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Research Article

Reciprocating to rotary motion by electromagnetic and spring forces: an analytical investigation with differential equation

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Abstract

The reciprocating motion of a typical piston is replicated using electromagnetic and spring forces. Electromagnets producing alternating magnetic fields are used to give a reciprocating sliding motion to a permanent magnet, the frequency of the AC current may be varied by modifying the oscillator used. A potentiometer is used to control the magnitude of the AC current, which varies the amplitude and speed of the reciprocating motion. A spring is used for providing an additional amount of force. The oscillatory motion of the piston in turn can be used to drive a crank mechanism and thus produce rotational motion.

Keywords: *Electromagnets, Reciprocating motion, Crank/Rotary mechanism*

1. Introduction

The motion of the piston of a typical 4 stroke IC engine in its power stroke is due to the large pressure exerted over it by the gasses in the combustion chamber. A similar effect may be achieved using electromagnets driven by an AC current.

Two electromagnets are fixed at the two ends of the base. A permanent magnet is allowed to slide along the track present in the base. The track is made almost frictionless using various lubricating techniques. For example oil lubrication, polymer lubrication, etc. A spring is used to exert an additional amount of force on the moving magnet when it is at its extreme positions. (Fig. 1)

The AC supply of the required frequency is obtained using an oscillator. The oscillator is driven by a DC supply produced by three stages-a bridge rectifier , a filter and a voltage regulator. The Alternating Currents supplied to the coils of the electromagnets produce an alternating magnetic field (which lags the current by 90°). The fields of the two electromagnets are 180° out of phase, which ensures that both the electromagnets produce a force in the same direction on the permanent magnet.

The spring is connected to the movable permanent magnet in such a way that it keeps the permanent magnet from attaining very high velocities or colliding with the electromagnets. It also brings the permanent magnet back to its starting position when the power supply is turned off .

The reciprocating permanent magnet is pin-joined to a connecting rod, which in turn drives a crank. This assembly produces a rotational motion of the crank which can be further utilized for various purposes. (Fig.2.)

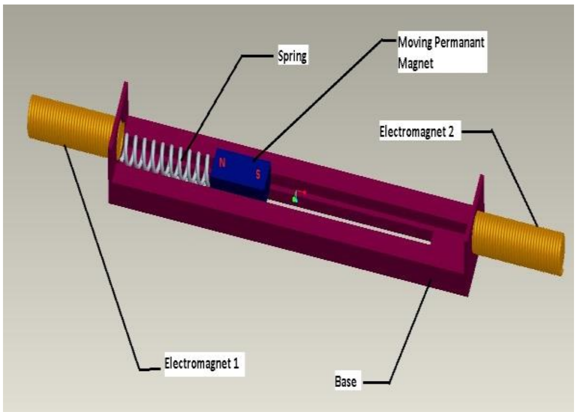

Fig.1. Assembly of the mechanism comprising of two fixed electromagnets and a moving permanent magnet mounted on a base with spring attached as described

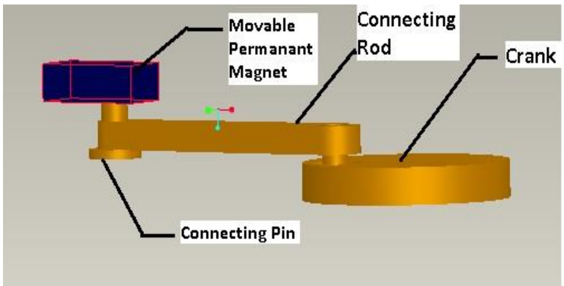

Fig.2. The crank mechanism comprising of a crank driven by a connected rod attached to a permanent magnet

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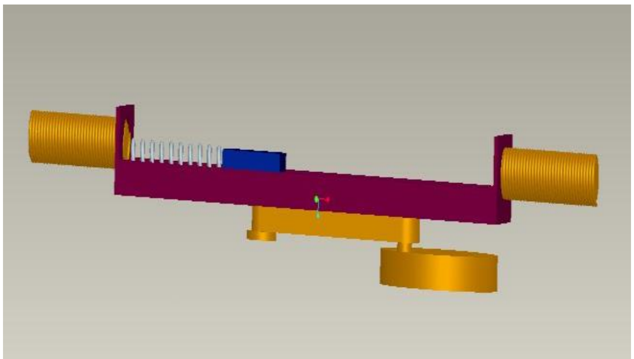

Fig.3. The entire mechanism — comprises of the components of the above two figures connected.

