

An Alternative Look at Operation of EM Drive. Role of the Electromagnetic Field Gyroscope

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The paper considers a physical process inside EM Drive. According to the proposed conception, there is an electromagnetic field gyroscope, EMFG, originated due to superposition of straight and reflected flows of the electromagnetic energy inside the resonant chamber. The considered model comes to conclusion of existence of a narrow area inside the EMFG where its mass-function experiences a break and even becomes negative. There are 3 models which deduce origination of the thrust of EM Drive on a base of the considered properties of the EMFG.

The first considered model states that there is a gradient of the gravitational potential inside the originated narrow area due to its heavy non-linear electromagnetic mass. Interaction of the originated gradient of the gravitational potential and the mass of the EM Drive results in origination of a net force, which is the thrust of the EM Drive. This thrust is furnished by the axial gradient of the gravitational potential inside the EM Drive.

The second model projects a property and theory of 4D gyroscope, developed by G.I.Shipov, onto EMFG. Operation of the mechanical 4D gyroscope results in the reactionless motion, due to a time-varying and frequency-dependable mass of the gyroscope. The EMFG has the time and frequency dependable mass and fits the above condition for the mechanical 4D gyroscope.

The third model considers a behavior of the EMFG in frames of N.A. Kozyrev's Casual Mechanics. The EMFG is a quantum object and its C2 indicator of movement of time trends to zero as well as the external force Φ_0 . The considered limit of their ratio brings a finite force which is a trust developed by the EM Drive.

EM-Drive, also known as a RF resonant cavity thruster, attracts an attention of the scientists in our days [1,2].

The concept was proposed by Roger Shawyer [1]

The major feature of the invention is a RF resonant tapered cavity, fed with a flux of the microwave radiation injected into the cone-like system, Fig.1

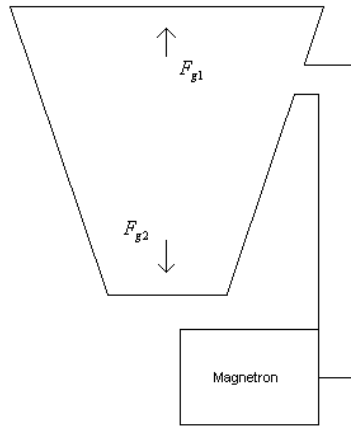


Fig.1. General Concept of EM Drive

Roger Shawyer considers that the group velocity of the electromagnetic wave at the end plate of the larger section is higher than the group velocity at the end plate of the smaller section. Therefore, the radiation pressure at the larger end plate is higher than that at the smaller end plate. Besides that R. Shawyer believes that the resulting difference force is multiplied Q times due to this value of a quality factor of the resonator.

For instance, the 720 mN thrust was measured at 2500 W of input power at 2.45GHz.

However, a classical light-pressure-based approach fails to explain the value of the thrust basing on the developed pressure P, defined by the following expression:

$$P = \frac{W}{c} \cos^2 \varphi \quad (1)$$

Here: W- flux of the electromagnetic radiation, $J s^{-1} m^{-2}$, C is a speed of light.

In this case, 2500 W radiation develops a pressure as much as $8.3E-6 N/m^2$. At the average diameter of EM drives of 0.2 m, the force has to be $2.6E-7 N$. This value can't explain the much higher real thrust developed by EM Drives. On the other hand, a certain number of the tests have been conducted as of today, which present a great variation of the thrust-to-power ratio, from 0 up to 1070 mN/kW [2]. This discrepancy stimulates to consider alternative explanations of the EM Drive phenomenon.

Present publication offers alternative concepts of origination of the thrust developed by EM Drive. All of them consider the Electromagnetic Field Gyroscope.

1. Origination of the Electromagnetic Field Gyroscope in EM Drive

The alternative approach to operation of EM Drive, developed by the author of this publication, is based on origination of Electromagnetic Field Gyroscopes, EMFG, inside the resonator cavity of EM Drive. The wavelength is $1.2E-1 m$ for 2.45 GHz. By this

reason sizes of EM Drives are compatible to this wavelength due to the cavity resonator conditions.

