REVERSED ELECTRIC OSCILLATION GENERATOR BASED ON A HARTMANN CONVERTER

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ABSTRACT

The development of compact and efficient power generators based on internal combustion engines for hybrid vehicles and other vehicles is a rapidly developing area. In the proposed design of the generator, ring magnets are placed on the piston, and the electric windings with a magnetic circuit are placed on the cylinder. In such system, there is no problem of the free piston hitting the cylinder head at a high compression ratio in the event of an injector malfunction, since the cylinder is also free. The serious problem of electronic control of the internal combustion engine and control of the fuel delivery system is also removed. The mathematical simulation of the operation of an electric internal combustion generator with a free piston and a cylinder in a linear variant is carried out. The work of an experimental pneumonic model of an electric generator made in a rotary version is demonstrated. A simplified mathematical model of an electric generator is used in the work and does not analyze many technical issues of practical design. Implementation of a generator based on gas-jet sound emitters allows generating high-power electrical vibrations with low volumetric-weight parameters of the device itself. Another great advantage is that the air flow required for its operation can be located in a closed air supply system.

Key words: electric generator, internal combustion engine, resonator, self-oscillation, pulse current power, Hartmann transducer.

INTRODUCTION

The various mobile autonomous mini-power plants used today are technical devices in the form of two independent units that, in conjunction, provide the conversion of fossil fuel energy into electricity. The first block is a piston internal combustion engine (ICE). The second block is the electric generator itself. Another rapidly developing area is the creation of compact and efficient ICE-based power generators for hybrid cars and other vehicles. Note that widely used power units are not capable of operating on low-calorific fuel.

Recently, a new type of extender has been developed - a mono-power unit built on the basis of a linear valveless internal combustion engine with a free piston [1, 2]. In terms of its energy and weight and size characteristics, such an internal combustion electric generator (ICEG) is much superior to a two-unit power plant.

1. At the same time, it is necessary to pay attention to the problems associated with free piston generators. The main ones are:
2. Risk of piston hitting the cylinder end in a single-piston generator circuit or collision of free pistons in a two-piston generator circuit.
3. The ICEG system with one free piston and two end combustion chambers is fundamentally unbalanced, therefore the operation of such an ICEG occurs with strong vibrations if there is no massive base.
4. The ICEG system with two free pistons moving in opposite directions and one

central combustion chamber can theoretically be balanced. However, such a generator requires a complex electronic control system and correction of the movement of each piston to ensure their synchronous movement.

MATERIALS AND METHODS

In [3, 4] the design of the ICE with a free piston is proposed, which is devoid of said defects. The system is not only a freely moving piston, but also a cylinder. Such an internal combustion engine is an absolutely balanced machine, since in the interaction of a free piston and a cylinder, the center of mass of the system is motionless (Fig. 1). This greatly simplifies the ICE control system.

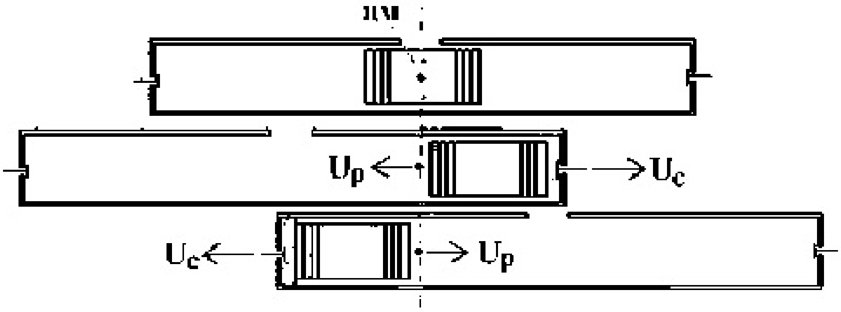
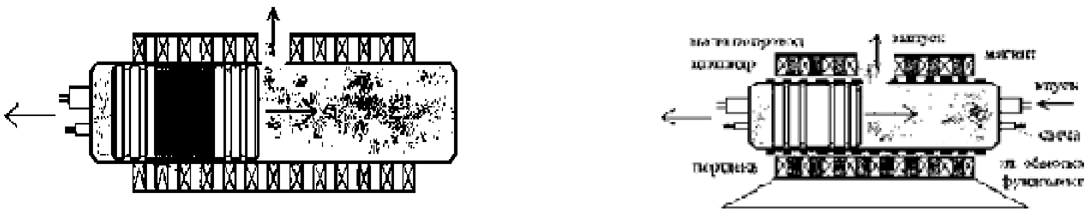


