Application of Inertial Forces for Generating Unidirectional Motion

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This study presents some of the most interesting at the same time less-known inertial drives in the world. These include inertial drives in the western countries such as USA and Canada as well as drives developed in Russia, Greece and other countries. The paper also comprises the work done by the author in developing and implementing some inertial drives in engineering practice. The aim of the paper is to bring this information to the scientific community and trigger the interest of researches in creating new inertial drives and implement them in the industry for the benefit of Science and Industry.
Key words: *inertial drive, rotating masses, centrifugal forces, frictionless drive, friction drives.*

INTRODUCTION

For many decades, since the beginning of the industrial revolution, researchers and enthusiasts from all over the world were trying to invent and build mechanical, electro-mechanical, gyroscopic and pure electrical devices that can challenge the Newton's laws of motion and achieve reactionless propulsion by using centrifugal forces or electrical principles. Unfortunately the academics trained in the classical Newtonian Mechanics do not admit inertial drives, considering them as impossible as they confront the laws of modern Physics. On the other hand there are scientists who consider inertial forces as another category of force instead of external or internal forces acting on mechanical systems. According to them inertial forces acting from inside of the system under special conditions might change the momentum; hence they can produce a unidirectional motion on frictionless grounds [4, 5, 7, 8, 9]. There are hundreds of patents issued to date but only few of them are functional reactionless drive [2, 8, 9, 11, 12]. Others remained misinterpreted today [3] but they are used in many industrial applications such as water and crude oil pumps [1, 6, 13], vibration conveyors, water pumps and inertial propulsion of vehicles [4, 6, 7].

In this paper an effort is made to summarize the most interesting inertial drives, which would motivate researchers for new designs and investigations of inertial mechanisms. The objective is to bring the knowledge about inertial drives to academics and enthusiasts for new developments and further progress in research and advances.

The most renowned among the inertial drives is that of Norman Dean [3], which inspired many practical applications, mathematical analysis and engineering research, such as inertial pumps, vibrating screens, vibration separators and conveyors in the mining industry, propulsion of ground vehicles, ship propulsion and other applications. The drive is a three-dimensional (3D) electro-mechanical system which converts the rotary motion of eccentric masses into unidirectional oscillations of a carrier which in turn accomplishes an upward pulsing motion. It uses the propulsion effect of centrifugal forces generated by the rotating masses for achieving the above motion.

Fig. 1 shows the Dean Drive with its electro-mechanical components designated as per the issued patent. Many researchers and engineers failed to understand how this mechanism operates because of its complexity and many electro-mechanical interactions of its components. In fact the mechanism moves vertically due to the effect of friction forces generated by a one-way friction break. The latter is properly synchronized with the equilibrium position of the oscillating system and with two electromagnetic actuators by means of micro switches. It is for this reason the Dean Drive is not a pure inertial drive as the inventor clamed in his patent. Irrespective of this fact the Dean Drive is widely used in today's industry and has many applications such as crude oil and water inertial pumps [6, 13], vibration elevators [4] as well as driving vehicles [7], etc. The drive is profoundly investigated by [8] showing that if the Dean Drive is set into a free fall the generated inertial force overcomes the gravity only instantly not continuously as desired. The latter effect was also verified experimentally by the author that the gravitational force cannot be overcome continuously during uniform motion of rotating masses when spinning along their paths irrespective of their trajectories shape.

