall cavity. In the simplest case, suppose that the Ohm's law is true so that, $\mathbf{j} = \sigma\mathbf{E} = -\sigma\mathbf{A}_t$, and thus we find

$$\begin{gathered}\mathbf{A}_{tt} - c^2\nabla^2\mathbf{A} = \frac{\mathbf{j}}{\varepsilon_0} = -\frac{\sigma}{\varepsilon_0}\mathbf{A}_t, \quad \nabla\cdot\mathbf{A} = 0 \\ \mathbf{E} = -\mathbf{A}_t, \mathbf{B} = \nabla\times\mathbf{A}\end{gathered} \qquad (1)$$

In the cylindrical coordinate system (r,φ,z) and for $\mathbf{A}=(0,A_\varphi(t,r,z),0)$ equations (1) reduced to the form

$$\begin{gathered}\frac{1}{c^2}\frac{\partial^2 A_\varphi}{\partial t^2}=\frac{\partial^2 A_\varphi}{\partial z^2}+\frac{\partial^2 A_\varphi}{\partial r^2}+\frac{1}{r}\frac{\partial A_\varphi}{\partial r}-\frac{A_\varphi}{r^2}-\frac{\sigma}{\varepsilon_0 c^2}\frac{\partial A_\varphi}{\partial t}-\frac{\tilde{j}_\varphi}{\varepsilon_0 c^2}\\ E_\varphi=-\frac{\partial A_\varphi}{\partial t},\ B_r=-\frac{\partial A_\varphi}{\partial z},\ B_z=\frac{\partial A_\varphi}{\partial r}+\frac{A_\varphi}{r}\end{gathered} \tag{2}$$

The input current oscillating with the frequency of the magnetron

$$\tilde{j}_\varphi=j_0 f(t)\sin(\omega t)\exp[-(r-r_c)^2/r_0^2-(z-z_c)^2/r_0^2] \tag{3}$$

Here, the function $f(t)$ and parameters j_0,ω,r_0,r_c,z_c describe the shape of the modulating signal, the current density, the frequency, the thickness and localization of the antenna ring respectively. The boundary conditions for the vector potential put zero everywhere on the outer surface of the cavity. This choice of boundary conditions due to the fact that high-frequency electromagnetic waves are attenuated in the conductive wall with the parameters of the electrical conductivity of copper at a depth of 1-2 microns, and it is the skin effect [20].

In Fig. 1 shows the field distribution in the cavity with dimensions (in meters) $2r_1=0.15875;\ 2r_2=0.2794;\ \Delta z=0.2286$ at signal frequency without modulation $\omega/2\pi=1.8804\ GHz$. In this case, according to [16] there is a noticeable traction, superior in 6390 the value of traction per unit of power established for the photon rocket as $F/W=1/c\approx 0.00333564\ mN/kW$. Excitation of oscillations is performed on the side wall, the parameters of the antenna (in meters) are $r_0=0.001;r_c=0.11;z_c=0.466$. Note that the antenna dipole radiation allocated to the lower-left figure in red and blue.

With the frequency and cavity dimensions pointed above there is the mode TE011 dominated. Note that in an ideal cavity at this frequency the mode TE012 is excited [16-17].

Along with non-stationary model (1) - (3) we consider a model with standing waves in a conductive cavity when excited by monochromatic electromagnetic oscillations source

$$\tilde{j}_\varphi = j_0 \exp(i\omega t)\exp[-(r-r_c)^2/r_0^2-(z-z_c)^2/r_0^2]$$

Assuming that the vector potential changes periodically over time in proportion to $\exp(i\omega t)$, we find from (1) the system of equations

$$\begin{aligned}&\omega^2\mathbf{A}+c^2\nabla^2\mathbf{A}=-\frac{\mathbf{j}}{\varepsilon_0}=\frac{i\sigma}{\varepsilon_0}\mathbf{A},\quad \nabla\cdot\mathbf{A}=0,\ \mathbf{A}=\mathbf{A}_1+i\mathbf{A}_2\\&\mathbf{E}=-i\omega\mathbf{A},\ \mathbf{B}=\nabla\times\mathbf{A}\end{aligned}\tag{4}$$

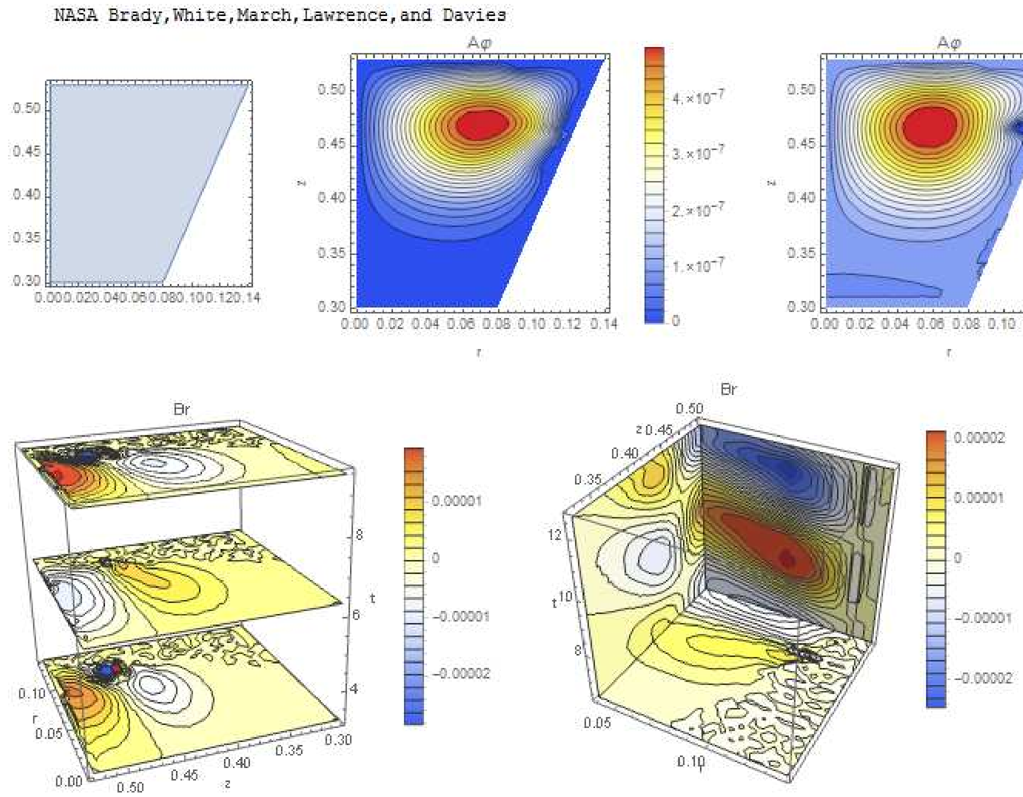

Figure 1: Spatial and temporal distribution of A_φ component of the vector potential and the radial component of the magnetic field in a conical cavity [16].

In the case of TE modes the complex vector potential is described by equation

$$\frac{\partial^2 A_\varphi}{\partial z^2}+\frac{\partial^2 A_\varphi}{\partial r^2}+\frac{1}{r}\frac{\partial A_\varphi}{\partial r}-\frac{A_\varphi}{r^2}-\frac{i\sigma A_\varphi}{\varepsilon_0 c^2}+k^2 A_\varphi=\frac{j_0\exp[-(r-r_c)^2/r_0^2-(z-z_c)^2/r_0^2]}{\varepsilon_0 c^2}$$
$$E_\varphi=-i\omega A_\varphi,\ B_r=-\frac{\partial A_\varphi}{\partial z},\ B_z=\frac{\partial A_\varphi}{\partial r}+\frac{A_\varphi}{r} \qquad (5)$$

The boundary conditions for the vector potential put zero everywhere on the outer surface of the cavity. Fig. 2 shows the distribution of the real and imaginary parts of the vector potential with the cavity parameters $2r_1=0.15875;\,2r_2=0.2794;\,\Delta z=0.2286$ in the resonator at a signal frequency $\omega/2\pi=1.8804\,GHz$ - top and at $\omega/2\pi=2.168\,GHz$ - the bottom. We see that in the first case in the cavity with conducting walls excited TE011 mode, and in the second case - TE012. Note that in an ideal cavity in both cases the mode TE012 is excited [16-17].

