

On the anomalous forces in microwave cavity-magnetron systems

Elio B. Porcelli¹ ✉, Victo S. Filho¹

¹H4D Scientific Research Laboratory, 04674-225, São Paulo, Brazil

✉ E-mail: elioporcelli@h4dscientific.com

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Abstract: In this work, the authors report positive results regarding their measurements of anomalous thrust forces in a resonant microwave cavity without dielectrics associated with a magnetron. They measure such forces and successfully compared these values with their corresponding theoretical values, based on the hypothesis of preexisting state of generalised quantum entanglement in which the momentum conservation principle is satisfied by the non-local interaction between the internal charge carriers of the system and the environment. It is explained why the system can provide us with a novel technology using thrust without ejecting any kind of propellant. It is also reported a novel property related to the external force induction projected from the system. They show that their theoretical calculations also present a good agreement with the experimental measurements of other authors working with such types of EM-Drives. The control and enhancement of the effect can allow the viability of a new technology of spatial transportation and the development of devices for force induction at a distance.

1 Introduction

In 2001, it was proposed for the first time by Roger Shawyer a device formed by a conical cavity which had the function of converting electrical energy into microwaves and then the latter would provide thrust to the system. The device was called Electromagnetic Drive or EM-Drive [1]. Although the effect is very weak, it can move a rocket or an airship through space because the thrust continuously acts over time, so that the speed increases very much after a long time. However, the device is still very polemical, and many researchers believe that the thrust effect cannot exist because it could violate Newton's third law, considering that it creates thrust without expelling fuel, needed for the reaction force described in the third law. However, in recent years, it has been developed intense research to verify the existence of anomalous thrust effects in such resonant microwave cavity systems [2–8]. In fact, the investigation for understanding and enhancing the phenomenon can mean the advent of a remarkable new space propulsion technology without fuels, based on electric propulsion.

As known, conventional space plasma thrusters are basically Hall thrusters and ion thrusters. Those engines are space propulsion devices of high performance and long life duration [9, 10]. So, EM-Drives are a new type of thruster, i.e. a microwave thruster. The basic component of the thruster is a cylindrical, tapered resonant cavity, which can also be pushed by microwave radiation, with the microwave source and the tapered resonant cavity integrated together. The microwave thruster is more compact, highly efficient, and easy to control the thrust level [7]. It is exactly that new type of propulsion device that was called by Shawyer as EM-Drive. A scheme of the device is represented in a simplified diagram in Fig. 1. The first prototype consumed 700 W power, producing 88 mN force; in the following, a second device was built improving the technology: for 300 W of microwave production, it was generated a force of 96.1 mN [7].

In the initial project of Shawyer, he used an engine formed by a conical cavity with the horizontal axis of symmetry which could rotate a structure of 100 kg. He measured a force of 96 mN by using an industrial magnetron of a few hundred watts below the cavity, which achieved 17 MW power as a result of multiplying the power with the Q factor of the cavity. The magnitude of that force was achieved with a filament current of 250 A. Since its invention, the device has been continuously improved in design. For instance,

in [6], it was implemented an experiment for the measurement of the impulsive thrust in vacuum radio-frequency (RF) tests. Such tests included the search for any sources of impulsive thrust, and they were verified. As a conclusion, the tests suggested that the system was consistently operating with a thrust-to-power ratio of magnitude (1.2 ± 0.1) mN/kW.

In other recent work [7], it was also reported successful theoretical and experimental results for the electromagnetic thrust generated by a microwave thruster system. Basically, the microwave thruster system described can convert microwave power directly to thrust without a gas propellant. The net electromagnetic thrust was experimentally measured in the interval [70, 720] mN when the microwave output power was in [80, 2500] W.

In [8], we can verify more experimental results concerning the operation of an EM-Drive with the magnetron. The generation of a weak anomalous thrust on a low-thrust torsion pendulum reported in [8] was also achieved by considering an RF resonant cavity without the need of propellant or other medium which allowed exchanging momentum. Basically, they reported experiments with an electromagnetic resonant cavity in a conic shape in which it was injected a stationary electromagnetic wave through a waveguide

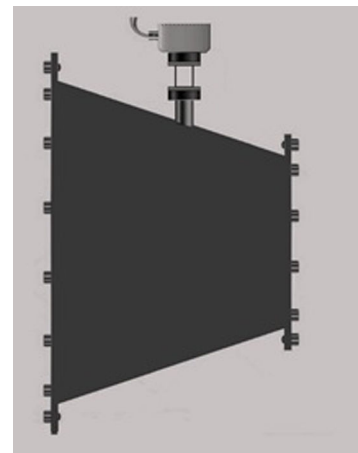


Fig. 1 Simplified diagram of the conic cavity, the waveguide and the magnetron

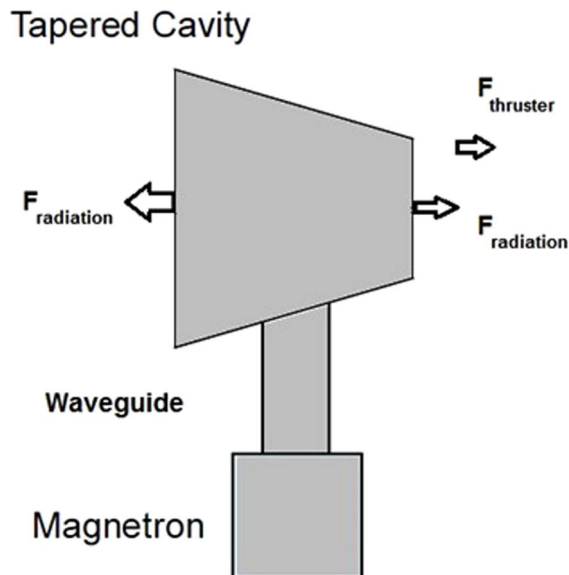


Fig. 2 Basic schematic diagram of the EM-Drive mounted in the experiments reported in [8]

