

# Free-swinging Piston Engine and Oscillating Generator as a Source of Electrical Energy

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**Abstract:** *The paper is devoted to the innovative unit consisting of the free-swinging piston internal or external combustion engine and oscillating rotary electrical generator. Advantages and possibilities of such units are presented to compare with shortcomings of the conventional units, as well as with the units of linear free-piston internal combustion engine and oscillating linear generator. Usage of the proposed unit as a source of electrical energy in the hybrid electric vehicles enables to create competitive hybrid electric vehicle.*

**Keywords:** Free-piston engine, Stirling engine, oscillating electrical machines, hybrid electric vehicles.

## 1. Introduction

This paper deals with a possibility to create the thermal engine and electrical generator system that can be clearer to compare with traditional one, and that could be used as a source of electrical energy in the hybrid electric vehicles and for other purposes.

Of course, there are also used other sources of electrical energy in the plug-in electric or hybrid electric vehicles: batteries and fuel cells. However, the hybrid vehicles on a basis of electrical generator driven by an internal combustion engine (ICE) dominate now and in the foreseeable future. Namely such sources of electrical energy are discussed in the paper. Despite of the persistent perfection of ICE, disadvantages of such engines are discussed. A possibility to avoid some shortcomings using the free-piston engines is presented. The main advantages in this case is realisation of the direct drive principle of the free-piston engine and oscillating electrical generator [1].

An original configuration of the free-swinging piston engine and oscillating rotary generator

[2] enables to avoid imperfections of the existing linear free-piston and oscillating linear generator units. The innovative configuration also enables to create Stirling engine (that is, the external combustion engine) having additional advantages.

## 2. Conventional aggregates of the ICE and electrical generator

Conventional internal combustion engines are widely used as a source of mechanical energy in many means of transport (so far, almost in all road vehicles). The conventional set of an internal combustion engine and electrical generator of continuous rotation is also used as a source of electrical energy (including the corresponding source of hybrid electric vehicles). General structure of such aggregate is shown in fig. 1.

In fig. 1 some imperfections of the conventional ICE are indicated. Firstly, the transformer of movement (the crankshaft mechanism) is used, that markedly increases

volume and weight of the aggregate, as well as the energy losses in the multiple frictional pairs of the transformer. Conventional ICE can operate only with storage of some amount of kinetic energy in the rotating bodies. Unfortunately, this energy is lost during the start-stop function of the hybrid vehicle.

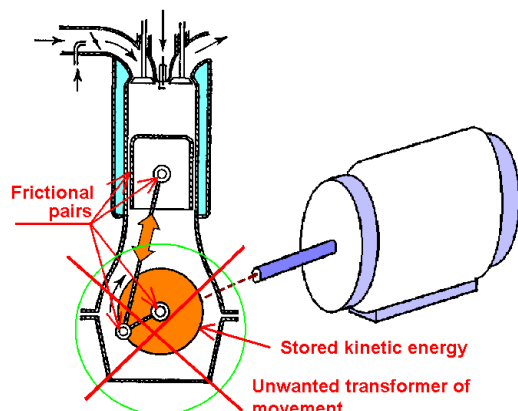


Figure 1: Structure of the conventional ICE and electrical generator.

Thus, in spite of the versatility of ICE, there are some their important shortcomings:

- limited efficiency,
- pollution of environment,
- predetermined kind of the fuel,
- over-large mass and volume,
- optimal operation only over limited range of the output power.

Incidentally, the latest shortcoming especially motivates creation of the hybrid vehicles.

Some of the shortcomings could be reduced by application of the variable compression ratio, variable valve timing. Unfortunately, it is unlikely that existing attempts to solve these problems by purely mechanical means could be successful. For example, the *MCE-5 DEVELOPMENT Company* (France) is proposing to realise variable compression ratio using a complicated gear mechanism between the piston and the crankshaft (fig. 2) [3].