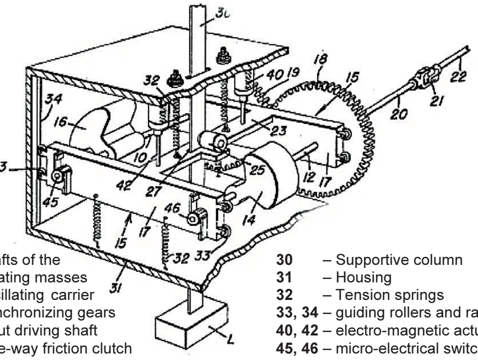

Fig. 1 displays the schematics of Dean's Drive mechanism

Another famous mechanism is that of Robert Cook, entitled Cook's inertial propulsion (CIP) engine [2], which is proved generating a propulsion unidirectional force by the Boeing Research Laboratories in the US. The mechanism is a complex 3D drive whereby an exchange of rotating masses takes place between the rotating carrier and the two contra-rotating pickup arms. The former incorporates the Dean Drive and specially designed electro-magnetic locking mechanisms. The unfortunate think with this mechanism is its electro - mechanical complexity and the heavy mass (127 kg) as compared to the size of the generated propulsion force being only - 35 N.

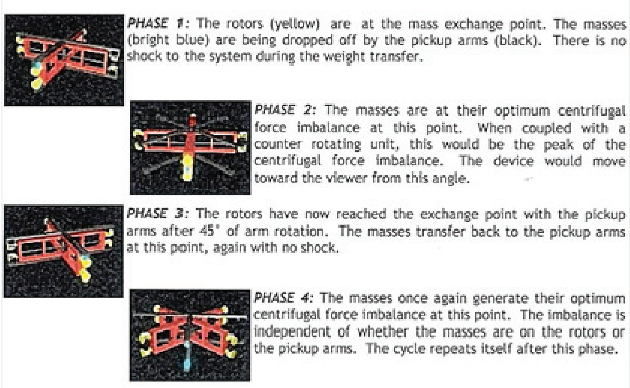

Fig. 2 shows the exchange of masses in the CIP engine

Fig. 2 shows the CIP engine animation schematics illustrating how the rotating masses (shown in a blue color) are exchanged between the counter rotating carrier and the pickup arms. This is achieved in four phases and the contra-rotating rotors appear to be the major components of the incorporated Dean Drive mechanism.

The Thornson drive [12] is a pure frictionless drive consisting of two contra – rotating epicycle mechanisms involving two masses, designated as M1, having variable radii and achieving a unidirectional thrust force. Fig. 3 below illustrates the schematic of the Thornson inertial drive along with the trajectories of rotating masses and the direction of the generated thrust. To verify that the mechanism is producing a thrust force it is installed on a canoe and tested in a swimming pool (low friction medium) having no contact with the adjacent water. It is measured that the canoe developed a velocity of 1.6 miles per hour (2.8 km/h), proving that the mechanism is functional and generates a forward inertial propulsion force.

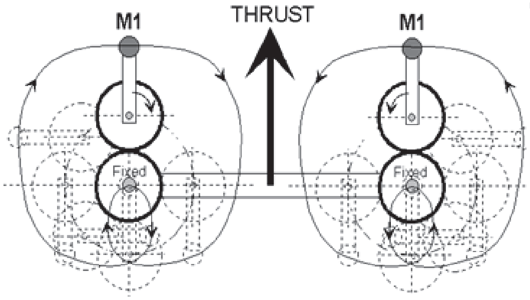

Fig. 3 The mass & thrust diagram of Thornson drive

The Russian engineer Tolchin [11] has invented a mechanism that created an inertial propulsion force by using two contra-rotating masses spinning along a circular path with variable accelerations as per specially designed phases of the rotation cycle. Fig. 4 (a) shows the pictorial view of the mechanism together with the schematic of phases of the rotating masses as seen in Fig. 4, (b). The rotation is arranged in such a way that during Phase **I** the two masses have an accelerating rotation, in Phase **II** they have retarding spin and during Phase **III** a uniform rotation. As a result a forward motion is achieved in the direction of Phase **I** with a slight reversed motion in Phase **II**. The components of the Tolchin drive include: 1 - rotating masses, 2 – motor-break, 3 - wheels and 4 - a spring motor. The above phases of rotation are accomplished by employing the motor-brake which accelerates the masses during Phase **I**, decelerates them during Phase **II** and keeps them rotating uniformly during Phases **III**. Throughout the experiments a trust force of 80 grams is measured as compared to total mass of the mechanism 0.95 kg. For skeptics the mechanism was enclosed in a box to avoid any external aerodynamic propulsion effects and was still working. It climbs slopes by overcoming partly the gravitational force and was performing better on low friction surfaces. In conclusion, it is proved that the mechanism is a pure inertial drive but its principle of operation cannot be explained by the Newtonian Mechanics.