Define the Poynting vector according to

$$\mathbf{S}=\mathbf{E}\times\mathbf{H} \qquad (6)$$

The electromagnetic field momentum in the cavity volume is

$$\mathbf{P}=\frac{1}{c^2}\int\mathbf{S}dV=\frac{1}{c^2}\int\mathbf{E}\times\mathbf{H}dV \qquad (7)$$

Abraham force applied to the cavity volume is defined as (8)

$$\mathbf{F}=\frac{d\mathbf{P}}{dt}=\frac{1}{c^2}\int(\partial\mathbf{S}/\partial t)dV \qquad (8)$$

Abraham force (8) applied to the volume of the medium filling the cavity, can be represented in two ways - in the non-relativistic form (taking into account the reaction of ether) [19] and in the relativistic form [19-20], therefore

$$\mathbf{F}_{AE}=\int\frac{\varepsilon_v\mu_v}{c^2}\frac{\partial\mathbf{S}}{\partial t}dV,\quad \mathbf{F}_{AR}=\int\frac{(\varepsilon_v\mu_v-1)}{c^2}\frac{\partial\mathbf{S}}{\partial t}dV \qquad (9)$$

Here ε_v, μ_v - the relative permittivity and the magnetic permeability of the medium respectively. Using the solution of the problem (4) - (5) we find that the Poynting vector oscillates in the cavity with double frequency, so whatever the expression (9) we did take, the average over many periods of oscillation value of the Abraham force is zero. This theoretical conclusion is the main argument for a critical assessment of the possibility of movement without the momentum radiation, in which, it seems obvious violated Newton's third law [22-23].

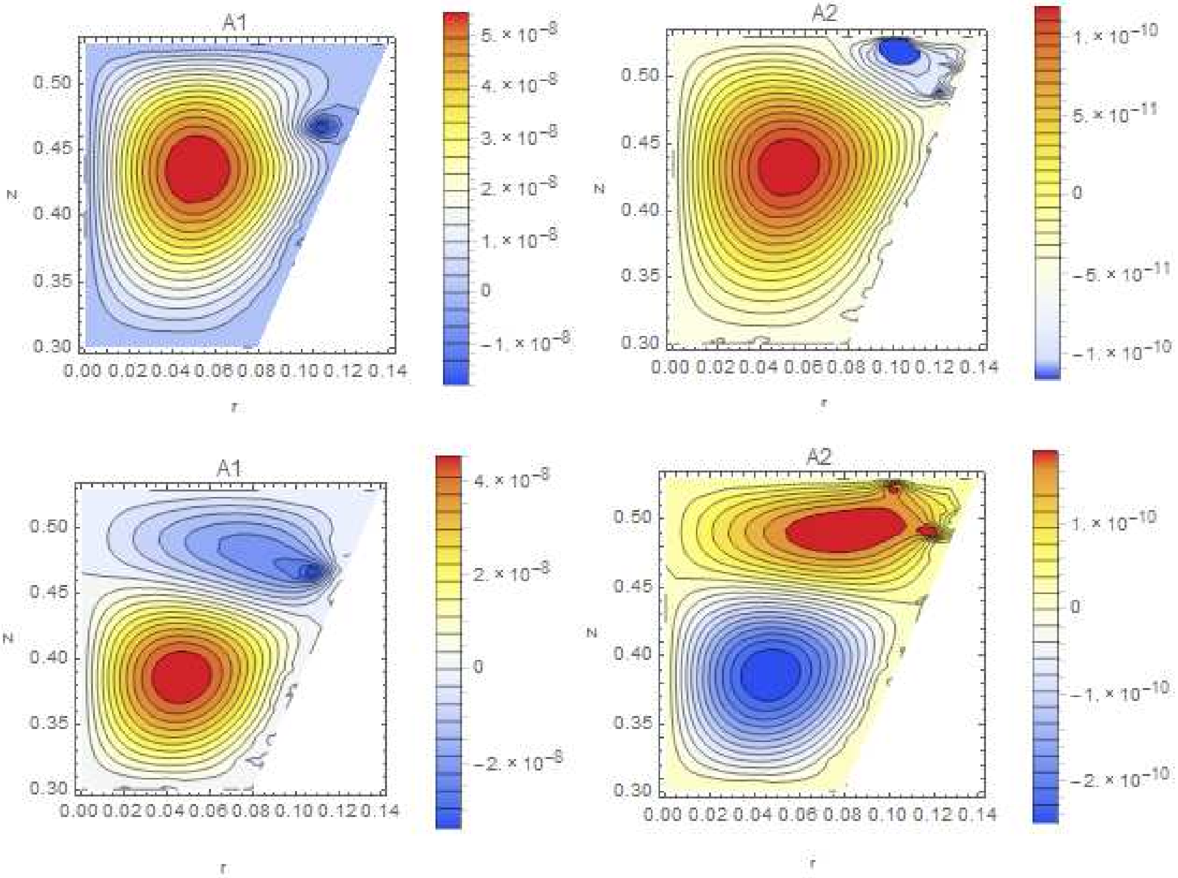

Figure 2: The spatial distribution of the real and imaginary parts of the vector potential in the conical cavity NASA [16]. In the upper figures show the TE011 mode at a frequency of 1.8804 GHz, the lower figures - TE012 mode at a frequency of 2.168 GHz.

On the other hand, numerous experimental data obtained by different research groups [21], strongly suggest the presence of a constant thrust that occurs in the conical cavity in the excitation of oscillations of the electromagnetic field of radio frequency.

Note that if in the expressions (9) we will consider the parameters ε_v, μ_v depending on certain fields - electromagnetic, gravitational, Yang-Mills, Higgs, and so on, the result of averaging the expressions there is force acting on the system [17-18]. In the Maxwell’s original theory the system moves relying on ether. In Einstein's theory of relativity, the system interacts with the space-time [17-18], in Yang-Mills theory the system reacts with hadrons and gluons [24-31].

The traction force, according to numerous experimental data [21], dependent on the quality factor Q - see Fig. 3. It should be noted that the thrust per unit of power, which is developing an electromagnetic drive according to [16, 21], considerably exceeds the same indicator for the photon rocket defined as $F/W = 1/c \approx 0.00333564\, mN/kW$.

If the cavity wall is made of a material having a strong dependence electric conductivity on the temperature, such as copper, there are nonlinear oscillation caused by temperature fluctuations observed in this system, in addition to the linear electromagnetic waves. Indeed, the wall temperature is dependent on the magnitude of the losses of electromagnetic energy in the cavity, which in according to Joule law is proportional to

$$\mathbf{j}^2/\sigma = \sigma(T)\mathbf{E}^2.$$

Excess heat is removed from the walls by conduction and radiation of different kinds. The heat equation in this case has the form

$$\rho c_p T_t = \lambda \nabla^2 T + \sigma(T)\mathbf{E}^2 - \sigma_{SB} T^4 \tag{10}$$

Here $\rho, c_p, \lambda, \sigma_{SB}$ - the density of the wall material, specific heat, thermal conductivity, and the parameter in the Stefan-Boltzmann law, respectively.

