



Optimization of Configuration of Inertial Propulsion System for Future Space Application

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Abstract: Conversion of centrifugal force to linear force is the basic principle of an inertial propulsion system. This thesis work describes an inertial propulsion system for developing a unilateral self-contained propulsion force in a predetermined direction using the effort of rotational-coupled mass motion. The system finds its applications in space transportation industry and satellite maneuvering. An attempt to study various mechanisms of inertial propulsion systems is made. Horizontal and vertical component of forces have been computed for one to five mass systems. The forces in both directions of different mass systems can be calculated with the aid of miscellaneous curves method (Inferior epitrochoid). The force patterns of corresponding mass systems are also plotted. The net propulsion force which is obtained in positive direction is in case of three mass systems and is selected for the configuration design. The force required for the application is in the vertical direction and hence the force in the radial direction has to be cancelled.

Keywords: centrifugal force; linear force; space transportation industry; satellite maneuvering; mechanisms; inferior epitrochoid; three mass system; radial direction

I. Introduction

"Inertial propulsion" (IP) is a novel principle producing movement in one direction using force from rotating inertial masses, which is physically equivalent to centrifugal force. Centrifugal force or thrust has not been used heretofore to produce directed motion in a predetermined direction. The centrifugal force produced by a body depends on the length of the radius connecting the axis of revolution to the rotating body. If the length of radius is increased in the desired direction of centrifugal thrust and then decreased in the opposite direction during rotation, an excess of force or thrust will be attained. This excess centrifugal force is exerted in the direction of increased radii. A greater excess force is produced by increasing the mass weight, and/or increasing the rpm and the length of the radii in the desired thrust direction at the expense of the length of radii in the opposite direction.

In accordance with this invention, the length of the radius connected to the rotating mass or body, which is centrifugally driven by a power source, is varied by rotating the radius member through a revolving axis of rotation, the axis being off centered with respect to the rotating mass. Thus by having a series of off centered rotating masses laterally separated from each other and by predetermined angles between them at a particular instant of time but in separate planes of rotation, the rotating masses produce a summation of directed thrust or torque in the desired direction. An Inertial propulsion engine is a purely electromechanical system which does not burn any propellant. So this system is the source of clean energy which can be used for propulsion application. It can find applications in space transportation industry and satellite maneuvering. Satellite maneuvering during space missions is generally done with the help of propellant. With the introduction of inertial propulsion, the operation time may be extended further. This research work describes the working of an IPE configuration with a simple principle for the trajectory control of inertial masses so as to generate the unidirectional force for propulsion. This thesis work proposes a model with its principle, sub system details and challenges.

II. Objectives

The project objective is to study and analyse different inertial propulsion systems and to converge to an optimized configuration in order to substitute conventional satellite maneuvering techniques and thus improve the life cycle.

III. Problem Definition

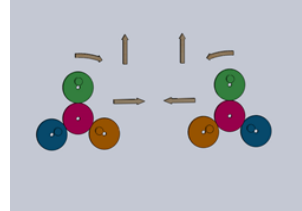
The operational life of the satellite is determined by the amount of propellant carried and the rate at which the propellant is used up. Propellant is used mainly for two purposes in case of satellite maneuvering. One is to maintain the satellite in its prescribed orbit and the other is to control rotation. Rotational operation, such as turning to a point in a new direction, is usually performed by angular momentum storage devices such as reaction wheels. It is generally preferable to use these devices instead of traditional thrusters, as they are powered by renewable electricity instead of propellant. Therefore, the less propellant that is used for

controlling rotation, the more life can be maintained. So inertial propulsion system is introduced for maintaining orbit with the use of renewable electricity instead of propellant.

IV. Principle of Inertial Propulsion

In an internal combustion engine, due to the fuel burning, linear impulse is created and the same is converted into angular momentum. A converse analogy of this process works in an inertial propulsion engine. It converts the angular momentum into linear momentum. The principal object of the present invention is to provide a machine or device operating as a variable radii centrifugal mechanism to produce torque or thrust in a prechosen direction. The invention is useful for producing oscillation or vibratory movement, for example, such as required for actuating agitators, shakers and the like equipment.