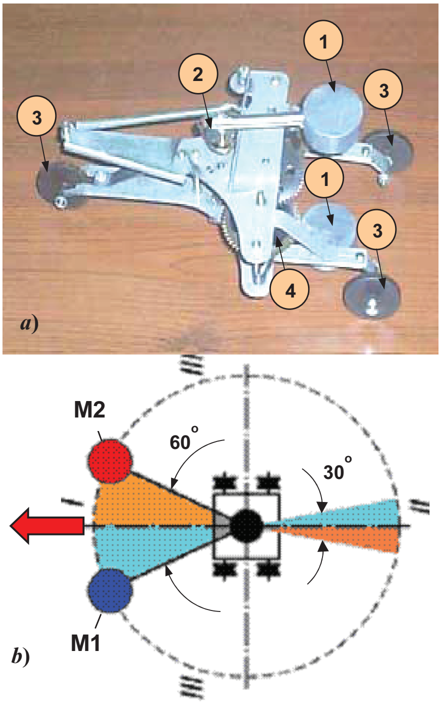

Fig. 4 (a) shows the pictorial view and (b) the phase diagram of Tolchin's drive

Another famous inertial propulsion mechanism developed in 2002 by Shipov [9] exemplifies the modified Tolchin drive being electrically driven and computer controlled. It has a total mass of 1.8 kg, rotating masses of 1 kg each and develops a pick thrust force of 147 N. These results were achieved by optimizing the angular duration of Phases **I** and **II** by means of specially designed software package. Fig. 5 shows a pictorial view of the Shipov's drive: where 1 is a servomotor, 2 - rotating masses, 3 - frictionless wheels and rails, 4 – a computer, 5 - the chasses of the drive, 6 - motion sensors and 7 – position sensors. Due to properly optimized lengths of phases the drive moves only in the forward direction although in a pulsing manner. Both the Tolchin and Shipov drives are considered to be 4D gyroscopes and their performance is explained by the torsion field theory developed by [9].

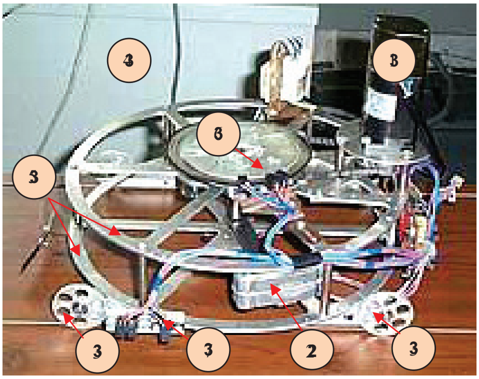

Fig. 5 shows the improved Shipov's drive

Later a new version of Tolchin inertial drive redesigned and build by a research team at Moscow Space Research Institute was installed to and tested on board of a jubilee satellite in 2008. Results revealed that the drive is promising and can be used to correct the orbit of satellites without ejecting any propellant mass in the space. It may be expected that in the near future inertial drives will be used for propulsion of space ships in a deep space exploration. A new recently developed 3D inertial drive is that invented, developed and profoundly investigated by Provatidis [8]. In short, this mechanism uses the modified Dean Drive to produce figure-eight-shape trajectories of rotating masses by spinning them around *x* and *y* axes at the same angular velocity. In addition to that the masses are given an extra rotation about the vertical *z*-axis. As a result a net impulse is obtained producing a vertical thrust of about 8% from the weight of the mechanism being 216 N and creating a thrust of 17 N.

