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LINEAR COMBUSTION ENGINE – CONTROL AND APPLICATION

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Abstract:

This contribution describes new types of the combustion engine, called as Linear Combustion Engine (LCE). The main features of this new engine are: Nonexistence of any shaft, flywheel or other rotation components. The output of this engine is not mechanical torque and power on the output shaft, but direct electric power on the linear motor-generator. This linear generator translates the mechanical periodic moving of the piston rod to electric energy as the output of this engine. The linear combustion engine is an electromechanical converter the chemical energy of hydrocarbon or hydrogen fuel as an input to electric energy as an output. Another solution of this problem is presented by an electrochemical converter well known as fuel cells for direct chemical energy changing to electric energy. Comparison of these both possibilities shows, that the linear combustion engine brings some advantages. The main advantage of LCE is higher power density and less production cost in comparison with fuel cells. These properties define such application areas as power source for serial hybrid vehicles, mobile UPS and light mobile electric source for military information systems. To achieve a good function, high reliability and low exhaust pollution of this system it is necessary to design a very sophistical powerful control system.

Key words:
Combustion engine, linear motor generator, two stroke combustion cycles, air assisted injection fuel system, spark system, Matlab, Simulink, magnetic incremental position sensor, manifold absolute pressure sensor, energy storage systems, ultra capacitors, linear 3 phase motor generator control, 3 phase step up converter, control systems

1. Introduction

The LCE (Linear combustion engine) is a specific kind of electric power generator intended for usage in so-called hybrid vehicles. It comprises a two-cylinder two-stroke combustion engine and an electric alternator into one small system. The main difference between the conventional combustion engine and the LCE is the absence of a crankshaft, flywheels, timing belts or other rotary devices. A basic model of LCE consists of two opposite oriented cylinders with two pistons connected by a rod. The pistons and the connecting rod are one moving part only. The desired electric energy is converted from a linear movement of these parts by a linear motor-generator. In comparison with a conventional configuration of the hydrocarbon-electric power converters, the LCE principle is supposed to bring some advantages such as higher efficiency, higher reliability and durability. Typical applications for LCE are for example is hybrid vehicles, mobile energy sources for military and industry, UPS and other similar applications. The basic mechanical arrangement of LCE is shown in fig.1.

