Development of an inertial propulsion drive by using motion simulation

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Abstract. Beginning with the last century, visionaries and researchers from all over the world have invested a lot of energy and time in the development of various drives for generating propulsion force. The present paper is dedicated to the kinematic and dynamic investigation of an inertial propulsion drive using the facilities of the Motion module from SolidWorks (SW) software. Following elements were considered: positional analysis, velocities and acceleration simulation, force generation and power consumption. As the obtained simulation results showed a good closeness to the analytical outcomes, the authors are optimistic regarding the possibilities to develop and improve the system.

1. Introduction
In the last decades, a plenty of enthusiast scientist and researchers have spent a significant amount of time and energy in the design of devices capable to move the object on which they are attached. Unfortunately, even we are discussing about previous [1-12] or recent pursuits [13-20], sadly, only a few of these patented devices were built and the inventions have not yet been used for technical issues.

One of the first inertial propulsion systems was patented at the beginning of last century by Marco Todeschini [1], who proposed a centrifugal propulsive force generated by a motor powered with dissociated water and gradual speed variation.

A well-known reactionless propulsion drive is the device developed by Norman Dean [2], who claimed that his device is able to generate a uni-directional force in free space, in opposition to Newton's third law of motion. His concept became a matter of debate but it also inspired hundreds of new patents.

Another drive was proposed by Haller [4]. His patent, namely a “Propulsion Apparatus” consists of 8 jet propulsion devices mounted on bars which are disposed at the same angle relative to the center of rotation. Each of the bars is foreseen with pairs of rollers which are radially sliding, being pushed outwards, to get in contact with the inner wall of a cylinder. The center of this cylinder is placed eccentricaly relative to the rotation point of the system. Thus, related to the device rotation center, during a complete rotation, the rollers have variable radii. This leads to the appearance of a resultant of the centrifugal forces in the direction of the line joining the cylinder center with the rotating center. This resultant force is used to produce linear motion.

Further, Cuff [9] proposed a system comprising of 8 rotating masses for converting the centrifugal forces into propulsive force. The generated force is acting in one direction which is perpendicular on the plane of the rotating masses. The propulsion is ensured by the continuously variation of the radius of gyration of each mass during its rotation.
More recently, Provatidis [21] proposes a device which is able to generate net impulse using two synchronized masses, which are moving along a figure-eight-shaped orbit.

Additionally, Anad et al. [22] proposed the optimization of an inertial propulsion system for future space application. Their amendment conducted to cancellation of the existent radial force and doubling the force which is acting upward.

As this domain is very challenging, the authors have started with the development and the optimization of their own inertial propulsion drive. Despite the initial concept [23], for which a patent application is in progress, this research has investigated a different shape of the retaining ring using an analytical approach and the facilities of Motion module from SolidWorks. Elements as positional analysis and velocities of the balls, displacement of the device and power consumption were explored. The simulation outcomes were very close to the analytical results, small differences occurring due to impact phenomenon’s which were not taken into account in the analytical procedure.

2. Geometry and main parameters of the proposed IPD

The proposed inertial propulsion drive (IPD) is based on generating a resultant centrifugal force for moving the assembly. The construction is shown in figure 1 and consists in a twin of constructive groups placed in mirror relative to the direction of movement. Each of the groups include 8 identical steel balls (1-8) with a diameter of 10 mmm, which are placed between two rotating discs (9) provided with radial slots for a popper guidance of the balls in radial direction. The path of the balls is provided by the inner bore of the retaining disc (10), which has a special design consisting of a semicircle with a radius R44.6 mm, two straight portions tangent to the semicircle and an arc of radius R61 mm, with the centre located in the centre of the above mentioned semicircle (see figure 3).

For driving the two constructive groups in rotational motion having the same speed, but opposite directions, two identical spur gears (11) are placed above the upper slotted discs (9), being driven by two shafts (12/1 and 12/2). One of the shafts (12/1) is connected to the driving motor which turns the assembly with a constant speed \( n = 1000 \text{ min}^{-1} \).

The retaining discs (10) are fixed on the bottom plate of the assembly (13), which is supported by four rubber wheels with fixes axis and a 40mm diameter.

![Figure 1. Cross section of the propulsion drive](image)

The operating principle of the IPD consists in developing a propulsion force as a reaction to the variable centrifugal forces acting on the 8 steel balls. The above mentioned centrifugal forces may be expressed as:

\[
F_{ci} = m \cdot R_i(t) \cdot \frac{\pi n}{30}
\]  

where \( m [\text{kg}] \) is the mass of a ball, \( n [\text{min}^{-1}] \) the rotational speed of the driving motor and \( R_i(t) [\text{m}] \) the trajectory radius of ball \( i \).
To have a better understanding of the proposed system, figure 2 provides a picture of the prototype at which the main components (slotted discs, retaining discs, spur gears and bearing bushings) were manufactured by 3D printing from polylactide (PLA) filament, where the motion driver is missing.