and generated by a magnetron coupled in a microwave oven. The conic resonant cavity, the waveguide, and the magnetron were strongly mechanically connected so that the force was measured by considering all the setup coupled with a balance of torsion inside a vacuum camera. One can note that the measurements of forces were not only performed in the resonant cavity, but in all the set, including the magnetron, which we consider as a fundamental element to explain such forces.

That setup schematically shown in Fig. 2 indicates the real presence of anomalous forces, but in magnitude lower than the theoretical predictions reported in their paper. Besides, the forces pointed out in directions to which they should not occur. Fig. 2 shows the diagram in which is indicated the right directions of the forces according to the actual theoretical analysis. With the symmetry axis of the conic cavity in the horizontal direction they measured forces with magnitude 18–27 μN while with symmetry axis pointing upwards the force measured was 24 μN . The absolute average magnitude of the force was 23 μN .

Beside EM-Drive, there are other types of designs in the development for such devices and which are capable of generating forces or thrusts, known as Tapered Drive or Cannae Drive. Basically the Cannae Drive corresponds to a device in a pillbox shape or formed by an asymmetric capacitor with internal dielectrics. It is a little different from the latter in the concept and arrangement. As it is formed by an asymmetric capacitor working in the AC regime (RF) the thrust effect can be understood by the same principle earlier analysed in our research works based on the anomalous effects in symmetrical capacitors [11, 12] or asymmetrical capacitors [13], as recently shown in our earlier work concerning EM-Drives [14]. That type of drive corresponds to a propulsion technology that does not demand onboard propellant to generate thrust, but Lorentz force imbalances created by thrusters to create propulsion. Since its initial report, the device has been improved so in the design as in performance, with the thrust generated increased.

Here we intend to describe our experimental measurements in a simple cavity operating in association to a magnetron, to detect possible anomalous forces at a distance generated by the system. We also intend to theoretically describe the experimental results obtained from our simple cavity + magnetron system.

In the following section, we describe in more detail our apparatus, the experimental methodology adopted, and the experimental results obtained in our procedure.

Next, we present our theoretical proposal applied to that system and compared the theoretical results obtained from the model proposed with our experimental measurements and the experimental results of other authors as well. Finally, we discuss our main conclusions and perspectives.

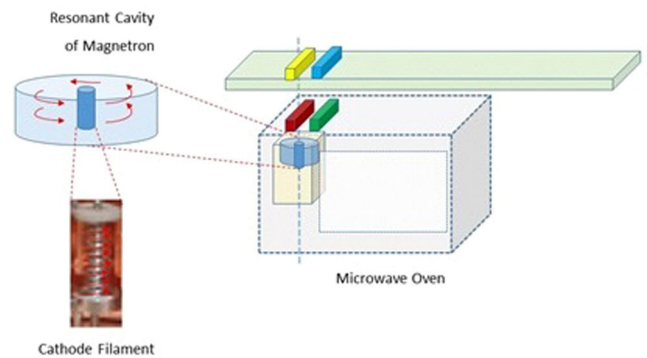


Fig. 3 Scheme of the device in which measurements of anomalous forces were realised in a resonant microwave cavity connected to a magnetron (EM-Drive)



Fig. 4 Photos of the measurements using an accelerometer placed directly over the microwave oven top (left) and placed on the shelf (right)

2 Experimental work

In the following, we describe our measurements of induced force at a distance by the operation of an EM-Drive without a dielectric, associated with a magnetron. The experimental procedure and the experimental devices used in the experimental setup are discussed in detail. Further aspects of the experimental methodology considering the effect of noises and external interferences are also taken into account.

The basic scheme of our setup is shown in Fig. 3. The setup is composed by the microwave oven, the magnetron and the support containing the accelerometer to measure the forces self-induced locally and induced at a distance during the operation of the system microwave cavity-magnetron. The schematic diagram shown in Fig. 3 indicates the experimental setup used in our experiments with a zoom on the magnetron inside the cavity. At right, we show the microwave oven with the magnetron. At left, we have a zoom of the magnetron and its cathode filament in which flow the high electric current responsible for generating forces. Above the cavity, we see the support in which is positioned the accelerometer to measure such forces.