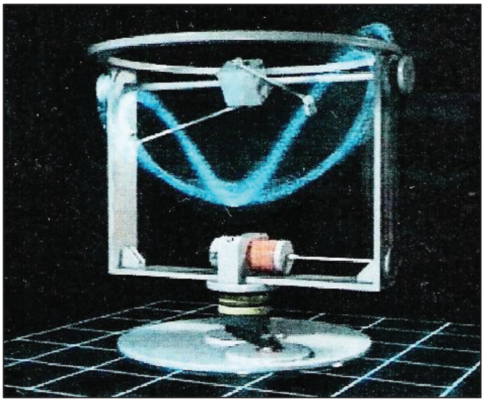

Fig. 6 shows pictorially the Provatidis drive

The Provatidis drive is presented pictorially in Fig. 6 along with figure-eight-shape paths of rotating eccentric masses. The equations of motion of the rotating masses and the equations of figure-eight-shape trajectories were derived and analyzed. The results revealed that the special shape of the trajectories is not enough to produce a thrust alone as the paths are repeated curves of the same shape for every revolution of masses. It is for this reason a third rotation is added about ***z***-axis, which is essential for generating the vertical thrust. Fig. 7 reveals the trajectories of rotating masses when different velocity ratios ω_z/ω is created. Fig. 7 b), c) and d) illustrate that the trajectories of rotating masses do not coincide after every rotating cycle of the mechanism, hence vertical thrust is generated.

During the last decade the author of this paper made numerous attempts to implement the Dean Drive for pumping water from deep boreholes in Botswana. Four model pumps and three prototype inertial pumps were designed, build and tested. Some of them are shown and discussed briefly to give a clue to the interested researchers.

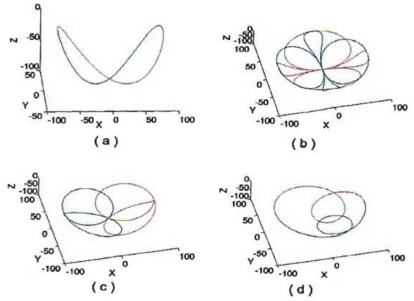

Fig. 7 Trajectories when a) $\omega_z/\omega=0$, b) $\omega_z/\omega=0.5$, c) $\omega_z/\omega=1.0$ and d) $\omega_z/\omega=2.0$

Fig. 8 illustrates the design and the operation of a low frequency inertial resonance pump employing the modified Dean Drive as an excitation system.

MATERIALS AND METHODS

It is important mentioning that inertial pumps operate in close to resonance conditions so that maximum accelerations - a, velocities - v and amplitudes - X are achieved. The oscillating system is a single degree-of-freedom operating at maximum to 20 Hz. The model inertial pump operates at 5.3 Hz, attains resonance amplitudes of 24 mm and reaches a flow rate of 12*l*/min using only 38 Watt.

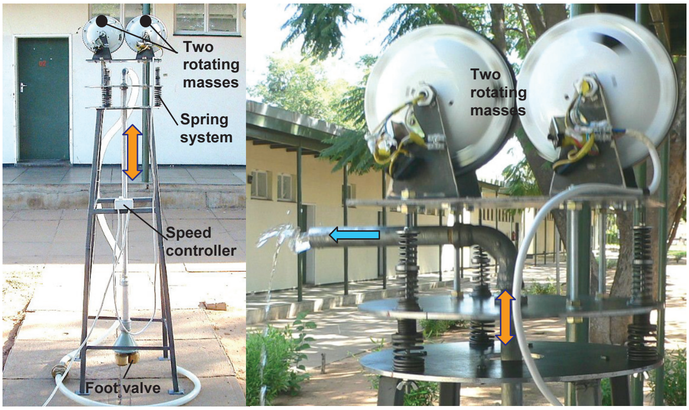

Fig. 8 illustrates the model inertial pump using the Dean Drive

One of the most powerful inertial pumps developed by the author for industrial application is the prototype shown in Fig. 9. It is designed to use an input power of 2.5 kW, draw water from 100 m, operates at 20 Hz, have rotating masses of 2×5 kg and achieves a flow rate of 30 *l*/min. Usually the efficiency of the inertial pumps varies depending upon the depth of pumping, the resonance frequency, maximum pipe's acceleration and the resonance amplitude. Tipical efficiency can reach 85% depending upon the pump requrement. The deeper the pump draws water from the higher the efficiency with no reducing effect on the flow rate [13].