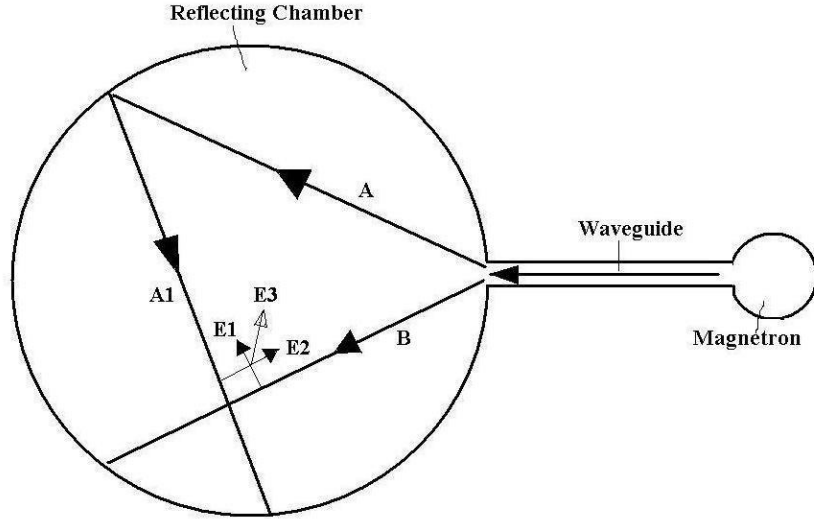


Fig.2.. Origination of the local spinning vectors E_3 as a result of superposition of two parent vectors E_1 and E_2 in the incident B and reflected A1 beams inside the reflecting chamber fed with the magnetron and the waveguide.

There are electric vectors E_1 and E_2 , shifted in a phase, at any arbitrary point of the resonant chamber. The phase shift takes a place due to different distances which the incident and reflected beam pass.

Both magnetic and electric component of incident and reflected EM wave will experience a superposition which will result in origination of a localized spinning vector, an electromagnetic Field Gyroscope, EMFG.

Fig.2 shows origination of the spinning vector E_3 , developed by its parent vectors E_1 and E_2 .

For the parent vectors we have:

$$\vec{E}(t)_1 = \vec{E}_{01} \sin(\omega t) \text{ and } \vec{E}_2(t) = \vec{E}_{02} \sin(\omega t + \varphi) \quad (2)$$

Origination of the phase shift φ is inevitable here due to different distances the beams pass before the superposition.

Generally, E_{01} and E_{02} are not equal, at least because of the beams experience multiply reflections that change their amplitudes. This makes their sum a time-variable.

If we denote the vector E_3 as E_s , stressing its spinning feature, then its variation can be shows as

$$|\vec{E}_s(t)| = \sqrt{E_1^2(t) + E_2^2(t)} \quad (3)$$

All the rotational power of EMFG inside the EM Drive is produced by the power of the magnetron. It has to be stressed that a labeled power of the magnetron generators claims their maximal power if a load which converts electromagnetic energy into dielectric losses (heating) is located in the resonant chamber. By this reason, the real power of EMFG is lower than the labeled power.

2. Some Specific Features of EMFG

It has to be said that EM Drive develops linear speeds of the end of the spinning vector E_s compatible with that of light, c . Experimental researches report average radius EM Drive as order of 0.1 m at 2 GHz=1.3E+10 rad/s average frequency. That is the end of the spinning vector E_s has a linear speed as order of $v=R\omega=1.26E+9$ m/s, which is compatible with speed of light and **has to be understood as a group speed here**. Taking into consideration the light-compatible speed of the vector, the mass of the field has to be calculated taking into account the relativistic law.

