It is an important need of the today's era to replace oil engines or to find their substitute, simply not because of the oil shortage, but also for environmental constraints. Development of the GOPI engine is a trial in this field. The engine can play major role in the power industries and transportation sector because of its unique features compared to other fuel based engines and requires no storage systems. The engine is environment friendly device as it produces no hazardous pollutants. The design and fabrication uniqueness, the operating methodology supports for more experimental investigations.

5.1 Significant Outcome of the Study

Some important conclusions of the GOPI engine based on the present research are explained here:

a) Engine Modeling- The Geometry

The uniqueness of the GOPI engine is power stroke as it does not require any fuel or any external source for power generation (except the battery which is required for operating the gate and sensors). The magnetic force associated with permanent magnets is used to produce power stroke. As the permanent magnet cannot be turned off, magnetic shield material is used to change the intensity of the permanent magnets used as fixed magnet and magnetic piston.

Magnetic shield material in the form of gate is used to operate the GOPI engine. It's observed that the thickness of the gate, material properties of the gate and geometry of the gate affect its workability (table 4.5).

High permeable material with hydrogen annealed is used for the gate modeling. Mu metal with 30,000 permeable value is used with thickness of 2mm. It is also observed during the dynamic analysis that the geometry of the gate plays an important role in the GOPI engine working. The magnetic field between the m_1 and $m_2$is mainly concentrated at center and about 70% of the magnetic field occur in the 30 % area of the circular magnet (fig 4.1, fig 4.2 and table 4.1, table 4.14). More magnetic thrust can be achieved in the power stroke when multi panel gate is used instead of single panel.

The operating speed of the gate and the piston movement is synchronized in such a way that the time taken to cover the distance by the gate in X direction should be equal to the time taken by the piston to cover the distance in Y direction. If single panel gate is used, the center of the m_1 will become uncovered when the m_2 moves away almost half of the stroke length and in this condition, a powerful stroke cannot be achieved at the piston head as strong repulsive magnetic field occurs only for a short distance between the magnets (table 4.9, table 4.13).

So a multi-paneled gate is desired for the GOPI engine to produce strong stroke. A two-panel gate is modeled for experimental analysis for the GOPI engine. The two panel gate performs better than the single panel gate as the center of the m_1 and m_2 will be uncovered instantly but in form of rectangle stripe. For maximum repulsion between the m_1 and m_2, the uncovered area must be in circular shape as the magnetic flux density in a permanent magnet decreases radially outward from center. To overcome this drawback of the single and two paneled gate, a four panel gate is suggested for designing of the GOPI engine. The four panel gate is more efficient as the center of the m_1 and $m_2$will be uncovered uniformly which can produce strong stroke.

Rare earth permanent magnets are chosen for magnetic piston and fixed magnet modeling. NdFeB magnets of N 42 series having Br equal to 1.2 T are selected. The geometry of both the magnets is chosen as circular solid cylinder having diameter equal to 60mm and thickness of 10 mm (table4.12). The dimension and geometry of both the magnets should be chosen same as otherwise the powerful magnet will disturb the magnetic field alignment of the weaker magnet.

As the complex fuel burning mechanism is eliminated in the GOPI engine, the piston can move unpacked in the piston cylinder as shown in the fig 3.1. This design not only reduced frictional losses but also reduces piston mass. The grooves in the cylinder provide better cooling against thermal expansion.

b) Mathematical Modeling

Mathematical modeling developed for the GOPI engine can be the bench marking for permanent magnetic engines series for simulation and experimental investigations. The working and non-working of the GOPI engine is provided in details for various different conditions in the section on mathematical modeling of the chapter 3.