3. Analytical investigation of the IPD

For calculating the physical quantities that characterize the kinematics of the system, one of the balls with the centre in \( C_i \) was treated. Further, a Cartesian system denoted with \( xOy \) was attached to the slotted disc (9) (see Figure 3). During the rotation of the slotted discs, this ball is always in contact with the inner bore of the retaining disc (11). Unlike previous research [24, 25], where the inner bore of the retaining disc was cylindrical, in the present study a special design was implemented. This time the inner bore consists of a semicircle with the centre in \( O \) and a radius \( R_1 = 44.6 \) mm, two straight portions tangent to the semicircle and an arc of radius \( R_2 = 61 \) mm and centre located in \( O \).

Figure 3 Kinematic of a ball

The \( x \) and \( y \) coordinates of the centre \( C_i \) of a certain ball \( i \) are calculated, depending on the angle of position \( \alpha = \omega \cdot t \) (\( \omega \) - angular velocity of the disk with slits and \( t \)-time), as follows:
Here deriving equations (10) and the stages of the motion study.

In the present study 4.1 Creation of the parts geometry and assembly mechanism

In order to reduce the computing time [26], a simplified geometry was used for simulation. Thus, figure 4 shows the upper and lower slotted disks (9), which were generated as a single part. Here, the Front Plane, the Central Axis, the Point on Central Axis was used to apply mates in the IPS assembly.

Figure 5 depicts the dimensions of the retaining disc (10), while figure 6 presents the retaining disc (10) and the bottom plate (13) of the assembly also generated as a single part. Here the box midpoint, Axis 1/2, Central Point 1/2 and the centers of the balls 1÷8 were used to apply mates in the IPS assembly. The centers of the balls 1÷8 were placed on a plane following the contour defined as offset of the inner hole of the retaining disc (10). The offset distance was imposed as the radius of the balls.
Figure 4 Generation of the slotted discs (9)

Figure 5. Geometry and main dimensions of the retaining disc 10

Figure 6. Retaining disc (10) and the bottom plate (13) generated as a single part
The components were placed in the assembly with *Insert Components* command from *Assembly* toolbar. A part or assembly may be selected from the *Part/Assembly to Insert list*, while to open an existing part, *Browse* command must be used. Next, for placing a component, within the graphic area has to be click or choosing \(\checkmark\) to place the component origin coincident with the assembly origin. Only the bottom table was placed with the origin coincident with the assembly origin.

By default, the first part placed in an assembly is fixed and has a (f) mark placed before its name in the *FeatureManager* design tree. The other components were placed without this restriction.

### 4.2 Stages of the motion study

Following steps [27], [28] were involved in the motion study:

- Initialization of the SolidWorks Motion module;
- Creation and specification of the study’s options;
- Establishment and stipulation of the study’s options;
- Statement of Rotary Motor;
- Statement of Gravity;
- Statement of SolidBody Contacts;
- Statement of the Mates;
- Running the design study.

To specify the rotary motor, *Motor* icon was choose, while the inner cylindrical face of the slotted disc (9) was selected, together with *Constant speed* from *Motor Type* list. Choosing \(\checkmark\), the *Rotary Motor1* branch was created in the *Motion Manager* design tree.

Further, selecting *Gravity* icon, axis Z as direction of action and the value of 9806.65 mm/s\(^2\), the gravitational forces acting on the mechanism were simulated. No friction between the components was imposed. Finally, the mates indicated in table 1 were applied in the motion study between the components of the assembly.

#### Table 1. Mates applied to the IPS mechanism

| Mate name | Mate type    | Component 1                     | Component 2                               |
|-----------|--------------|---------------------------------|-------------------------------------------|
| Mate 1    | Coincident   | Box axis                        | Horizontal table axis                     |
| Mate 2    | Coincident   | Midpoint of the box axis        | Left edge of the horizontal table         |
| Mate 3    | Coincident   | Axis 1 of the left retaining disc (10) | Central axis of the left rotating disk (9) |
| Mate 4    | Coincident   | Central Point on axis 1 of the left retaining disc (10) | Point on central axis of the left rotating disk (9) |
| Mate 5    | Coincident   | Axis 2 of the right retaining disc (10) | Central axis of the right rotating disk (9) |
| Mate 6    | Coincident   | Central Point on axis 2 of the right retaining disc (10) | Point on central axis of the right rotating disk (9) |
| Mate 7    | Gear mate ratio=1 | Axis 1 of the right retaining disc (10) | Central axis of the right rotating disk (9) |
| Mates 8÷15 | Coincident | Points 1 ÷ 8 of the left retaining disc (10) | Central points of the left balls 1 ÷ 8 |
| Mates 16÷23 | Coincident | Points 1 ÷ 8 of the right retaining disc (10) | Central points of the right balls 1 ÷ 8 |
| Mate 24   | Coincident   | Vertex 1 of the horizontal table | Vertex 1 of the retaining disc (10) + bottom plate-single part |
| Mate 25   | Coincident   | Front plane of the left rotating disk (9) | Front plane of the right rotating disk (9) |
| Mate 26   | Parallel     | Front plane of the left rotating disk (9) | Right plane of the assembly |
The mates 8÷23 were only necessary to specify the initial position of the balls. Mate 24 was used to specify the basic locations of the retaining disc (10), the bottom plate (13) and the horizontal table on which the assembly is sliding without friction. Lastly, mates 25 and 26 were involved to specify the initial position and the direction of the first ball. Before starting the motion analysis calculation all these mates were suppressed.

