SOLENOID ENGINE

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***ABSTACT*: Electric Vehicle are becoming increasingly attractive alternative to the car with combustion engine, considering the effect on the environment as well as economic factors such as gradual increasing price of fluid fossil fuels, maintenance and others. Due to the fact that these vehicles are widely known for their zero emission and powered by renewable energy sources. The idea of the project is to take another alternative design of EV prime mover to replace existing electric motor. In general, EV are driven and controlled by the integration of electrical, electronics and also mechanical components but the main component that actually moves these vehicles is the electric motor. Electric motor works on principles of the electromagnetic induction by converting electrical energy to kinetic energy. This energy conversion is the main purpose of an electric motor and this actuator are highly popularised in most EV's designs. So a solenoid will be used to replace the electric motor as a prime mover. For this a prototype of a solenoid is designed, built, and tested. The solenoid will be used as kicking device. As earlier studies have investigated a solenoid as shooting mechanism. In one study the solenoid is investigated as most suitable kicking device. The other study designed and optimized a solenoid. In this study a prototype solenoid is designed and tested.**

***Keywords*:- EV- Electric vehicle, Kicking device**

I INTRODUCTION

A solenoid is a type of electromagnet when the purpose is to generate a controlled magnetic field. If the purpose of the solenoid is instead to impede changes in the electric current, a solenoid can be more specifically classified as an inductor rather than an electromagnet. In engineering, the term may also refer to a variety of transducer devices that convert energy into linear motion. The term is also often used to refer to a solenoid valve, which is an integrated device containing an electromechanical solenoid which actuates either a pneumatic or hydraulic valve, or a solenoid switch, which is a specific type of relay that internally uses an electromechanical solenoid to operate an electrical switch; for example, an automobile starter solenoid, or a linear solenoid, which is an electromechanical solenoid. Solenoid bolts, a type of electronic-mechanical locking mechanism, also exist. Solenoid is the generic term for a coil of wire used as an electromagnet. It also refers to any device that converts electrical energy to mechanical energy using a solenoid. The device creates a magnetic field from electric current and uses the magnetic field to create linear motion. Common application of solenoids is to power a switch, like the starter in an automobile, or a valve, such as in a sprinkler system.

A solenoid consists of a coil and a moving metal rod, also known as armature or plunger. The operation of solenoids is based on conversion electrical energy into mechanical energy, and therefore solenoids are being considered as electromechanically actuators. Normally, the coil is a copper wire wound a tiny pitch and placed in a metal (iron-based material) case, also known as a C-frame. The C-frame is a supporting structure that also contributes to the magnetic field produced by the coil. Applying an electric current to a solenoid coil generates a magnetic field or flux with intensity proportional to the current. The magnetic field pulls the plunger in. The reason for the plunger attraction is a ferromagnetic material with high magnetic permeability, whereas air which has very low magnetic permeability. Pulling the plunger inside closes the air gap and intensifies the field concentration inside the solenoid.

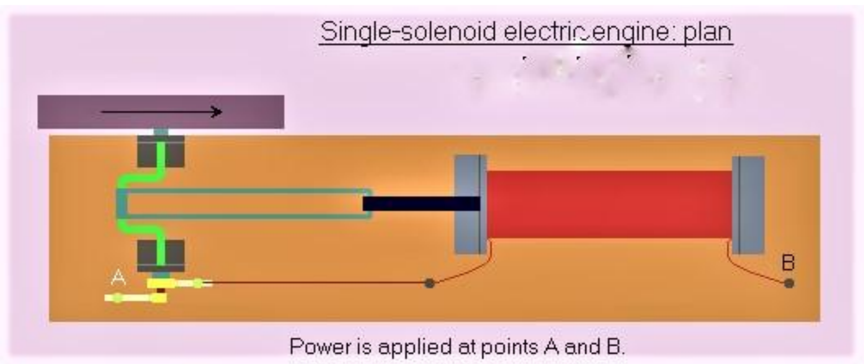


Fig 1 Schematic diagram of solenoid engine

The plunger (armature) of the solenoid can only be attracted by the magnetic field, hence the solenoid can only generate force in one direction. Normally when the solenoid is in the rest the plunger is kept far from the coil using a spring. However, solenoid has been used as servo actuator in engine mount application. Arzanpour and Golnaraghi have replaced the plunger of a solenoid with a permanent magnet and retrofitted it inside an active engine bushing. It enables them to both attract and repel the actuator and create sinusoidal motion with it. Also Mansour et. al have replaced the spring of a solenoid with a stronger one and gave the solenoid a bias current to use it a as a servo actuator.