The measurements were performed by using a high-resolution accelerometer configured to collect 320 samples per second. It was positioned in the horizontal wood platform (shelf) above the closed microwave device, without any mechanical link or contact between the platform and microwave device, so that it was not possible to transfer mechanical vibrations. There was also a careful work to reduce the environment sound noises. By placing the components at the same level, the accelerometer was placed around 15 cm above the resonant cavity of the magnetron, with its sensor Z parallel to the vertical direction and to the symmetry axis of the magnetron. The geometrical centre of the accelerometer was displaced 7 cm (Y-axis) in relation to the centre of symmetry of the magnetron. Fig. 4 shows photos of the setup used in the experimental measurements. The experimental procedure adopted is similar to the method earlier described with more details in the literature [11, 12]. The measurements were performed in the three-step sequence: after turning on the accelerometer, the magnetron is turned off 30 s, next turned on 10 s and at last turned off 10 s. We considered samples in 'off'-phase between 20 and 24 s after the activation of the accelerometer to avoid any possibility of the mechanical damping because the manual activation of the accelerometer can affect the experimental results. The samples in 'on'-phase were collected between 33 and 37 s after turning on the

Table 1 Technical specification of the devices used in the experiment

Device	Feature
digital ampere meter	UNI-T model UT30B current range 200 μ A–10 A resolution 100 nA (for 200 μ A DC current) 3 $\frac{1}{2}$ digits LCD display
USB accelerometer	Gulf Coast Data Concepts Model X6-2 educational purposes; stand-alone operations; three-axis accelerometer 2 g or ± 6 g range in each axis sample rates of 20, 40, 80, 160 and 320 Hz
microwave oven	Toshiba model ERS-7755C; 1.34 kW; 120 V–60 Hz; 2450 MHz operating frequency; 4000 VDC magnetron; 720 W maximum output

accelerometer. The values for the magnitude of induced forces were obtained by the difference between the accelerations of ‘off’-period and ‘on’-period.

It is important to emphasise that the accelerometer has MEMS sensors which are insensible to electromagnetic influences and the electromagnetic influence of the magnetron is negligible because the microwave oven used is shielded to avoid leaking of electromagnetic radiation according to the safety standard.

The sensors X , Y and Z measured gravitational acceleration (Z -axis) with negative values, and there was a clear increasing of the value of that acceleration in the three directions, mainly in the X -axis. The X -axis detected the induction of tangent force due to the angular acceleration of the electrons in the cathode in the interior of the magnetron.

Table 1 provides us the technical specifications of the devices used in the experiment.

In a second experiment, we have measured the magnitude of induced forces with the accelerometer placed on top of the microwave cavity device. The accelerometer was 7 cm above the resonant cavity of the magnetron with its Z -sensor parallel to the symmetry axis of the magnetron, at upwards direction. The geometrical centre of the accelerometer was displaced 7 cm (Y -axis) about the symmetry centre of the magnetron. That position was a vertical extension downwards about the earlier position on the platform. The same method of collecting experimental data was implemented, but the instants were between 23 and 27 s in ‘off’-phase and between 23 and 27 s in ‘on’-phase. The results show significant values for the magnitude of induced forces.

As seen, both sets of measurements had a similar procedure so in the first case as in the case of the accelerometer supported directly on the microwave device. We tested the apparatus by considering the influence of perturbations on the system, as noises and vibrations in the measurements of the accelerometer. We also tested the influence of the microwave device opened, with the accelerometer closer to the resonant cavity and same conditions of alignment about the symmetry axis of the magnetron. In such conditions, the forces were more intense.

It is also important to report that some noises were not totally vanished at all, due to a weak sound noise generated by the high-voltage transformer of the magnetron activated, but the vibration is characterised because it occurs in the Z -axis and it has very weak magnitude due to the position of the transformer, placed in the low part of the microwave oven.

3 Theoretical description

As described in our earlier works [11, 15] the theoretical framework that leads us to a macroscopic description of our systems is based on the Generalised Quantum Entanglement (GQE) framework, successfully applied to a lot of different physical systems analysed in our works [11–20]. As already known from the literature [21, 22], the quantum entanglement is the

consequence of an interaction between two or more particles in an arbitrary past time, so that subsequently each particle in the combined state keeps the information from each other, even for large distances, a feature of non-local phenomena [21]. The possible effect of generalised quantum entanglements in systems of a huge number of particles is an important issue to be analysed if we desire to understand and even quantify their influence on our macroscopic world. Due to very complex theoretical treatment, the problem of analysing if every particle in the universe could be entangled with every other or even if they would already be all entangled with each other has always been avoided. However, some attention has lately been given to the problem, as is reinforced in a recent work [23].

In summary, we suppose like a hypothesis that in especial or extreme conditions, the effects of quantum entanglements can be revealed and the microscopic particles of our system can collectively affect some macroscopic observables describing the system. The conjectures of preexisting quantum entanglement and its influence on the macroscopic observables of the system can be checked in a lot of physical systems, as the system constituted by electric dipoles or constituted by photons and electrons. Our GQE hypothesis has been applied with very reasonable accuracy in other physical systems, e.g. in anomalous forces involving the operation of symmetrical capacitors [11, 12], asymmetrical capacitors [13], magnetic cores [15], piezoelectric materials [16, 17], superconductors [18, 19] and semiconductor laser diodes [20]. In the case of capacitors, it is needed the application of a high voltage to realise the presence and or the effects of the GQE among the dipoles of the dielectric and the external environment.

