

# Is the EM-Drive a Closed System?

Carmine Cataldo

Independent Researcher, PhD in Mechanical Engineering, Battipaglia (SA), Italy  
Email: catcataldo@hotmail.it

**Abstract**—Since its disclosure, the so-called EM-Drive, an apparently reactionless electromagnetic thruster conceived by Roger Shawyer, has simultaneously caused wide scepticism, related to the physical principles that may allow its functioning, and understandable enthusiasm, by virtue of the astonishing scenarios potentially offered by such a device. On the one hand, thrust without exhaust is de facto impossible, unless we deny the Law of Action-Reaction, whose evident violation would result in acknowledging the concrete need for a new Physics; on the other hand, it would appear that opportunely shaped resonant cavities, when fuelled with microwaves, deliver a certain thrust, apparently without a detectable exhaust. In this paper, instead of discussing the validity of the various tests to date independently carried out, speculating about misleading side-effects or inadequate instrumental precision, we simply suppose that the thrust may be an actual phenomenon. Therefore, we try to provide a qualitative explanation to the functioning of the alleged reactionless device, by resorting to a theory elsewhere proposed and herein briefly discussed.

**Keywords**—EM-Drive, Closed System, Resonant Cavity Thruster, Hidden Coordinate, Reflectors Temperature.

## I. INTRODUCTION

Very qualitatively, the EM-Drive is nothing but a resonant cavity fuelled by microwaves, basically consisting of a hollow conical frustum and a magnetron. According to Shawyer [1], the principle of operation of his revolutionary contraption is essentially based on the radiation pressure: in a few words, the alleged thrust would arise from the difference between the forces exerted upon the reflectors (the bases of the frustum). In spite of the fact that such a device, as long as it is considered as being a closed system, explicitly violates the conservation of momentum and Newton's well-known third law, it would appear, according to several tests to date carried out, that the EM-Drive can concretely deliver a certain thrust without a detectable exhaust [2]. As implicitly suggested in the foregoing sentence, the easiest way to solve the paradox may consist in demonstrating, first and foremost, that the device in question cannot be properly regarded as a closed system.

For the sake of clarity, we reveal in advance that the detectability of the exhaust [3], a term that actually will turn out not to be entirely suitable for the hypothesized scenario, is not herein addressed.

## II. THE CONSERVATION OF ENERGY

We hypothesize a closed Universe, globally flat, characterized by four spatial dimensions, belonging to the so-called oscillatory class [4] [5] (“O Type” in Harrison’s classification) [6]. Time is postulated as being absolute [7]. The Universe is modelled as a 4-Ball whose radius is herein denoted by  $R$ . On the contrary, the Universe we are allowed to perceive is identified with a hypersphere whose radius of curvature, herein denoted by  $z$  (with  $z$  not null and not greater than  $R$ ), depends on the state of motion. Net of the symmetry [8], what we perceive as being a material point may actually be a material straight-line segment, whose (four-dimensional) mass is herein denoted by  $M$ , bordered by the centre of the Universe and the point itself. If a material point is at rest, the radial extension of the corresponding material segment is equal to the radius of the Universe. If a point starts moving with a constant tangential speed, denoted by  $v$ , the radial extension of the corresponding material segment undergoes a reduction. Similarly, the mass (of the segment) in motion, herein denoted by  $M_z$ , is less than the one at rest, even though the linear density remains the same. Denoting with  $c$ , as usual, the speed of light, the conservation of energy (for a free particle-segment) can be written as follows [9]:

$$E = Mc^2 = E' + E'' + E''' \quad (1)$$

Let’s now make explicit the three energetic components:

$$E' = M_z v^2 \quad (2)$$

$$E'' = \left(\frac{z}{R}\right)^2 M_z c^2 \quad (3)$$

$$E''' = (M - M_z)c^2 = \left(\frac{M}{M_z} - 1\right) M_z c^2 \quad (4)$$

For the reduced mass, since the linear density is considered as being constant, we banally have:

$$M_z = \frac{z}{R} M \quad (5)$$

By virtue of (2), (3) and (4), taking into account (5), we can evidently write (1) as follows:

$$Mc^2 = M_z v^2 + \left(\frac{z}{R}\right)^2 M_z c^2 + \left(\frac{R}{z} - 1\right) M_z c^2 \quad (6)$$