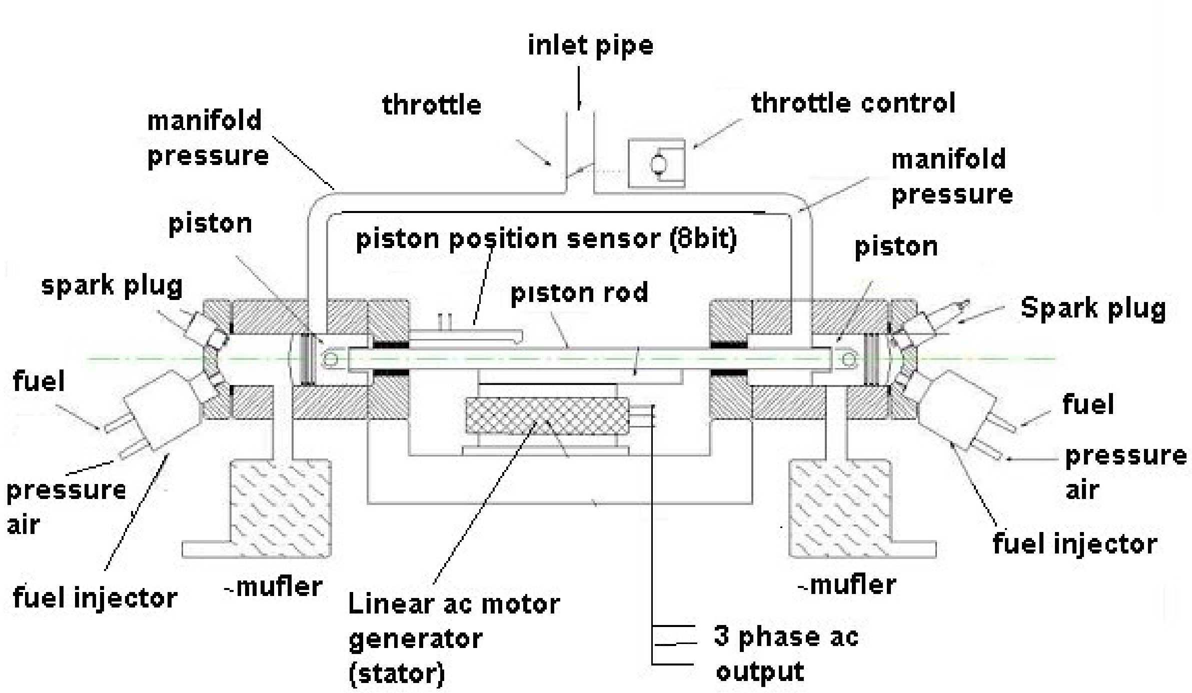

Fig. 1 Linear Combustion Engine – the basic mechanical arrangement

According to Fig.1 the mechanical arrangement of LCE requires a two-stroke thermodynamic cycle. Another mechanical conception of LCE consist only one piston two-stroke engine. The piston with a piston rod is connected with a linear motor generator and a spiral spring. The force optimalizated of this spring is for standard load conditions. [1]. This mechanical conception is probably a good solution for small power units with power < 10^{2-3} [W]. The Miniature Internal Combustion Engine (MICE) has been developed to provide high energy density electric power in a lightweight, compact unit at power levels ranging from 10W to 1000W. Electric power output is inherent to the MICE design and results in oil-free operation with very low frictional losses. Aerodyne Research, Inc. developed LCE with technology MICE as a part of DARPA program for Army lightweight mobile sources. Mechanical design of this miniature engine is shown in fig. 2. http://www.asc2002.com/summaries/f/FP-02.pdf. Two-stroke engine cycle is necessary for this configuration.

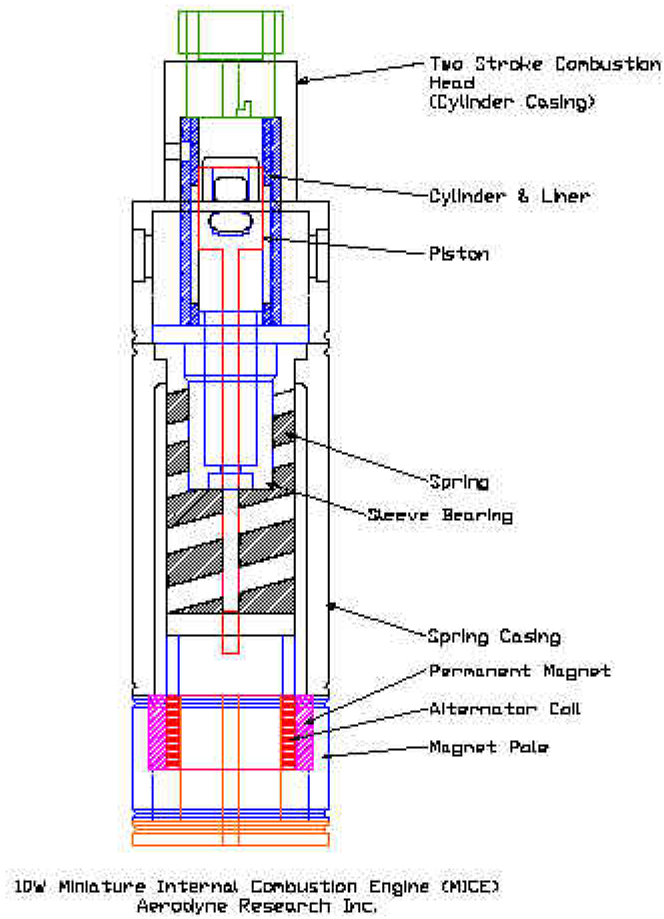

Fig. 2

On the other hand, the large variety of linear combustion engines is possible designed as four stroke cycled and the minimal number of the valves is four. [2].