Figure 1 Illustration of principle

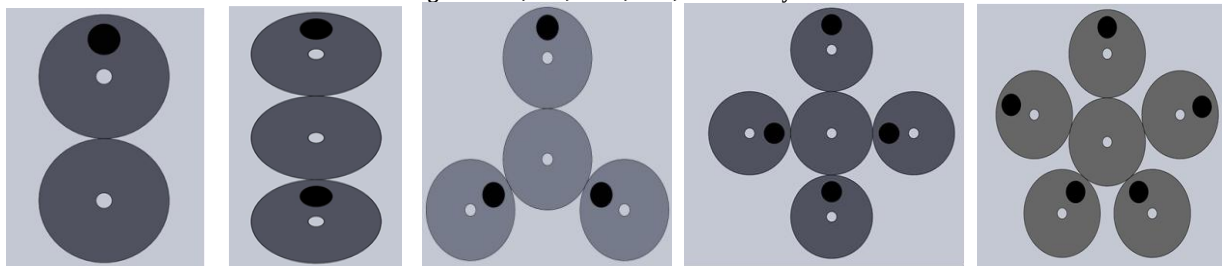


A pair of counter rotating planetary gears fitted with eccentric masses around a sun gear is positioned in a plane. The sun gear does not rotate. During working, both units are rotated in opposite direction at same speed. Due to this movement of the masses, traction is generated in each and every point. The net traction force acting in the system would be the propulsion force generated by the device. Due to rotation, horizontal and vertical forces are generated in the system. The horizontal forces are balanced with each other with the introduction of two identical systems operated in opposite direction in same plane, where as we constantly get a vertical component of force.

V. Configuration of Inertial Propulsion System

The configuration of inertial propulsion system utilizes centrifugal force for propulsion. It contains series of off-center rotating masses timed to take advantage of the positive centrifugal force. The configuration of different mass systems is shown in figure 2 to 6. That is from one mass system to five mass systems. Each configuration is selected for configuration design and force analysis for finding which system produces the positive propulsion force. In the case of configuration design, all gears used are selected with same module, pitch diameter and number of teeth for the purpose of getting the desired propulsion force.

Figure 2 one, two, three, four, five mass systems



The configuration of one mass system in which the eccentric mass position clearly understands from the figure. The gear without mass is fixed and the gear with eccentric mass is rotating. An eccentric mass is attached on the rotating gear for producing the propulsion force in the desired direction. The configuration design of two mass systems consists of arrangement of two gears 180° apart. The force which is required is in the upward direction so the arrangement of eccentric mass in the bottom rotating gear is always in the inner side. So the radius from the center of the fixed gear and the mass position is less and as a result net propulsion force is getting in the upward direction. The configuration design of three mass systems consists of arrangement of three gears 120° apart. The configuration design of four mass systems consists of arrangement of four epicyclic gears with eccentric masses at 90° apart. The configuration design of five mass systems consists of arrangement of five epicyclic gears with eccentric masses at 72° apart.

VI. Force Analysis of Inertial Propulsion System

The force analysis of the configuration of inertial propulsion system can be done for finding the force generated by different mass system. Force generated both in horizontal ("X") and vertical ("Y") direction of different mass system is calculated. Net force of different mass system is to be calculated and tabulated. Force pattern can be plotted in both directions of net force. The net propulsion force required is in the "Y" direction and the force in "X" direction is not required and is to be cancelled.

Propulsion force analysis can be done with aid of graphical method. Mass path trajectory of single, two, three, four and five mass systems can be done with the aid of Miscellaneous Curve (Inferior epitrochoid) method. Propulsion forces of different mass systems in 30° increments can be calculated using the mathematical formula shown below.

Also plotted force pattern in “x” and “y” direction for different mass systems and select the suitable mass system for the design of inertial propulsion system. The constant values used for finding the net propulsion forces are $m = 250\text{g} = 0.25\text{ kg}$, $N=500\text{ rpm}$.

$$F = mr\omega^2 \quad (1)$$

Where,

F = Propulsion force in Newton’s

m = Mass of inertia disc in kg

r = distance of inertia disc from the center of fixed gear in meters

ω = Angular speed in rad/sec

θ = Angular position from prime axis (center axis) in degrees

A. Single Mass System

Figure 3 Distance of eccentric mass

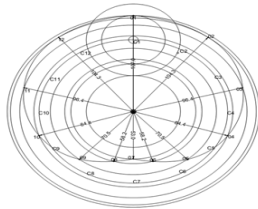
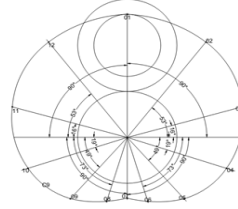


Figure 4 Angular position values



The mass path trajectory of single mass system is traced using inferior epitrochoid method is shown in figure 3 and 4. The path of the mass is traced for finding the radius which is the distance from the center of the fixed gear to the eccentric mass. Angle of mass from the horizontal or vertical axis of the fixed gear is also required for finding the propulsion force. The net propulsion force is shown in table I and force patterns are shown in figure 5 & 6.

