Analytical investigation of an inertial propulsion system using rotating masses

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Abstract. The paper proposes an inertial system capable of generating a propulsive force from the rotation on an eccentric circular path of 8 steel balls placed between two rotating discs constructed with a radial slot system. In addition to a detailed description of the mechanical components of this proposed device, particular attention is paid to the theoretical treatment of the innovative principle upon which the device is based. The paper begins by detailing the equations of motion of the steel balls, from which the propulsion force of the system is computed. Furthermore, the influence of the ball radius on the propulsion force is investigated. The obtained findings support the capability of the proposed system to achieve a linear propulsive force.

1. Introduction

Starting with the industrial revolution, for many decades, researchers and visionaries around the world have made extraordinary efforts to invent and build devices capable to challenge Newton's laws of motion and to produce linear motion by using centrifugal forces. During the documentation phase, hundreds of such patents were found, but only a few of them have industrial utilization, such as oil and water pumps [1-3], vibration conveyors, inertial propulsion of vehicles [1] and mobile robots [4], [5]. These devices are known as inertial drives, impulse engines, inertial propulsion engines, non-linear propulsion systems, reactionless drives etc. but they are unfortunately not unanimous accepted by the conservative nucleus of the scientific community.

A classification of inertial propulsion systems can be done according to several criteria. A first criterion targets the type of inertial force. In this respect, the following types of propulsion may be considered:

- systems that use centrifugal force [6], [7];
- systems that use the inertial force resulting from the alternative translation motion [6], [8];
- systems that turn the continuous rotation motion into discontinuous rotation [9];
- systems that turn the rotational movement of multiple simple inertial rotary motion mechanisms [7];

Depending on the type of energy used, inertial propulsion systems can be classified into:

- systems that use mechanical energy [10], [11];
- systems that use both mechanical and electromechanical energy [10];
- systems that use propulsion energy [11];

Depending on the state of the body in which the inertia force appears, we can have:

- systems where the inertial force is provided by a solid;
- systems where the force of inertia is provided by a liquid [12].

The paper is dedicated to the theoretical research of an inertial system capable to produce propulsion force by rotating 8 identical steel balls placed between two slotted discs and a retention disc. The equations of the geometrical coordinates, the velocities and the accelerations are deducted for a ball, from which the propulsion force is computed for a specific case. In addition, the study investigates the influence of the balls radius on the propulsion force.

2. Proposed inertial propulsion system

The operating principle of the propulsion system is based on generating a resultant centrifugal force, acting in the movement direction of the device. The device consists of two identical constructive groups, placed in mirror in relation to the direction of movement (see Figure 1).

