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Analytical investigations on the influence of the geometry of an inertial drive on the propulsion force

Attila Gerocs, Zoltan-Iosif Korka, Gilbert-Rainer Gillich

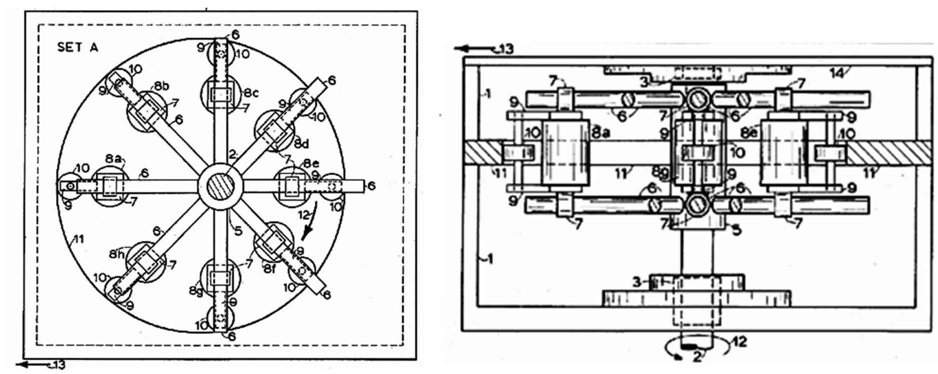
Since the beginning of the last century, worldwide, researchers and visionaries have spent a lot of time and energy to develop devices capable to use the centrifugal forces for generating linear motion. The present paper presents an inertial driving system designed to produce a propulsion force from the kinetic energy of 8 steel balls which are rotating on an eccentric circular path. The balls are placed between two rotating discs provided with radial slots. After presenting the equations of motion for the steel balls and deducting the propulsion force of the driving system, the paper pays a particular attention to the investigations on the influence of the geometry of the device on the generated linear force. Based on the obtained findings, the authors are confident about the system's ability to produce propulsive force and linear motion.

Keywords: *geometry, inertial drive, propulsion force.*

1. Introduction

Starting with the industrial revolution, and until the present time, when we are in the Industry 4,0 era [1], dozens of inertial propulsion devices have been patented. Whether we are talking about earlier [2-14] or newer attempts [15-19], unfortunately, only a few of these devices have been built and the technologies have not yet been exploited for commercial use.

Thus, Cuff [4] proposes a device which uses 8 rotating masses 8a, 8b,...8h for converting the centrifugal forces into a propulsive force acting in one direction which is perpendicular to the plane of rotating masses. The propulsion is generated due to the continuously variation of the radius of gyration of each mass during its complete revolution. This system produces an unbalanced centrifugal force by varying the radius of rotation for the eight rotating masses at predetermined moments in their cycle of revolution by means of an eccentrically disposed circular member. The position of that predetermined sector in which the rotating masses achieve their maximum radial distance corresponds to the direction of movement and that predetermined sector in which the rotating masses attain their minimum radial distance corresponds to the direction that is in opposition to the desired direction of movement.



a. b.

Figure 1. Cuff's propulsion system [4]
a. revolving masses; b. cross section of the device)

Another example is the "Propulsion Apparatus" proposed by Haller [8], where the resultant of the centrifugal forces is used for generating linear movement. The system (see figure 2) consists of the jet propulsion devices 1-1 ', mounted on the bars 2, which are disposed at the same angle relative to the center of rotation located in point 3. On each of the bars, pairs of rollers are radially sliding, being pushed outwards, in contact with the inner wall of cylinder 7. Cylinder 7 has the center in point 6, which is placed eccentrically relative to point 3.