Table I Shows net propulsion force

Sl.No	Net propulsion force [Fx (N)]	Net propulsion force [Fy (N)]
1	0	73.33
2	42.89	56.92
3	63.51	18.21
4	54.69	-18.83
5	31.7	-36.46
6	11.66	-38.14
7	0	-36.32
8	-11.66	-38.14
9	-31.7	-36.46
10	-54.69	-18.83
11	-63.51	18.21
12	-43.02	57.09
13	0	73.33

Figure 5 Horizontal force vs mass angle

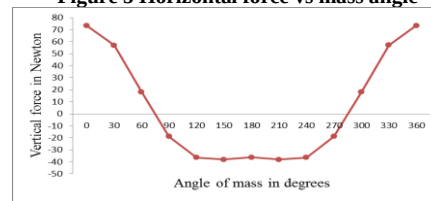
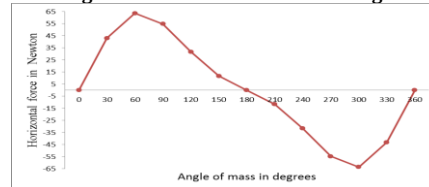


Figure 6 Vertical force vs mass angle



B. Two Mass System

The mass path trajectory of two mass systems uses the same figure 3 & 4 for finding the net propulsion force. In case of two mass systems the second mass position is starting on the seventh point of the first mass system. The table II shows the net propulsion force and force patterns are shown in figure 7 & 8.

Table II Shows net propulsion force

Sl.No	Net propulsion force [Fx (N)]	Net propulsion force [Fy (N)]
1	0	37.01
2	9.24	30.22
3	31.81	-18.25
4	0	-37.66
5	-31.81	-18.25
6	-31.36	18.95
7	0	37.01
8	31.36	18.95
9	31.81	-18.25
10	0	-37.66
11	-31.81	-18.25
12	-31.36	18.95
13	-31.36	18.95

Figure 7 Horizontal force vs mass angle

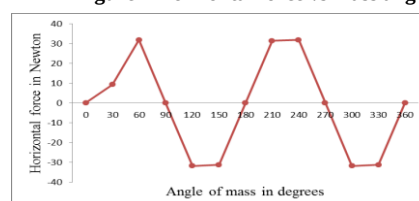
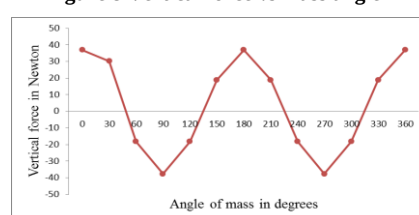


Figure 8 Vertical force vs mass angle



C. Three Mass System

Figure 9 Distance of eccentric mass

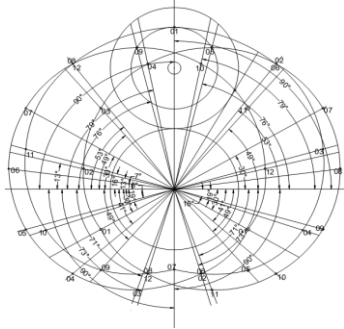


Figure 10 Angular position values

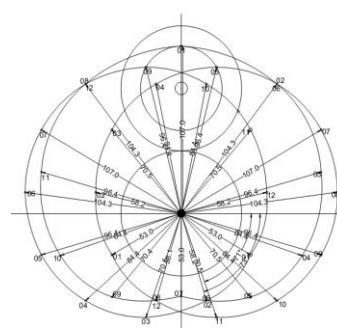


Table III Shows net propulsion force

Sl.No	Net propulsion force [Fx (N)]	Net propulsion force [Fy (N)]
1	0	37.01
2	15.82	27.92
3	16.08	8.99
4	0.01	0
5	-15.83	9.43
6	-16.27	27.66
7	0	37
8	16.27	27.66
9	15.83	9.43
10	-0.01	0
11	-16.08	8.99
12	-15.82	27.92
13	-15.82	27.92