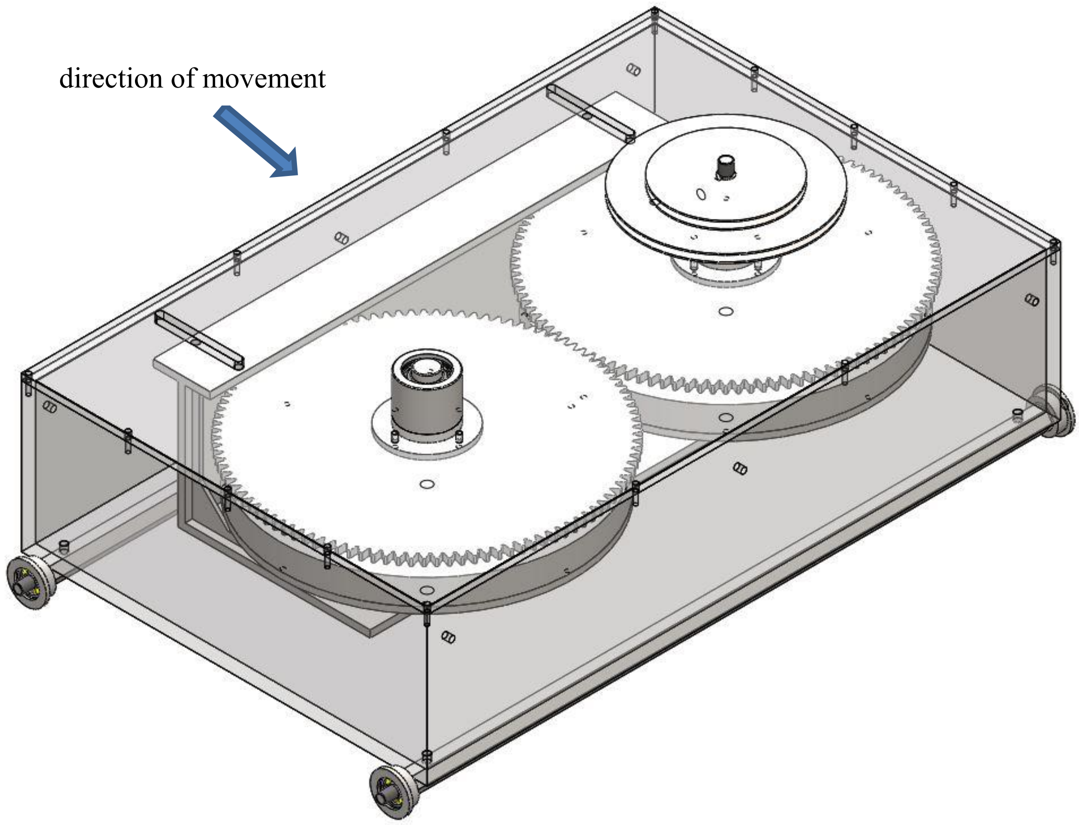


Figure 1. Overview of the inertial propulsion system

As shown in Figure 2, the centrifugal forces are generated by 8 identical steel balls (1-8) having the radius r and being placed between two rotating discs (10), which are foreseen with radial slots. The circular path of the balls is ensured by the inner bore of the retaining disc (9). The center O_2 of the disc (9) is displaced eccentrically relative to the center O_1 of the discs (10). The eccentricity e is in the movement direction of the system.

By rotating at constant angular speed ω the slotted discs (10), a centrifugal force is applied to each of the 8 steel balls. Because these balls are forced to follow a circular trajectory having the rotational center placed eccentrically to the rotation center of the slotted discs, the balls will have, during a complete rotation of the discs (10), variable radii relative to O_1. The centrifugal forces acting on each of the 8 balls is given by:

$$F_{c_i} = m_0 \cdot \omega^2 \cdot R_i \tag{1}$$

where:
F_{ci} [N]- centrifugal force acting on the balls;
m_o [kg]- mass of the balls;
ω [rad/s]- angular velocity of the slotted discs;
R_i [m]- trajectory radius of ball i.

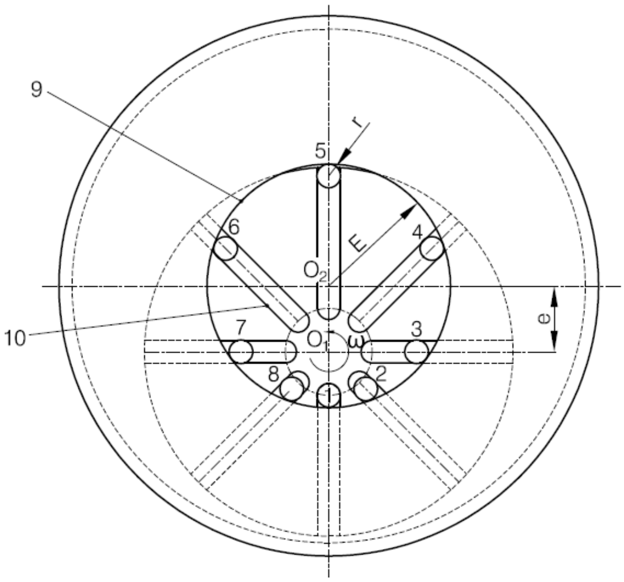


Figure 2. Arrangement of the steel balls

Since the trajectory radii R_i of the 8 steel balls are varying during a complete rotation of the slotted discs, there are resulting variable centrifugal forces which are acting on these balls. The resultant of these 8 centrifugal forces generates the linear propulsion of the system.

To have a better understanding of the system, Figure 3 provides a section through the device. Please note that the assembly is drawn for an eccentricity $e=0$. The eccentricity can be varied by moving the retaining disc (9) in the direction marked with the blue double arrow.

