

Permanent Magnetic Model Design and Characteristic Analysis of the Short-stroke Free Piston Alternator

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ABSTRACT

Due to the free piston engine alternator potential advantages in terms of fuel efficiency, a magnetic dynamic model was developed to describe the dynamic characteristics of free piston alternator as the Hybrid Electric Vehicle power source. The mathematic model for the permanent magnet linear alternator was introduced. A function was designed to describe the relation between the individual coil fluxes and the mover motion. And then, the total system model was simulated, and extensive simulation results are presented, giving insight into the free piston alternator operating characteristics and performance. The free piston alternator performances based on the mathematical model were also discussed comparing with prototype experiments.

CITATION: Ding, H., Yu, X. and Li, J., "Permanent Magnetic Model Design and Characteristic Analysis of the Short-stroke Free Piston Alternator," *SAE Int. J. Fuels Lubr.* 5(3):2012, doi:10.4271/2012-01-1610.

INTRODUCTION

The free piston engine concept was developed by Pescara, and engines of various sizes were manufactured between 1930-1960 by GM, Ford, Renault, Junker, Sigma and others [1,2,3,4,5]. The total structure is showed as Fig.1. The free piston engine system is a new electromechanical energy conversion system which can use a linear motion of a piston as it is, while the conventional rotary engine system converts a linear motion of a piston into a motion of shaft by using the mechanical motion conversion devices like a crankshaft, a connecting rod, etc.

The advantages of free piston comparing with conventional engine are: Lower frictional losses, reduced manufacturing costs, compactness, lower maintenance costs and increased lifetime. Most importantly: Free piston engine breaks through the structure limitations for the combustion of traditional engine. It's much easier to realize the variable compression ratio for the free piston engine. At the same time, the output of the free piston engine is electric power or hydraulic power, which is much easier to apply to the hybrid vehicle or electric vehicle.

Several challenges should be the research hot points: increasing efficiency through longer expansion phase or higher compression ratio, making possible larger range of

high efficiency operation, implementing new technologies, but with minimal cost etc. What's more, these technologies are limited by the structure of current engines and vehicle's driver theories. We have to find a suited engine structure for this novel combustion type from the classic combustion cycles, and what's important is that this new engine can be used on the vehicle no worse than on a conventional vehicle.

The authors' previous work on free piston alternator topic includes the development of the combustion model, analysis on the piston operation principle. The target for this research is to achieve a novel energy convert machine which has a better efficiency than the conventional engine.

Three solutions should be considered for the research target. First of all, the differences between the free piston engine and the conventional engine should be studied. The differences should be clarified before continuing this research. Secondly, combustion design should be researched to optimize the efficiency. Since the parameters are totally different with the conventional engine, novel correct thermal models should be designed. Also some novel combustion styles, such as HCCI combustion, should be modified and then used on this engine concept. Thirdly, the magnetic alternator model should be researched so that it may completely operate the whole system. The authors discussed the previous two parts in another paper (in the publishing

procession). In this paper, the authors focus on the magnetic model based on the application of Hybrid Vehicle power source in order to describe its dynamic characteristics. The mathematic model for the permanent magnet linear alternator was introduced. A function was designed to describe the relation between the individual coil fluxes and the mover motion. And then, the total system model was simulated, and extensive simulation results were presented, giving insight into the free piston alternator operating characteristics and performance. The free piston alternator performances based on the mathematical model were also discussed.

MODEL DEVELOPMENT FOR THE LINEAR MAGNETIC ALTERNATOR

Model Configuration

The research for this paper is focus on the short stroke, the stroke length of the alternator is limited. Three-phase voltage generation (with a, b, c phase rotation) is not obtainable due to the phase reversal in the return stroke, only AC generation is considered practical [1]. Therefore, in the following we only discuss single-phase linear AC alternators or linear alternators having a short stroke.

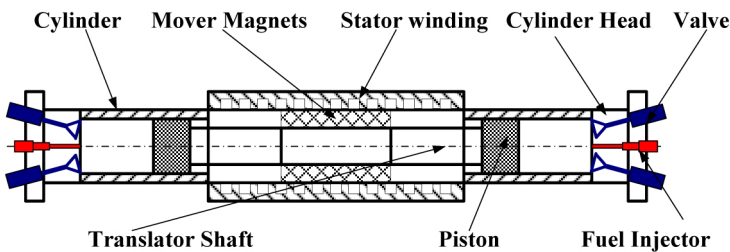


Figure 1. Permanent magnetic free piston alternator configuration

Just like rotary counterparts, linear alternator operates on the basis of Faraday's law of electromagnetic induction.

$$e = \frac{d\lambda}{dt} \quad (1)$$

Here e is induced voltage in a coil if its flux linkage λ varies with time t .

All alternators are driven by a source of mechanical power, which usually called the "prime mover" of the alternator. A prime mover for free piston linear alternator is the engine piston. Different movers can be separated as moving coil alternator, moving magnet alternator and moving iron alternator [1]. This research focuses on using moving magnets alternator.

Model Fundamental and Basic Equations

For the moving magnet linear alternator, finding the air gap field produced by magnet is very important. Many researchers focus on determining this air gap field precisely

based on finite-element analysis [2, 3]. However, the full finite element optimization was impractical due to the extraordinarily long time necessary to complete the optimization. Due to the computational time required for the finite element solutions, this research used a simplified approach for the optimizations, for the practical purposes, the magnetic circuit approach yielding approximate results is acceptable. Hence, the permanent magnet operation flux density can be written as equation (2).

$$B_m = B_g = \mu_0 H_g \quad (2)$$

Where, B_m is Permanent Magnet (PM) operation flux density; B_g is PM operation field intensity;

Neglecting the core reluctance, we can write the Ampere's Law functions as equation (3), and assuming rare-earth magnets, the system demagnetization characteristic is shown as equation (4).

$$k_s H_g(2g) + H_m h_m + H_m h_s = 0 \quad (3)$$

$$B_m = B_r + \mu_{rc} H_m \quad (4)$$

Where, H_g is air gap magnet thickness; H_m is PM operation field intensity; h_m is main magnet thickness; h_s is spring magnet thickness (being backed by iron core); B_r is residual flux density; μ_{rc} is PM recoil permeability;

From equation (2) and equation (4), we can get the permanent magnet operation flux density as equation (5). And then, the induced Electromagnetic Field can be written as equation (6).

Magnetizing inductance was shown in equation (7), and leakage inductance can be written as equation (8), hence the synchronous inductance can be written as equation (9). From equation (10) and equation (11), the equation (6) can be rewrite as equation (12).

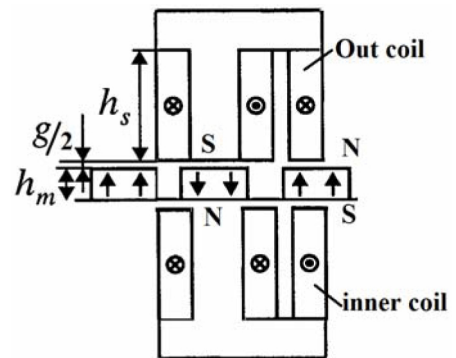


Figure 2. magnetic linear alternator structure