Here the entire mechanism can be used to produce a rotary motion of constant R.P.M (Rotation per minute),but it won't give a constant circular motion as we have derived a circular motion from a reciprocating motion of the permanent magnet which is further fixed to a connecting rod by a connecting pin and then it is connecting to a crank which can rotate in circular motion about its axis (which is at its center perpendicular to its circular plane)(Fig.3), crank can also be light weighted (unlike that used in engines) as no inertia force is required to keep the permanent magnet and hence the connecting rod in motion, the required forces are adequately given by the electromagnets and spring.

The force of gravity is not considered as it is horizontal motion and there is no need of gravity for the permanent magnet to perform the reciprocating motion (Fig.3), which makes our mechanism feasible for use at places where gravity is variable or there is no gravity for example satellites and other space application which in turn increases its scope of application over other mechanisms.

Speed of the permanent magnet can be controlled by controlling the current by using potentiometer, which further increases the scope of application of the mechanism over other mechanism, such properties of the mechanism makes it a versatile mechanism by providing advantages over other mechanism.

The analytical analysis of the mechanism provides us with the result which states that the instantaneous angular speed varies with the rotation in such a way that it exert high torque when the permanent magnet is at extreme position which enables it to handle high loads or provide a motion even in high load conditions further increasing the applications of this mechanism.

Further we can analyze this mechanism by replacing the crank by a gear box and this mechanism can drive it as it gives a rotary motion which has various applications in field of engineering and science

2. Equations of the motion of the permanent magnet

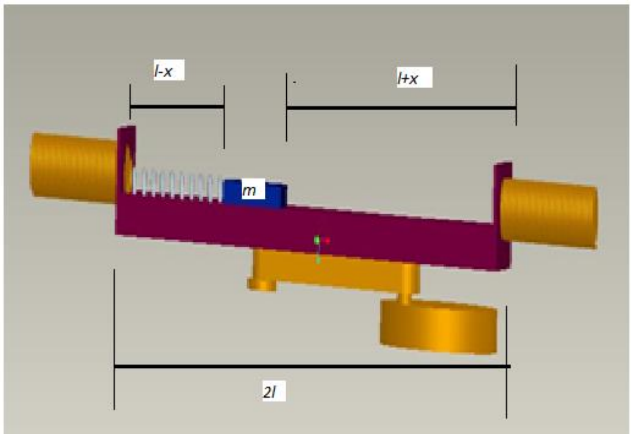

Fig.4. Notations used in the following equations

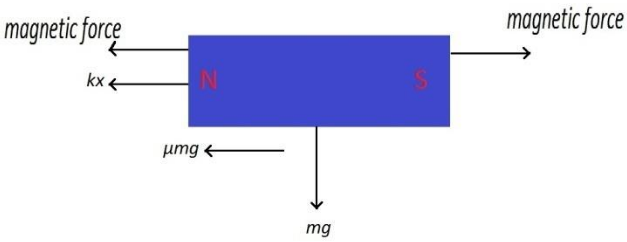

Fig.5. The Free-Body-Diagram of the moving permanent magnet

The spring force in the free body diagram is given by $F = -kx$ (Fig.5.)

By D'Alembert's Principle, the equation of the motion of the moving permanent magnet that we have derived is given by

$$m\frac{d^2x}{dt^2} + kx = J\cos(\omega t)\left(\frac{1}{(l+x)^2} + \frac{1}{(l-x)^2}\right) - \mu mg$$

Where, m is the mass of the permanent magnet,
x denotes displacement
t denotes time
k *is* the spring constant
ω is the angular velocity
μ is the coefficient of friction
l is the distance between the electromagnets and the magnet

$$J = \frac{\mu M_1 M_2}{4\pi}$$

Where, μ is the permeability of air
M_1, M_2 are the magnetic pole strengths of the electromagnets and the permanent magnet

The complementary function of the above differential equation is

$y = C_1 \sin(\omega t) + C_2 \cos(\omega t)$

Where C_1 and C_2 are constants, and $\omega = \sqrt{\frac{k}{m}}$

This equation in turn can be utilized to control the frequency of the reciprocation motion of permanent magnet which can further help us the control the speed of rotator motion and attain a constant R.P.M.

Conclusions and Discussion

When the A.C supply is constant, number of rotation per minute is constant, however, instantaneous angular speed varies during rotation. The torque applied is higher at extreme positions of permanent magnet as this is a reciprocating motion.

Results of analysis

Thus we have analyzed the above mechanism theoretically and the following are its properties and our results are:

1) Gravity is not considered in the above mechanism. It does not rely on gravitational force.
2) The number of rotations per minute of the crank can be kept constant by holding the frequency of the AC supply constant. However, instantaneous angular speed varies during the rotation.
3) Speed can be controlled by controlling the current using a potentiometer.
4) The torques applied on the crank at the positions when the permanent magnet is at extreme potions is higher.

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