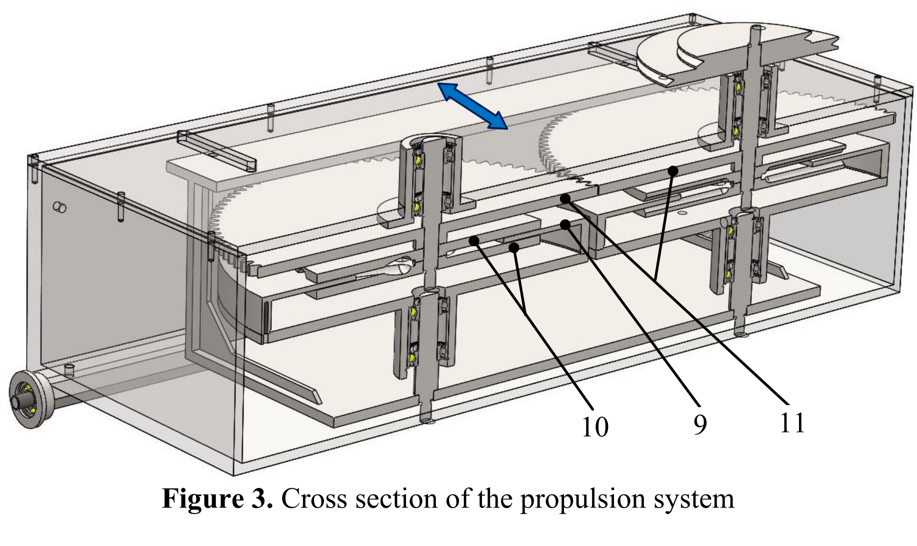


Figure 3. Cross section of the propulsion system

3. Cinematic and dynamic analysis of the propulsion system

In order to calculate the propulsion force generated by the system, as a resultant of the forces acting on the 8 steel balls, the cinematic of the balls was analyzed. For this purpose, a Cartesian system (xO_1y) was attached to the one of the slotted discs (10). Further, it was considered one of the balls, having the center noted with C_i (Figure 4). During the rotation of the slotted discs, this ball is always in contact with the inner bore of the retaining disc (9), being tangent to the circle of radius E.

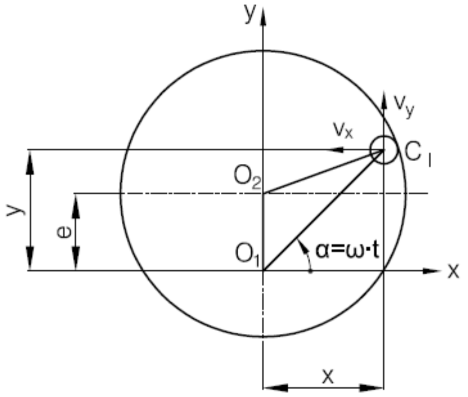


Figure 4. Cinematic of a ball

For deducting the relation of the trajectory radius R(t) of a ball i, which is a function of time, the generalized Pythagorean theorem is applied in the triangle O1O2Ci. Knowing that:

$$O_2C_i = E - r \ , \quad O_1O_2 = e \ , \quad O_1C_i = R(t) \ , \quad \alpha = \omega t \ , \tag{2}$$

were ω is the angular velocity of the slotted discs, we can write:

$$(E - r)^2 = e^2 + R^2(t) - 2eR(t)\cos\left(\frac{\pi}{2} - \omega t\right) \ , \tag{3}$$

or:

$$R^2(t) - 2eR(t)\sin\omega t + e^2 - (E - r)^2 = 0 \ , \tag{4}$$

which is a second degree equation, with the unknown *R(t)*, having the solutions:

$$R(t) = e\sin\omega t \pm \sqrt{(E - r)^2 - e^2\cos^2\omega t} \tag{5}$$

From the two possible solutions, the negative one is eliminated, so that the trajectory radius of the ball is:

$$R(t) = e\sin\omega t + \sqrt{(E - r)^2 - e^2\cos^2\omega t} \tag{6}$$

The Cartesian coordinates of the center of the ball are:

$$x(t) = R(t)\cos\omega t \ \text{ and } \ y(t) = R(t)\sin\omega t \ , \tag{7}$$

Considering equation (6), these coordinates may be expressed as:

$$x(t) = \frac{e}{2}\sin 2\omega t + \cos\omega t\sqrt{(E - r)^2 - e^2\cos^2\omega t} \tag{8}$$

$$y(t) = e\sin^2\omega t + \sin\omega t\sqrt{(E - r)^2 - e^2\cos^2\omega t} \tag{9}$$

The velocity of the ball can be decomposed along the axes *x* and *y*, the components being calculated as derivatives of the Cartesian coordinates *x(t)* and *y(t)*:

$$v_x(t) = \dot{x}(t) = \frac{2\omega e}{2}\cos 2\omega t - \omega \sin\omega t\sqrt{(E-r)^2 - e^2\cos^2\omega t} + \cos\omega t\frac{-2\omega e^2\cos\omega t\cdot(-\sin\omega t)}{2\sqrt{(E-r)^2 - e^2\cos^2\omega t}} \tag{10}$$

and:

$$v_y(t) = \dot{y}(t) = 2\omega e\sin\omega t\cdot\cos\omega t + \omega\cos\omega t\sqrt{(E-r)^2 - e^2\cos^2\omega t} + \sin\omega t\frac{-2\omega e^2\cos\omega t\cdot(-\sin\omega t)}{2\sqrt{(E-r)^2 - e^2\cos^2\omega t}} \tag{11}$$