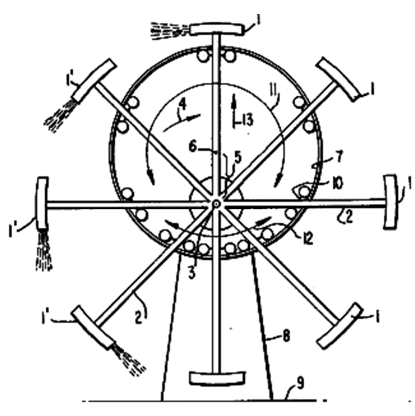
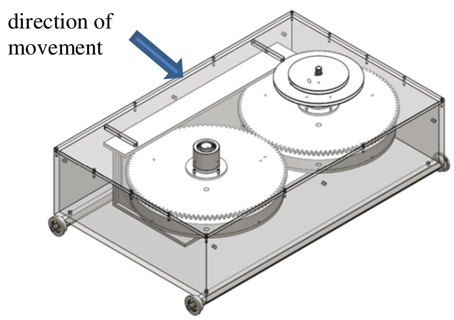


Figure 2. Haller's propulsion apparatus [8]

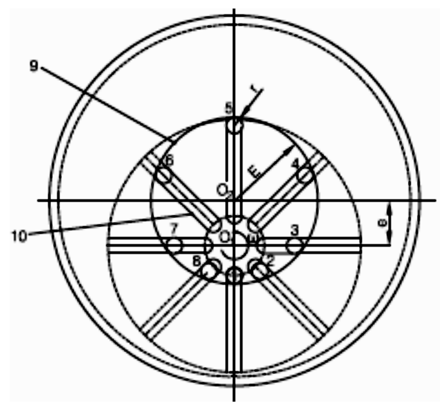
Thus, related to point 3, the rollers 10 have variable radii during a complete rotation, which leads to the appearance of a resultant of the centrifugal forces in the direction of the line joining points 3 and 6. This resultant force can be used to generate a linear motion.

2. Construction of the drive and computation of the propulsion force

The operating principle of the Inertial Propulsion System (IPS) bases on the generation of a resultant centrifugal force which acts in the movement direction of the device. Its construction is presented in figure 3 and consists of two identical assemblies, which are rotating in opposite direction and are placed in mirror relative to the direction of movement.



a.



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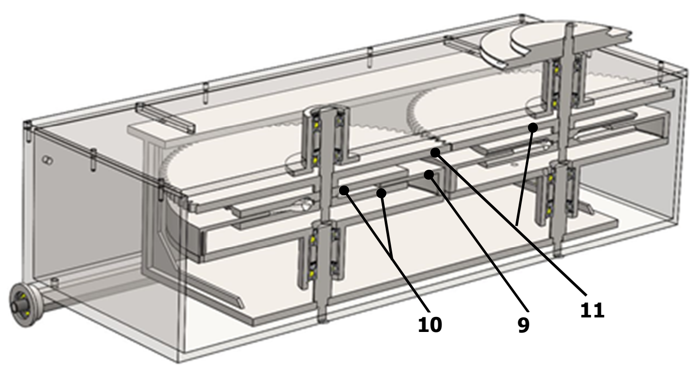

c.

Figure 3. Construction of the IPS [20]
a. general view; b. arrangement of the balls; c. cross section

Each of the two assemblies consists of 8 identical steel balls (1-8) of radius r, which are placed between two rotating discs (10), foreseen with radial slots. The steel balls are in contact with the inner bore of the retaining disc (9), which ensures their circular trajectory. The centers of the discs (9) and (10) are eccentrically displaced (O_2, respective O_1) in the movement direction of the system with the distance e. The movement in opposite direction of the two assemblies is ensured by the two identical spur gears (11).

By rotating the slotted discs (10) with a constant angular speed ω, on each of the 8 balls is acting a centrifugal force. As the balls are forced to follow a circular trajectory having the rotational center placed eccentrically to the rotation center of the slotted discs, they will have, during a complete revolution, variable radii of rotation relative to O_1. The centrifugal forces which are acting on the balls may be expressed as:

$$F_{c_i} = m_0 \quad \omega^2 \quad R(t), \tag{1}$$

where: m_o is the mass of the balls and $R(t)$ the trajectory radius of ball i.