II PRINCIPLE OF WORKING

An engine powering device with magnetic components that aid in the operation of piston propelled engines by attaching the device individually to the pistons, causing the pistons to perform the up and down thrusts Without the use of fuel thereby mobilizing the engine, eliminating the necessity of fuel and preventing pollution exhausting into the atmosphere.

This engine has magnetic shielding safety components to protect people and other electronic devices from strong rare earth magnets and electromagnets. A straight current carrying conductor produces a circular magnetic field around itself at all points along its length and that the direction of rotation of this magnetic field depends upon the direction of current flow through the conductor, the Left Hand Rule. The force that sets up the magnetic field depends on the number of turns on the coil and the magnitude of the current flowing. This force is called the Magneto Motive Force and the unit of measurement is the Ampere-turn. This equals the current times the number of turns. (MMF = I x n). The material that the magnetic field is being built up in, in this case air, has a resistance to being magnetized. This resistance to the flux build up is called Reluctance. The magnetic field does not appear instantly, it starts when the current is first turned on and as the current increases so the magnetic field increases. When the current is turned off the field takes a little time to decade again.

$$H = (I \times N)/L$$

Where:
H - Is the strength of the magnetic field in ampere turns/meter, At/m
N - Is the number of turns of the coil.
I - Is the current flowing through the coil in amps, A
L - Is the length of the coil in meters, m

III MERITS OF SOLENOID ENGINE

The demand for fossil fuels keeps on increasing and there will be a time when the world will have to depend on electricity as the only source of fuels. Though electric engines are heavy and require more power, they have lesser efficiency when compared to IC engines. A magnetic engine is a promising alternative to the internal combustion engines due to the following factors.

i. There is no hazard to the surroundings because solenoid engines cause no atmospheric pollution.
ii. Serves as a promising alternative to the fossil fuels.
iii. Better efficiency for operations requiring lesser torque.
iv. Less maintenance is required.
v. Very much lighter than an internal combustion engine.

IV DESIGNING OF SOLENOID

The prototype solenoid will be based on the solenoid optimization as described in [9]. The design is based on optimizing a Finite Element Method Magnetics (FEMM) model. FEMM is program to calculate 2-dimensional and axis-symmetric time independent magnetic problems. The program uses Maxwell equations in combination with the finite element method [8]. How the FEMM program performs the calculations, is described in the subsection below. Then the originally designed solenoid [9] is based on the optimizing of these calculations.

V CALCULATION WITH FEMM

First the prototype of the solenoid is drawn in the program. When al the components are drawn, the material properties are attached to the components. The FEMM material library contains all the material properties (for the B and H values) to calculate the magnetic field co-energy Wc. Now FEMM can calculate the magnetic field using (1). In this formula, H represents the nonlinear field intensity.

$$Wc = \int_0^H B(H)\, dH dV \qquad (1)$$

To compute the force from the co-energy, the currents, trough the coil, is held constant. The position of the object upon which the force acts is perturbed slightly. The force can then be estimated by

$$F = \frac{W_c(x+\delta) - W_c(x)}{\Delta} \qquad (3)$$

Where x denotes the initial position and x + δ denotes the perturbed position. The calculated force F acts along the direction of the perturbation. When the force F is calculated for all points the total energy of the solenoid can be calculated as

$$E_{solenoid} = \sum_{i=1, 2\ldots,}^{n} F\, x_i\, \delta i. \quad (4)$$

This is the energy which is stored in the plunger. When the mass of the plunger is known, the speed is easy to calculate with