2. LCE –01 development

At the Department of Control Engineering, Faculty of Electrical ,CTU Prague, an experimental model of LCE (see Fig.1)has been developed. The development has been supported by the Department project.This conception has next advantages:

- Wide band of output power in range 10^3 W to 80 kW is sufficient for the main power unit of serial hybrid cars.
- High power density at small size scales and compact low package, because the alternator is integrated in the system (absence of flywheel and crankshaft frame)
- Low friction losses thanks to the absence of any rotation components and bearings
- Probable ability to operate without oil lubrication (in final production form)
- Very simple mechanical design created by a well known combustion engines technologies (in comparison with the high technology of fuel cells)
- Compression ratio is possible to change very easy by software commands (various usage for different octane number and type of fuel, hydrogen or LPG)
- Full power is reached in one themodynamical cycle
- Zero power is reached to in one themodynamical cycle
- Low level of exhaust pollution
- Higher thermodynamical efficiency in comparison with classical combustion engine
- Compact mechanic design and independent position of the LCE power unit on the vehicle board (any output shaft and mechanic connection with vehicle wheels)

LCE 01 is two stroke, two-cylinder combustion engine without any crankshaft. The stroke of the piston is not defined by the mechanical design (crankshaft diameter), but it is a result of the powerful motor control system. During operation, the pistons are accelerated by mixture explosion and moved from one side to the opposite side. The gained energy is partially used to compress the fuel mixture in the opposite cylinder. This action is periodically repeated. Energy difference between the energy gained by the mixture explosion and the energy consumed by the mixture compression and mechanical losses is drained from the system as electric energy by a linear planar electro-motor generator. It is used as a starter during the start of the LCE. Finally, the motor- generator enables to prevent LCE from stopping when a misfire occurs. Possible misfires must be detected and appropriate interventions to the system (by means of linear motor-generator) must be performed. In case of misfire the motor-generator have to return the pistons to the opposite side in order to enable the periodical cycle to continue. This is why an intelligent control system is necessary to keep LCE operation steady. Another reason for the intelligent control usage is fact that the crankshaft does not limit the movement of the moving part. Thus also precise control of moving part position is necessary to avoid a collision between the piston and the cylinder head. The capability to keep LCE operation steady determines the feasibility of the LCE. The main drawbacks of the conventional two-stroke engine could be eliminated by the use of precise mixture forming (e.g. air assisted fuel injection into the cylinder heads).

2.1. LCE Control System

The LCE is quite a non-conventional system, which demands studying of its behavior. In order to do that, M. Šindelka [4] created a mathematical model. The LCE was decomposed into four subsystems, which were modeled separately. There are-model of mechanical system, model of thermodynamic processes, model of fuel burning and model of linear motor-generator. The model of the mechanical system is second order linear/nonlinear system (depending on the way of the friction modeling). The model of the thermodynamical processes is based on the gas state equation and the first thermodynamic law and is first order non-linear. One of the inputs in this model is the time increment of the in-system delivered energy, gained by burning of air fuel mixture. The value of this variable is computed by the fuel-burning model, which respects the dependency of burning speed on in-cylinder pressure. Finally, the model of the linear motor-generator describes the dependencies between from system drained (or in system delivered, in case of a startup cycle) energy and force extorting the system. Many experiments were done on this model. The LCE had to be forced in to near-steady operation. The simplest way to do it to derive the requested breaking force from the velocity of the connecting rod and set amount of in system delivered energy experimentally to such a value, which corresponds to the steady operation. Steady operation means that there is no energy concentration in the mechanical system. Simulation results show the high guess of efficiency about 45% at output power approx. 1 kW.