To complete the theoretical framework, we assume that the macroscopic observables representing the physical system can be classically calculated, as proposed in works in which the concept of quantum witness is introduced and discussed [24–27]. Such a feature of manifestation of quantum entanglement for many particles in the macroscopic level allows us to use the classical formulation in our calculations. That is a consequence of the inequality relating local and non-local quantities (respectively Q_1 and Q_{n1}) in [24], e.g. $Q_1 + Q_{n1} \leq 1$. So, it is needed to find out the classical representative of the system.

We here propose a similar theoretical model for our cavity system that corresponds to an EM-Drive, i.e. the case of drive that provides thrust without the presence of dielectrics in the resonant cavity. As the dielectric material does not provide the thrust the anomalous effect must be caused by the momentum exchanging via the preexisting condition of generalised quantum entanglement between the charge carriers of the electric current (electrons) of the internal filament of the magnetron and external environment. As indicated by our earlier works, the force self-induced and induced at a distance by the physical systems analysed are in general dependent on the square of the electric current in the devices in operation, as in the case of superconductors [18] and in lasers [20]. Here we conjecture that the cavity also can be described by such a relation, i.e. our theoretical framework is for any cavity which does not use dielectrics and whose anomalies are explainable by considering the existence of a longitudinal force raised by the filament current of the magnetron, i.e.

$$F = \mu_0 I^2, \quad (1)$$

in which μ_0 is the dielectric constant of vacuum and I is the magnitude of the current. Hence, we conclude that the same theoretical proposal already used in earlier works can also be used in this new physical system in a successful way within the error range of each experiment. It is relevant to report that the effect of generating longitudinal forces has already been reported in the literature in the context of an alternative explanation of superconducting wire breakage for very high currents [28]. Rather more specifically, the same (1) was successfully used in the case of laser diodes. As the induction occurs due to the quantum entanglements, the geometrical factor G in [28] that refers to the magnetic field and its bound conditions does not influence the magnitude of the force, so that the value was set to 1. The direction and sense of the non-local induction are the same as the current

electric. Although our theoretical and experimental results to be presented in Section 5 indicate a weak magnitude, there is a wide margin for the enhancement of the phenomenon. In fact, NASA has started experiments with devices like Shawyer's one and constantly has improved it. Besides, Chinese researchers have also obtained much higher forces [7] in their studies involving the engine and other groups also have developed research in the area, involving advances in technology of propulsion, in studies of microwave devices or thrusters and photonic propulsion [29–32], showing how important has been the study of such a subject nowadays. The phenomenon of breakage of wires in which elevated currents flow has not been theoretically explained for a long time. Recently, there was the proposal [28] for a consistent explanation, based on the idea that the wires break due to a magnetic longitudinal Weber force proportional to G and I^2 . For an experimental current of $I = 6 \times 10^3$ A, the calculation in [28] indicated a force of 1 N. However, for breakage of aluminium wire of 1.2 mm^2 it is needed a force of 50 a 500 N/mm^2 . Our calculation is neglecting the geometry influence or using only the term $\mu_0 \times I^2$ provides us 45.24 N , while for a wire area $0.62 \times \pi \text{ mm}^2$ provides us 40 N/mm^2 , i.e. practically the minimum value for the tension needed to the wire breakage. This is the non-local force induced by the charge carriers circulating in the wire, and that depends on the non-geometrical factor. In other words, we can say that such a term can be considered as the natural or basic force element whose direction points out in the sense of the current (longitudinal).

It is interesting to observe that (1) represents a good enough theoretical explanation so for the EM-Drive as for forces generated

by semiconductor laser diodes or superconductors, indicating that there is a more profound physical source for the anomalies that occur in so many physical systems. According to our explanation and theoretical framework, the reason for that is the generalised quantum entanglements generated in the microscopic world.

In the next section, we discuss our main results by comparing the experiments presented in the section of our experimental work with our theoretical proposal.

4 Results

In Tables 2–4, we show our experimental measurements concerning to the forces generated by the operation of the system cavity + magnetron. In the first column, we see a number that represents the label of the sample. In the sequence, we have the average values of the acceleration measured the accelerometer in the three directions of the device and the standard deviation for the 'on' and 'off' phases of the procedure, as described in [11] and in the section describing our experimental methodology.

The measurements are done in g/counts, unit adopted in the accelerometer, applied to the output of the axis. For the maximum resolution adopted in our experiment, the device presents the number of counts or the deadband setting value set to the integer 16,384. So, the reading in the axis provides the local value of g if we divide the results by 16,384 and the force variation if we multiply by the mass of the device.

In Table 2, we obtained the measurements of acceleration with the respective standard deviation for the accelerometer positioned

Table 2 Measurements of average values of acceleration with respective standard deviations for the accelerometer on the microwave cavity, with the sensor Z placed in the upwards direction