Figure 11 Horizontal force vs mass angle

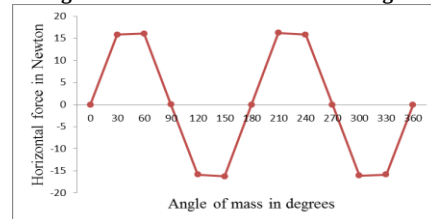
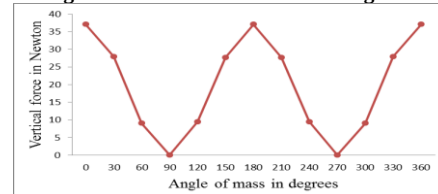


Figure 12 Vertical force vs mass angle



The mass path trajectory of three mass systems is shown in figure 9 & 10. In case of three mass systems the three masses are positioned 120° apart. The table III shows the net propulsion force and force patterns are shown in figure 11 & 12.

D. Four Mass System

Figure 13 Distance of eccentric mass

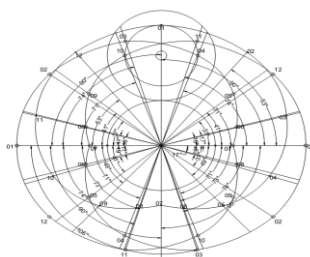


Figure 14 Angular position values

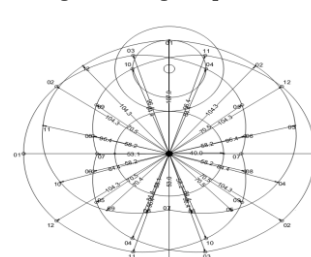


Table IV Shows net propulsion force

Sl.No	Net propulsion force [Fx (N)]	Net propulsion force [Fy (N)]
1	0	37.01
2	31.36	18.95
3	31.81	-18.25
4	0	0
5	-31.81	-18.25
6	-31.36	18.95
7	0	37.01
8	31.36	18.95
9	31.81	-18.25
10	0	0
11	-31.81	-18.25
12	-31.36	18.95
13	0	37.01

Figure 15 Horizontal force vs mass angle

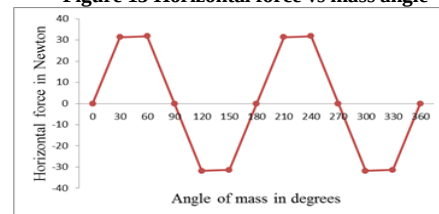
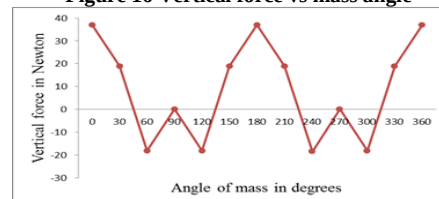


Figure 16 Vertical force vs mass angle



The mass path trajectory of four mass systems is shown in figure 13 and 14. In case of four mass systems the masses are positioned 90° apart. The tables IV show the net propulsion force. The force patterns are shown in figure 15 & 16.

E. Five Mass System

Figure 17 Distance of eccentric mass

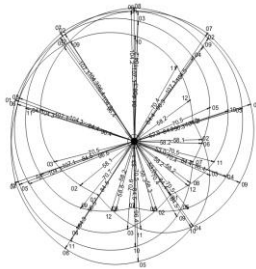


Table V Shows net propulsion force

Sl.No	Net propulsion force [Fx (N)]	Net propulsion force [Fy (N)]
1	-35.02	48.72
2	24.36	54.66
3	59.54	51.4
4	35.06	-48.4
5	-24.12	-54.73
6	-59.42	56.36
7	-35.29	48.41
8	24.25	54.43
9	59.76	6.17
10	35.41	-48.45
11	-24.37	-54.75
12	-59.64	49.79
13	-35.02	48.72

