

Two Stroke High Efficient Gate Operated Magnetic Engine: Basis for Modeling Approach

Manoj Gattani, Pradeepta K Sahoo, Parag Diwan
College of Engineering Studies
University of Petroleum and Energy Studies
 Dehradun, INDIA
 manoj.gattani@hotmail.com

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Abstract— The present report focuses on the fundamentals of modeling of a permanent magnet based gate operated repulsive magnetic piston engine further referred to as GOPI engine, applicable to electrical and mechanical power generation in large-scale system. In GOPI engine, the motion of the piston is controlled with help of a gate made up of magnetic shield material. The working of the engine depends upon magnetic and mechanical material properties of the gate like thickness of the gate, type of the shield material, distance of the gate from magnets, the pole strength of magnets and mechanism used to operate the gate. In GOPI engine the removal of complete mechanism of fuel burning process of the traditional engine gives a number of advantages like low frictional losses, reduced manufacturing cost, maintenance cost and compactness.

Key Words: Magnetic engine, GOPI engine, gate, shield material, permanent magnets

I. INTRODUCTION

Magnetic engine as alternate energy source can be the new hope for power industry as these engines have many benefits over existing energy sources like possible multi fuel operation, simple design, compact in size and reduced frictional losses due to lesser number of moving parts. The magnetic engine as a prime power generation source can have many other benefits like no damage to environment and human health if it is shielded properly with magnetic shield materials; no generation of waste and no need of extra cost for power storage system. It has also many benefits over existing techniques like its running cost is very less compared to fuel based engines, nearly maintenance free, one time investment for the end users, portable, independent of climatic conditions and eco-friendly device. Generally magnetic engines can be classified into three major categories viz. electromagnetic engine, permanent magnetic engine and hybrid magnetic engine where both permanent magnet and electromagnet are used.

II. THE GOPI ENGINE BASIS

In GOPI engine, only repulsive force of the permanent magnets has been used to produce thrust or power stroke. For this, the gate of the magnetic shield material is introduced between the fixed magnet and the movable magnet. A fixed magnet (m1) and other movable magnet in the form of magnetic piston (m2) are arranged in such a way that m2 is brought again and again near to the m1 (after a fix interval). [1]

The gate remains in closed position except the piston is at its TDC.

In ordinary piston engine, piston is powered by fuel and then it rotates the crank which is attached with it. After one complete cycle the piston is at its initial position. For continuous motion the power to the piston should be supplied at fixed interval. In the GOPI engine the fixed magnet is clamped at the place which is just above the Top Dead Center (TDC) of the piston. The movable magnet is clamped on the piston head. Now when the piston moves up and down in the piston cylinder then the m2 will also move up and down with the piston head. After a fix interval the m2 will come very near to the m1 where it will experience repulsive force from the m1 and will start moving down wards. The m2 should experience the repulsive force only when it approaches the minimum approach distance, a magnetic shield material in form of a gate which fills the gap between the m1 and m2 is used. This gate will open when the piston just starts moving downward from TDC. The reciprocating movement of the piston is converted in to rotation motion with the help of a crank –shaft arrangement. This motion is made continuous by arranging more pistons in rows and columns.

2.1 Driving Force

In conventional engine, the power stroke happens because fuel burn in combustion chamber and the chemical energy of the fuel produce high thrust on the piston head which rotate the attached crank and flywheel. In GOPI engine, the power stroke produces with the help of repulsive force between the fixed magnet and the magnetic piston. Magnetic force remains there for all the time but the intensity of the field is changed with help of the gate.

The piston motion for GOPI engine can be derived from Newton's second law, avoiding complex mechanism of the crank rotation, given by the following equation.

$$\sum F = M_p(d^2X/dt^2) \quad (1)$$

Where $\sum F$ is the net force acting on the piston head in the GOPI engine and it can be given as

$$\sum F = F_m - F_a - F_r - F_n \quad (2)$$

F_m = Magnetic force between the m1 & m2,
 F_a = Magnetic field blocked by the gate,

Fr=Frictional force between the track and piston cylinder,
 Fn=Reduced magnetic strength of the magnet in due course of time
 Mp= moving mass (piston crank assembly),
 x= position of the piston in the time frame.

There may be some more factors on which the net force on piston head depends. Theoretically the above equation for the net force satisfies the working of the engine. Now, detailed discussions of the first two individual components of the Eqn. (2) are described here.