Mass of EMFG can be found as

$$m = \frac{W}{c^2}, \quad (4)$$

where W is a total energy pumped in the chamber by the magnetron. It's a sum of potential and kinetic energies of EMFG. This mass experiences a variation according to the time-dependable vector $E_s(t)$.

The mass variation, MT^{-1} , is

$$\frac{dm}{dt} = \frac{1}{c^2} \frac{d(W_{\max} \sin \omega t)}{dt} = \frac{1}{c^2} \omega W_{\max} |\cos \omega t| \quad (5)$$

If $dW/dt = 1000$ Wt, dm/dt is as order of 1E-14 kg/s.

On the other hand, the mass of EMFG depends on its frequency as well, as it was shown earlier [3,4].

We have to understand that all the energy inside the EM Drive is delivered by the magnetron. At GHz frequencies of the EM Drive, the end of E_s vector has a speed of light compatible value. By this reason, the relativistic effects have to be taken into account.

$$W(\omega, R, t) \approx \frac{c^2 \sqrt{1 - \left(\frac{\omega R}{c}\right)^2} W(t)_0}{2c^2 \sqrt{1 - \left(\frac{\omega R}{c}\right)^2} - \omega^2 R^2}, \quad (6)$$

where W_0 is initial energy before the spinning.

Formula (6) shows how the total energy depends on the speed of the end of the spinning vector \mathbf{E}_s .

This non-linear function (the fraction factor before $W(t)_0$) experiences a break even before reaching speed of light, Fig.3.

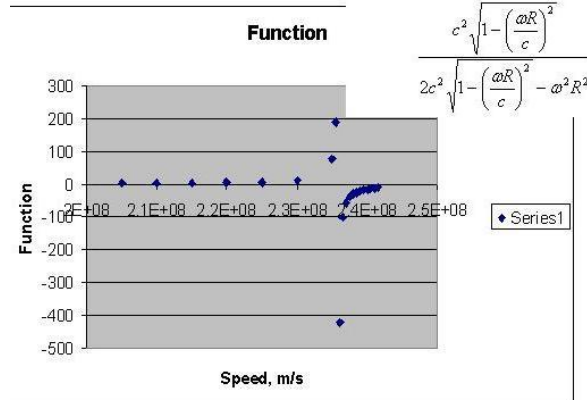


Fig.3. A function of the formula (6) experiences a break at subluminal speed of the end of the spinning vector \mathbf{E}_s .

A physical sense of its negative portion can say that a portion of EMFG performs a work by itself.

The positive energy corresponds to the work, performed by the magnetron-resonator system and contributed into EMFG, while the negative value corresponds to the work performed by EMFG.

If we consider a narrow field ring of the radius R , the mass of EMFG inside the ring can be shown as a function of time, angular frequency and radius R ;

$$m_i(\omega, R, t) \approx \frac{\sqrt{1 - \left(\frac{\omega R}{c}\right)^2} W(t)_0}{2c^2 \sqrt{1 - \left(\frac{\omega R}{c}\right)^2} - \omega^2 R^2} \quad (7)$$

It has to be said that when the condition $\omega R \ll c$ is not observed, we have to consider the mass as an integral

$$m = \int_V \frac{\sqrt{1 - \left(\frac{\omega r}{c}\right)^2} \rho(x, y, z, \omega, t)}{2c^2 \sqrt{1 - \left(\frac{\omega r}{c}\right)^2} - \omega^2 r^2} dx dy dz, \quad (8)$$

where ρ is a density of energy and r is a current location of the considered point along the radius.

A major concentration of the EMFG mass takes a place in the very limited gap, Figs. 4 and 5.

Actually, there are two adjacent narrow rings having opposite sign masses.