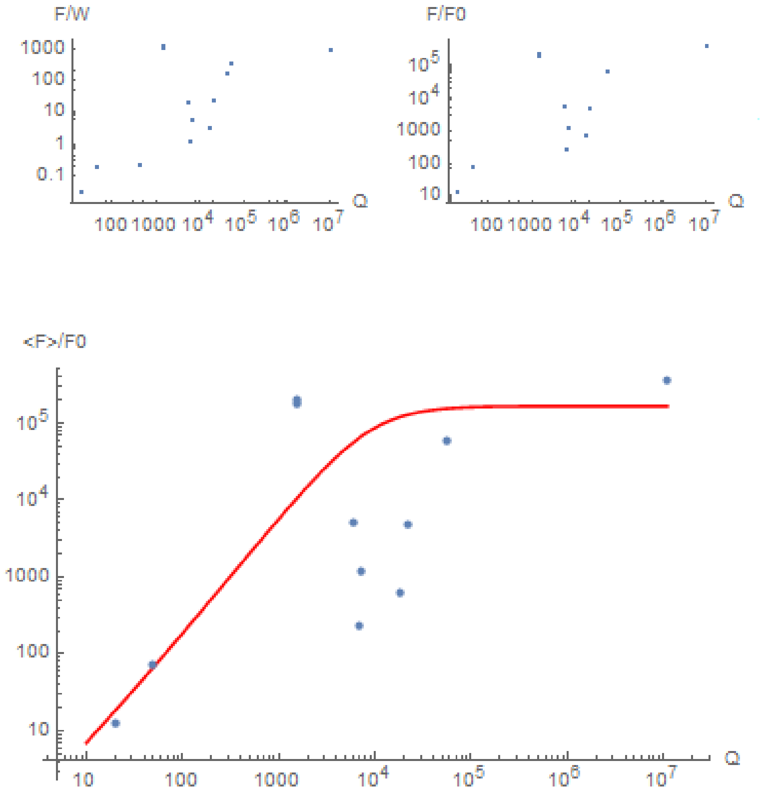

Figure 3: The dependence of the traction force per unit of power from the quality factor Q according to [21] (top) and the calculated value of the dependence of the normalized traction force from the Q parameter in the model (12) (bottom) together with the data [21].

Note that in the case of the Yang-Mills theory the equilibrium radiation also follows Stefan-Boltzmann law [24]. However, consideration of the effect of the Yang-Mills field on the processes in the cavity is not limited to the account of possible losses. The main contribution of the Yang-Mills field is in the excitation of particle currents, which lead to a change in the value of the displacement current in the Maxwell equations [18].

A dynamic model of the electromagnetic drive

The system of dynamic equations describing the processes in the cavity, is [17-18]

$$\begin{aligned} & L\frac{dI}{dt}+R\left(1+\frac{1}{R}\frac{dR}{dT}(T-T_0)\right)I+\frac{1}{C}\int_0^t Idt=U_0\cos(\omega t) \\ & \frac{dT}{dt}=\frac{\lambda B}{mc_p}(T_0-T)+\frac{R}{mc_p}\left(1+\frac{1}{R}\frac{dR}{dT}(T-T_0)\right)I^2-\frac{\sigma_{SB}}{\rho c_p}T^4 \end{aligned} \tag{11}$$

Here C, L, R, m - capacitance, inductance, resistance and mass of the resonator; U_0, ω - amplitude and frequency of the excitation signal; B, T_0 - the heat transfer parameter and temperature of the thermostat accordingly. Let $\omega_0 = 1/\sqrt{LC}$ - the main frequency of the resonator, we define the dimensionless parameters

$$\begin{aligned} & \tau=\omega_0 t,\quad q=\frac{1}{CU_0\omega_0}\int_0^\tau Id\tau,\quad u=T/T_0,\quad k=\omega/\omega_0 \\ & \alpha=\frac{T_0}{R}\frac{dR}{dT},\quad a=\frac{\sigma_{SB}}{\omega_0\rho c_p}T_0^{\,4},\quad b=\frac{\lambda B}{\omega_0 mc_p},\quad \mathrm{Q}=\frac{1}{RC\omega_0},\ \beta=\frac{CU_0^2}{mc_pT_0} \end{aligned}$$

In this notation the system (11) takes the form

$$\begin{aligned} & q''+\mathrm{Q}_0^{-1}\left(1+\alpha(u-1)\right)q'+q=\cos(k\tau) \\ & u'=b(1-u)+\beta\mathrm{Q}_0^{-1}\left(1+\alpha(u-1)\right)q'^2-au^4 \end{aligned} \tag{12}$$

Let us express the Abraham force through the parameters of the model (12). To do this, we divide the Abraham force into two parts

$$\mathbf{F}=\frac{1}{c^2}\int(\partial\mathbf{S}/\partial t)dV=\frac{1}{c^2}\int\mathbf{E}_t\times\mathbf{H}dV+\frac{1}{c^2}\int\mathbf{E}\times\mathbf{H}_t dV \tag{13}$$

In Maxwell's theory two parts of force (13) applied to ether. We assume in the theory of relativity, that the system has other fields - gravitational field, the Yang-Mills field, the Higgs field, which break the symmetry of the system, which leads to the appearance of traction.

According to [17-18], only the first integral on the right side of (13) gives a contribution to the force of traction. This is because the displacement current in Maxwell's theory depends on the dielectric polarization, i.e., from microscopic processes, whereas Faraday's law of induction is determined by macroscopic parameters - the relative velocity and geometry of the body.

Consequently, in the excitation of vacuum fluctuations it is necessary to take into account the dependence of the displacement current from the elementary particles current [18].

Note, as a vector potential is proportional to the current $A \sim \mu I$ then magnetic field in the cavity associated with current, and the electric field - with the time derivative of the current. Hence, we find

$$\mathrm{F}_z = \frac{1}{c^2}\int (\mathbf{E}_t \times \mathbf{H})_z \, dV = -F_0 q' q''', \quad F_0 = \kappa \frac{\omega I_0 U_0 l}{c^2} \tag{14}$$

Here l - the characteristic size of the cavity, κ - a numerical coefficient of order unity. The average value of the force is defined as

$$\overline{\mathrm{F}}_z = -F_0 \lim\nolimits_{\tau\to\infty} \frac{1}{\tau}\int_0^\tau q' q''' d\tau \tag{15}$$

We also define the average on a time interval

$$\langle \mathrm{F}_z \rangle = -\frac{F_0}{\tau}\int_0^\tau q' q''' d\tau \tag{16}$$

The results of calculation of the average thrust obtained from the numerical solving of the equation system (12) shown in Fig. 3. In double logarithmic scale it looks like calculated curve is in a qualitative agreement with experimental data.

Dynamics of the Yang-Mills field

Let consider the dynamics of the Yang-Mills field in macroscopic devices such as an electromagnetic drive [18]. We assume that in a conical cavity, along with the electromagnetic field there is the Yang-Mills field excited, which takes the part of the momentum emitted by the system.

In the case of the *SU*(3) symmetry the Yang-Mills equations are reduced to the form [25-28]

$$\begin{aligned} &\partial_\mu F^B_{\mu\nu} + g_{YM} f^{BCD} A^C_\mu F^D_{\mu\nu} = 0 \\ &F^B_{\mu\nu} = \partial_\mu A^B_\nu - \partial_\nu A^B_\mu + g_{YM} f^{BCD} A^C_\mu A^D_\nu \end{aligned} \qquad (17)$$

Here $B, C, D = 1,2,3,...,8$ - the color indices (the number of color fields is eight); g_{YM} - the coupling constant, f^{BCD} - structure constants of the gauge group *SU*(3).