It is stated that a vehicle with the presented in fig. 2 mechanically complex engine of mass production should have many advantages in comparison with the hybrid electric vehicle. If this statement is insufficiently reasoned, but it also accentuates expensiveness of the existing hybrid vehicles. On the other hand, a challenging remark is presented here: "Hybridization would not add anything to a thermal engine with constant efficiency over its whole range of use, except to recover a part of the vehicle's kinetic energy normally lost during braking" [3].



Figure 2: Variable compression ratio engine proposed by *MCE-5 DEVELOPMENT Company* [3].

Hybridization of the vehicle with an conventional ICE could help to solve mentioned above problems in the near future. Corresponding correction of the resulting torque-speed characteristic, optimisation of operation of the engine, regenerative braking, engine start-stop mode enable to achieve partly the objectives. Because these vehicles can use the same infrastructure of the fuel as conventional ones, the quick development of such hybrid vehicles in the near future is predicted.

On the other hand, the increased mass and cost of the hybrid vehicle diminishes the desirable effect. Consequently, there are attempts to use other structures of the engine, namely, the free-piston engine.

### 3. Free-piston ICE and oscillating linear generators

The weight and volume of internal combustion engine can be markedly reduced using the free-piston structure. In this case, the free-piston engine directly drives an oscillating generator [1]. Thus, the more optimal structure

of the series hybrid vehicle could be created [4]. To this end the linear free-piston engines with an oscillating linear generators are proposed (e.g. fig. 3 [5]). It is to notice that the free-piston engine only theoretically can realise optimal operation in large range of the output power.

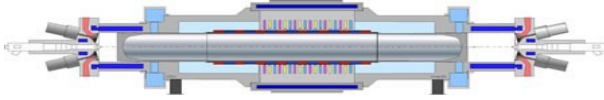


Figure 3: 1. Principal layout of the so-called *Free Piston Energy Converter* [5].

In spite of many advantages of the linear free-piston units (avoidance of movement transformer, minimised number of frictional pairs), some their shortcomings are also observed: problems of vibration of the frame, remaining frictional losses in the linear guides, non-optimal magnetic circuit of the linear oscillating electrical machine (causing non-full usage of permanent magnets), etc. However, the possibility only two-stroke operation of the linear free-piston ICE (with problems of the scavenging) is the main it shortcoming, because optimal operation of such engine practically is possible only over limited range of the output power (as one of the conventional ICE).

#### 4. Free-swinging piston engine and oscillating rotary generator

The proposed “Free-swinging piston heat machine” [2] is pre-eminent to compare with the traditional free-piston devices of linear movement. This machine can operate as an internal or external combustion engine, and as a compressor or pump. The principle of structure is shown in fig. 4.

The free swinging piston heat machine comprises housing with a cylindrical cavity (e.g., formed by cylindrical ring 1 and covers 2, 3) in which two analogous assemblies of pistons 4, 5 are placed. The assembly of pistons consists of cylindrical hub 6 with two or more vanes (e.g., 5', 5'') having form of symmetrical star. The assemblies of pistons could independently pivot around axis of the housing.

Guidance of the assemblies of pistons could be realised by rotary bearings (including roller bearings) mounted in the hubs. This structure enables to avoid a friction between the

swinging parts and housing, and simplifies solution of the sealing. The direct connection of external driven or driving devices without any transformer of mechanical movement also simplifies structure and reduces losses.

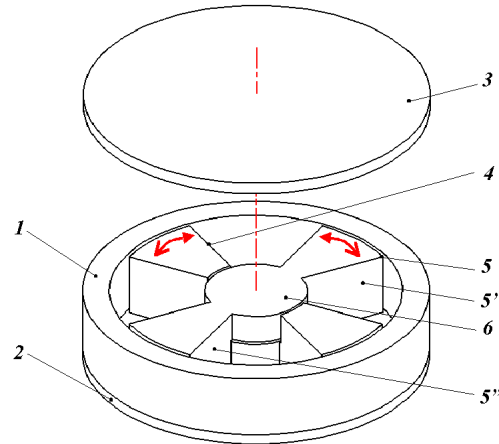


Figure 4: Principle of structure of the free-swinging piston engine.