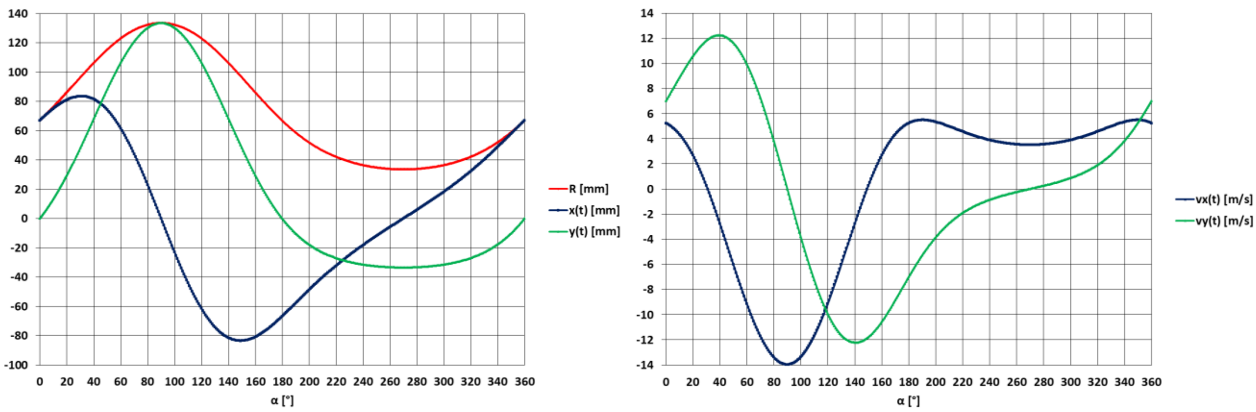
or:

$$v_x(t) = \omega e\cos 2\omega t - \omega\sin\omega t\sqrt{(E-r)^2 - e^2\cos^2\omega t} + \frac{\omega e^2\cos\omega t\cdot\sin 2\omega t}{2\sqrt{(E-r)^2 - e^2\cos^2\omega t}} \tag{12}$$

and:

$$v_y(t) = \omega e\sin 2\omega t + \omega\cos\omega t\sqrt{(E-r)^2 - e^2\cos^2\omega t} + \frac{\omega e^2\sin\omega t\cdot\sin 2\omega t}{2\sqrt{(E-r)^2 - e^2\cos^2\omega t}} \tag{13}$$

Admitting for the constructive elements of the system the values: *E= 92.5* mm, *e= 50* mm, and *r= 9* mm, respective a rotational speed for the slotted discs *n= 1000* rpm, Figure 5 depicts the variation of the geometrical coordinates of the ball (*R(t)*, *x(t)* and *y(t)*), respective of the velocities $v_x(t)$ and $v_y(t)$ at a complete rotation of the slotted disc (α=0 to 360°).



a) Variation of geometrical coordinates b) Variation of the velocities

Figure 5. Geometrical coordinates and velocities of the ball during a complete rotation of the slotted discs

Further, considering the variation of the velocity, it will result in an acceleration of the ball, which can be decomposed along the axes *x* and *y* in the components $a_x(t)$ and $a_y(t)$, these being calculated as derivatives of the velocities $v_x(t)$ and $v_y(t)$:

$$a_x(t)=\dot{v}_x(t)=-2\omega^2 e\sin 2\omega t-\omega^2\cos\omega t\sqrt{(E-r)^2-e^2\cos^2\omega t}-\omega\sin\omega t\frac{-2\omega e^2\cos\omega t\cdot(-\sin\omega t)}{2\sqrt{(E-r)^2-e^2\cos^2\omega t}}+$$
$$+\frac{\left(-\omega^2 e^2\sin\omega t\cdot\sin 2\omega t+2\omega^2 e^2\cos\omega t\cdot\cos 2\omega t\right)\cdot 2\sqrt{(E-r)^2-e^2\cos^2\omega t}}{4[(E-r)^2-e^2\cos^2\omega t]}-$$
$$-\frac{\omega e^2\cos\omega t\cdot\sin 2\omega t}{4[(E-r)^2-e^2\cos^2\omega t]}\cdot\frac{-4\omega e^2\cos\omega t\cdot(-\sin\omega t)}{4\sqrt{(E-r)^2-e^2\cos^2\omega t}} \tag{14}$$