The problem can be simplified by considering some average parameters [28]. By averaging the Lagrangian of the system $L_{SU(3)} = \frac{1}{4} F^A_{\mu\nu} F^{A\mu\nu}$, we find the Lagrangian of the new model and system of dynamic equations [28]

$$\begin{aligned} &c^{-2}\phi^a_{tt} - \nabla^2\phi^a + \left[(\chi^m\chi^m) + \lambda_1(\phi^a\phi^a) - \phi_0{}^2\right]\phi^a = 0 \\ &c^{-2}\chi^m_{tt} - \nabla^2\chi^m + \left[(\phi^a\phi^a) + \lambda_2(\chi^m\chi^m) - \chi_0{}^2\right]\chi^m = 0 \end{aligned} \qquad (18)$$

Here $a = 1,2,3; m = 4,5,...,8$ - the color indices, with repeated indices is assumed summation, $\lambda_1, \lambda_2, \phi_0, \chi_0$ - the model parameters.

Consider a two-component system, suggesting that only two fields in the system (18) with indices $a = 1; m = 4$ contribute to the dynamics of the Yang-Mills field in the cavity. In this case, the standing waves of the Yang-Mills field excited in the cavity - Fig. 4-5.

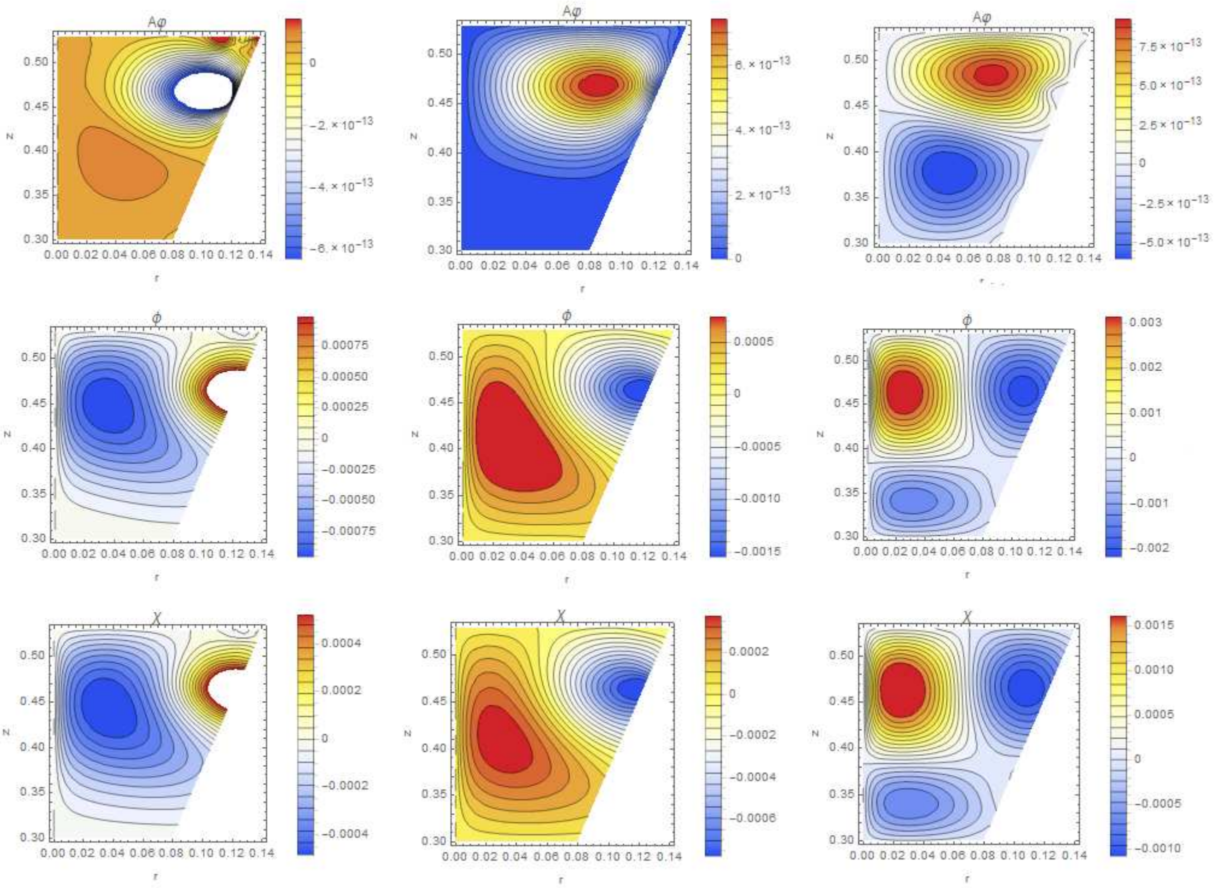

Figure 4: The dynamics of an electromagnetic field interacting with the Yang-Mills field in NASA conical cavity [16] with excitation electromagnetic waves at a frequency of 1.8804 GHz on a side surface at different points in time $\omega t = (8\pi + 0.1)/3, (8\pi + 0.1)/2, 8\pi + 0.1$ - from left to right, respectively.

Assuming that the Yang-Mills field interacts with the electromagnetic field through the conduction current and displacement current, we write the system of two equations in the form

$$\begin{aligned} &\frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2}-\nabla^2\phi+\left(\chi^2+\lambda_1\phi^2-{\phi_0}^2\right)\phi=(\mathbf{k}_\phi.\mathbf{j}) \\ &\frac{1}{c^2}\frac{\partial^2\chi}{\partial t^2}-\nabla^2\chi+\left(\phi^2+\lambda_1\chi^2-{\chi_0}^2\right)\chi=(\mathbf{k}_\chi.\mathbf{j}) \end{aligned} \tag{19}$$

The conduction current is given by equation $\mathbf{j}=\sigma\mathbf{E}=-\sigma\mathbf{A}_t$, and vectors $\mathbf{k}_\phi,\mathbf{k}_\chi$ characterize the environment in which the interaction occurs. It can be assumed that the permittivity of vacuum varies in the presence of the Yang-Mills field. Indeed, the Yang-Mills field interacts with the whole set of hadrons [27-29]. Consequently, currents of charged particles can be excited in the volume of the cavity and in the walls [18]. We model the dependence of the permittivity of the Yang-Mills field in the form

$$\varepsilon=\varepsilon_0[1+k_{YM}(\phi_t^2+\chi_t^2)] \tag{20}$$

Here k_{YM} - coupling parameter of the Yang-Mills field to the electromagnetic field. Note that the parameter k_{YM} can be either positive or negative. Such a change in the electric constant, leading to a change in the speed of light, can be viewed as a change in the metric of system. Indeed, for the effect associated with the change in the metric we have the following expression for traction force [17]

$$\varepsilon=\varepsilon_0/\sqrt{g_{00}},\ \mu=\mu_0/\sqrt{g_{00}} \quad , \qquad \mathbf{F}_{AR}=\int\frac{(1-g_{00})}{c^2 g_{00}}\frac{\partial\mathbf{S}}{\partial t}dV \tag{21}$$

Here g_{00} is a component of the metric tensor. Note that the Yang-Mills field contributes to the variation of the metric along with the electromagnetic field [30-31]. Therefore, it can be assumed that the traction force is determined according to the second expression (9), in which the parameters of the medium depends on the parameters of the Yang-Mills field in accordance with (20), thus we have

$$\mathbf{F}_{AR}=\int\frac{(\varepsilon_v\mu_v-1)}{c^2}\frac{\partial\mathbf{S}}{\partial t}dV=\int\frac{k_{YM}(\phi_t^2+\chi_t^2)}{c^2}\frac{\partial\mathbf{S}}{\partial t}dV \tag{22}$$

Note that in the expression (22) we take into account the full contribution of the Poynting vector changes in the volume of the system, without selecting the displacement current, as we have done in the derivation of the expression (14). This means that the thrust model [6, 12, 14], based on Maxwell's theory can also be described by the expression (22).