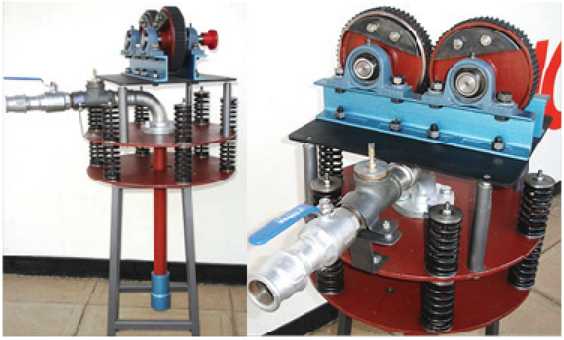

Fig. 9 displays the third prototype of inertial pump

Apart of using the Dean Drive in inertial resonance pumps the author has developed a gyroscopic inertial mechanism creating figure-eight-shape trajectories of rotating masses and an inertial drive system intended for low speed and high traction vehicle propulsion.

Fig. 10 illustrates the gyroscopic inertial drive. The numbers used in this figure are as follows: 1 – a DC motor, 2 – reduction gear train, 3 – rotating eccentric masses, 4– synchronous belt drives, 5 – synchronizing gears, 6 – planetary gear trains, 7 – the chasses and 8 – the carriers. The mechanism comprises four gyroscopic-like rotors mounted in pairs on two separate carriers. The carriers rotate opposite to each other as well as the same does each rotor to its counterpart. The rotors are synchronized to rotate opposite to each other by means of gears located on their peripheries, forcing the eccentric masses to move along individual figure-eight-shape paths, situated on the top surface of four separate hemispheres. The device was tested at two speeds, 500 rpm and 1000 rpm on elastic and stiff grounds. When tested on flexible ground the device jumps from the surface and then falls back on it. It was found that there is no reactionless thrust force due to the fact that the motion of the rotating masses is uniform along the closed loop of trajectories although they are of figure-eight-shapes, as shown in Fig. 7(a). This conclusion agrees to the mathematical and experimental findings of [8] stating that inertial force can overcome the gravitational force in a free fall instantly, however not continuously. Testing the device on stiff ground indicated no jumps or separation from the surface with a tendency of crawling in the direction of the nearby slope. In addition to these experiments the drive was tested as a pendulum hanged on 1.5 m long wires but indicating to thrust. To resolve this problem necessitates using Tolchin's principle of non-uniform motion of rotating masses. This may be achieved by using servo motor controlled electronically or by a special cam and follower mechanism.