- Fm is the magnetic force between two identical cylindrical solid magnets placed end to end is approximately given by the following Eqn. [2]-[3]

$$F_m = \left[\frac{(B_0^2 A^2 (L^2 + R^2) / \mu \pi L^2) \left(\frac{1}{X^2} + \frac{1}{(X + 2L)^2} + \frac{2}{(X + L)^2} \right) \right] \quad (3)$$

B₀=The magnetic flux intensity very close to each pole,
 A =The area of each pole,
 L =The length of each magnet,
 R =The radius of eac magnet,
 x =The separation between the two magnets.

The Fm depends upon the magnetic properties of the permanent magnet used for the engine development. Before selecting magnets, it is very essential to understand the basic properties and type of the magnets. Several basic magnetic properties like Magnetic field intensity, magnetization and demagnetization are of critical important for the permanent magnets in a permanent magnet engine [4]-[7].

Based upon various properties of the magnetic materials It is reported by Do Hyun Kang and his team that the size and performance of high speed permanent magnet engine depends on the permanent magnet material properties [8]. The engine output, heat rise, weight and cost are a few of the characteristics which are directly influenced the selection of the engine materials. Because of cost and weight are interrelated the magnet must be selected to provide the necessary air gap magnetic field and ample coercive force to compensate for possible damaging effects while minimizing the volume of material . Permanent magnet materials come in many varieties and the four most common types for machine applications are Alnico, Ferrites, SmCo material and NdFeB material [9]-[11].

It is reported by many authors that technological advancement in the rare-earth magnets, SmCo and NdFeB, in recent years, these materials have become more popular for high performance applications because of their greater power density, high coercivity and high flux densities[12]-[19].

- Fa is the blocked magnetic field by the gate and Fag is the amount of force required to pull away the gate from its neutral mode (the gate is in closed position) to produce power stroke when the m₂ (magnetic piston) approaches the TDC.

The Fa, F'a and Fag entirely depends upon the shielding nature of the gate material. The shielding of a magnetic material can be described in the terms of permeability of the material[20]-[21].

The Fag, the magnetic inertia force is required because the gate will virtually attach to the magnets m1 and m2 as presented in the Fig 1. This happen because when the gate is placed in between or near the magnets, the magnetic field lines coming out from the magnets may retain on it, may diverted from it or may passes through it completely or may partially blocked, retained and diverted from the gate depends upon the gate properties. In any of the situations stated above, some external force is required to pull the gate away from the neutral mode and this force is known as Fag, the attaché force between the m1 and gate & m2 and the gate.

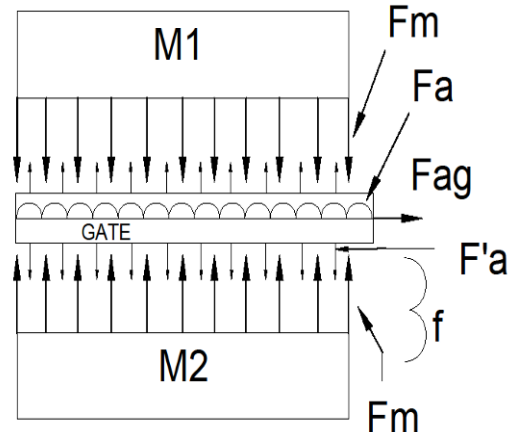


Figure 1: The Gate and the magnetic forces

The magnetic field near the gate can be understood by taking an example of a light beam passing through a material sheet where a part of light transmitted through the sheet, a part is reflected and a part of the light is absorbed by the sheet as shown in the Fig 2. The values of light which is passes through the sheet or reflected or absorbed by the sheet can be presented in their coefficient values as coefficient of absorption(a), coefficient of reflection(r) and coefficient of transmission(t). Mathematically,

$$a + r + t = 1 \quad (4)$$

To understand the working mechanism of the gate, the magnetic field very close to the gate can be treated in same manner as that of light beam near the material sheet and the gate itself as material sheet.

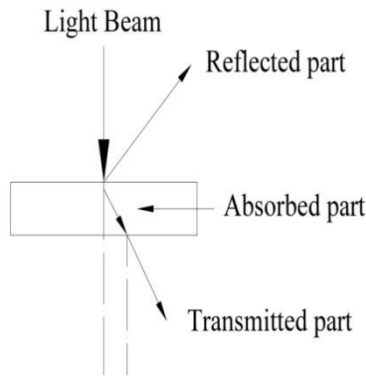


Figure 2: Light beam passes through a material sheet

The magnetic field lines may be blocked or retained (absorbed) by the gate, or may pass (transmitted) through the gate or may get diverted (reflected) by the gate depending upon the magnetic properties of the material as shown in the Fig 3. The total value of the magnetic field near the gate can be given by the Eqn. (5)

