A Mathematical Analysis of an Internal Magnetic Piston Engine

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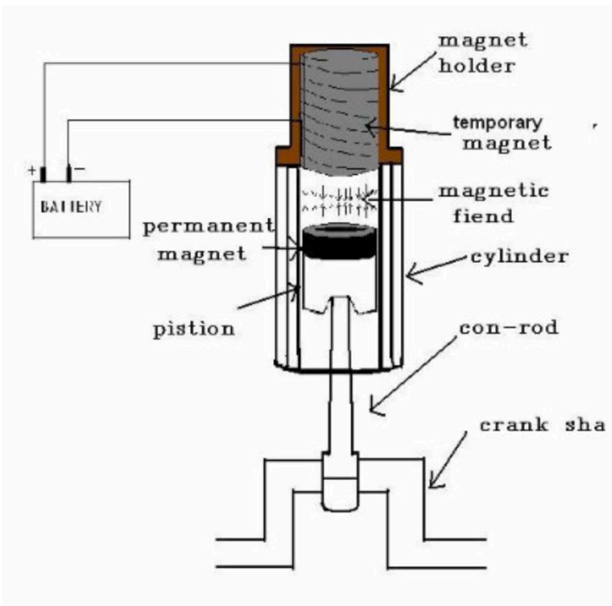
Electric cars are the future. At least that is what people say. But is it the best solution to replace ICE cars? Despite the zero-tailpipe emissions from electric cars, the production of electricity for these cars is a major contributor to pollution and global warming. According to Our World In Data, roughly 30% of the electricity is from renewable sources. The rest of the electricity is generated from fossil fuels, therefore still damaging our environment. Another environmental concern is the lithium-ion batteries of EV's, as mining the materials for the batteries produces toxic fumes and is also more energy and water intensive compared to producing ICE's. There are also other drawbacks to purchasing EVs for consumers, such as long charging times, lower range, and for some enthusiasts, it is less fun to drive an EV.

So if ICEs and EVs are not the future, then what is? Magnetic Piston Engine (MPE) ideas have been designed in theory, to power cars with electromagnetic induction. But so far no engine has been made that functions effectively with such methods. In this essay I am about to briefly analyse the potential of a magnetic 2 stroke piston engine designed by undergraduates from the University of Pune.

The proposed design is -



Since this design uses electromagnets that require electricity, the key question is whether this engine can work more efficiently than electric motors in EVs.
The aim is to produce around 200Nm of torque, which is suitable for a light to a mid-sized passenger vehicle. From here we work backwards to get to the electric requirements from the battery. Such cars usually have a 4 cylinder engine, so the torque required per piston is 50Nm.

The maximum turning effect produced by the piston is when it is at an angle of 90° to the crankpin. We use the formula Moment = Force x perpendicular distance.

We rearrange the formula to $F = \frac{T}{L}$

$F = \frac{50}{0.04} = 1250N$

Where F is the force from the piston. T is the torque produced on the crankshaft. L is the crank radius.

If it were a perfect world, the force from the magnet and electromagnet would be fully converted to the force exerted by the piston. But in reality, we need to account for friction, drag, and load.

$F_{piston} = F_{magnet} - F_{drag} - F_{friction} - F_{load}$

To calculate the force from the magnet we combine Maxwell's magnetic pressure equation with Ampere's law.

$F = P \times A$

Maxwell's magnetic pressure equation -

$P = \frac{B^2}{2\mu_0}$

Where B is the magnetic flux density, and μ_0 is the permeability of free space which is how a magnetic field behaves in vacuum.

Ampere's law for solenoids -

$B \approx \frac{\mu_0 Ni}{s}$

Where N is the number of turns in the coil. i is the current. s is the air gap in the piston cylinder.

So substituting B into Maxwell's equation, and then multiplying by Area to get the force finally leads to -

$$F_{magnet} = \frac{\mu_0 N^2 A i^2}{2s^2}$$

$\mu_0 = 4\pi \times 10^{-7}\, m\, kg\, s^{-2} A^{-2}$

$N = 1000$

$A = \pi r^2$ where $r = 0.0175m^2$, substituting which gives $A = 9.62 \times 10^{-4} m^2$
$s = 0.005m$

Substituting these values and rearranging in terms of i gives

$$F_{magnet} = 24.2i^2$$

To calculate friction we use the equation -
$F = \mu N$
Where μ is the coefficient of friction and N is the normal reaction force between the piston and the cylinder.
A rough estimate of friction in the piston is about 200N.

The equation for Drag is given by -
$F_{drag} = \frac{1}{2}\rho C_d A v^2$
Where ρ is the density of air, C_d is the coefficient of drag, A is the cross-sectional area, v is the velocity of the piston.
Rough approximations of the values based on various online sources give -
$\rho = 1.225 kg\, m^{-3},\ C_d = 1.2,\ A = 9.62 \times 10^{-4} m^2,\ v = 30\, m\, s^{-1}$
Substituting these values into the equation for drag force leads to
$F_{drag} = 0.63N$

The value of drag force is almost negligible in such an engine, because unlike an internal Combustion Engine there is no mixture of compressed fuel and air which would create much larger resistive forces on a piston.

For the Force of the load on the crankshaft -

$F_{load} = \frac{T_{load}}{r sin\theta}$

Where T_{load} is the torque on the crankshaft from the load. A common misconception is that it is the same as the torque of the crankshaft. But instead this is the resistive torque, so the crankshaft and pistons have to do work against this torque to produce the engine torque.
r is the crank radius and θ is the crank angle (although as we are considering the angle to be 90°, $sin\theta = 1$

An approximation for $T_{load} = 350Nm$
Substituting this value and the crank radius into the equation results in -

$F_{load} = 20000N$

Finally combining all of these equations leads to -

$$F_{piston} = \frac{\mu_0 N^2 A i^2}{2s^2} - \frac{1}{2}\rho C_d A v^2 - \mu N - \frac{T_{load}}{r\sin\theta}$$

Inserting all the results from the previous equations leads to a required current of 29.8A

A typical battery in an EV supplies a power of 100kW, with a voltage of 800V and a current of 125A. Since the calculations suggest a lower required current for an internal magnetic piston engine compared to an electric motor EV, it leads to several potential advantages such as reduced thermal energy being produced which makes the car more electrically efficient as well as a reduced demand from the thermal management system. Therefore with further research and development, internal magnetic piston engines have the potential to be the method of powering cars in the future instead of traditional electric motors.

Bibliography

https://www.carwow.co.uk/guides/choosing/disadvantages-of-electric-cars#gref

https://ourworldindata.org/data-insights/renewable-electricity-2023?utm_source=chatgpt.com

https://earth.org/environmental-impact-of-battery-production/

https://www.academia.edu/67052090/Magnetic_Piston_Operated_Engine

https://www.sciencedirect.com/topics/engineering/engine-torque?utm_source=chatgpt.com

https://www.researchgate.net/publication/292139328_Kinematics_and_Load_Formulation_of_Engine_Crank_Mechanism

https://www.sciencedirect.com/topics/engineering/engine-torque?

https://www.supermagnete.de/eng/faq/How-do-you-calculate-the-magnetic-flux-density

https://pdf.sciencedirectassets.com