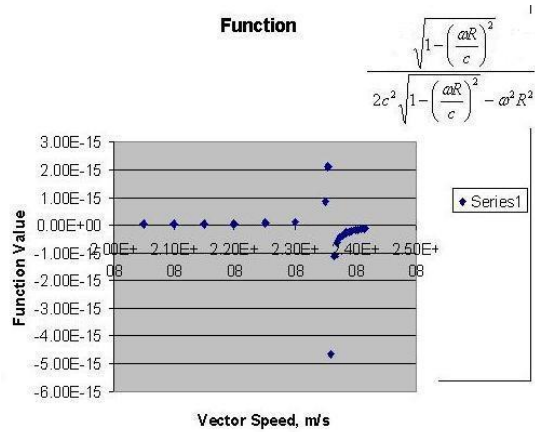


Fig.4. A function of the arbitrary mass of EMFG in vicinity of the break point.

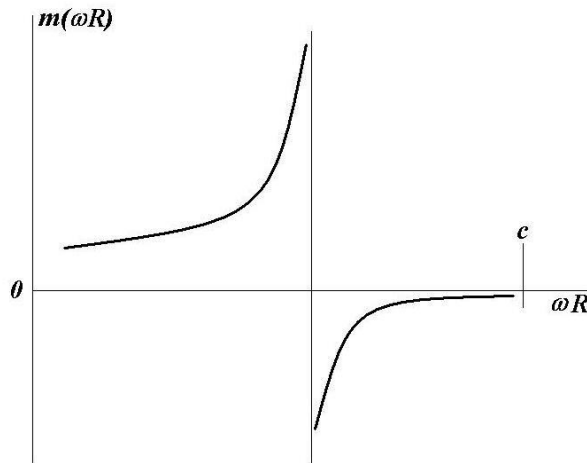


Fig.5. Allocation of the mass function of EMFG on the vector speed scale.

At $\omega R \sim 2.4E+8$ m/s the mass experiences a break. So, the critical frequency is $\omega_{cr} \sim 2.4E+8$ m/s * R^{-1} .

Even a narrow-band originated EMFG produces a complex movement of the E_s vector due to combinations of frequencies inside the band.

Fig.6 shows a natural EMFG, obtained with a band-pass filter near various objects. As seen in the images, vector E_s moves along complex discrete trajectories developed by superposition of orthogonal fields of different frequencies. This confirms the concept of $m = m(\omega, t)$.

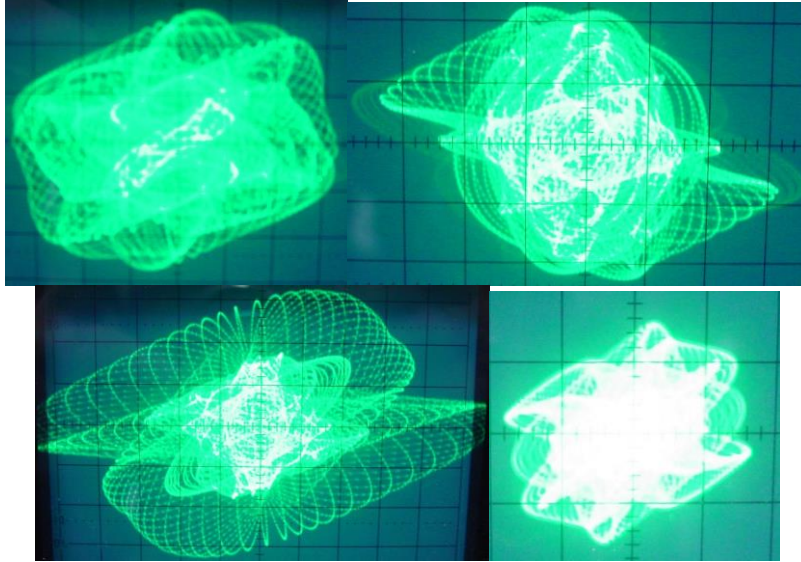


Fig.6. Trajectories of natural EMFG in vicinity of various objects recorded with a narrow-band pass filter.

Having a quantum mass (at $\omega R < c$) and discrete orbits, EMFG is a quantum object.