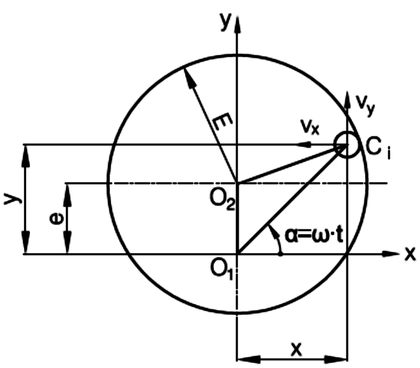

Figure 4. Kinematic of a ball

In order to compute the propulsion force generated by the system, one of the balls with the center C_i was considered. To the slotted disc (10) was attached a Cartesian system denoted with xO_1y. As the ball is permanently in contact with the inner bore of the retaining disc (tangent to the circle with radius E), based on the notations from figure 4, the coordinates of the center C_i can be written as:

$$x(t) = R(t)\cos\omega t \text{ and } y(t) = R(t)\sin\omega t \ , \tag{2}$$

where: the trajectory radius R(t) can be computed, by applying the generalized theorem of Pythagoras in the triangle $O_1O_2C_i$, as:

$$R(t) = e\sin\omega t + \sqrt{(E-r)^2 - e^2\cos^2\omega t} \tag{3}$$

Thus, the coordinates of the center of the ball can be expressed as:

$$x(t) = \frac{e}{2} sin 2\omega t + cos\,\omega t\sqrt{(E-r)^2 - e^2 cos^2 \omega t} \quad (4)$$

$$y(t) = e\,sin^2 \omega t + sin\,\omega t\sqrt{(E-r)^2 - e^2 cos^2 \omega t} \quad (5)$$

Consequently, the components of the velocity along the x and y axis can be computed as derivatives of the coordinates *x(t)* and *y(t)*:

$$v_x(t) = \omega e cos 2\omega t - \omega sin\omega t\sqrt{(E-r)^2 - e^2 cos^2 \omega t} + \frac{\omega e^2 cos\omega t \cdot sin 2\omega t}{2\sqrt{(E-r)^2 - e^2 cos^2 \omega t}} \quad (6)$$

and:

$$v_y(t) = \omega e sin 2\omega t + \omega cos\omega t\sqrt{(E-r)^2 - e^2 cos^2 \omega t} + \frac{\omega e^2 sin\omega t \cdot sin 2\omega t}{2\sqrt{(E-r)^2 - e^2 cos^2 \omega t}} \quad (7)$$

Further, deriving the upper expressions of the velocities, the components of the acceleration are obtained as:

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

and:

$$\begin{aligned} a_y(t) = &\,2\omega^2 e cos 2\omega t - \omega^2 sin\omega t\sqrt{(E-r)^2 - e^2 cos^2 \omega t} + \\ &+ \frac{\omega^2 e^2 sin\omega t}{\sqrt{(E-r)^2 - e^2 cos^2 \omega t}} - \frac{\omega^2 e^4 sin\omega t \cdot sin^2 2\omega t}{8[(E-r)^2 - e^2 cos^2 \omega t]^{3/2}} \end{aligned} \quad (9)$$

Moreover, applying Newton's second low of motion in an inertial frame of reference, each ball of mass m_o is generating a propulsion force $\vec{R} = -m_0\vec{a}$. Additionally, considering the superposition principle, the components of this propulsion force, along the *x* and *y* axis can be expressed as:

$$\vec{R}_x = -m_0 \sum_{i=1}^{8} \vec{a}_{x_i} \qquad \vec{R}_y = -m_0 \sum_{i=1}^{8} \vec{a}_{y_i} \quad (10)$$

Because the system is consisting of two identical assemblies rotating in opposite directions, the R_x components of the two assemblies are canceling each other, the total propulsion force acting along the y axis and being computed as:

$$T = 2 \cdot R_y \tag{11}$$

As it can be noticed, the propulsion force and the accelerations are in opposite directions. Therefore, the movement sense of the system can be changed by setting the eccentricity in the opposite sense.