Next step of our research is to create an experimental LCE –01 with an intelligent control system to verify the simulation results. Our main research target consists of the data collection for the system identification of the experimental LCE, multiparametric intelligent control system design and power management for optimal distribution of the electric energy in both directions.

Multiparametric intelligent control system consist of several different control system as:

- Control system for spark advance
- Control system for electronic injection system
- Control system for optimal piston rod position control
- Control system for throttle position
- Control system for power control of output linear electric generator
- Control system for automatic control power symmetries of two opposite pistons
- Control system for short time electric storage system to start LCE and to eliminate of random misfire.

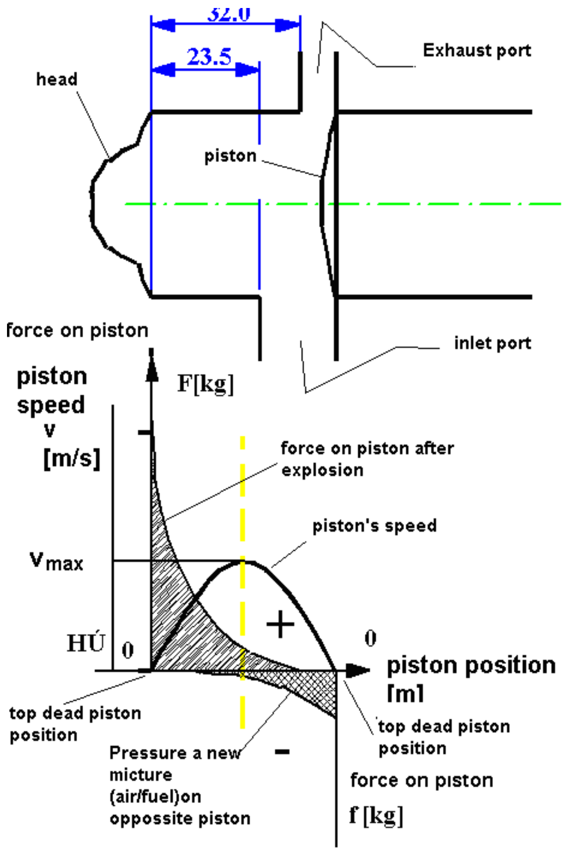

Fig.3 Piston speed and kinetic energy as function of piston position

This is only a short list of the main important auxiliary units for normal LCE working conditions. All these functions are realized by a very powerful microcomputers system and this system warrant described the LCE advantages.

Next very important problem of LCE consist in control of the electric energy transfer out of LCE. Electric generator enables to convert kinetic energy of the LCE moving part to electric energy. Fig. 3 shows the basic problem of this energy conversion. The moving part of LCE has a relative low weight (pistons, pistons rod and moving part of electric motor-generator). This mechanical system is accelerated after an explosion of the fuel mixture, when position of the active piston is near top dead piston position. The pressure of expanded gases on the piston accelerates a moving part. Maximum of the piston speed and maximum of the kinetic energy is near midway piston stroke. The opposite piston compresses the new fuel mixture and this force has an opposite direction, too. This force is lower then force after explosion on the opposite side. Kinetic energy of the moving part is converted into electric energy, so that kinetic energy at the end of the piston stroke is equal to zero and all the difference between the explosion energy and energy needed to compress the new fuel mixture is changed into electric energy.

The electric linear motor-generator is a linear 3-phase synchronous motor with permanent magnets in the moving part. This machine is controlled by 3-phase power Switch Bridge. When LCE is started this 3-phase Switch Bridge is controlled so that rotating field is created. The frequency of voltage is derived on frequency of LCE moving part. The control system consists of current loop and creates a pulse train for the 3-phase switch bridge according to the immediate position of the moving part. When LCE is running, the control system operates as a step-up converter. The 3-phase switch bridge also performs this function, but control system is different. Fig. 4 shows principal basic LCE power managements and control system.