3. Models of Origination of the Net Force in EM Drive on a Base of EMFG

When the speed of the end of the E_s vector exceeds speed of light, it has to be considered as a phase speed. The real flow of the rotating electromagnetic energy will not exceed speed of light in vicinity of the wall of the chamber. Formal calculation of the speed of the end of E_s brings $1.3E+9$ m/s at 0.1 m radius, which is acceptable for the phase speed. At $2GHz=1.3E+10$ rad/s operating frequency, the value of the active radius according to formula (6) is $2.4E+8(1.3E+10)^{-1}=1.8E-2$ m, which is smaller than the average radius of the tested drives, as order of $1E-1$ m. The existing sizes of the EM Drive are needed to support the resonance, but the operating radius is lower than that.

The experiments of the author of this publication have shown a reality of a torque originating in spinning electromagnetic fields. More detailed it's considered in [3,4] and video experiments [5]. The proposed here models explain origination of the net mechanical force inside the EM Drive.

3.1. Model 1. A Joint of Negative and Positive Mass Inside the EM Drive Chamber

According to (7), the mass of EMFG depends on the radius and the frequency. At 2.45 GHz the cone-like chamber reaches its critical point at $1.8E-2$ m along the radius. This point is a border between positive and negative mass portions of EM Drive. Less radius zone corresponds to a positive mass, while the $x > 1.8E-2$ m brings the mass to its negative value, because the linear speed v of the end of the radius-vector exceeds the critical speed v_{cr} at some point along EM drive axis: $v > v_{cr}$, Fig.7. Moreover, there is an axial gradient of the mass inside the chamber, which results in a gradient of the gravitational potential, φ , Fig.8.

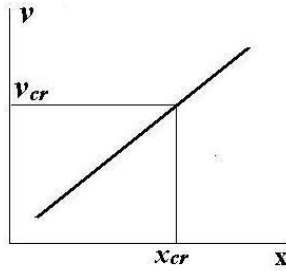


Fig.7. Speed of the spinning radius-vector of EMFG increases along the axis of EM drive passing its critical value $v_{cr} =$ at some critical point x_{cr} along the X axis.

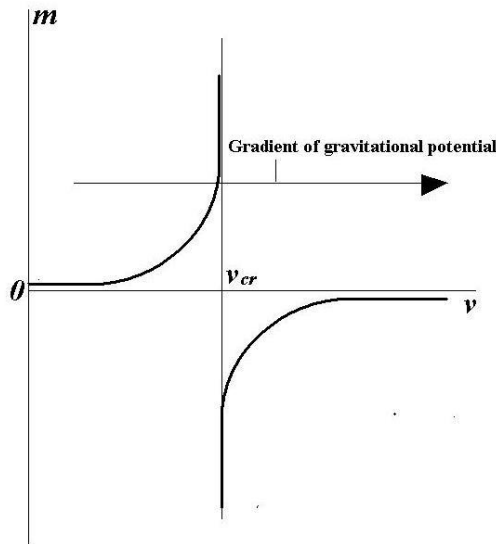


Fig.8. Origination of a gradient of the gravitational potential inside the cone-like resonant chamber due to EMFG activity which results in breaking the $m(v)$ function of the EMFG. Beside the radial gradient of the gravitational potential, there is an axial gradient which furnishes the thrust as a result of interaction of the center of mass of EM Drive and the gradient of gravitational potential.

The center of mass of EM drive gets inside this gradient of the gravitational potential φ . Therefore, this center of the mass M of EM Drive experiences an action of the force

$$\vec{F} = -\vec{\nabla} \varphi \cdot M \quad (9)$$

It has to be said that the major portion of the mass of EMFG is localized inside a very narrow area around v_{cr} . **Therefore, the efficiency of EM drive gets maximal if location of its center of mass gets within location of the break of $m(x)$ function.**

Beside the radial gradient of the gravitational potential, there is an axial gradient which furnishes the axial force.

3.2. Model 2. Origination of the Net Force with Regard to G.I. Shipov's Theory of 4D Gyroscope. A Field Gyroscope Inertoid.