The oscillating electrical machine could be arranged concentrically with the engine (around of the engine), at it is shown in fig. 5 (here the engine is shown without covers). The oscillating electrical machine must have two rotors (7, 8), which are connected with the corresponding assemblies of pistons and which oscillate in opposite directions too. The stator of electrical machine 9 can be common.

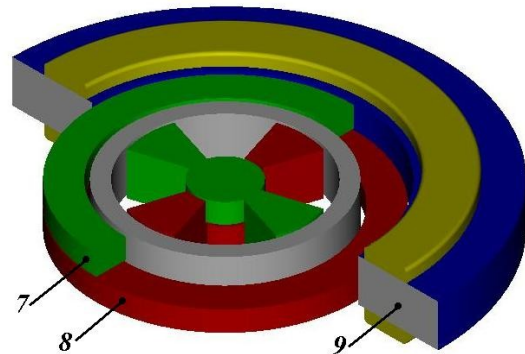


Figure 5: Structure of the unit of the free-swinging piston engine and oscillating rotary electrical machine.

The oscillating electrical machine can be used as engine starter. The oscillating electrical machine also realises control of operation of the free-piston engine (control of the oscillation amplitude, position of oscillation centre, and oscillation spectrum).

The free-swinging piston heat machine becomes a balanced mechanical system of

three bodies, when the centres of mass of two swinging in opposite directions bodies are located in the axis of rotation. Therefore operation of such machine does not provoke vibrations of the frame.

Fig. 6 shows the principal layout and dimensions of the considered unit of free-swinging piston ICE and oscillating rotary generator. The main data are as follows: the output power 65 kW, the frequency of oscillation 70 Hz, the weight (without auxiliaries) about 60 kg.

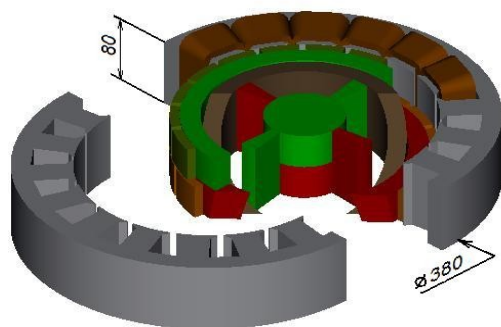


Figure 6: Principal layout and dimensions of the estimated unit.

The doubled unit depicted in fig. 5 enables to realise the Stirling engine (an external combustion engine). In this case, the necessary movement of pistons and displacers of the Stirling engine could be realised by corresponding control of separate oscillating electrical machines. Variant of the Stirling engine enables to achieve real multi-fuel operation (including a solid fuel), what is impossible in ICE. Moreover, in principle the Stirling engine can operate in reverse mode (i.e. with storage of some heat during regenerative braking of the hybrid vehicle).

Consequently, the main advantages of the considered device are as follows:

- compactness (decreased up to 50 % the weight and volume),
- minimum frictional losses in the rotary bearings,
- reduced (or absent) wear of the pistons and cylinder (housing) surfaces, possibility to simplify sealing and lubrication,
- full-balanced mechanical system, without vibration of the frame,
- possibility of four-stroke operation of the internal combustion engine,
- controllable compression ratio of the internal combustion engine,

- possibility to realise the Stirling engine,
- possibility of optimal operation (in terms of efficiency and minimum pollution) of the internal or external combustion engine in large range of the output power,
- multi-fuel operation (especially of the Stirling engine),
- optimal magnetic circuit of the oscillating rotary electrical machine,
- increased efficiency (in comparison with such conventional systems).

Because the considered free-swinging piston engine in principle can optimally operate over whole range of the output power, the amount of stored energy is predetermined by the energy of regenerative braking and by the necessary energy reserve for extra-acceleration of the vehicle. This amount of energy enables to use the supercapacitors as the energy storage in the hybrid vehicle instead of expensive batteries.

## 5. Conclusion

The competitive hybrid electric vehicle can be created using the free-swinging piston engine and oscillating generator as a source of electrical energy. Such cleaner source of electrical energy can be successfully used for other transport and stationary devices.

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