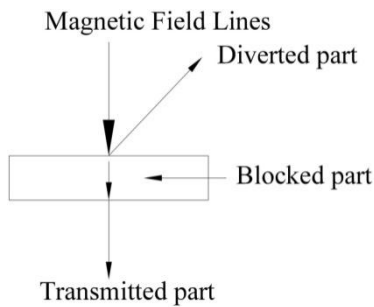


Figure 3: Magnetic field lines passes through a shield material

$$b + d + p = 1 \tag{5}$$

b=coefficient of blocked (retaining) magnetic field by gate

d=coefficient of diverted magnetic field from the gate

p=coefficient of passing (transmitting) of magnetic field through the gate

- Fr is the frictional force between the engine track and the magnetic piston. The magnetic piston moves on the track in a non-packed situation, though there are frictional forces between all contacts. Many other losses are also associates with magnetic engines like eddy current losses, thermal stress losses demagnetization losses [22]-[25], but for modeling of permanent magnet GOPI engine, these losses are not considered at the first stage
- Fn is the value of magnetic strength which reduces in due course of time. Generally it is found that a magnet in stationery condition does not lose its magnetic strength in time but there is no experimental relation available between the magnetic strength reductions with continuous movement in time.

2.2 Operating conditions

To produce power stroke, it is most important that the gate should be in active mode and the gate cycle should be synchronized with the piston movement. For synchronization, the design of the gate plays a very important role. The design of the gate affects the power in the stroke. Mathematically it can be presented as

$$F_m = F_a + F'a \tag{6}$$

F_m= magnetic force between the fixed magnet (m₁) and the magnetic piston (m₂) (when there is no gate between the m₁ & m₂ or magnetic field lines are passing through the gate completely)

F_a= magnetic field blocked by the gate

F'a=Magnetic field not blocked by the gate

Now, the F_a can be expressed as

$$F_a = a * F_m \tag{7}$$

Here, a= gate factor. Its value lies between 0 and 1. i.e. 0≤a≤1. The gate factor is a variable that indicates how efficiently the gate is performing i.e. how much magnetic field is diverted or blocked or passing through the gate.

The gate factor depends upon many parameters of the gate like type of gate material, thickness of material, distance of gate from the m₁ and m₂, magnetic pole strength of the m₁ and m₂. When the magnetic field is blocked or diverted completely by the gate, the value of the gate factor is 1 and when there is no gate in between the magnets or the magnetic field lines is passing through the gate completely as in the case when the permeability of the gate is one, the value of gate factor will be zero. In other situations its value remains between 0 and 1. When the engine is performing efficiently, the value of gate factor will be equal to one. This time the magnetic field is either diverted or blocked completely by the gate. The value of p coefficient in Eqn. (5) will become zero and the values of b and d coefficients combined together will be one. Mathematically;

When a=1; p=0 and b+d=1; here, 0≤b≤1 and 0≤d≤1

Further if b=1, the gate is blocking the magnetic field lines completely. The engine will work less efficiently as the value of F_{ag} will be more in this situation and hence more input power is required to operate the gate. When d=1, the gate is diverting magnetic field lines completely. The engine will work with highest efficiency as the F_{ag} will be equal to zero and the power required to operate the gate is minimum.

When the gate is performing with least efficiency or not working at all, the value of gate factor will be equal to or near to zero. This time the magnetic field passes through the gate completely. The value of d coefficient will be equal to zero and value of b and p coefficient combined will be equal to one. Mathematically

When a=0; d=0 and b+p=1; here, 0≤b<1 and 0<p≤1

it is to be noted that when a=0, the value of b_{max} will be less than one(b<1) and p_{min} will be greater than zero (0<p), further if the value of b approaches to 1, the gate will block maximum of the magnetic field lines but even the magnetic piston may stick to somewhere in its upward motion as some magnetic field lines will passes through the gate all the time

and the nonzero value of counter force $f (f \neq 0)$ will produce hindrance in the piston movement in upward direction. The gate cycle cannot be matched with the piston movement and the engine will stop working after few cycles.

The reason behind it is that as F_m is not equal to zero, the magnetic piston cannot approaches to TDC because the repulsive force between m_1 and m_2 will produce hindrance in the piston movement.