Sample no.	Average acceleration in counts						Standard deviation in counts					
	X sensor	Y sensor	Z sensor	X sensor	Y sensor	Z sensor	X sensor	Y sensor	Z sensor	X sensor	Y sensor	Z sensor
	OFF1–ON	OFF1–ON	OFF1–ON	ON	OFF1	ON	OFF1	ON	OFF1	OFF2	OFF2	OFF2
478	–1.22	–0.21	–0.81	4.60	4.87	4.98	5.10	15.56	15.52	5.03	5.03	15.44
479	–0.59	–0.15	1.21	4.75	4.71	5.15	5.20	16.12	14.95	4.75	4.94	15.17
481	–0.86	0.41	1.13	4.92	4.77	5.22	4.96	16.12	15.59	4.88	5.00	15.51
482	–0.90	–0.50	–0.96	5.50	5.29	5.29	5.25	16.12	15.42	4.90	5.09	15.50
483	–0.99	–0.33	–0.48	4.87	4.66	5.30	5.04	16.12	14.97	4.72	5.05	15.22
484	–0.75	0.48	–0.15	5.11	4.86	5.23	4.94	16.12	14.90	4.69	5.06	15.74
486	–0.49	–0.37	–0.34	4.97	4.91	5.29	5.20	15.86	15.40	4.81	5.23	15.67
487	–0.36	–0.98	0.26	5.21	4.56	5.45	5.05	15.86	15.42	5.21	5.48	15.60
488	–0.45	–0.57	–1.28	4.87	4.53	5.18	4.83	15.86	15.50	4.75	5.23	15.68
490	–0.05	–0.10	0.15	5.11	4.90	5.22	5.25	15.86	15.98	4.61	5.24	15.17
average>	–0.67	–0.23	–0.13	4.99	4.81	5.23	5.08	15.96	15.37	4.84	5.14	15.47
					0.19		0.15		0.60	–0.16	–0.10	–0.49
					ON–OFF1 Δ		ON–OFF1 Δ		ON–OFF1 Δ	ON–OFF2 Δ	ON–OFF2 Δ	ON–OFF2 Δ

Table 3 Average values of acceleration with respective standard deviations for the accelerometer on horizontal support and directly positioned on the waveguide connected to the magnetron

Sample no.	Average acceleration in counts			Standard deviation in counts					
	X sensor	Y sensor	Z sensor	X sensor	Y sensor	Z sensor	X sensor	Y sensor	Z sensor
	OFF1–ON	OFF1–ON	OFF1–ON	ON	OFF1	ON	OFF1	ON	OFF1
464	0.36	0.36	0.66	58.66	36.65	62.08	65.71	370.24	365.76
465	0.92	–2.19	–2.02	165.85	5.55	99.28	5.10	755.33	16.52
466	2.25	–0.69	1.29	39.58	26.59	29.45	32.28	270.36	158.59
467	1.72	0.21	0.70	43.01	35.83	43.03	39.48	223.15	257.62
468	1.30	–1.50	0.98	32.91	27.44	39.99	54.44	194.67	138.25
469	1.06	–1.42	–1.47	27.24	28.43	25.45	27.31	97.51	169.90
470	1.34	–0.78	–0.53	31.65	22.40	33.49	22.49	95.88	140.91
471	1.29	–0.96	–0.86	33.61	38.40	33.88	37.32	125.25	308.27
472	1.39	–0.29	–0.62	29.92	28.48	31.92	26.66	107.53	149.44
average>	1.29	–0.81	–0.21	51.38	27.75	44.29	34.53	248.88	189.47
					23.63		9.75		59.41
					ON–OFF1 Δ		ON–OFF1 Δ		ON–OFF1 Δ

on the microwave cavity. The sensor Z is positioned in the upwards direction.

In Table 3, the same measurements were implemented for the accelerations in the sensors X, Y and Z of the accelerometer, but with the device on the horizontal support (samples 492 and 476) and directly on the top of the waveguide connected to the magnetron (sample 491), in all of the configurations with the sensor Z aligned in the upwards direction.

In Table 4, we obtained the measurements of acceleration with respective standard deviation for the accelerometer positioned on a support shelf placed over the microwave cavity. The sensor Z is positioned in the upwards direction.

We performed some measurements with the accelerometer supported on a wood basis that was not connected to the microwave oven and positioned a few centimetres above the oven, as shown in Fig. 3. To decrease the acoustic noise, all of the internal elements of the oven were turned off, as the motor of rotating basis and fan, except the magnetron and the high-tension transformer connected to it. If all of those elements were connected, the acoustic noise would achieve about 90 dB, but it was reduced to closely 60 dB (it remained a very small noise) which is practically the environment noise in the room in the exact position of the accelerometer. The support and the accelerometer were precisely positioned in the horizontal so that the sensor Z was positioned upwards. The symmetry axis of the sensor Z of the accelerometer was a little dislocated about the symmetry axis of the magnetron (filament–cathode). In such conditions, we performed ten sets of measurements of acceleration with the accelerometer (sets labelled 478, 479, 481, 482, 483, 484, 486, 487, 488 and 490) so that each set contained 288,000 samples of high resolution collected (320 samples per second for each sensor X, Y and Z). Tables 2–4 show in an organised way a summary of those measurements. The objective of the measurements was to verify if the magnetron could induce an external force in the support and in consequence to vary the values of the acceleration measured in the accelerometer. The magnetron was turned on during 5 s in a definite time interval between 38 and 42 s after turning on the accelerometer (called phase ‘ON’). The values of thousands of samples obtained in that period ON were subtracted from the values of thousands of samples obtained in the period between 20 and 24 s after the accelerometer was turned on (a period called ‘OFF1’). The columns two, three and four of Table 4 show the average values OFF1–ON of each set of measurements for each sensor and in the last line of the columns is presented the average total values. One can easily observe that the values of the accelerations varied when the magnetron was turned on. The columns 5–13 of Table 1 show the standard deviations of the measurements for each sensor so in the periods ON as in the periods OFF1.