and:

$$a_y(t)=\dot{v}_y(t)=2\omega^2 e\cos 2\omega t-\omega^2\sin\omega t\sqrt{(E-r)^2-e^2\cos^2\omega t}+\omega\cos\omega t\frac{-2\omega e^2\cos\omega t\cdot(-\sin\omega t)}{2\sqrt{(E-r)^2-e^2\cos^2\omega t}}+$$
$$+\frac{\left(\omega^2 e^2\cos\omega t\cdot\sin 2\omega t+2\omega^2 e^2\sin\omega t\cdot\cos 2\omega t\right)\cdot 2\sqrt{(E-r)^2-e^2\cos^2\omega t}}{4[(E-r)^2-e^2\cos^2\omega t]}-$$
$$-\frac{\omega e^2\sin\omega t\cdot\sin 2\omega t}{4[(E-r)^2-e^2\cos^2\omega t]}\cdot\frac{-4\omega e^2\cos\omega t\cdot(-\sin\omega t)}{4\sqrt{(E-r)^2-e^2\cos^2\omega t}} \tag{15}$$

or:

$$a_x(t)=-2\omega^2 e\sin 2\omega t-\omega^2\cos\omega t\sqrt{(E-r)^2-e^2\cos^2\omega t}+\frac{\omega^2 e^2\cos 3\omega t}{\sqrt{(E-r)^2-e^2\cos^2\omega t}}-$$
$$-\frac{\omega^2 e^4\cos\omega t\cdot\sin^2 2\omega t}{8[(E-r)^2-e^2\cos^2\omega t]^{3/2}} \tag{16}$$

and:

$$a_y(t)=2\omega^2 e\cos 2\omega t-\omega^2\sin\omega t\sqrt{(E-r)^2-e^2\cos^2\omega t}+\frac{\omega^2 e^2\sin\omega t}{\sqrt{(E-r)^2-e^2\cos^2\omega t}}-$$
$$-\frac{\omega^2 e^4\sin\omega t\cdot\sin^2 2\omega t}{8[(E-r)^2-e^2\cos^2\omega t]^{3/2}} \tag{17}$$

For a better understanding of the way how the acceleration components $a_x(t)$ and $a_y(t)$ are varying at a complete rotation of the slotted discs, Figure 6 provides the corresponding graphs.

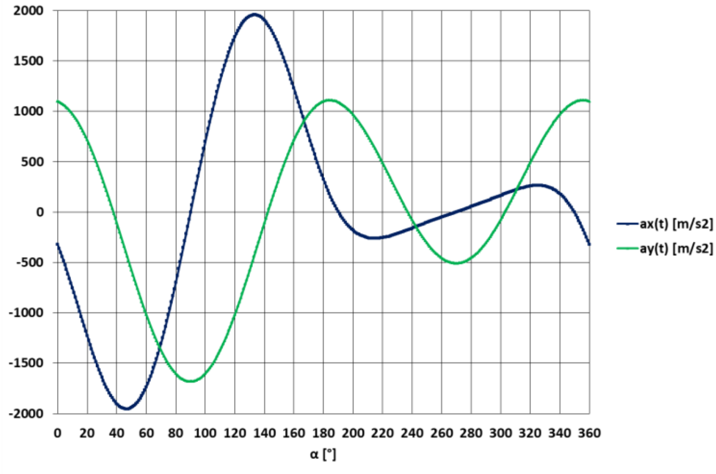


Figure 6. Acceleration components of the ball during a complete rotation of the slotted discs

According to Newton's second low of motion, in an inertial frame of reference, the mass m_0 of each ball multiplied by its acceleration $\vec{a}$ is equal to the vector sum of the forces $\vec{F}$ which are acting on the ball. This means that each ball is generating a propulsion force $\vec{R}$ equal to the product $m_0\vec{a}$, but of opposite direction. In addition, applying the superposition principle, the components of the propulsion force along the axes x and y may be written as:

$$\vec{R}_x = -m_0 \sum_{i=1}^{8} \vec{a}_{x_i} \qquad \vec{R}_y = -m_0 \sum_{i=1}^{8} \vec{a}_{y_i} \tag{18}$$

As the device consists of two identical constructive groups (see Figure 1), placed in mirror in relation to the y axis and rotating in opposite directions because of the engagement of the gears 11 (Figure 3), the R_x components of the two constructive groups are cancelling each other and the system is generating a total propulsion force $T = 2 \cdot R_y$, along the y axis.