In 60s-70s of the past Century, the scientific world was agitated with claims of reactionless drives, V. N. Tolchin [6] and N.L. Dean [7] drives, which could generate a net force.

It met a resistance of the official scientific community then.

Later, G.I Shipov, a well-known Russian theoretician, had developed his Theory of Physical Vacuum which includes Fields and Forces of Inertia as a subject of scientific study [8].

He shows that mass is a function of spinning, $m=m(\omega)$.

Considering motion of a small cart having an angular speed-varying gyroscope, when no external force is applied, $F=0$, he gets the equation for this closed system

$$m(\omega)\frac{d}{dt}\vec{v} = -\vec{v}\frac{d}{dt}m(\omega) \quad (10)$$

If the angular frequency of the gyroscope varies, as it was realized in the experiment, then the right portion of (10) not equals to zero, which means origination of the $m(\omega)dV/dt$ force. In the experiments with inertoids, they could change direction of the motion depending on a mode of the gyroscope.

As we see from the formulas (7,8), the mass of EMFG is both frequency- and time dependable and, therefore, can match and contribute into equation (10).

The wide spectrum of the magnetron can contribute into the time-variability of the mass due to combination of the component of the spectrum.

Real magnetrons are supplied with periodic voltages, Fig.9.

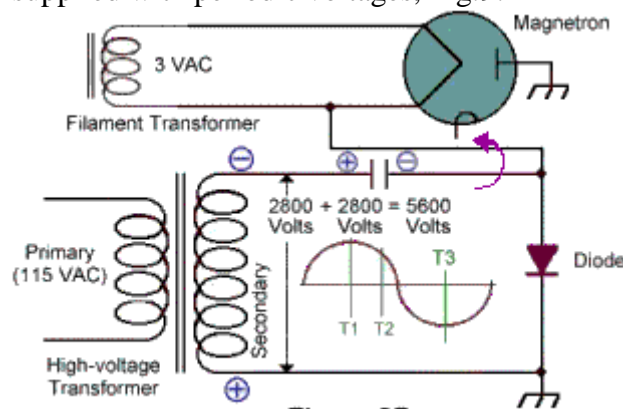


Fig.9. (From Internet). Pulse feeding a magnetron, 60Hz in USA. Each of the half-period the magnetron irradiates time varying radio-pulses of central 2.45 GHz frequency with its cavity resonator (not shown).

By this reason, they produce radio pulses which have a wider spectrum if compared to that originated at continuous voltage feeding. Real spectra of the pulse-fed magnetron are shown in Fig.10

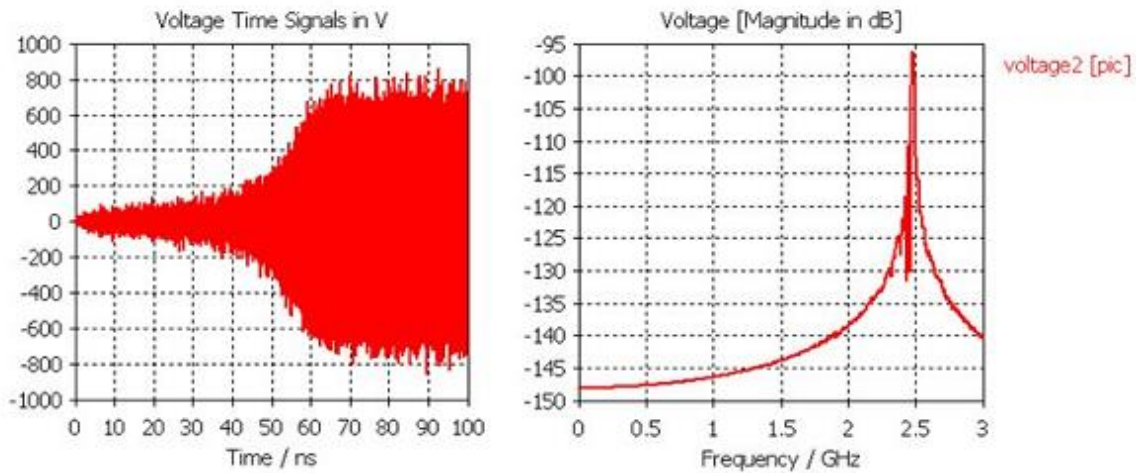


Fig.10. (From Internet). Dynamics of developing amplitude of magnetron (left), and spectrum of the 2.45 GHz magnetrons.