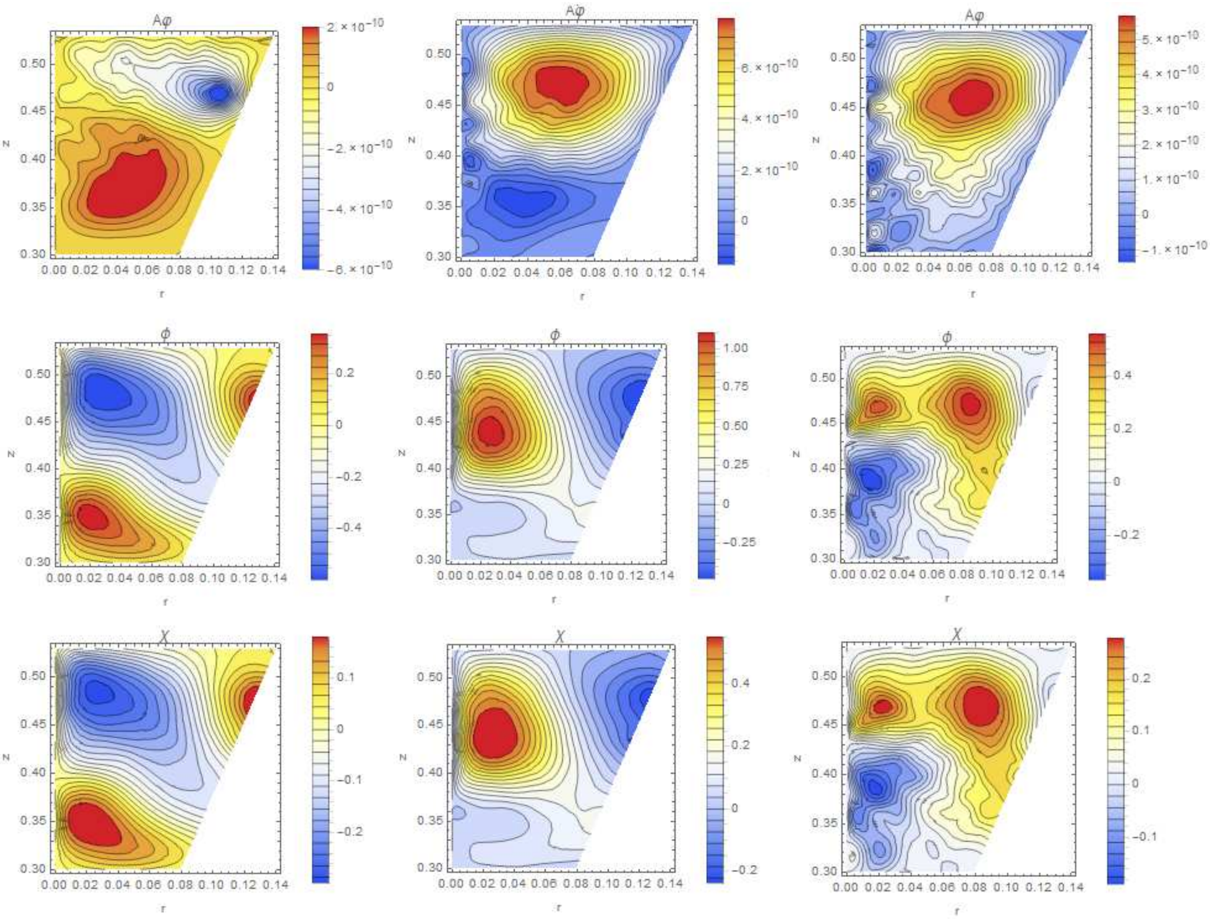

Figure 5: The dynamics of an electromagnetic field interacting with the Yang-Mills field in NASA conical cavity [16] with excitation electromagnetic waves at a frequency of 1.8804 GHz on a side surface at different points in time $\omega t = (8\pi + 0.1)/3, (8\pi + 0.1)/2, 8\pi + 0.1$ - from left to right, respectively. System parameters correspond to the resonance conditions.

The system of equations (1) and (19) was used to model the dynamics of the electromagnetic field interacting in a cavity with conducting walls and with the Yang-Mills field - Fig. 4-5. In the first equation (1)we assume that the speed of light is related to the electric constant, $c^2 = 1/\varepsilon\mu_0$, which is expressed in the form (20). In the case of conical cavity we use the equation (2) and (3). As a result, we find the distribution of the field on the side of resonance - Fig. 4, and at resonance - Fig. 5. Note that in the case of resonance parameters of the electromagnetic field and the Yang-Mills field increased by three orders - Fig. 5. In this case there is a characteristic ripple, indicating the transition to chaotic behavior in the Yang-Mills theory [32-33].

We form a dynamic model describing the processes in the cavity based on the Yang-Mills theory. As the base model using the system of equations (11), in which we assume that the conductivity of the system and its capacity is dependent on the Yang-Mills field, thus we have

$$\begin{aligned}
&L\frac{dI}{dt} + R(T,\phi,\chi)I + \frac{1}{C(\varepsilon)}\int_0^t I dt = U_0 \cos(\omega t)\\
&\frac{dT}{dt} = \frac{\lambda B}{mc_p}(T_0 - T) + \frac{R(T,\phi,\chi)}{mc_p}I^2 - \frac{\sigma_{SB}}{\rho c_p}T^4\\
&\frac{d^2\phi}{dt^2} = c^2\phi(\chi^2 + \lambda_1\phi^2 - \phi_0^2) + k_\phi I,\\
&\frac{d^2\chi}{dt^2} = c^2\chi(\phi^2 + \lambda_2\chi^2 - \chi_0^2) + k_\chi I
\end{aligned} \tag{23}$$

As can be seen from the first equation (23) a periodic change in capacitance leads to a parametric resonance in the system since the main frequency$1/\sqrt{LC(\varepsilon)}$ is not a constant in this case. On the other hand, according to (19), we have the excitation of the Yang-Mills field through interaction with the conduction current.

In equations (19) and (23) there are constants calculated in the Yang-Mills theory [25-26, 28, 32]: $\lambda_1 = 0.1; \lambda_2 = 1; \phi_0 = 1.6171579, \chi_0 = 1.49273856$.

The thrust is expressed through the parameters of the model (23) (see [34])

$$\begin{gathered} F_z = \frac{1}{c^2}\int k_{YM}(\phi_t^2 + \chi_t^2)\partial(\mathbf{E}\times\mathbf{H})_z / \partial t dV = F_0 \frac{(\dot\phi^2 + \dot\chi^2)}{\langle\dot\phi^2 + \dot\chi^2\rangle}\frac{(q'q''' + q''^2)}{(1+\alpha(u-1))}, \\ F_0 = \kappa_{YM}\frac{I_0 U_0 \omega l}{c^2} \end{gathered} \tag{24}$$

Here we used the dependence of the interaction parameter on the temperature [18, 34]. Fig. 6 presents options to optimize traction in the presence of the Yang-Mills field. Note that in the Yang-Mills field, there is a delay in the establishment of traction due to the development of non-linear process – see Fig. 6.