Fig. 1. Piston and cylinder movement diagram



a) b)

Fig. 2. Linear electric internal combustion generator with a free composite piston with internal (1) and external (2) magnets according to the scheme of a two-stroke engine

In the proposed design of the generator, ring magnets are placed on the piston, and the electric windings with a magnetic circuit are placed on the cylinder. In such a system, there is no problem of the free piston hitting the cylinder head at a high compression ratio in the event of an injector malfunction, since the cylinder is also free. The serious problem of electronic control of the internal combustion engine and control of the fuel supply system is also removed. In essence, the design of a perfectly balanced linear electric generator is realized with only the feature that the movement of the armature and stator is caused by the direct action of pressure from the combustion of the fuel-air mixture. This is the main idea of the new type of electric generator. With the mutual movement of the piston and cylinder, a change in the magnetic flux occurs, and an EMF is induced in the electric winding. Note that the relative speed of movement of the piston magnets relative to the electric windings of the cylinder is higher in the considered system than in the fixed cylinder circuit.

An even simpler two-stroke circuit of electric generator with a single piston and external magnets is shown in Fig. 2b. A light magnetic circuit is placed on the cylinder. Here, the external electromagnetic system is connected to the foundation, since it is structurally difficult to make it free by connecting it with a free piston. However, due to the possibility of a significant reduction in the masses of the piston and cylinder, the vibration level is reduced.

It is possible to create a compact closed system in the form of a two-stroke rotor engine with a rotor piston (fig. 3). The problem with the variant in Fig. 2b is easily solved. The rotor is connected to a ring electromagnetic system, which is located around the circumference of the free housing. The supply of the fresh mixture and the release of combustion products occurs through a hollow shaft with window-type valves. The theory of a rotary engine with a free rotor is presented in [4].

Mathematical simulation of the operation of an electric internal combustion generator with a free piston and a cylinder in a linear variant is carried out in this article. The features of the functioning of such a system are analyzed. The work of an experimental pneumonic model of an electric generator made in a rotary version is demonstrated. Note that a simplified mathematical model of an electric generator is used in this work and does not analyze many technical issues of practical design. The aim of the work is to present two new promising ideas, as opposed to the already advanced work on a linear free piston generator:

1. Make the cylinder free, which will make the structure perfectly balanced.
2. Go from the linear generator circuit to the rotary one.

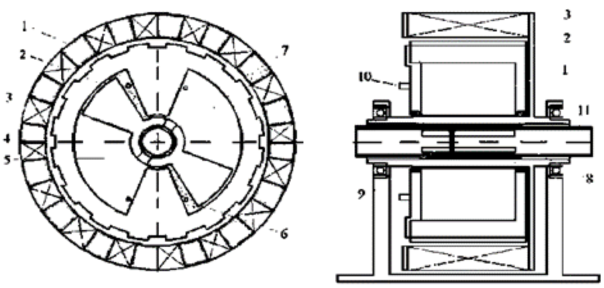


Fig. 3. Diagram of a possible variant of electric generator based on a two-stroke rotor engine with free rotor and hull: 1-free hull with a magnetic circuit; 2 - free rotor; 3 - electrical winding; 4 - magnets; 5 - the volume filled with the working mixture; 6 - combustion of the compressed mixture; 7 - hollow shaft with windows; 8 - outlet valve window; 9 - inlet valve window; 10 - spark plug; 11 - fixed shaft with distribution windows

At the ends of the cylinder there are inlets for the supply of fresh methane-air mixture, and in the center of the cylinder - the outlet of combustion products. The cylinder ends are provided with inlets for supplying a fresh methane-air mixture, and in the center of the cylinder are provided with an outlet of combustion products. The inlets and outlets are equipped with valves of appropriate action. The piston and cylinder move in opposite directions so that the center of mass of the system remains stationary. A two-stroke cycle of the system is implemented. At the stage of exhausting combustion products through the outlet valve at a certain pressure, the inlet valve of the corresponding chamber is opened, and thus the chamber is purged and filled with fresh mixture. The useful work performed during the combustion of the mixture is converted into electrical energy, while, in order not to detail the electromagnetic system of the generator, it is assumed that the electrical power in the load, determined by the electromagnetic force of the interaction of the piston and cylinder, is proportional to the square of their relative speed.