It is also visible that the values of the standard deviations were bigger than the values in the period ON, i.e. during the activation of the magnetron. Besides, one can also observe that the sensor Z had the bigger variation (see the values of standard variation identified as ON–OFF1 in the bottom part of the table). Such a result can be explained by the existence of the weak acoustic perturbation coming from downwards to upwards, but the bigger variation of the acceleration was measured by the sensor X (–0.67 counts). That result suggests that the magnetron really induced a force in the support that was detected by the accelerometer and it was not caused by acoustic effects because such perturbations generate mechanical vibrations around an average position in the Z-direction whose resultant is null. It is worth to emphasise that the support shelf also remained positioned in the floor of the laboratory

on rubber support to reduce acoustic and seismic vibrations. Perturbations of electromagnetic origin are not very probable because the microwave oven was electromagnetically shielded to avoid leaking of radiation and because the sensors of the accelerometer were piezoelectric, that is, with certain electromagnetic insensibility. The three last columns of Table 3 indicate values of standard deviation for a period called ‘OFF2’ which corresponds to the time interval between 55 and 59 s when the accelerometer was turned off. We made the subtraction between the standard deviation of that period (OFF2) and the activation of the magnetron (ON) and observed that the values of standard deviation almost decrease for the values before the activation (OFF1). The values of the accelerations measured by the sensors acquired more negative values (normally the accelerometer measures negative values of acceleration due to the gravitational acceleration in the three sensors), indicating induction of force upwards on the support shelf. The summation of the modulus of the forces calculated according to the subtraction of the values of the accelerations in the periods (OFF1–ON) in the three directions (X, Y and Z) provided us the approximate value 23 μN . As one can see, it was a very small value, but detectable. More measurements (samples 492 and 476) were performed in the same conditions earlier mentioned, but there was a trial of aligning the sensor Z of the accelerometer with the symmetry axis of the magnetron, as shown in the vertical line connecting the magnetron and the accelerometer in Fig. 3.

The results of the measurements shown in Table 2 follow the same format as Table 3. It is clear that the average value of the accelerations in the set 492 measured by the sensor Z increased too much (0.97 counts) and also presented positive signs in relation to the average value of the accelerations (–0.13 counts) of the sets shown in Table 3, although the values of other sensors (X and Y) did not present significant alterations in comparative terms beside they have remained with negative signs. Such results suggest that a force pointing out upwards has decreased the value of the gravitational force whose main component was measured by the sensor Z of the accelerometer and such a force was possibly caused by the electric current flowing in the vertical straight line conductor localised exactly in the symmetry axis of the magnetron. The summation of the modulus of all the components (X, Y and Z) of that force measured by the accelerometer was $\sim 41.5 \mu\text{N}$. The measurements of the set 476 whose data are shown in Table 3 were similar to the values of the set 492 (sensor Z of the accelerometer aligned with the symmetry axis of the magnetron) with the difference that all the internal elements of the microwave oven (fan and rotator motor) were connected, including the own magnetron and the high-voltage transformer. During the activation of the microwave oven, all of those elements produced an increase of the acoustic noise (up to 90 dB) in the environment and possibly occurred stationary modes of mechanical vibration in all the structure in the directions X, Y and Z. By supposing that the cathode (filament) of the magnetron induces a force responsible by variations on the measurements of the accelerometer, such modes of static vibrations have spatial influence increased in all of the directions so that the range of the accelerometer was optimised. That is the case at least apparently to the effect that occurred in the set 476, i.e. a significant increase in the reading of the accelerations. A force pointing out upwards decreased the value of the gravitational force whose main component was measured by the sensor Z of the accelerometer and so there was a change in the sign of the acceleration (2.36 counts). Again that suggests and reinforces the possibility that the force induced has been generated by the electric current mainly in the vertical straight line conductor

Table 4 Average values of acceleration with respective standard deviations (accelerometer over the cavity)

Sample no.	Average acceleration in counts			Standard deviation in counts					
	X sensor	Y sensor	Z sensor	X sensor	Y sensor	Z sensor			
	OFF1–ON	OFF1–ON	OFF1–ON	ON	OFF1	ON	OFF1	ON	OFF1
492	–0.61	–0.20	0.97	4.75	4.74	5.23	4.93	15.54	15.39
476	–1.58	–1.16	2.36	6.21	5.1	5.75	5.24	17.57	15.84
491	–3.31	–0.24	1.87	26.88	4.96	21.53	5.18	58.33	15.07

localised exactly on the symmetry axis of the magnetron. The summation of the modulus of all the components (X , Y and Z) of that force measured by the accelerometer was $\sim 119 \mu\text{N}$. Such an experimental value is consistent with the theoretical value calculated in our model, i.e. $125.66 \mu\text{N}$ for a filament current (cathode of the magnetron) of 10 A according to the calculations shown in this work, with an error of only 5.3% .