3. Influence of the geometry of the system on the propulsion force

For the investigated IPS were considered following main dimensions:
- inner radius of the retaining disc: $E= 92.5$ mm;
- eccentricity: $e= 50$ mm;
- radius of the 8 steel balls: $r= 9$ mm.

and a rotational speed of the slotted discs $n= 1000$ rpm.

Computing the propulsion force for the above mentioned data by using equations (9)- (11), allowed obtaining a variation in time as depicted in figure 5.

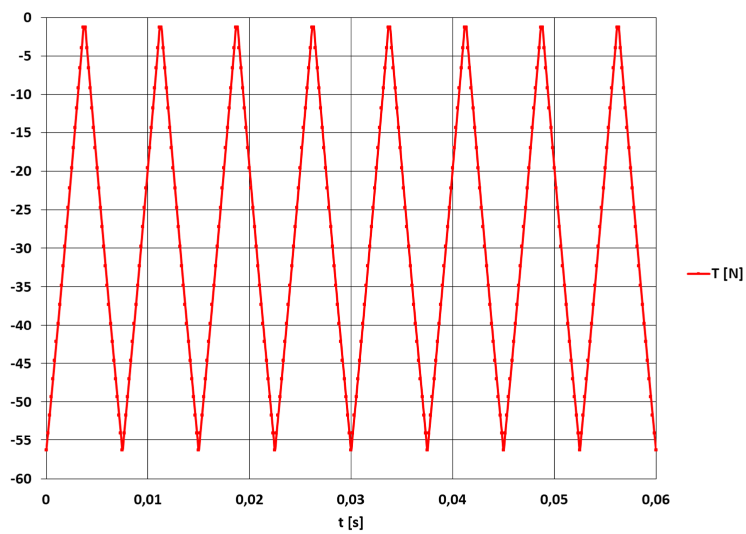

Figure 5. Variation of the propulsion force

As it can be observed, the propulsion force generated by the IPS is a pulsatory one, having a saw-teeth shape and a period of 0.0075 s. Further, the study has investigated the influence of the main geometrical parameters of the system (radius of the steel balls, eccentricity and radius of the retaining disc) on the propulsion force.

3.1. Influence of the steel balls radius *r*

One of the objectives of the present exploration was to analyze the way how the radius of the balls and, consequently, their masses, influences the propulsion force generated by the system. Therefore, involving the analytical methodology described in the previous section, the propulsion force of the IPS was calculated, in case of using balls with the radii *r*= 4, 5, 6, 8 and 9 mm respectively, by keeping the other main dimensions (*E*= 92.5 m and *e*= 50 mm). The computation results of the maximum propulsion force are presented in a graphical form in figure 6.

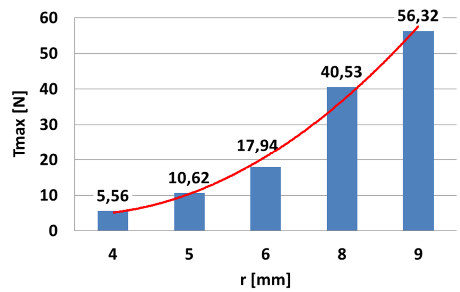

Figure 6. Impact of the ball radius *r* on the maximum propulsion force

One can see that by doubling the radius of the balls from 4 to 8 mm, the propulsion force increases about 8 times, which denotes and exponential impact of the ball radius on the force generated by the IPS.

3.2 Influence of the eccentricity *e*

For this purpose, the eccentricity *e* between the slotted disc (10) and the retaining ring (9) was set at six different values: *e*= 0, 10, 20, 30, 40 and 50 mm, while the other main dimensions were preserved (*E*= 92.5 mm and *r*= 9 mm). Following the previous presented calculation approach, the maximum thrust force generated by the IPS was computed. The results are depicted in figure 7.