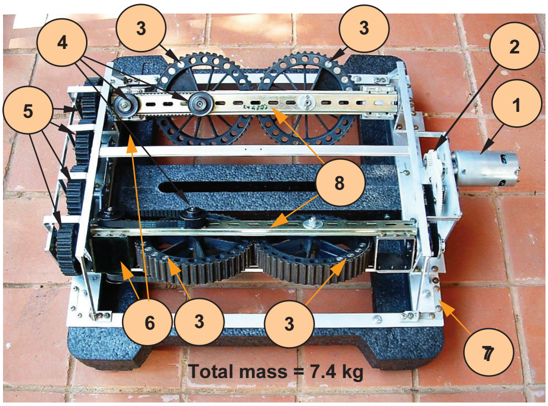

Fig. 10 shows four gyroscopic-rotors inertial drive

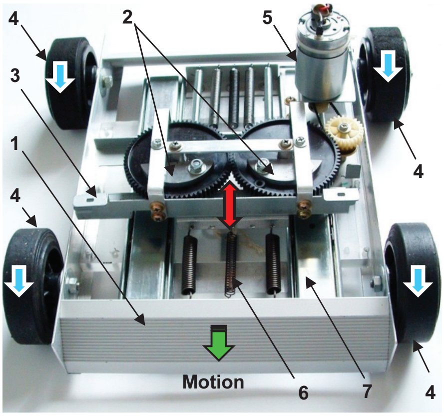

Fig. 11 shows the front view of the II^{-nd} drive

The second inertial drive developed uses the modified Dean Drive and is intended for vehicle propulsion. Two prototype models of the proposed drive are designed, constructed and successfully tested. Both prototypes developed strong unidirectional motion on any friction surface but the first one was generating a tough turning moment when approaching resonance. It is for this reason the old drive was redesign and built to obtain a new drive. The second version of the proposed inertial drive is shown in Fig. 11. It is made of the following parts: 1- outer frame (chasses), 2 – rotating masses, 3 – inner frame (carrier), 4 – support wheels, 5 – DC motor, 6 – spring system, 7 – linear bearings. The operation of the driving system is achieved by using a modified version of the Dean Drive, converting the rotary motion of eccentric masses into resonance oscillations of the carrier. The latter generates inertial forces at the front and rear dead positions of the carrier, which are transmitted to the chasses through the spring system. Thus a forward motion is obtained by using one-way roller bearings mounted in the wheels hubs. They allow forward rotation during the accelerative action of the transmitted force and prevent the backward rotation of the wheels in the rear direction. This is achieved by means of friction forces between the wheels and the surface of contact. The bigger the transmitted force and the greater the frequency of oscillations the faster and smoother the motion of the vehicle is. These also contribute significantly to the magnitude of the towing force attained by the vehicle until the maximum friction force is reached. The most important property of the drive is that no torques are acting on the wheels, so there will be no slippage on the surface. The motion is simply accomplished in the way similar to pushing a trailer by a variable pulsing force. This feature of the drive is significantly important if used as a real vehicle moving upon mud-covered, icy or slippery off-roads.

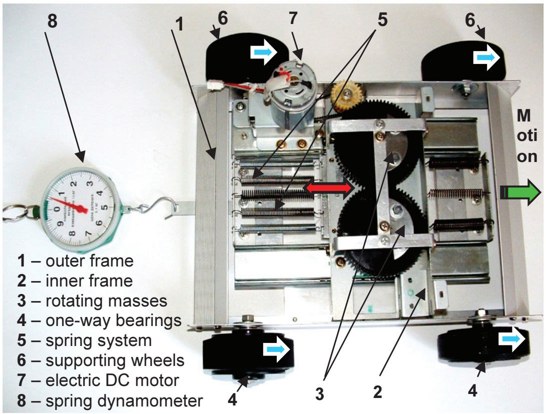

Fig. 12 Top view of the **II**-nd inertial drive

Fig. 12 displays the top view of the second drive when tested displaying a towing force of 5 N on tiled surface as seen on the dial of a dynamometer. During measurements of the towing force an additional soft springs (not shown) were attached between the dynamometer and the chasses to avoid resonance of its pointer in order to get steady readings.

To understand the principle of operation and confirm which parameters affect the motion and towing ability of the drive, a simplified dynamic model assumed to be two-degrees-of-freedom oscillating system is arranged. In fact to simplify the analysis the relative oscillations of the carrier with respect to the chasses is further considered and discussed.

Fig. 13 shows the simplified dynamic model of the proposed inertial drive along with the modified Dean Drive used in this application. The latter is composed of two contra-rotating masses mounted on two gears and placed horizontally, a spring system connecting the carrier - 2 to the chasses 1, and support wheels – 3 furnished with one-way- bearings, also known as one-way clutches, mounted into wheel's hubs. The coordinate of the relative motion of the carrier with respect to the chasses is denoted as $x_r(t)$ and that of the

absolute motion of the vehicle is designated as $x(t)$. Other parameters involved are: m and e symbolize the full mass and the eccentricity of the rotating masses respectively, c – the system damping constant, k – the resultant spring stiffness, ω – angular velocity of rotating masses, and t - is the time.
According to [10] the differential equation governing the relative motion of the carrier is

$$M\ddot{x}_r + c\dot{x}_r + kx_r = me\omega^2 \sin(\omega t). \quad (1)$$

The resonance amplitude is given by $X_r = \dfrac{me\omega^2}{\sqrt{(k - M\omega^2)^2 + (c\omega)^2}}$. (2)