$$E_{solenoid} = \frac{1}{2} m_{plunger}\, \upsilon^2. \quad (5)$$

The momentum of the plunger can then be calculated by

$$P = m\upsilon. \quad (6)$$

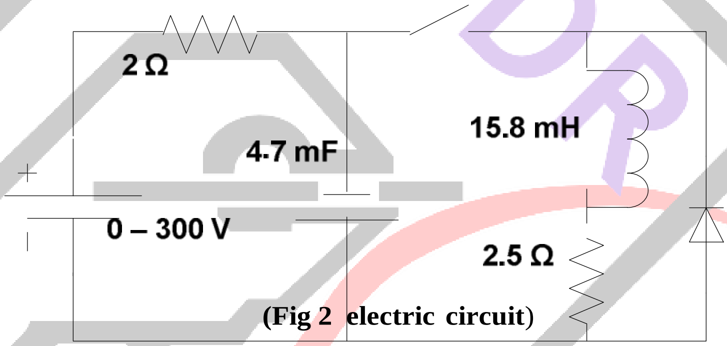
When the momentum of the plunger is known the impulse (to the ball in the end) can calculated as

$$J = F\Delta t \quad = \Delta t. \quad (7)$$

EXPERIMENT AND RESULTS

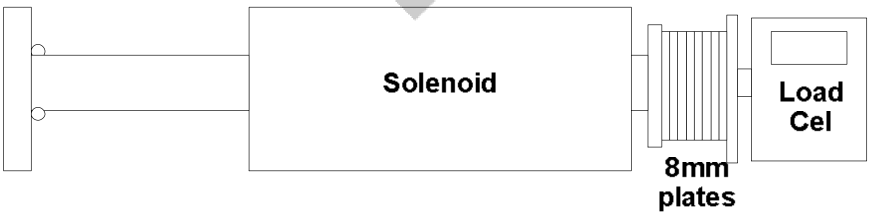
VI TEST SETUP

When the solenoid prototype is built it has to be tested. To test the solenoid, an electric circuit is developed. The circuit is designed such that the electric parameters can varied easily. The first thing which is needed is a power source. The source can vary from 0 to 300 V. The source charges a capacitor whit a capacity of 4.7 mF. Between the capacitor and the source, a resistor is placed. When the capacitor is full, the switch can be closed and the full energy of the capacitor is released over the coil of the solenoid. The coil has an inductance of 15.8 mH and a resistance of 2.5 Ω. An extra diode is placed over the coil. In this way, the coil can unload its energy when the switch is open. The electrical circuit is shown in Fig 2 .



(Fig 2 electric circuit)

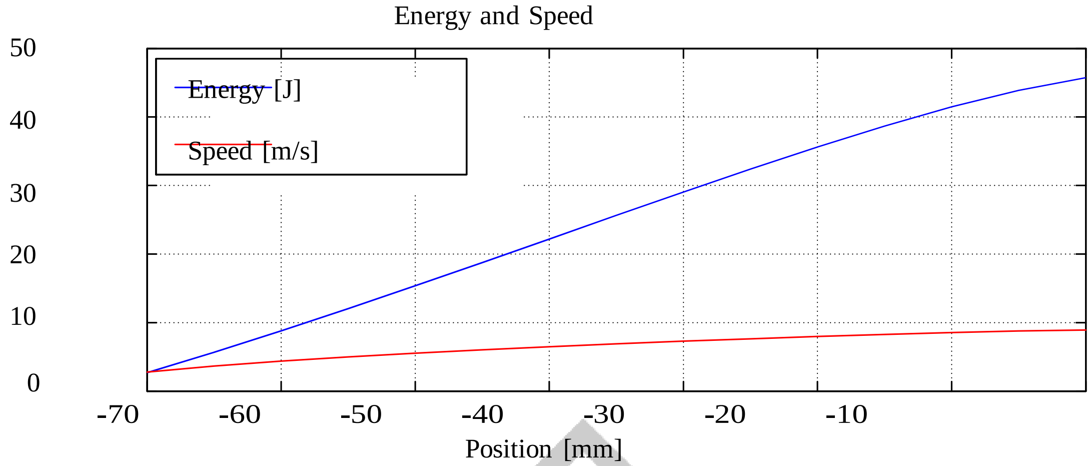
To compare the test with the simulation the motor constant has to be determent. This is done by measuring the force with a special load cell. The motor constant is different at every position of the plunger. To get a good indication, several plates of 8 mm are placed. In this way the motor constant can be determent at intervals of 8 mm. The test setup for this experiment is shown in Fig 3.