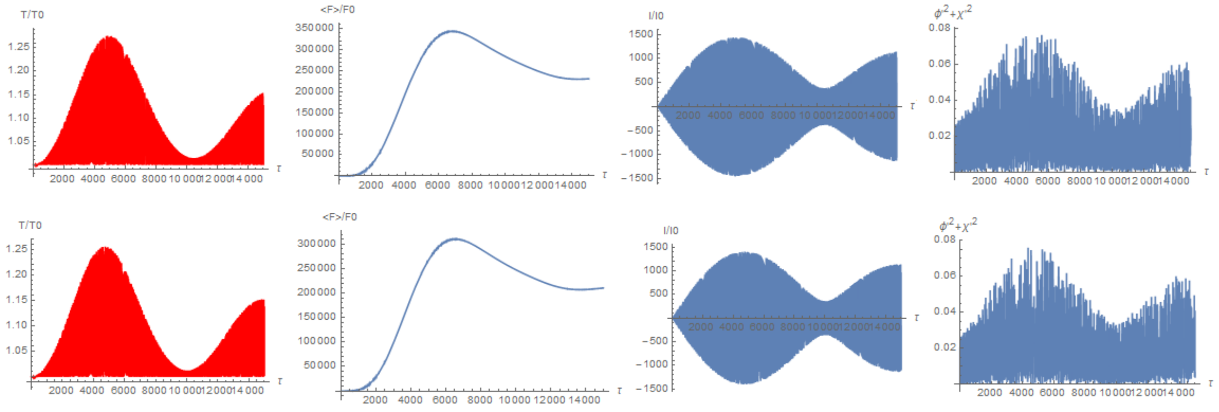

Figure 6: The temperature, normalized force, the current and parameters of the Yang-Mills field in the cavity with quality factor $Q = 10^4$ calculated from the model (23) - (24) with parameters (25). The upper and lower drawings obtained with interaction parameter $k_{YM} = \mp 10^{-3}$ respectively.

Model (23) - (24) was used to calculate the dependence of the thrust of the cavity quality factor Q - Fig. (7), with the following parameters

$$\begin{gathered}\lambda_1 = 0.1; \lambda_2 = 1; \phi_0 = 1.6171579, \chi_0 = 1.49273856; k_{YM} = \pm 10^{-3}; k_\phi = k_\chi = 10^{-4}\omega^2/c^2; \\ \alpha = 1.2; \beta = 1.0031; a = 1.0221; b = 10^3; \phi(0) = \chi(0) = 0.01\omega/c; \dot{\phi}(0) = \dot{\chi}(0) = 0.\end{gathered} \tag{25}$$

Comparing the data in Fig. 3 and 7, we find that in the double logarithmic scale the curves of traction depending on the Q qualitatively similar in two models - (12) and (23). Furthermore, it was found that in the investigated range of parameters traction value slightly depends on the sign $k_{YM} = \pm 10^{-3}$- left and right in Fig. 7, respectively.

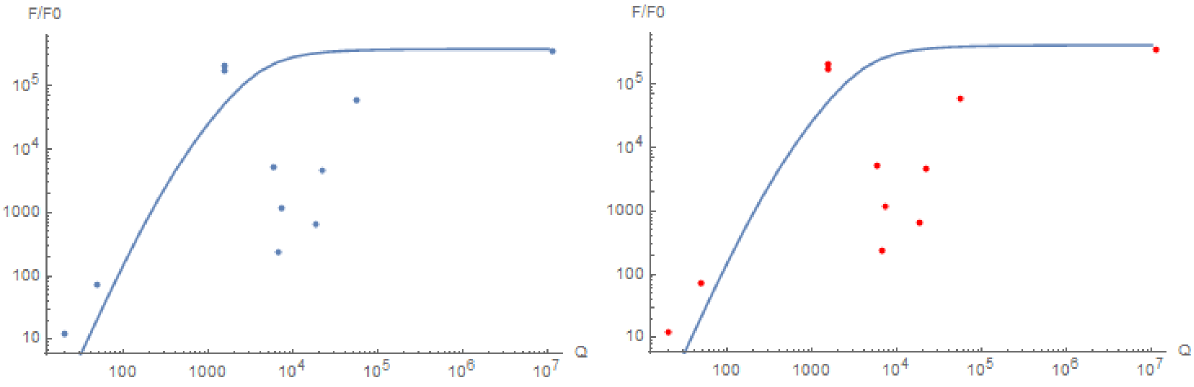

Figure 7: Dependence of normalized thrust of the quality factor Q according to [21] (points) and the normalized force dependent on the parameter Q (solid lines) calculated in the model (23) - (24). The curves on the left and right figures obtained for $k_{YM} = \pm 10^{-3}$ respectively.

Let consider the question of the implementation of the law of conservation of momentum in the system when there is force such as (12) or (24). Note that the principle of motion of photon rockets and gravitational waves rockets in the metric of the photon rockets [35-37] can be used in modeling the thrust force generated by the wave radiation of any nature - gravitational, electromagnetic or waves in the Yang-Mills field. The basic concept of the rocket in the theories [17, 35-37] and others, based on the principle of relativity, is that the mass of the system is reduced by the wave radiation of any nature.

Note that the model (18) describes, as well, particles with mass of $m_{gl} \approx 1500 MeV / c^2$ called glueballs [24, 38]. This type of waves in the Yang-Mills theory solves the problem of conservation of momentum in the electromagnetic drive.

Indeed, in the emission of photons or weak gravitational waves thrust per unit of power in the case of photonic rocket is about $F / W = 1 / c$. Using the expression (24), we find out that force scale $F_0 = \kappa_{YM} \frac{I_0 U_0 \omega l}{c^2} \approx W / c$ provided that $\kappa_{YM} \omega l / c \approx 1$. Therefore, we have $F_0 / W \approx 1 / c = 0.00333564 mN / kW$ that coincides with this value for the photon rocket.

The data shown in Fig. 3 and 7 demonstrate that in the electromagnetic drive [6-16] thrust increases by several orders of magnitude compared to photon rockets. In the Yang-Mills theory, this increase can be explained by the fact that nonlinear waves carry momentum from the system more effectively than photons.

In the present study we examined the mechanism of excitation waves in the Yang-Mills field, leading to the appearance of traction effect at resonance of electromagnetic waves in a conical cavity. The inclusion of the Yang-Mills field in the model has a double scientific interest. On the one hand, this model allows us to explain the processes in electromagnetic drive [6-16]. On the other hand, these devices themselves may be used to register the mechanical effects caused by the Yang-Mills field.

References

1. Choueiri E. Y. New dawn of electric rocket// Scientific American 300, 58–65, 2009.

2. Hoskins A. W. 30 Years of Electric Propulsion Flight Experience at Aerojet Rocketdyne/ Paper IEPC-2013-439, 33rd International Electric Propulsion Conference, Washington DC, October 2013.

3. Fisher Richard. Defying gravity: UK team claims engine based on microwaves could revolutionise spacecraft propulsion// The Engineer (London) 293 (7663), 5 November 2004.

4. Tom Shelley. No-propellant drive prepares for space and beyond// Eureka Magazine. 14 May 2007.

5. Hambling David. Propellentless Space Propulsion Research Continues// Aviation Week & Space Technology, 5 November, 2012

6. Shawyer Roger. A Theory of Microwave Propulsion for Spacecraft// New Scientist. September 2006

7. Shawyer Roger. Second generation EmDrive propulsion applied to SSTO launcher and interstellar probe// Acta Astronautica 116: 166–174, 2015.

8. Shawyer Roger. Microwave Propulsion - Progress in the EmDrive Programme/ 59th International Astronautical Congress (IAC 2008). Glasgow, U.K.: International Astronautical Federation, 29 September – 3 October 2008.

9. Yang Juan, Wang Yuquan, Li Pengfei, Wang Yang, Wang Yunmin, Ma Yanjie. Net thrust measurement of propellantless microwave thrusters// Acta Physica Sinica (in Chinese), Chinese Physical Society, 2012, http://wulixb.iphy.ac.cn

10. Yang Juan, Wang Yu-Quan, Ma Yan-Jie, Li Peng-Fei, Yang Le, Wang Yang, He Guo-Qiang. Prediction and experimental measurement of the electromagnetic thrust generated by a microwave thruster system// Chinese Physics B (IOP Publishing) 22, 5 May 2013.