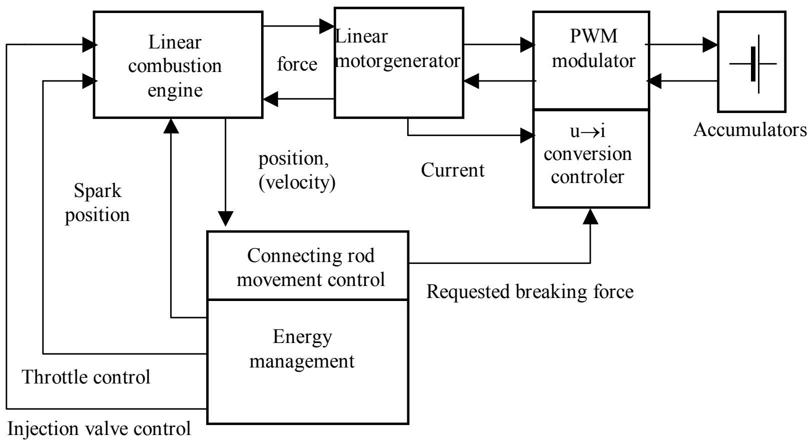

Fig. 3 Basic LCE control system and power management

2.2. Basic applications of LCE

The main advantage of LCE is higher power density [W/kg] and energy density [Wh/kg] of this system in comparison with other alternative independent power sources as electrochemical accumulators, fuel cells, power flywheel etc. These properties predestined the LCE as the main power unit for hybride vehicles. Hybride vehicles contain several power units with different power and energy density. Common control system defines optimal working conditions for these power units under all working condition. A typical arrangement of the hybride vehicle consists of an internal combustion engine as a main power unit and electric accumulators as auxiliary power source. Electric accumulators serve as a peak power source for vehicle acceleration or slow vehicle maneuvering, internal combustion engine serves as main power source for long time vehicle high speed. Very important property of the hybride cars is a possibility of regenerative braking, when kinetic energy of the vehicle charges the electrochemical accumulators. Fig.5 shows two basic hybride car arrangements. Parallel hybride car has a classical internal combustion engine with a gearbox and electric motors connected by a clutch. An electric motor increases the total torque of the power unit. Serial hybride vehicles have a main motor-generator (by example LCE) and traction motor or some electric motors coupled with the vehicle wheels.

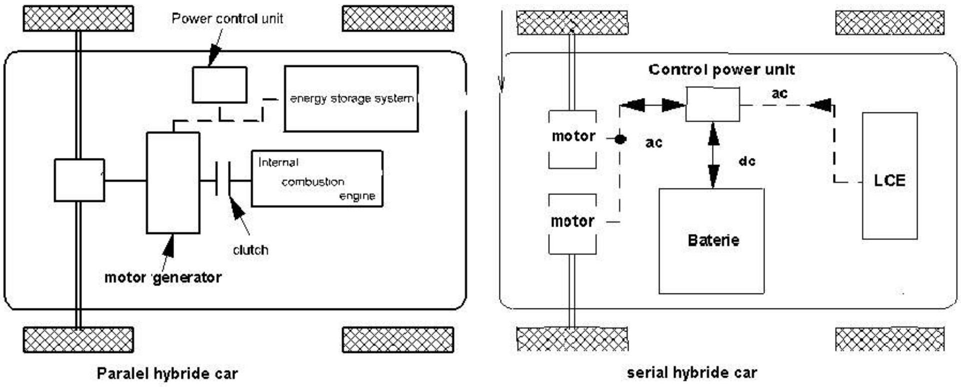

Fig. 4 Parallel and serials conception of hybride vehicles

First generation of hybride vehicles is usually constructed in the in parallel conception (Toyota Prius, VW golf hybride etc.). Contemporary fundamental progress in new power electronic elements increases energetic efficiency of electric traction. The new generation of hybride vehicles is designed as serial hybride vehicle and linear combustion engines LCEs are very perspective main power units for these applications. Fig.6 shows construction of our LCE 01 in the present time.

Fig. 5 Experimetal Linear Combustion Engine LCE 01

Literature:

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