During the simulation and experimental investigation of the GOPI engine, it is observed that high permeable gate can block the magnetic field properly when the magnets are shielded from both sides. One of the objectives of the mathematical modeling of the GOPI engine is to find out force at piston head, the force required to pull and push the gate, the magnetic thrust in the power stroke and overall efficiency of the engine. Hence to produce strong stroke, the gate should perfectly insulate the magnetic field and should be opened in fraction of time when the piston is at TDC, so the center area of the magnets during the power stroke should be uncovered immediately.

c) Development of Engine

It is observed that the working of the GOPI engine not only depends upon the magnetic field intensity of the $m_1$and m_2 but also strongly depends upon the gate geometry and operating mechanism. The thickness, geometry and permeability of the gate material affect the engine efficiency and also the working of the engine It is observed in the dynamic analysis that high permeable gate can block the magnetic field properly but at the same time it attaches with the magnets strongly and to pull the gate from its neutral position, a huge force is required which affects the efficiency and working of the engine (fig 4.18 & fig 4.19, table 4.13).

It is observed during the study that when the gate is placed near the permanent magnet, the flux induced towards the gate and the magnetic circuit completes. If the gate is placed a long away from the magnet, losses in the magnetic circuit increases as more flux will be induced into the surrounding air (table 4.15).

The shielding properties of the gate depend upon its thickness and the geometry. The more is the thickness, more will be the shielding and if the gate is used multi panel, the power in the stroke will be more. The value of input power which is required to operate the gate increases as the magnetic flux passes through the gate increase but the condition when the flux passes through the gate completely, the engine will not work.

The simulated and experimental outcomes are summarized in the table 5.1 for three key parameters like magnetic force at piston head, magnetic field blocked by the gate, and the magnetic counter force.

Table 5.1: Major parameters of GOPI engine

Parameter	Simulation values	Experiment values	Remarks
Magnetic force at piston head (air medium)	1.02 T (table 4.1)	1.05 T (Gauss meter)	magnetic flux losses at edges
Magnetic field blocked by the gate	0.18 to 0.44 T (field block$_{avg}$= 29%) (Table 4.5)	0.23 to 0.49 T (fieldblock$_{avg}$= 31%) (heading 4.7)	When permeability of the gate material is less, the field blocked by the gate will also be less. Engine will work with least efficiency
Magnetic counter force	Decreased by 9.2% (Fig 4.4 Table 4.2 &table 4.14)	Decreased by 4.3% (maximum approach distance increased by 5-6 mm wrt to total stroke length of 139.7mm)	If the gate blocks the magnetic field properly, the magnetic counter force will be decreased. This large gap between the simulation and experimental values is because of the fact the gate is operated manually.

Some unique features of the GOPI engine are listed below

- GOPI engine is a viable concept as it eliminates complete complex fuel burning mechanism of the IC engines.
- The working of GOPI engine entirely depends upon the gate coefficients.
- High permeable material for shielding purpose (gate development) is the best choice but the stronge attachment with m_1 and m_2 decreases the engine efficiency.
- Less permeable material is not suited to block the magnetic field and hence the engine may not work if the gate is fabricated with it.
- The design of the piston cylinder helps to reduce frictional losses and provides better cooling against thermal expansion.

- Four-panel gate is more efficient than single panel gate to produce strong power stroke.

5.2 Suggestion for Future Work

Yet, for GOPI engine, the thrust required to run vehicles is not achieved because perfect magnetic shield between the two magnets is not properly achieved and the efficiency of the engine depends mainly on the magnetic field shielded by the gate.

- It is observed that the virtual attachment of the gate with m_1 and m_2 affects the synchronization of the engine and hence the efficiency of the engine. To make the GOPI engine or any magnetic engine in the series of permanent magnet a viable option for power generation, synthesis of new material based on the gate coefficient (b+d+p=1) is required in such a way that the d=1 and b=0 and p=0.
- Operating mechanism of the gate is an important design parameter of the GOPI engine as maximum flux density of m_1 and m_2 concentrated at very small area of the magnets. So to produce a strong stroke the center of the m_1 and m_2 should be uncovered from the gate in very short of time otherwise a powerful stroke cannot be generated.
- Experimental investigation of the engine efficiencies, working mechanism, input and output power, working conditions are desirous for further development of the engine. Establishment of relation between the engine parameters is highly focused area for future study of the GOPI engine.