11. Shi Feng, Yang Juan, Tang Ming-Jie, Luo Li-Tao, Wang Yu-Quan. Resonance experiment on a microwave resonator system// Acta Physica Sinica (in Chinese) (Chinese Physical Society) 63 (15), September 2014.

12. ZHU Yu, YANG Juan, MA Nan. The Performance Analysis of Microwave Thrust Without Propellant Based On The Quantum Theory// Journal of Astronautics (in Chinese) 29 (5): 1612–1615, September 2008.

13. White Harold, March Paul, Nehemiah Williams, O'Neill William. Eagleworks Laboratories: Advanced Propulsion Physics Research. -NASA Technical Reports Server (NTRS) (Technical report) (NASA). JSC-CN-25207, 5 December 2011.

14. Brady David A., White Harold G., March Paul, Lawrence James T., Davies Franck J. Anomalous Thrust Production from an RF Test Device Measured on a Low-Thrust Torsion Pendulum/ 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference. American Institute of Aeronautics and Astronautics, – NASA, 30 July 2014.

15. Fetta Guido P. Numerical and Experimental Results for a Novel Propulsion Technology Requiring no On-Board Propellant/50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference. American Institute of Aeronautics and Astronautics. 30 August 2014

16. Brady D.A., White H.G., March P., Lawrence J.T., Davies F.J. Anomalous Thrust production from an RF Test Device Measured on Low-Thrust Torsion Pendulum// AIAA 2014-4029.

17. Трунев А.П. Принцип относительности и теория движителя электромагнитного типа// Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета (Научный журнал КубГАУ) [Электронный ресурс]. – Краснодар: КубГАУ, 2015. – №10(114). С. 812 – 836. – IDA [article ID]: 1141510061. – Режим доступа: http://ej.kubagro.ru/2015/10/pdf/61.pdf

18. Трунев А.П. Теория движителя электромагнитного типа с учетом тока элементарных частиц и поляризации вакуума / А.П. Трунев // Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета (Научный журнал КубГАУ) [Электронный ресурс]. – Краснодар: КубГАУ, 2016. – №01(115). С. 1247 – 1269. – IDA [article ID]: 1151601080. – Режим доступа: http://ej.kubagro.ru/2016/01/pdf/80.pdf .

19. Абрагам-Беккер. Теория электричества. – М., ОНТИ, 1936.

20. Л.Д. Ландау, Е.М. Лифшиц. Электродинамика сплошных сред. – М., Наука, 1982.

21. Experimental Results/ emdrive.wiki/Main_Page

22. Greg Egan. Resonant Modes of a Conical Cavity/ http://www.gregegan.net/SCIENCE/Cavity/Cavity.html

23. Higgins A.J. Reconciling a Reactionless Propulsive Drive with the First Low of Thermodynamics// arXiv:1506.00494v1, 7 May 2015.

24. Dzhunushaliev V.D. Phase transition for gluon field: a qualitative analysis // Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета (Научный журнал КубГАУ) [Электронный ресурс]. – Краснодар: КубГАУ, 2013. – №06(090). С. 1051 – 1061. – IDA [article ID]: 0901306071. – Режим доступа: http://ej.kubagro.ru/2013/06/pdf/71.pdf

25. Трунев А.П. Усилитель поля Янга-Миллса// Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета (Научный журнал КубГАУ) [Электронный ресурс]. – Краснодар: КубГАУ, 2015. – №07(111). С. 1202 – 1228. – IDA [article ID]: 1111507077. – Режим доступа: http://ej.kubagro.ru/2015/07/pdf/77.pdf

26. Трунев А.П. Конденсатор поля Янга-Миллса// Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета (Научный журнал КубГАУ) [Электронный ресурс]. – Краснодар: КубГАУ, 2015. – №08(112). С. 2014 – 2034. – IDA [article ID]: 1121508145. – Режим доступа: http://ej.kubagro.ru/2015/08/pdf/145.pdf

27. Девитт Б.С. Динамическая теория групп и полей. – Москва, Наука, 1987.

28. Dzhunushaliev V. Scalar model of the glueball// Hadronic J. Suppl. 19, 185, 2004.

29. Трунев А.П. Динамика преонов и структура кварков и лептонов / А.П. Трунев // Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета (Научный журнал КубГАУ) [Электронный ресурс]. – Краснодар: КубГАУ, 2013. – №04(088). С. 895 – 926. – IDA [article ID]: 0881304064. – Режим доступа: http://ej.kubagro.ru/2013/04/pdf/64.pdf

30. Кривоносов Л.Н., Лукьянов В.А. Связь уравнений Янга-Миллса с уравнениями Эйнштейна и Максвелла// Journal of Siberian Federal University, Mathematics & Physics 2009, 2(4), 432-448.

31. Кривоносов Л.Н., Лукьянов В.А. Решение уравнений Янга-Миллса для центрально-симметрической метрики при наличии электромагнитного поля./ Пространство, время и фундаментальные взаимодействия, Вып.3, 2013.

32. Matinyan S. Chaos in the Yang-Mills theory and cosmology: quantum aspects// arXiv:hep-th/0612102v1, 11 Dec 2006.

33. Трунев А.П. Моделирование нелинейных цветовых колебаний в теории Янга-Миллса / А.П. Трунев // Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета (Научный журнал КубГАУ)

[Электронный ресурс]. – Краснодар: КубГАУ, 2015. – №06(110). С. 1654 – 1673. – IDA [article ID]: 1101506108. – Режим доступа: http://ej.kubagro.ru/2015/06/pdf/108.pdf

34. Трунев А.П. Динамическая модель движителя электромагнитного типа / Трунев А.П. // Политематический сетевой электронный научный журнал Кубанского государственного аграрного университета (Научный журнал КубГАУ) [Электронный ресурс]. – Краснодар: КубГАУ, 2016. – №02(116). – IDA [article ID]: 1161602105. – Режим доступа: http://ej.kubagro.ru/2016/02/pdf/105.pdf

35. Bonnor W. B. The photon rockets// Class. Quantum Grav., 11:2007, 1994.

36. Bonnor W. B. Another photon rocket// Class. Quantum Grav. 13 (1996), 277.

37. Bonnor W.B. and Piper M.S. The gravitational wave rocket//Class.Quant.Grav. 14 (1997) 2895-2904.

38. Ochs W. The Status of Glueballs//J. Phys. G. 40, 6, 2013.

References

1. Choueiri E. Y. New dawn of electric rocket// Scientific American 300, 58–65, 2009.

2. Hoskins A. W. 30 Years of Electric Propulsion Flight Experience at Aerojet Rocketdyne/ Paper IEPC-2013-439, 33rd International Electric Propulsion Conference, Washington DC, October 2013.

3. Fisher Richard. Defying gravity: UK team claims engine based on microwaves could revolutionise spacecraft propulsion// The Engineer (London) 293 (7663), 5 November 2004.

4. Tom Shelley. No-propellant drive prepares for space and beyond// Eureka Magazine. 14 May 2007.

5. Hambling David. Propellentless Space Propulsion Research Continues// Aviation Week & Space Technology, 5 November, 2012

6. Shawyer Roger. A Theory of Microwave Propulsion for Spacecraft// New Scientist. September 2006

7. Shawyer Roger. Second generation EmDrive propulsion applied to SSTO launcher and interstellar probe// Acta Astronautica 116: 166–174, 2015.

8. Shawyer Roger. Microwave Propulsion - Progress in the EmDrive Programme/ 59th International Astronautical Congress (IAC 2008). Glasgow, U.K.: International Astronautical Federation, 29 September – 3 October 2008.