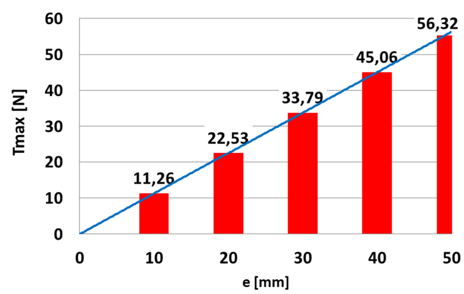

Figure 7. Influence of the eccentricity *e* on the maximum propulsion force

It can be noticed that for an eccentricity $e= 0$ mm, the system doesn't generate any thrust, as the centrifugal forces which are acting on the steel balls are canceling each other in both of the assemblies. By increasing the eccentricity, the propulsion force grows, observing a linear interdependence between the eccentricity and the generated propulsion force.

3.3. Influence of the inner radius *E* of the retaining disc

For the scope of this study, the inner radius of the retaining disc (9) was considered to have following four different values: E= 85, 87.5, 90 and 92.5 mm, as long as the other two main dimensions were preserved (e= 50 mm and r= 9 mm). Succeeding the same calculus procedure as for the other investigated geometrical parameters, the maximum propulsion force of the system was calculated. The obtained results may be observed in figure 8.

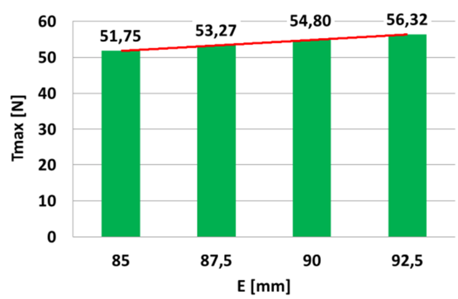

Figure 8. Influence of the radius *E* on the maximum propulsion force

Analyzing figure 8, one can notice that, for the investigated range of the inner radius E, the influence on the thrust force generated by the IPS is minor. Furthermore, interdependence between the radius E and the generated propulsion force is a linear one.

4. Conclusion

The paper presents the construction of an IPS which uses the eccentric rotation of 8 steel balls (so-called active masses) for generating a one-way propulsion force.

Starting from the equations of motion for the balls, the resulting propulsion force was deducted and computed. It was found that this force is pulsatory, with a variation having the shape of saw teeth. Additionally the study has concluded that the propulsion force generated by the system is in opposition to the sense of eccentricity between the slotted discs and the retaining ring.

The analysis regarding the impact of the main geometrical elements of the IPS (r, e and E) on the resulting thrusts force, showed as most significant the influence of the ball radius r. Thus, at doubling of the radius of the balls (from 4 mm to 8 mm), the propulsive force grows about 8 times. Also, the raise of the eccentricity and the inner radius of the retaining disc are likely to contribute to the increase of the propulsion force. When the centers of the slotted discs and the retaining ring coincide ($e=0$), the system doesn't generate any thrust, because the centrifugal forces acting on the 8 steel balls are in opposition two by two, canceling each other.

Finally, based on these findings, the authors are confident that the proposed system is capable to generate propulsion force, constituting the premises of a further practical materialization of this design.

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Addresses:

- PhD. Stud. Eng. Attila Gerocs, "Eftimie Murgu" University of Resita, Traian Vuia Square, No. 1-4, 320085 Resita, atti.gerocs@gmail.com
- Lect. Dr. Eng. Habil. Zoltan-Iosif Korka, "Eftimie Murgu" University of Resita, Traian Vuia Square, No. 1-4, 320085 Resita, z.korka@uem.ro
- Prof. Dr. Eng. Gilbert-Rainer Gillich, "Eftimie Murgu" University of Reşița, Traian Vuia Square, No. 1-4, 320085 Resita, gr.gillich@uem.ro