The sets of measurements of Table 2 are shown in the same pattern shown in Tables 3 and 4 (corresponding to labels 465–472) and indicate measurements of the accelerometer supported directly over the microwave oven, with the sensor Z upwards and dislocated a few centimetres in the direction Y in relation to the vertical symmetry axis of the magnetron, as shown in Figs. 3 and 4. Such sets shown in Table 2 were realised to verify if the magnetron auto-induces a force which affects all the body of the microwave oven. It is relevant to remember that only the magnetron and the transformer feeding it was turned on in the tests, i.e. other elements of the apparatus were turned off. It was notable that the values of standard deviation were bigger than in other measurements possibly due to the small seismic vibrations from the ground to the microwave oven, which was correctly positioned in the horizontal, as indicated by the values of the average of the standard deviation in the columns five to ten in Table 2. Due to that procedure, the biggest values of standard deviation were measured by the sensor Z , but the biggest values of variation of average acceleration (columns two and four of Table 2) were measured by the sensor X (1.29 counts) while the sensor Z measured the smallest value (-0.21 counts). That fact again suggests that the auto-induced forces in the activation of the magnetron were not generated from acoustic or seismic sources. The summation of the modulus of all the components (X , Y and Z) of that average force measured by the accelerometer was about $56.4 \mu\text{N}$. Despite of its weak magnitude, indicating that, in fact, the microwave oven suffered the perturbation of a force generated by the activation of the magnetron. To optimise the effects of that perturbation was performed a set of measurements (label 491) whose data are shown in Table 3. The procedures of the measurements of that set were similar to the ones in the sets of measurements indicated in Table 2, i.e. the accelerometer was supported directly above the microwave cavity, but with two improvements:

- i. It was tried to align the sensor Z with the vertical symmetry axis of the magnetron (vertical straight line conductor of the filament–cathode).
- ii. It was eliminated the upper cover of the microwave oven so that the accelerometer was supported directly above the waveguide (without leaking of electromagnetic radiation). The result was the increasing in the value of the variations of accelerations so that the summation of the modulus of all the components (X , Y and Z) of that average force measured by the accelerometer was $\sim 126 \mu\text{N}$, which is impressively close to the theoretical result predicted: $F = 125.66 \mu\text{N}$. A force pointing upwards decreased the value of the gravitational force whose main component was measured by the sensor Z of the accelerometer. There was a change in the acceleration (1.87 counts), suggesting and reinforcing the possibility that the induced force has been generated by the electric current, mainly in the vertical straight line conductor exactly localised in the symmetry axis of the magnetron.

The main general conclusions from our experimental results are the presence of a force of induction that produces an external perturbation, an auto-induction that disturbs the own microwave oven and that the force is produced by the electric current mainly flowing in the filament (cathode) of the magnetron. The magnitude of that force experimentally measured from our setup is consistent with the theoretical forecast; then there is apparently an agreement so qualitatively as quantitatively. Despite that, we intend to perform a lot of other measurements to increase the accuracy in more controlled conditions, for instance, by using a better acoustic shielding (vacuum) aiming to decrease any possibility that such effects are caused by trivial sources.

We also applied our theoretical proposal to the other experiments involving EM-Drives, as the case of Tajmar group [8]. According to our theory, which predicts the force as dependent on a non-local interaction of the charge carriers with the external environment, for the average force measured ($23 \mu\text{N}$), we have an electric current in the filament of the magnetron theoretically calculated of 4.28 A and such a value is in very good agreement with the maximum value of current indicated in their work (5 A) for the technical specifications of the magnetron used in their experiments. In relation to the fact of they have measured forces in different directions with relation to the symmetry axis of the conic cavity suggests that the electric current flowing in the filament is the responsible for the effect because the current flows by segments of different geometries so in the filaments of the magnetron (in which there are straight line segments and spiral filaments) as in the conductors of external connection with the high-voltage transformer.

In the case of Shawyer's experiment [7] mentioned before, in which a 100 kg structure was rotated, we do not know more details regarding the peak filament current of the magnetron, but a 276.39 A current is needed to explain the 96 mN average force measured according to (1) and it is close to the value of the average current of the 17 MW magnetron, i.e. 250 A .

It is relevant to mention that a theoretical proposal described in [33] could indicate an alternate explanation to the phenomenon here reported, associating it to a gravitational variation due to a strong electromagnetic field. In [33], the calculation indicates a new way to understand the gravity and shows to be possible to measure such variations on the gravitational energy. Hence we would be able to manipulate the gravitational field as nowadays we control the electromagnetic one. Additional investigation is needed to verify if such a coupling can influence the effect here analysed.

To reinforce the conclusion of the real existence of anomalous thrust in the device, we need to consider that two possible sources of errors in the measurements would be the influence of the Earth's magnetic field – as suggested in [34] and possible weak magnetic shields or fails in the magnetic shielding of the system. The magnitude of the perturbation caused by the former source can be estimated if we consider that the force on the filament of the magnetron must be of the order of a thin straight conductor affected by the weak magnetic field of the Earth. In other words, consider as an initial estimation such a force being calculated as [35]:

$$F = B i l \sin \theta, \quad (2)$$

In which F is the interaction magnetic force in the vertical straight filament segment of the magnetron (in Newton), B is the Earth magnetic field in the experiment location ($24 \mu\text{T}$ – measured), i is the DC current in the filament (10 A), l is the length of the vertical straight segment of the filament (3 cm) and θ is the angle between the Earth magnetic field and the vertical straight filament (90°). Note that in the literature the intensity of the Earth magnetic field ranges from 22.4 to $70 \mu\text{T}$ [36, 37] and in South America its value is $\sim 24 \mu\text{T}$, according to Geological Service of Brazil (CPRM) [37]. So, according to (2), the magnitude of the magnetic interaction between the vertical straight filament segment current the Earth magnetic field is $7.2 \mu\text{N}$ in the microwave location. However, the magnitude of the Earth magnetic field is reduced approximately in half ($12 \mu\text{T}$ inside the microwave according to our measurements), so that the magnitude of the interaction magnetic force is $3.6 \mu\text{N}$. This value is much less than the value of the force magnitude measured by the accelerometer ($\sim 126 \mu\text{T}$) and it cannot explain it.