The relative oscillations of the carrier with respect to chasses is defined as

$$x_r(t) = X_r \cdot \sin\left(\omega t - \frac{\pi}{2}\right) \quad (3)$$

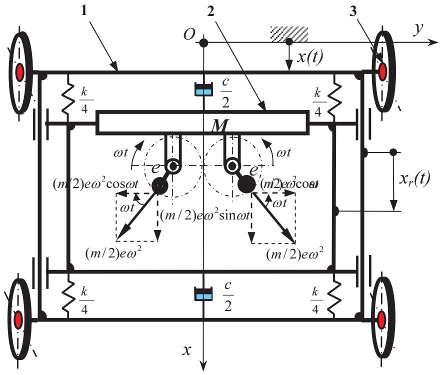

Fig. 13 Dynamic model of the inertial drive

The carrier transmits a dynamic force to the chasses having a magnitude of

$$F_T = (kX_r) \cdot \sqrt{1 + \left(\frac{2\varsigma\omega}{\omega_n}\right)^2}, \quad (4)$$

where ς are ω_n are the damping factor and natural frequency of the undamped system respectively. The ratio of amplitudes of the transmitted force to excitation one is known as the system transmissibility – TR, given by the expression

$$TR = \frac{F_T}{F_o} = \sqrt{\frac{1 + (2\varsigma\omega/\omega_n)^2}{[1 - (\omega/\omega_n)^2]^2 + [2\varsigma\omega/\omega_n]^2}}. \quad (5)$$

Neglecting the damping in springs, assumed to be small (ζ≈0), then Eq. (5) reduces to

$$TR = \frac{F_T}{F_o} = \frac{1}{1 - (\omega/\omega_n)^2}. \quad (6)$$

Since we are interested in maximizing the transmitted force ***$F_T(t)$*** to get stronger thrust, it is likely that the value of ω/ω_n <1 and the system will operate on the left-hand side of the resonance graph. At these settings the phase angle is $\varphi \approx \pi/2$ regardless of the damping value. So the transmissibility can be controlled explicitly by varying the excitation frequency ω. Thus the equation of ***$F_T(t)$*** may be written based on the fact that the system response lags the action of the excitation force F_o by a phase angle of -π/2. Or

$$F_T(t) = (TR)(F_o) = \frac{me\omega^2}{1 - (\omega/\omega_n)^2} \cdot \sin(\omega t - \frac{\pi}{2}). \quad (7)$$

Applying the principle of linear momentum to the mass center of the system during the forward action of transmitted force $\boldsymbol{F_T(t)}$ in the $\boldsymbol{x}$ - direction gives

$$M_T(v_x - v_{o,x}) = +\int_0^{T/2} F_T(t)dt - F_r \int_0^{T/2} dt \cdot \qquad (8)$$

In Eq. (8) v_{ox} and v_x are the initial and final velocity of the mass center of the system and $F_r = f.N$ is the rolling resistance force, where $f_r = r/a$ is the coefficient of rolling resistance, r is the effective wheel radius and a is the offset of the normal reaction in the direction of motion, acting on the wheel. Now the full impulse of $\boldsymbol{F_T(t)}$ may be written as

$$I_{F_T(t)} = \int_0^T F_T(t)dt = \frac{me\omega^2}{1-\omega/\omega_n} \cdot \int_0^T \sin(\omega t - \frac{\pi}{2})\, dt \cdot \qquad (9)$$

Fig. 14 illustrates the full impulse of the transmitted force $\boldsymbol{F_T(t)}$ showing the period $\boldsymbol{T}$ and the positive and negative elements of the impulse. Now if the wheels of the model are free to rotate, then the vehicle would be moving forth and back due to the symmetrical shape of the impulse graph and the conservation of linear momentum. To achieve a forward motion it is necessary to get rid of the negative impulses of the transmitted force by some means. This is practically done by using one-way-roller bearings integrated in the wheel hubs, allowing only a forward rotation due to the positive impulses. As a result the graph of the remaining impulse of $\boldsymbol{F_T(t)}$ appears to have only positive impulses as shown in Fig. 15.