Figure 18 Angular position values

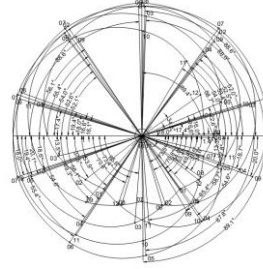


Figure 19 Horizontal force vs mass angle

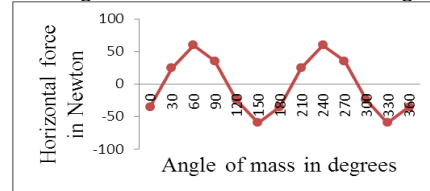
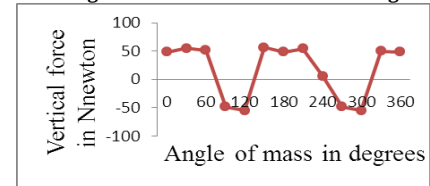


Figure 20 Vertical force vs mass angle



The mass path trajectory of five mass systems is shown in figure 17 & 18. In this case the masses are positioned 72° apart. The tables V show the net propulsion force. The force patterns are shown in figure 19 & 20.

F. Assessment of propulsion force analysis

From the propulsion force analysis the net propulsion force which is obtained in the upward direction is in case of three mass systems. But the radial force which exists is not applicable. So the radial force wants to be cancelled.

G. Radial force cancellation in three mass system

In case of inertial propulsion system the required force is only the vertical force. But the result obtained from the propulsion force calculation there is both horizontal and vertical force. For cancelling the horizontal force and adding up the vertical force, we required the same unit which is placed on the same plane and rotates in the opposite direction [From the result of the propulsion force the positive upward force i.e. vertical force is calculated in three mass system]. So the cancellation of radial force is done on this three mass system.

Calculations of propulsion force based on the rotations; clockwise and anticlockwise is done from the figure 9 & 10. The tables VI & VII show net propulsion force. The force pattern in both directions is also shown in fig 21 & 22. Horizontal forces cancel each other results as the net force in horizontal direction is zero.

Table VI Shows net propulsion force (clockwise)

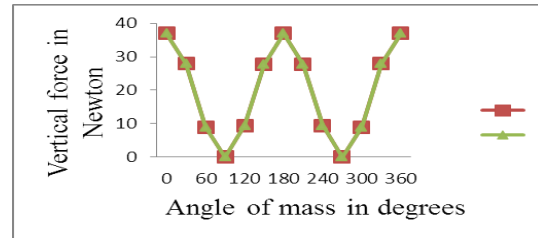
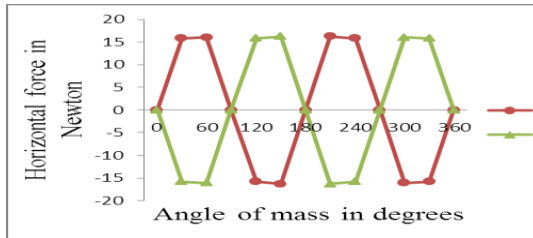
Sl.No	Net propulsion force [Fx (N)]	Net propulsion force [Fy (N)]
1	0	37.01
2	15.82	27.92
3	16.08	8.99
4	0.01	0
5	-15.83	9.43
6	-16.27	27.66
7	0	37
8	16.27	27.66
9	15.83	9.43
10	-0.01	0
11	-16.08	8.99
12	-15.82	27.92
13	-15.82	27.92

Figure 21 Variation of horizontal force vs mass angle

Table VII Shows net propulsion force (counter-clockwise)

Sl.No	Net propulsion force [Fx (N)]	Net propulsion force [Fy (N)]
1	0	37.01
2	-15.82	27.92
3	-16.08	8.99
4	-0.01	0
5	15.83	9.43
6	16.27	27.66
7	0	37
8	-16.27	27.66
9	-15.83	9.43
10	0.01	0
11	16.08	8.99
12	15.82	27.92
13	15.82	27.92

Figure 22 Variation of vertical force vs mass angle



VII. Conclusion

From the result obtained from the calculation of propulsion force of different mass systems, the net propulsion force which is obtained is positive in case of three mass systems. So the configuration of three mass systems is applicable to the design. The force required for the application is only upward force and hence the horizontal force which exists in the system has to be cancelled. So for this purpose another unit is introduced on the same plane and rotates in the opposite direction. The result obtained is that the radial force is cancelled and the upward force is adding twice. From the analysis, a three mass configuration is selected in which two units are placed in a single plane.

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