Our experiment with the microwave oven magnetron and other experiments [6, 8] mentioned in this paper indicate that the anomalous force is proportional to the square of current magnitude according to (1) and it is not proportional to the current magnitude as shown in (2). This fact reinforces that the magnetic interaction between the magnetron filament and earth magnetic field cannot explain the anomalous force.

About the other possible source of error (fail in the magnetic field), our device was built according to the International Regulation IEC 335-2-25, which determines the maximum

microwave leakage to avoid human body hazard [38]. The microwave leakage usually happens in front of the glass display and the door edges, i.e. negligible in the metallic top side of the microwave oven where the accelerometer was positioned accordingly. In fact, according to [39] the magnitude of the magnetic field leaked from microwave ovens up to 15 cm is very weak (2.0×10^{-5} T), so that it does not explain the effect as well. Further, the piezoresistive, piezoelectric and DC MEMS stick accelerometers usually have no electric field susceptibility [40] for the frequency range between 2 MHz and 18 GHz and 200 V/m electric field. We must remark that the frequency of the microwave oven used in our experiment is the standard one, i.e. 2.45 GHz and the maximum electric field leaked estimated is 18 V/m at 5 cm in front side of our 720 W output power microwave oven [38]. Considering this, we suppose that some effect of the electromagnetic exposure of our stick accelerometer is negligible even more considering that the measurements were performed in the top side of the microwave oven (closed part of the waveguide) where the electric field is even weaker.

It is relevant to report that an improved version of our setup to reinforce our recent results has been analysed in new experimental work. Basically, our setup can produce a more definitive result if we consider a vacuum camera and a torsion balance. To detect a visible motion of the device, we must place the oven in a vacuum camera, and the motion must be measured by a very accurate torsion balance. In this way, any other hypothesis concerning to heat or motion of the air possibly affecting the accelerometer can be refused with more emphasis, although both have not been detected in our experiments because the accelerometer was externally placed far away from the influence of the magnetron. Despite of that, our theoretical results also explain the results of other experiments in which the torsion balance was used, showing the consistency of our hypothesis.

5 Conclusion

In this work, we present our experimental and theoretical investigations concerning the existence of a weak induced force or thrust in microwave cavities in devices formed by a resonant cavity and a magnetron (EM-Drive). Our experimental results show that there are positive results for the presence of anomalous induced forces raised in the cavity. Our theoretical calculations indicate that the magnitude of forces raised in those systems can be described within the error range by GQE hypothesis. This reinforces our hypothesis related to the non-local interaction between micro and macro systems (quantum witness), from a preexisting state of generalised quantum entanglement among all particles, revealed by the operation of devices subjected to extreme conditions as very high fields. An alternative theoretical framework has also been proposed in [41], and it reinforces the idea of a possible connection between micro and macro systems to explain the EM-Drive anomalous thrust. Other work analysing the possibility of thrust in drives was also reported in [42], in which it is considered open problems in physics to explain the phenomena, as the sources and mechanisms of inertial frames, the coupling of gravitation to the other fundamental forces, and the nature of the quantum vacuum. Our theoretical framework reported in the literature considers that from GQE hypothesis, we can describe some macroscopic observables as representative of the physical system of the microscopic quantum entanglements between the particles of the devices and the environment, so that it is worth to calculate the magnitude of the forces generated in the cavity via equations using classical quantities. The application of that hypothesis in the physical system cavity + magnetron + environment described in this work indicated the existence of weak forces induced at a distance and a very good accuracy between the experimental and theoretical results. It is relevant to describe that in a recent work [34] it was reported that the thrust in EM-Drives could be caused by the influence of the Earth's magnetic field due to magnetic interactions from twisted pair cables and amplifiers. However, our simple simulation concerning to our setup indicates that the order of the magnitude of such interferences does not represent the main source of error for the measurements being very below the

magnitude of the forces raised on the cavity. Further, the shielding in the device is also very lower than the one needed to conclude that a fail in the shield does not cause perturbations strong enough to conclude that it is a significant source of error in the force measurements.

Our results encourage us to search to pursue a more profound analysis of such devices aiming to technological applications in the spatial area. We intend in a next step to studying how new materials or other possible configurations with the devices analysed or new setup possibilities could enhance the magnitude of the interaction so that one can use it in technological applications as electric propulsion for rockets or airships as substitutes of the actual technology based on fuel propulsion.

As futures perspectives for this work, we intend to implement a new, improved experimental setup in which the oven can operate in a vacuum camera, and the measurements of the induced forces can be implemented by a very accurate torsion balance so that possible motions in a long time can be detected.

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7 References

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