From the previous equation we immediately deduce the underlying identity:

$$M_z c^2 = M_z v^2 + \left(\frac{z}{R}\right)^2 M_z c^2 \quad (7)$$

If we introduce the Lorentz factor [10] [11], we have:

$$\gamma = \frac{1}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \quad (8)$$

$$\left(\frac{v}{c}\right)^2 = \beta^2 = 1 - \frac{1}{\gamma^2} \quad (9)$$

From (7), exploiting the definition of the Lorentz factor, we immediately obtain:

$$z = R \sqrt{1 - \left(\frac{v}{c}\right)^2} = \frac{R}{\gamma} \quad (10)$$

Taking into account (5), the linear density can be defined as follows:

$$\bar{M} = \frac{M}{R} = \frac{M_z}{z} \quad (11)$$

As for the specific energies (the energies per unit of length), we consequently have:

$$\bar{E} = \bar{E}' + \bar{E}'' + \bar{E}''' = \frac{Mc^2}{z} = \frac{\bar{M}}{R} c^2 = \frac{\bar{M}c^2}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \gamma \bar{M}c^2 \quad (12)$$

$$\bar{E}' = \frac{M_z}{z} v^2 = \bar{M} \beta^2 c^2 = \left(1 - \frac{1}{\gamma^2}\right) \bar{M}c^2 \quad (13)$$

$$\bar{E}'' = \left(\frac{z}{R}\right)^2 \frac{M_z}{z} c^2 = \frac{\bar{M}c^2}{\gamma^2} \quad (14)$$

$$\bar{E}''' = \left(\frac{R}{z} - 1\right) \frac{M_z}{z} c^2 = (\gamma - 1) \bar{M}c^2 \quad (15)$$

By virtue of (13), (14) and (15), taking into account (12), we immediately obtain:

$$\gamma \bar{M}c^2 = \left(1 - \frac{1}{\gamma^2}\right) \bar{M}c^2 + \frac{\bar{M}c^2}{\gamma^2} + (\gamma - 1) \bar{M}c^2 \quad (16)$$

Denoting with  $E_0$  the energy at rest, we can banally write:

$$\bar{E}_0 = \frac{Mc^2}{R} = \bar{M}c^2 \quad (17)$$

$$\bar{E} = \gamma \bar{M}c^2 = \bar{E}_0 + (\gamma - 1) \bar{M}c^2 \quad (18)$$

By dividing both members of (7) by  $z$ , making explicit the Lorentz factor, we immediately obtain:

$$\bar{M}c^2 = \bar{M}v^2 + \frac{\bar{M}c^2}{\gamma^2} \quad (19)$$

By multiplying both members of the foregoing equation by the Lorentz factor, we have:

$$\gamma \bar{M}c^2 = \gamma \bar{M}v^2 + \frac{\bar{M}c^2}{\gamma} \quad (20)$$

$$\bar{E} = \frac{\bar{M}c^2}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \frac{\bar{M}v^2}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} + \sqrt{1 - \left(\frac{v}{c}\right)^2} \bar{M}c^2 \quad (21)$$

The concept of dimensional thickness has been elsewhere expounded [9]. Very briefly, the three-dimensional curved space we are allowed to perceive may be characterized by a thickness, denoted by  $\Delta z_{min}$ , that may represent nothing but the “quantum of space”. Consequently, the mass we perceive, denoted by  $m$ , may be provided by the underlying banal relation:

$$m = \bar{M} \Delta z_{min} \quad (22)$$

As for the energy we perceive, with obvious meaning of the notation, we can write:

$$E_m = \bar{E} \Delta z_{min} = (\bar{E}' + \bar{E}'' + \bar{E}''') \Delta z_{min} \quad (23)$$

$$E_m = E'_m + E''_m + E'''_m \quad (24)$$

By multiplying both members of (16) by  $\Delta z_{min}$ , we have:

$$E_m = \gamma mc^2 = \left(1 - \frac{1}{\gamma^2}\right) mc^2 + \frac{mc^2}{\gamma^2} + (\gamma - 1) mc^2 \quad (25)$$

By multiplying all the members of (21) by  $\Delta z_{min}$ , we immediately obtain the well-known underlying equation

$$E_m = \frac{mc^2}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \frac{mv^2}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} + \sqrt{1 - \left(\frac{v}{c}\right)^2} mc^2 \quad (26)$$

Denoting with  $p$  the momentum, with  $L$  the (relativistic) Lagrangian, and with  $H$  the Hamiltonian, we have:

$$p = \frac{mv}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \quad (27)$$

$$L = -\sqrt{1 - \left(\frac{v}{c}\right)^2} mc^2 \quad (28)$$

$$E_m = H = pv - L \quad (29)$$

### III. REFLECTORS TEMPERATURE

If something can be heated, it is surely characterized by a microstructure. Obviously, this intuitive concept also applies to the *EM-Drive* reflectors. Very approximately, when a solid is heated, its atoms start vibrating faster (around points that can be considered as being fixed). In other terms, as the temperature increases, the average kinetic energy increases (and vice versa). Several thermal analyses of the *EM-Drive* have shown how the bases of the above-mentioned device (when in operation) reach different temperatures [12]. For the sake of simplicity, we ignore how the temperature is distributed (in other terms, two generic points belonging to the same base are regarded as characterized by the same temperature). Consequently, let's denote with  $T_1$  and  $T_2$  the average temperatures reached by the bases (with  $T_2$  greater than  $T_1$ ).