Let this repulsive force between the m_1 and m_2 be known as counter force and represented by f , then the counter force can be given by

$$f = F_m - F_a \tag{8}$$

$$f = F_m - a * F_m \tag{8a}$$

$$f = (1 - a) * F_m \tag{9}$$

Two conditions under which the engine may works are described here

When there is no gate in between the magnets m_1 and m_2 (or magnetic field lines passes through the gate completely), then

$$f = (1 - a) * F_m$$

$$f = F_m \text{ as } a = 0$$

$$f = F_m \tag{10}$$

This means, the counter force between the magnets m_1 and m_2 will be maximum and equal to F_m . In this condition, the magnetic piston will stick to somewhere in its way and the attached crank will not complete its cycle.

So for complete rotation of the crank the counter force f should be less than the magnetic force produced by the magnets of the engine at every point of the motion otherwise the engine will not work at all.

When gate block the field completely or divert the same completely i.e. $a=1$, then

$$f = (1 - a) * F_m$$

$$f = (F_m - F_m) \text{ as } a = 1;$$

$$f = 0 \tag{11}$$

This means, there will be no repulsive force or counter force between m_1 & m_2 when the magnetic piston is moving towards TDC. The piston will move upwards without any restriction and in this condition the speed of the piston will not be affected.

The efficiency of the engine depends upon the value of b and d coefficients. The efficiency of the engine may be very less if $b=1$ i.e. the gate will attach with the magnets and when $d=1$, engine will work with highest efficiency as all magnetic field lines are diverted from the gate and the value of F_{ag} will be minimum, the power required to operate the gate will be less. Theoretical relation between the coefficients of the engine are presented in the table 1

Table 1: Theoretical relation between the GOPI engine coefficients

Sr. No.	b	p	A	F _{ag}	η
1	0.0	1	=0	~ 0	=0
2	0.25	0.75	1 >> a > 0	> 0	η ~ 0 but η > 0
3	0.5	0.5	1 > a > 0	>> 0	1 >>> η > 0

4	0.75	0.25	1 > a >> 0	>>> 0	1 >> η > 0
5	1.0	0.0	a = 1	F _{ag} = max	1 >> η >> 0

In the table 1, relation between the gate coefficients, gate factor, magnetic inertia force and efficiency are presented. As it is mentioned in the Eqn. (6) and Eqn.(9) as the permeability of the gate is 1, the engine will not work and the coefficient p will have value equal to 1. But as the permeability of the gate increases, the value of b coefficient will increase and p coefficient will decrease and at the same time the value of gate factor will increase.

III. THE INPUT POWER

To produce power stroke, it is most important that the gate should be in active mode and the gate cycle should be synchronized with the piston movement. For synchronization, the design of the gate plays a very important role. If the design of the gate is not done properly, the engine may not work. Power required to operate the gate can be supplied from some storage means of energy like battery or flywheel. For smooth working of the GOPI engine, power is required to operate the signal system to control the frequency of the engine and to operate the gate mechanism (signal system of the GOPI engine is not described in the present paper). The total power required to operate the GOPI engine is represented as P_i and is given by

$$P_i = P_{gt} + P_s \tag{12}$$

P_{gt} = power required to operate the gate from its virtual attachment with m_1 & m_2 (P_a) + power required to operate the gate from its rest i.e. neutral state (P_{mi})

$$P_{gt} = P_{ag} + P_{mi} \tag{13}$$

P_{ag} is the power required to operate the gate against magnetic inertia and

P_{mi} is the power required to operate the gate against mechanical inertia

P_s is the power required to operate the signal system of the Gopi engine

IV. ENGINE EFFICIENCIES

As described, efficiency of the GOPI engine depends upon many parameters like selection of permanent magnets for magnetic piston and fixed magnet, shield material for gate, operating mechanism of the gate, distance of the gate from the m_1 and m_2 . For this research paper, a theoretical conclusion is drawn for the engine efficiency.

As the F_a , the magnetic field blocked, is a part of the net force on the piston head, the efficiency of the engine depends upon F_a which further depends upon the gate factor and the gate coefficients (b, d, p). So the working as well as the efficiency of the engine depends upon the basic properties of the permanent magnets and the shield material to be selected for the engine development. The gate coefficients depend upon magnetic flux density (B), distance between m_1 & gate (x_1) and m_2 & gate (x_2), permeability of the gate material (μ) thickness of

the gate (t). Mathematically, b, d and p depends upon these parameters as

$$b, d, p = f(B, \mu, t, x_1, x_2) \quad (14)$$

Now the dependency of the gate factor (a) on b, d, p can be explained as

$$a = k_1 * (b m_1) * (d m_2) * (p m_3) \quad (15)$$

And the magnetic inertia force, F_{ag} as

$$F_{ag} = k_2 * f(a, b, d, p, m) \quad (16)$$

Here, it is to be noted that when $a=0$; $F_{ag} \neq 0$ as some external force is required to pull out the gate from its neutral position. The mass of the gate (gate mechanical inertia) is presented as m in the Eqn. (16). The power stroke of the engine not only depends upon the engine parameters like gate factor, gate coefficients, net force available at piston head but also on the gate geometry and the gate velocity with which the gate operates. Power in the stroke (P_s) can be explained by the Eqn. (17) as