(Fig 3 force measuring setup)

VII RESULT

Now the design of the prototype is ready, all the final dimensions are known. To get a good simulation outcome, the final prototype is modeled in FEMM and al the calculations are made. The most important thing which does not match the theory is the coil. The wire is not exactly 1.25 mm in diameter. Another important difference is the Weight of the plunger. This is 1.0 kg instead of 0.6 kg. Also for the test the current is set at approximately 45 A. When running the simulation again for the prototype, the energy and speed are recalculated. The result is shown in Fig 6.1. The end speed of the plunger is about 8.2 m/s at 5 mm (because a rubber ring of 5 mm is added). The distance is the distance that the plunger move before it hits the shield.

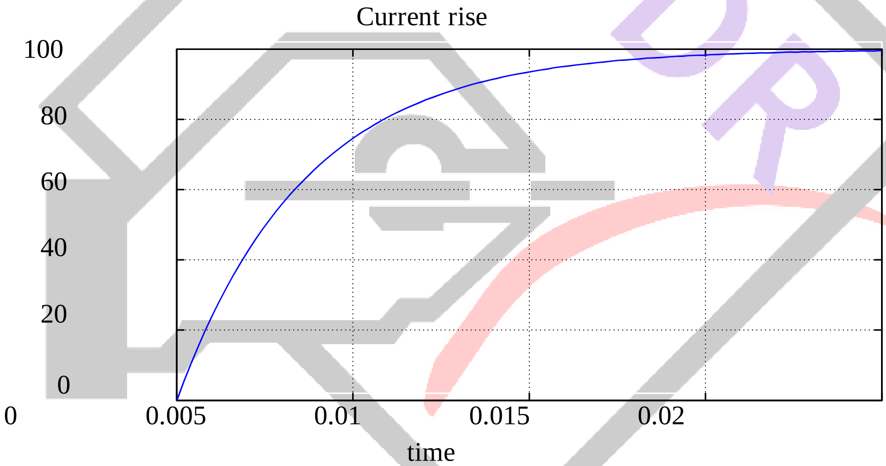


(Fig 4 Calculated energy and speed for the prototype)

The above simulation is at the full current. As described before, an inductor has a time constant. So the plunger must be held on its initial position until the current is at its maximum. The time constant equals

$$\tau = \frac{L}{R} = 0.0150 \quad (8)$$

When plotted (see Fig.5), it is easy to see that the plunger must be released after 0.06 seconds. After this time, the current is at 98% of its maximum and the solenoid works at almost full power.



(Fig 5 current rise in the L-R circuit

VIII CONCLUSION

The solenoid shoots the ball with a sufficient 8 m/s. It is also possible to shoot with different speeds. This can be done by varying the power through the coil with some simple electronics. The switch can be replaced by a transistor which is controlled by a pulse source. The speed of the ball is now linked to the time the transistor is open. The time the transistor is open, is controlled by the pulse source.

The tests with the prototype solenoid approximate the simulation good. In table 1 the end speeds of the ball are shown.

Test	Free Shot	Motor constant	Simulation
Speed	7.2 [m/s]	7.9 [m/s]	8.2 [m/s]

(Table 1: Results)

When comparing the test, in which the motor constant is determent, with the simulation there is a very good similarity. The difference in end speed is only 0.3 m/s. One of the reasons is possibly the material of the plunger. The material of the plunger cannot handle a high magnetic field (only 1 Tesla). When the field is much higher the plunger became saturated. This material saturation looks responsible for this little incorrectness.

Comparing the test with the free shot with the simulation the difference is 1.0 m/s. The difference between the test in which the motor constant is determent and test with the free shot, is only 0.7 m/s. Friction because of the movement of the plunger is probably the main reason for this. The simulation as well as the test in which the motor constant is determent are static. For this reason friction is not taken into account during simulation and the test in which te motor constant is determent.

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