RESULTS AND DISCUSSION

As can be seen, such a generator scheme can be modified if, instead of an internal combustion engine to use Hartmann generator, who found that if a stationary jet flowing from a supersonic nozzle flows onto an obstacle - a tube, the open end of which is directed towards the jet, then the flow observed in this case can be both stationary and pulsating. Strong pressure fluctuations occur with a pulsating process in such a system, generating a sound of high intensity. The classical Hartmann generator is a design consisting of a supersonic axisymmetric nozzle and a semi-closed cylindrical cavity (resonator), the axes of which coincide. The supersonic jet flowing into the resonator, depending on the internal dimensions of the system and flow parameters, implements powerful self-oscillations. If, instead of a piston, an air mixture of magnetic ferro particles is used in this design, then their electromagnetic interaction with the external electric winding makes it possible to generate significant electrical power of the pulsed current. In such Hartmann converters, an annular slot jet directed radially to the central axis of symmetry of the resonator serves as a source of energy for exciting and maintaining pulsations in the cavity of a resonator formed by two disks. The excess of the average pressure over the stagnation pressure of the jet and high values of the amplitudes of pressure fluctuations were also obtained here. [7].

The purpose of this work is to study the passage of disturbances through the internal and external channels, and their influence on the nature (frequency and mode) and the intensity (amplitude) of oscillations in the HT (Hartmann transducer).

To simulate a two-dimensional unsteady flow of an ideal gas, consider the two-dimensional Euler equations:

$$\frac{\partial \mathbf{f}}{\partial t}+\frac{\partial \mathbf{F}}{\partial x}+\frac{\partial \mathbf{G}}{\partial y}=\mathbf{Q}$$

$$\mathbf{f}=\begin{bmatrix}\rho\\ \rho u\\ \rho v\\ \rho e\end{bmatrix}\mathbf{F}=\begin{bmatrix}\rho u\\ p+\rho u^2\\ \rho uv\\ \rho u\left(e+\dfrac{p}{\rho}\right)\end{bmatrix}\mathbf{G}=\begin{bmatrix}\rho v\\ \rho uv\\ p+\rho v^2\\ \rho v\left(e+\dfrac{p}{\rho}\right)\end{bmatrix}\mathbf{Q}=-k\frac{\rho v}{y}\begin{bmatrix}1\\ u\\ v\\ \left(e+\dfrac{p}{\rho}\right)\end{bmatrix} \tag{1}$$

where $$e=\frac{1}{\gamma-1}\,\frac{p}{\rho}+\frac{u^2+v^2}{2}. \tag{2}$$

Here ρ - gas density; p - its pressure; u, v - x- and y- velocity components; x, y - Cartesian axials; $\gamma = c_p / c_v$ - specific heats ratio.

The generator consists of a slotted annular nozzle, a radial resonator consisting of a disk and an end cylinder. The axis of symmetry of the resonator is perpendicular to the plane of symmetry. The planes of symmetry of the resonator and the nozzle coincide. The radial generator, in general, is characterized by the following geometrical parameters: height of the nozzle exit section - H; nozzle radius - R; resonator width - h; disc radius – r_2 and end cylinder radius – r_1.

To simulate a gas-dynamic flow in a disk generator, the computational domain shown in Fig. 4 was considered.