$$P_s = k_3 * f(B, \mu, x_1, x_2, t, v, g_e) \quad (17)$$

Here, g_e is the geometry of the gate and v is velocity with which the gate opens. The value of the constants k_1 , k_2 , k_3 , m_1 , m_2 , m_3 used in the Eqn. can be find out by conducting experiments on the GOPI engine.

It can be concluded from the table1 that the efficiency of the engine is maximum when the gate coefficient d is equal to 1. Its maximum value and the b and p coefficients equal to zero. The F_{ag} is zero as virtual attachment between the magnets and the gate does not exist and the required input power to operate the gate is minimize. But it is also to be noted that when the gate factor is one for different values of the b and d coefficients, the efficiency and the F_a and F_{ag} varies accordingly.

V. OBSERVATION

A. Relation between input and output of the engine

In IC engines (diesel and petrol engine), chemical energy (fuel) is changed into mechanical energy to run the output shaft. In these engines output is dependent on the input and we have to supply fuel as input to get the output. In magnetic engine, magnetic force is used to move the output shaft. In the magnetic engine, output is independent of the input as only gates and control units of the engine require input for their operation. The magnetic force is available all the time and depends only on magnetic pole strength but intensity of it at a place is changed using gate movement.

B. Magnetic engine can be a combination of engine and generator

This means, at the same time we can get mechanical and electrical output. In this design configuration, an electrical coil is wrapped round the magnetic piston cylinder. When the magnetic piston moves through the electrical coil, an electrical current will be produced. And at the same time the moving crank and flywheel will produce mechanical power at its shaft. So when we require mechanical output, we can use it as an engine or when we require electricity as output, we can use it as a generator or it can be used to produce both forms of power simultaneously.

C. Efficiency of the engine

The working efficiency of the GOPI engine depends upon many parameters like operating speed of the gate, frequency of the gate cycle, field blocked by the gate, operating mechanism of the gate, working efficiency of the signal system of the control units, material used for gate fabrication and virtually attachment of gate with m_1 & m_2 . The input power is used to run and operate gates and control systems only. Since gates are less massive and are operating in small distance so the requirement of input power is not too much. The output power of the engine is collected at the end of the shaft.

D. Low cost of the engine

In GOPI engine power stroke can be attained at every 900 with four piston systems but in other engines of similar category power stroke at 900 can be attained only with more than 6/8 piston systems. So fewer pistons are required in GOPI engine to produce same power that is produced in the RAT or Slipper based engines. At the same time solenoid cylinder can be used to increase the magnetic strength of the fixed magnet and this can produce more repulsive force between the magnets and this further can produce more torque in the power stroke.

E. Simplicity

The simplicity of the magnetic engine compared to conventional technology is one of the driving forces behind many of the recent developments. The elimination of complete mechanism of fuel burning process of the traditional engine reduces the number of parts and the complexity of the G engine significantly and this potentially gives a number of advantages like low frictional losses, reduced manufacturing and maintenance cost and compactness.

VI. CONCLUSION

It is important need of the today's era to replace oil engines or to find its substitute not because of the oil shortage but also based on environmental concerns. The engine can play a major role in the power industries and transportation sector as its running cost is very less as compared to other fuel based engines and requires no storage systems. The engine is environment friendly since it does not produce any hazardous pollutants.

Although several reports have confirmed that the magnetic engine is a viable concept, more research is required to investigate potential advantages over conventional technology. The area with most uncertainty is clearly that of piston motion control. In GOPI engine the motion of the piston is controlled with help of gate which further depends upon many parameters like thickness and type of shield material, distance of gate from magnets and mechanism used to operate the gate. A detailed study is required to investigate experimental relation between these parameters.

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Mr. Manoj Gattani had completed his engineering and master degree from Jodhpur University (India). Currently he is working as Assistant Prof at University of Petroleum and Energy Studies, India. He is working on magnetic engines for power generation from last 4 years. He has five Indian patents (pending) and won several awards like young scientist award 2011, best technology of the year, 2011 etc. He is pursuing his Ph D in magnetic engine modeling and simulation from University of Petroleum and Energy Studies, Dehradun, India