The scenario is qualitatively depicted in *Figure 1*.

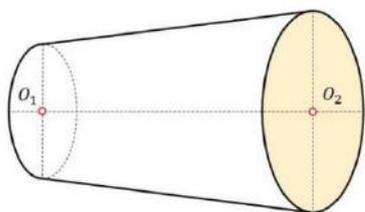


Figure 1. Hollow Conical Frustum

According to the model briefly expounded in the previous paragraph,  $O_1$  and  $O_2$ , the centres of the bases, are not the endpoints of an ideal (the cavity is empty) straight line segment. When the device is completely at rest,  $O_1$  and  $O_2$  can be approximately considered as being the endpoints of an (ideal) arc of circumference whose radius is equal to  $R$ . Moreover, bearing in mind the four-dimensional model herein exploited, the above-mentioned points are actually straight line segments whose radial extension, at rest, equates the radius (of curvature) of the Universe.

### IV. IS THE EMDRIVE A CLOSED SYSTEM?

At the beginning, when the device is not in operation, the bases are characterized by the same temperature, and the *EM-Drive* can be obviously regarded as a closed system. When the device is in operation, the bases, after a certain time, reach the temperatures  $T_1$  and  $T_2$ . Consequently, we can (statistically) state that the average kinetic energy (and, consequently, the average vibrational speed) of the points belonging to *Surface 1* is less than the average kinetic energy of the points belonging to *Surface 2*. According to the theory we have being resorting to, this means that the radial extension of the material segment that corresponds to  $O_1$ , denoted by  $z_1$ , is greater than the one that corresponds to  $O_2$ , denoted by  $z_2$ .

The scenario is qualitatively depicted in *Figure 2*.

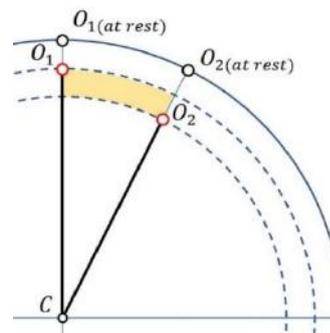


Figure 2. The "Hidden" Exhaust

In other terms, we have:

$$\overline{CO_2} = z_2 < z_1 = \overline{CO_1} \quad (30)$$

Since the electromagnetic radiation can propagate at any level [8] (for any value of  $z$  less than or equal to  $R$ ), photons are allowed to leave the cavity if  $z$  is greater than  $z_2$  (and the thrust is so legitimized). On balance, notwithstanding our perception of reality, the *EM-Drive* can be considered as being a closed system only for  $z$  less than  $z_2$ .

### V. FINAL REMARKS AND CONCLUSIONS

Firstly, it is worth highlighting how the dissertation in its entirety has been carried out by introducing several heavy approximations and intentionally ignoring a great deal of subjects, among which the detectability of the alleged exhaust and a more accurate description of the device stand out. In particular, as far as the principle of operation of the *EM-Drive* is concerned, we have evidently avoided discussing Shawyer's explanation [1] (who, among other things, explicitly resorts to Special Relativity) [13], as well as further interesting theories [14] [15], limiting ourselves to referring to the contents of the official *EM-Drive* page. However, as implicitly suggested by the title, the aim of this paper fundamentally lies in providing an alternative explanation, expounded as qualitatively and understandably as possible, to the alleged functioning of the device. According to our theory, if a material point (actually a material segment) is provided with a certain kinetic energy, its radial coordinate (the radial extension of the material segment) is different from  $R$ : on this subject, we underline that if  $z^*$  is the value taken by the radial (de facto hidden) coordinate, there is no mass for  $z$  greater than  $z^*$ . Consequently, radiation (but not mass) can, as it were, pass through the point (the segment). The third addend in the second member of (1), that represents the energy needed to produce the motion (in this specific case vibrational), is clearly related to the non-material component of the particle. In this regard, although the

wave-particle duality is not herein addressed, we would like to simply highlight how the above-mentioned energetic component is somehow connected to the well-known concept of quantum potential [16] [17] [18]. Ultimately, returning to the title of this paper, the answer is: the *EM-Drive* can be simultaneously a closed and an open system. More precisely, the device is completely closed when it is concretely at rest (actually, this is an ideal condition), and partially closed when it is in operation. Moreover, the opening of the (hidden) exhaust basically depends on the difference between the reflectors temperatures.

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