Even high-quality cavity resonators have some finite bandwidth. Components of this spectrum interact with each other producing a complex spinning of the vector \mathbf{E}_s . Its angular frequency ω experiences variations and can be shown as $\omega = \omega(t)$. Fig.6 shows an image of real natural EMFG for the narrowband resonator having $Q=4096$. It shows the quantum nature of EMFG having discrete orbits and experiencing a precession/ So, its mass is time-variable according to (7) and (8) and has a finite $\frac{d}{dt}m(\omega)$ derivative.

Therefore we have an electromagnetic analog for the equation (10) describing a support-less motion.

3.3. Model 3. N.A. Kozyrev's Casual Mechanics and EMFG

The Casual Mechanics by N.A. Kozyrev considers a relation between the cause and effect resulting in their mechanical manifestation [9]. According to Kozyrev, if there is some spatial interval between the cause and effect, δx , and there is some temporal interval between them, δt , then one can say there is some speed $C_2 = \frac{\delta x}{\delta t}$ which, according to Kozyrev, shows a speed of that how the cause converts into the effect. He claimed that the value of C_2 is nothing but a movement of the time. Considering C_2 for two extremities like the classical and quantum mechanics, Kozyrev comes to conclusion that, for the classical Newton's mechanics $C_2 = \infty$, while for the quantum mechanics $C_2 = 0$.

Taking into consideration the extreme nature of this approach, we can write down $C_2 \rightarrow \infty$ for the classical mechanics, while $C_2 \rightarrow 0$ for the quantum mechanics.

Considering interaction of mechanical gyroscope with the move of time C_2 , he derived the following additional force $\Delta\Phi$ and its reaction ΔR acting on the gyroscope.

$$\Delta\Phi = \Phi - \Phi_0 = +j \frac{u}{C_2} |\Phi_0| \quad (11)$$

$$\Delta R = R - R_0 = -j \frac{u}{C_2} |R_0| \quad (12)$$

Here: j is a unit vector; u is a linear speed of rotation, Φ_0 is an original force applied to the gyroscope.

EMFG is a quantum object by its mass and discrete properties []. Therefore, we have to consider $C_2 \rightarrow 0$ for it. On the other hand, we don't have a real finite external force Φ_0 applied to EMFG in EM Drive beside the gravitational one. Therefore, $\Phi_0 \rightarrow 0$ and we can write down:

$$\Delta\Phi = \lim_{C_2 \rightarrow 0, \Phi_0 \rightarrow 0} +j \frac{u}{C_2} |\Phi_0| \quad (13)$$

$$\Delta R = \lim_{C_2 \rightarrow 0, \Phi_0 \rightarrow 0} -j \frac{u}{C_2} |R_0| \quad (14)$$

We have two infinitesimal values, C_2 and Φ_0 (as well as R_0) and the limit of their ratio can be a finite value, which is the thrust developed by the EM Drive.

Conclusion.

All the proposed models are based on existence of the Electromagnetic Field Gyroscope inside the EM Drive.

- The first considered model states that there is a gradient of the gravitational potential inside the originated narrow area due to its heavy non-linear electromagnetic mass. Interaction of the originated gradient of the gravitational potential and the mass of the EM Drive results in origination of a net force, which is the thrust of the EM Drive. This thrust is furnished by the radial gradient of the gravitational potential inside the EM Drive.
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