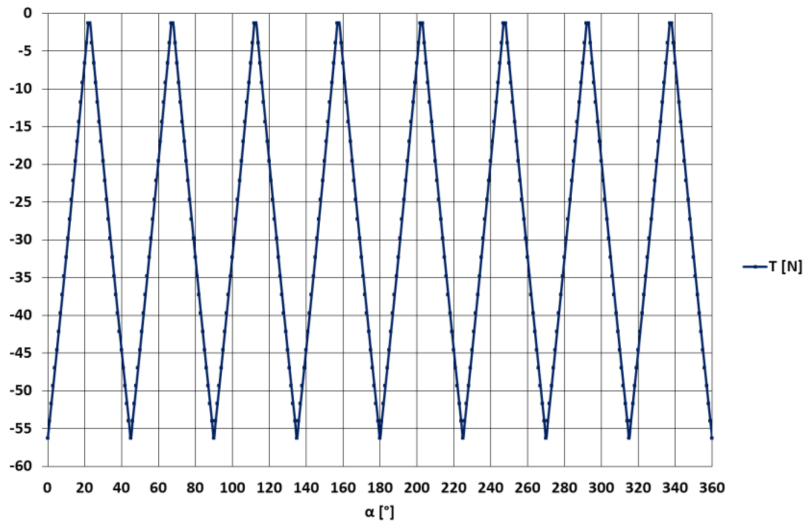


Figure 7. Variation of the propulsion force during a complete rotation of the slotted discs

The variation of the total propulsion force generated by the system during a complete rotation (α=0...360°) of the slotted discs and calculated according to the above mentioned is presented in Figure 7. As it can be observed, the propulsion force is negative, which means that the assembly is moving backwards (against the sense of the eccentricity). The sense of the movement can be changed by setting the eccentricity in the opposite sense (negative). The variation of the propulsion force is periodic having the shape of saw teeth, with values between 0 and a maximum, respectively a period corresponding to a rotation angle of the slotted discs of 45°.

4. Influence of the ball radius on the propulsion force

This study has investigated the influence of the radius of the steel balls and consequently of their masses on the propulsion force generated by the system. Using the calculation methodology presented in the previous section, the resultant propulsion forces of the system were computed, in case of employing balls of radius r= 4, 5, 6, 8 and 9 mm respectively. The calculus results of the maximum force are presented in Table 1.

Table 1. Propulsion force generated by different ball radii

Ball radius r (mm)	Max. prop. force T_{max} (N)
4	5.56
5	10.62
6	17.94
8	40.53
9	56.32

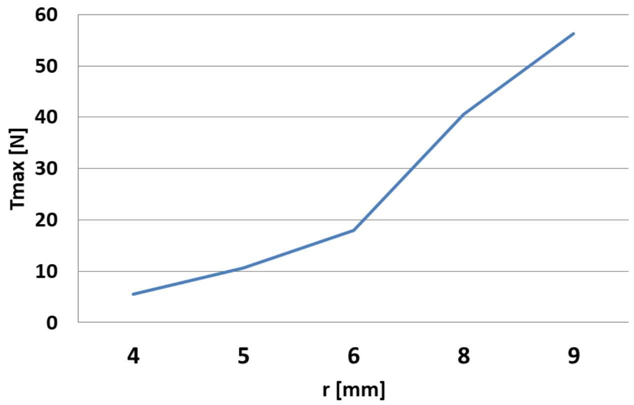


Figure 8. Influence of the ball radius on the maximum propulsion force

Furthermore, Figure 8 presents in graphical form the influence of the ball radius on the maximum propulsion force T_{max}. As it can be noticed, the evolution trends to have the shape of a power function.

5. Conclusion

The paper presents the structure of an inertial propulsion system with rotating masses. The operating principle is based on achieving an eccentric motion of 8 balls (active masses) in rotation. Due to variable rotating radii, the 8 balls are generating a one-way propulsion force.

From the calculations presented in this study, it follows that the resulting propulsion force is periodic during a complete rotation, having the shape of saw teeth. Furthermore, the sense of the force is in opposition to the eccentricity of the retention ring. The analysis of the influence of the balls radius on the resulting propulsion force showed that at a doubling of the balls radius (from 4 mm to 8 mm), the propulsive force increases about 7.3 times.

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