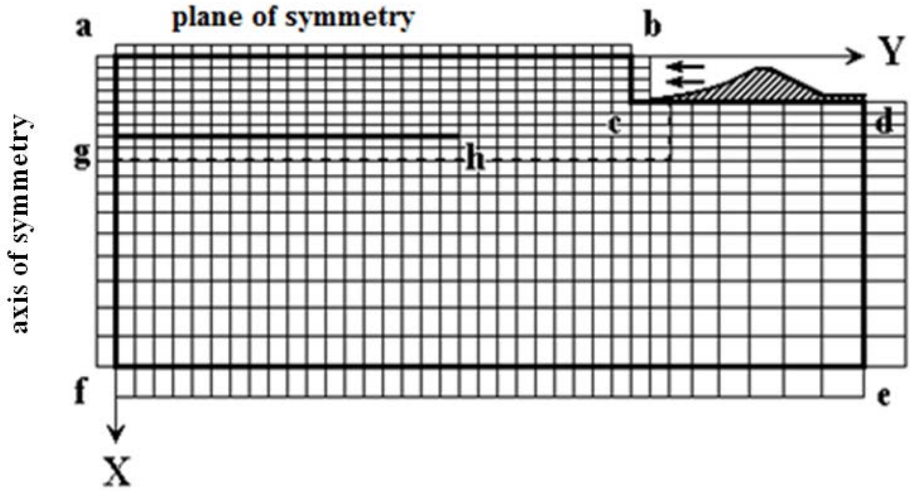


Fig. 4. Scheme of the computational domain

Fig. 4 shows the boundary of the computational domain abcdefghga. On the ab af cd gh hg borders simulating the plane of symmetry, the axis of symmetry and solid smooth walls were set the conditions of reflection. Since all these boundaries were straightforward, setting the boundary conditions on them is the simplest and does not cause any difficulties. So, for example, for the boundary ab, the conditions were specified as follows:

$$\rho_{1,j} = \rho_{2,j} \; ; \; u_{1,j} = -u_{2,j} \; ; \; v_{1,j} = v_{2,j} \; ; \; p_{1,j} = p_{2,j} .$$

The inlet boundary **bc** simulated the outlet section of the supersonic nozzle. The values of the gas-dynamic parameters in this section were set constant and unchanged throughout the calculation:

$$\rho_{i,M0} = \rho(P_0, T_0, n) \; ; \; u_{i,M0} = 0 \; ; \; v_{i,M0} = v(P_0, T_0, n) \; ; \; p_{i,M0} = p(P_0, T_0, n) \; ,$$

where P_0 and T_0 - respectively, the stagnation pressure and temperature, and n is the degree of off-design of the jet flowing from the nozzle.

At the output boundaries of the **de** and **ef** exterior domain, strict conditions were applied to set the environment if the Mach number in the boundary cell of the calculation grid was less than 1 *(M <1)* or the gas-dynamic parameters were extrapolated from the computational domain to the boundary if the Mach number was greater than 1 (M>1).

To solve the problem of natural vibrations, we solve the wave equation [14]:

$$\Delta\varphi - \frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2} = 0, \tag{3}$$

where *r* - radial coordinate. In a monochromatic wave, the velocity potential has the form $\varphi = e^{-i\omega t} \cdot F(r)$, and thus for the function *F (r)* we get the equation:

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial\varphi}{\partial r}\right) - \frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2} = 0, \tag{4}$$

where *r* - radial coordinate. In a monochromatic wave, the velocity potential has the form $\varphi = e^{-i\omega t} \cdot F(r)$, and thus for the function *F (r)* we get the equation:

$$F'' + \frac{1}{r}F' + k^2 F = 0, \tag{5}$$

where $k = \omega/c$ - wave number (*ω*- circular frequency). Replacing the variable *r* by *z* = *k·r* equation (5) is simplified:

$$G'' + \frac{1}{z}G' + G = 0, \tag{6}$$

where *G*(*z*) = *F*(*r*).

The general solution to this differential equation is a linear combination of the Bessel functions $J_0(z)$ The general solution to this differential equation is a linear combination of the Bessel functions and Neumann $N_0(z)$ of zero orders [9]:

$$G(z) = aJ_0(z) + bN_0(z),$$

whence we get:

$$F(r) = aJ_0(kr) + bN_0(kr), \tag{7}$$

The function *F (r)*, as can be seen, has three free parameters *a*, *b*, *k* and three conditions are required to determine them.