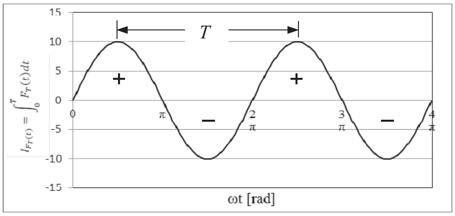

Fig. 14 displays the impulse of force $\boldsymbol{F_T(t)}$

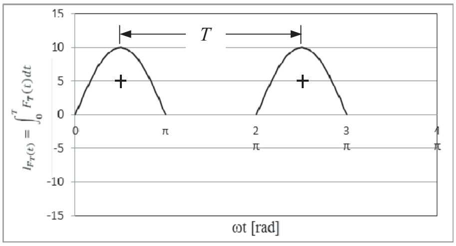

Fig. 15 shows the positive impulses only

Under these settings linear momentum changes and the motion will occur in the direction corresponding to the positive impulses, hence a unidirectional motion will be achieved. When tested the model vehicle shown in Fig. 12 generated a towing force of 8.5 N measured on cemented surface at resonance frequency of 13.6 Hz. In the course of analysis It was found that the towing force depends upon the rotating unbalance $\boldsymbol{me}$, the angular velocity of rotating masses ω (the resonance frequency $\boldsymbol{f}$ of the system), the mass $\boldsymbol{M}$ of the carrier, the coefficient of static friction $\boldsymbol{\mu_s}$, and the total mass $\boldsymbol{M_T}$ of the vehicle. The limiting condition for the forward motion is that $\boldsymbol{F_T(t)}$ should be smaller than $F_s = \mu_s N$.

DISCUSIONS AND CONCLUSIONS

This paper presents a summary of the best inertial drives along with the drives developed by the author and their industrial applications. It is evident that majority of the drives incorporate the modified Dean Drive used as an excitation means. While certain inertial drives are reactionless [5, 9, 11, 12], some others are using friction forces to achieve propulsion [3, 4, 7]. The proposed inertial drive for vehicle propulsion is useful as it moves without using any torque acting on the wheels. This allows the vehicle to propel itself on soft soil, sand, ice or mud covered roads offering lesser risk for slipping, getting trapped on the road, or losing control on the vehicle. In addition to these benefits the new propulsion system does not require any transmission devices such as gearboxes, prop shafts, differentials, or final drives as seen in Figs. 11 and Fig. 12. It is also evident that the new drive does not challenge the Newton's laws of motion and the principle of momentum as it uses friction forces to provide ground support and achieve a forward motion. Based on this study it may be concluded that the drive requires further perfections to increase its efficiency and towing capacity, as now it utilizes only 50% of the input power. The latter corresponds only to the forward action of the transmitted force. It looks possible to employ the rest of the input energy for better propulsion and better efficiency by accumulating that energy into a system of springs and deliver that during the forward motion of the vehicle. Another improvement may be achieved by allowing the vehicle to reverse when required. The latter will finally improve its maneuver ability in a real use.

In conclusion the inertial propulsion drive is simple, low-cost and easy to maintain propulsion system as compared to any modern vehicles e.g. passenger cars, Lorries, tractors, etc. Possible areas of applications of the new inertial drive may include: Heavy duty low speed earthmoving vehicles such as tractors, caterpillars, bulldozers, graders etc., where the low speed is not a problem but the traction ability is an added advantage.

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