9. Yang Juan, Wang Yuquan, Li Pengfei, Wang Yang, Wang Yunmin, Ma Yanjie. Net thrust measurement of propellantless microwave thrusters// Acta Physica Sinica (in Chinese), Chinese Physical Society, 2012, http://wulixb.iphy.ac.cn

10. Yang Juan, Wang Yu-Quan, Ma Yan-Jie, Li Peng-Fei, Yang Le, Wang Yang, He Guo-Qiang. Prediction and experimental measurement of the electromagnetic thrust generated by a microwave thruster system// Chinese Physics B (IOP Publishing) 22, 5 May 2013.

11. Shi Feng, Yang Juan, Tang Ming-Jie, Luo Li-Tao, Wang Yu-Quan. Resonance experiment on a microwave resonator system// Acta Physica Sinica (in Chinese) (Chinese Physical Society) 63 (15), September 2014.

12. ZHU Yu, YANG Juan, MA Nan. The Performance Analysis of Microwave Thrust Without Propellant Based On The Quantum Theory// Journal of Astronautics (in Chinese) 29 (5): 1612–1615, September 2008.

13. White Harold, March Paul, Nehemiah Williams, O'Neill William. Eagleworks Laboratories: Advanced Propulsion Physics Research. -NASA Technical Reports Server (NTRS) (Technical report) (NASA). JSC-CN-25207, 5 December 2011.

14. Brady David A., White Harold G., March Paul, Lawrence James T., Davies Franck J. Anomalous Thrust Production from an RF Test Device Measured on a Low-Thrust Torsion Pendulum/ 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference. American Institute of Aeronautics and Astronautics, – NASA, 30 July 2014.

15. Fetta Guido P. Numerical and Experimental Results for a Novel Propulsion Technology Requiring no On-Board Propellant/50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference. American Institute of Aeronautics and Astronautics. 30 August 2014

16. Brady D.A., White H.G., March P., Lawrence J.T., Davies F.J. Anomalous Thrust production from an RF Test Device Measured on Low-Thrust Torsion Pendulum// AIAA 2014-4029.

17. Trunev A.P. Princip otnositel'nosti i teorija dvizhitelja jelektromagnitnogo tipa// Politematicheskij setevoj jelektronnyj nauchnyj zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta (Nauchnyj zhurnal KubGAU) [Jelektronnyj resurs]. – Krasnodar: KubGAU, 2015. – №10(114). S. 812 – 836. – IDA [article ID]: 1141510061. – Rezhim dostupa: http://ej.kubagro.ru/2015/10/pdf/61.pdf

18. Trunev A.P. Teorija dvizhitelja jelektromagnitnogo tipa s uchetom toka jelementarnyh chastic i poljarizacii vakuuma / A.P. Trunev // Politematicheskij setevoj jelektronnyj nauchnyj zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta (Nauchnyj zhurnal KubGAU) [Jelektronnyj resurs]. – Krasnodar: KubGAU, 2016. – №01(115). S. 1247 – 1269. – IDA [article ID]: 1151601080. – Rezhim dostupa: http://ej.kubagro.ru/2016/01/pdf/80.pdf .

19. Abragam-Bekker. Teorija jelektrichestva. – M., ONTI, 1936.

20. L.D. Landau, E.M. Lifshic. Jelektrodinamika sploshnyh sred. – M., Nauka, 1982.

21. Experimental Results/ emdrive.wiki/Main_Page

22. Greg Egan. Resonant Modes of a Conical Cavity/ http://www.gregegan.net/SCIENCE/Cavity/Cavity.html

23. Higgins A.J. Reconciling a Reactionless Propulsive Drive with the First Low of Thermodynamics// arXiv:1506.00494v1, 7 May 2015.

24. Dzhunushaliev V.D. Phase transition for gluon field: a qualitative analysis // Politematicheskij setevoj jelektronnyj nauchnyj zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta (Nauchnyj zhurnal KubGAU) [Jelektronnyj resurs]. – Krasnodar: KubGAU, 2013. – №06(090). S. 1051 – 1061. – IDA [article ID]: 0901306071. – Rezhim dostupa: http://ej.kubagro.ru/2013/06/pdf/71.pdf

25. Trunev A.P. Usilitel' polja Janga-Millsa// Politematicheskij setevoj jelektronnyj nauchnyj zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta (Nauchnyj zhurnal KubGAU) [Jelektronnyj resurs]. – Krasnodar: KubGAU, 2015. – №07(111). S. 1202 – 1228. – IDA [article ID]: 1111507077. – Rezhim dostupa: http://ej.kubagro.ru/2015/07/pdf/77.pdf

26. Trunev A.P. Kondensator polja Janga-Millsa// Politematicheskij setevoj jelektronnyj nauchnyj zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta (Nauchnyj zhurnal KubGAU) [Jelektronnyj resurs]. – Krasnodar: KubGAU, 2015. – №08(112). S. 2014 – 2034. – IDA [article ID]: 1121508145. – Rezhim dostupa: http://ej.kubagro.ru/2015/08/pdf/145.pdf

27. Devitt B.S. Dinamicheskaja teorija grupp i polej. – Moskva, Nauka, 1987.

28. Dzhunushaliev V. Scalar model of the glueball// Hadronic J. Suppl. 19, 185, 2004.

29. Trunev A.P. Dinamika preonov i struktura kvarkov i leptonov / A.P. Trunev // Politematicheskij setevoj jelektronnyj nauchnyj zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta (Nauchnyj zhurnal KubGAU) [Jelektronnyj resurs]. – Krasnodar: KubGAU, 2013. – №04(088). S. 895 – 926. – IDA [article ID]: 0881304064. – Rezhim dostupa: http://ej.kubagro.ru/2013/04/pdf/64.pdf

30. Krivonosov L.N., Luk'janov V.A. Svjaz' uravnenij Janga-Millsa s uravnenijami Jejnshtejna i Maksvella// Journal of Siberian Federal University, Mathematics & Physics 2009, 2(4), 432-448.

31. Krivonosov L.N., Luk'janov V.A. Reshenie uravnenij Janga-Millsa dlja central'no-simmetricheskoj metriki pri nalichii jelektromagnitnogo polja./ Prostranstvo, vremja i fundamental'nye vzaimodejstvija, Vyp.3, 2013.

32. Matinyan S. Chaos in the Yang-Mills theory and cosmology: quantum aspects// arXiv:hep-th/0612102v1, 11 Dec 2006.

33. Trunev A.P. Modelirovanie nelinejnyh cvetovyh kolebanij v teorii Janga-Millsa / A.P. Trunev // Politematicheskij setevoj jelektronnyj nauchnyj zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta (Nauchnyj zhurnal KubGAU) [Jelektronnyj resurs]. – Krasnodar: KubGAU, 2015. – №06(110). S. 1654 – 1673. – IDA [article ID]: 1101506108. – Rezhim dostupa: http://ej.kubagro.ru/2015/06/pdf/108.pdf

34. Trunev A.P. Dinamicheskaja model' dvizhitelja jelektromagnitnogo tipa / Trunev A.P. // Politematicheskij setevoj jelektronnyj nauchnyj zhurnal Kubanskogo gosudarstvennogo agrarnogo universiteta (Nauchnyj zhurnal KubGAU) [Jelektronnyj resurs]. – Krasnodar: KubGAU, 2016. – №02(116). – IDA [article ID]: 1161602105. – Rezhim dostupa: http://ej.kubagro.ru/2016/02/pdf/105.pdf

35. Bonnor W. B. The photon rockets// Class. Quantum Grav., 11:2007, 1994.

36. Bonnor W. B. Another photon rocket// Class. Quantum Grav. 13 (1996), 277.

37. Bonnor W.B. and Piper M.S. The gravitational wave rocket//Class.Quant.Grav. 14 (1997) 2895-2904.

38. Ochs W. The Status of Glueballs//J. Phys. G. 40, 6, 2013.