A Solid Body Contact 1 was imposed between first group, defined as the left balls 1 ÷ 8 and the second group, defined as the left retaining disc (10) and the bottom plate (13) generated as a single part together with the left rotating disk (9).

A Solid Body Contact 2 was imposed between first group, defined as the right balls 1 ÷ 8 and the second group, defined as the right retaining disc (10) and the bottom plate (13) generated as a single part together with the right rotating disk (9).

For both of Solid Body Contacts two type of material applicable to touching faces during contact were imposed. First material combination was Steel with Steel Greasy. The second material combination was Acrylic with Steel. For every material combination the elastic properties of the materials involved in contact phenomenon are selected automatically by SolidWorks Motion.

The analysis time of the study was imposed to 0.3 s. Within this time, as the rotational speed is n=1000 min\(^{-1}\), the slotted discs are rotating 5 times, the duration of a complete rotation being 0.06 s.

5. Results and discussion
In the first stage of simulations, the coordinates and the velocities of a ball (no. 1 in figure 4) where computed for a complete rotation of the slotted disc, the obtained outcomes being compared with the analytical calculations performed with equations (2) and (3). The obtained results for \( R \), \( x \) and \( y \) as functions of the rotation angle \( \alpha \) are shown in figure 7.

![Figure 7. Comparison of the coordinates of a ball resulted from analytical calculation and SW simulation](image)

The analytical results were calculated for a complete rotation of the slotted disc (9), during which time it was assumed that the steel ball remains in contact with the retaining disc (10). The simulation results (marked with dashed lines in figure 7) are a little bit different near the points where the trajectory of the balls changes from circular to linear. In this inflection point’s collisions between the ball and the retaining disc (10) occur, after which the ball approaches, in the hemispherical slots, the center of discs (9). The movement changes its sense when the centrifugal force acting on the ball succeeds to cancel the impulse received by the ball after the collision.
For the radial distance of the ball center were simulated two combinations of materials for the ball and the retaining disc: Steel with Steel Greasy, respective Steel with Acrylic. As it can be observed (the pointed line in figure 7), the effect of collision is softer in the case in which the retaining disc is manufactured from a plastic material (the case of the prototype).

![Figure 8. Comparison of the velocities of a ball resulted from analytical calculation and SW simulation](image1)

Figure 8. Comparison of the velocities of a ball resulted from analytical calculation and SW simulation

Figure 8 depicts the comparison of the $v_x$ and $v_y$ velocities of a ball resulted from analytical calculation and SW simulation (dashed lines). The differences between simulation and the analytical approach occurred due to impact phenomenon’s which were neglected in the analytical procedure.

![Figure 9. Simulation of the device displacement](image2)

Figure 9. Simulation of the device displacement

The movement of the device, reproduced by the displacement of the bottom plate (13), was also simulated. The results are presented in figure 9 as function of time. As it can be observed, immediately
after initializing the rotation of the slotted discs, due to the high inertia of the system, the box gets an impulse ($y = 0.62$ mm), but after a very short time ($T < 0.03$ sec), the system stabilizes and the displacement of the box increases linearly (trend line marked with blue color in figure 9).

![Figure 10. Simulation of propulsion force generated by the IPD](image)

Another important benefit of the *Motion* module from *SolidWorks* is that it supplies in quick way information concerning the propulsion force generated by the IPD and the power consumption for driving the system, data that are harder to obtain by analytical approaches. Appropriate information on this topic is shown in figures 10 and 11.

![Figure 11. Simulation of power consumption for driving the system](image)

As it can be observed from figure 10, the system generates an oscillating propulsion force, which contributes to the jerky movement of the device, as already noticed in figure 9. Further, from figure 11, one can notice that during the simulation time, there are some periods when the power consumption becomes negative. This means that the device “produces” power that is transferred to the motor which is driving the system through the shaft (12/1).
6. Conclusions
The present study reveals the results of a kinematic and dynamic study of an IPD which uses the movement of 8+8 steel balls (active masses) to develop linear motion.

The geometrical coordinates of one ball and its velocities were calculated by analytical established equations and were examined in contrast to the simulation results accomplished with the Motion module from SolidWorks software. The results of both approaches have shown a good agreement of the outcomes. The differences appear due to impact phenomenon’s which were ignored in the analytical approach.

Moreover, the simulation results allowed making the observation that, immediately after starting, due to the inertia of the components, the displacement of the system is unsteady, stabilization occurring after about 0.03 s. Furthermore, this research confirms that the IPD projected by the authors is operative and able to achieve unidirectional propulsion force. The acquired results are encouraging the authors to extend their researches in the direction of improving the system.

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