The first boundary condition is taken from the condition of no leakage at the resonator bottom *v*=0. By convention of the velocity potential function $v = \partial\varphi/\partial r$ get the condition:

$$\left.\frac{\partial F}{\partial r}\right|_{r=r_1} = 0$$

The second boundary condition determines the node by pressure at the resonator cut:

where p' - deviation of the pressure value from the mean value. Whence expressing p'

through the function φ we obtain: $\left.\frac{\partial^2\varphi}{\partial t^2}\right|_{r=r_{12}} = 0$ or $F(r_2) = 0$

The third condition is an arbitrary normalization condition: $F(r_1) = 1$

Finally, we obtain the following system for determining *a*, *b* and *k*:

$$\begin{aligned} aJ_1(kr_1) + bN_0(kr_1) = 0 \\ aJ_0(kr_2) + bN_0(kr_2) = 0 \\ aJ_0(kr_1) + bN_0(kr_1) = 1 \end{aligned} \quad (8)$$

An analytical solution to this system is obtained if r_1=0, then we have *b*=0 (since $N_0(0)=-\infty$), *a*=1; and to determine *k* we have the equation:

$$J_0(kr_2) = 0, \quad (9)$$

which in the asymptotic approximation of the Bessel function:

$$J_0(z) = \sqrt{\frac{2}{\pi}} \cdot \frac{\cos(z) - \pi/4}{\sqrt{z}},$$

easily solved:

$$\cos\left(kr_2 - \pi/4\right) = 0,$$

$$kr_2 - \pi/4 = \pi/2 + \pi n,\ n = 0,\ 1,\ 2, \quad (10)$$

Whence for the frequency of natural vibrations *f*=*kc*/2π we obtain:

$$f_n = \frac{3+4n}{8} \cdot \frac{c}{r};\ n = 0,\ 1,\ 2,\ ... \quad (11)$$

where *n* =0 corresponds to the fundamental frequency (mode) of natural vibrations, *n* = 1 - to the first mode, etc. Accordingly, for the 0th, 1st, 2nd, and subsequent modes, the Strouhal numbers $Sh = fr_2/c$ are:

$$Sh = 3/8,\ 7/8,\ 11/8,\ 15/8, \text{ and etc.} \quad (12)$$

In this paper, system (8) is generally solved numerically for any set of parameters r_1, r_2 using the MatCad service program on a personal computer. The source disturbing the flow is the decelerating jump (DJ) in front of the obstacle due to its instability, and thus it can be considered as the starting and ending point of the passage of the disturbance. Then, when determining the oscillation frequency in the generator, in equation (12) we can take the value $l = r_2 - r_1 + \Delta L$ for the channel length (resonator depth), where ΔL – is the length from the resonator cut to the middle position of the DJ.

The motion of compression and rarefaction waves along the resonator was considered earlier. When the jump moves towards the resonator, a compression wave arises, propagating deep into the resonator and, after being reflected from the end face, returning to the jump, moving it away from the resonator cut. Further, when the jump moves from the resonator, a rarefaction wave arises, which also propagates deep into the resonator and, after reflection from the end face, also returns to the DJ. Thus, the path of propagation of the perturbation inside the resonator (internal path) in the fundamental mode was considered.

Obviously, when the oscillations in the resonator occur in the fundamental mode, the oscillation period is the sum of the time of the compression wave and the rarefaction wave passing along this path.

CONCLUSION

Mathematical modeling of the operation of an electric generator with a free piston and a cylinder in a linear version has been carried out. Two variants of the generator are considered - with an internal and external arrangement of magnets. The features of the functioning of such a system are analyzed. It is shown that in the non-optimized version, the efficiency of conversion of chemical energy into electrical energy reaches almost 50%

As for the application of the resonant structure of the Hartmann transducer, the conclusions will be as follows:

1. The nature of the flow - the frequency and amplitude of the pulsations, is determined by the passage of disturbances through the inner and also through the outer channel.
2. With an increase in the resonator depth, a nonmonotonic increase in the amplitude of flow oscillations is observed. In both series, dips in the magnitude of the pressure amplitude are observed at the same resonator depth or when the frequency of natural oscillations in the resonator is half the frequency of the jet oscillations.
3. Oscillations in the resonator occur in the first mode, when the frequency of natural oscillations for the first mode in the resonator corresponds to the frequency of the jet oscillations.

Implementation of a generator based on gas-jet sound emitters allows generating high-power electrical vibrations with low volumetric-weight parameters of the device itself. Another great advantage is that the air flow required for its operation can be located in a closed air supply system.

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