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ЕЛЕКТРИЧНИЙ ТРАНСПОРТ

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FREE-PISTON ENGINE-AND-HYDRAULIC PUMP FOR RAILWAY VEHICLES

Purpose. The development of the free-piston diesel engine-and-hydraulic pump for the continuously variable hydrostatical transmission of mobile power vehicles. **Methodology.** For a long time engine builders have been interesting in the problem of developing free piston engines, which have much bigger coefficient of efficiency (40…80%). Such engines don't have the conversion of reciprocating motion for inner combustion engine piston into rotating motion of crankshaft, from which the engine torque is transferred to the power machine transmission. Free-piston engines of inner combustion don't have the crank mechanism (CM) that significantly reduces mechanical losses for friction. Such engines can be used as compressors. Free-piston engine compressor (FPEC) – is a free-piston machine in which energy received from engine's cylinder is being transferred directly to compressor's pistons connected with operational pistons of engine without crank mechanism. Part of the pressed air is being consumed for engine cylinder drain and the other part is going to the consumer. **Findings.** The use of free-piston engines-and-hydraulic pumps as power-transmission plants of power vehicles (diesel locomotives, combine harvester, tractors, cars and other mobile and stationary power installations) with the continuously variable transmissions allows cost effectiveness improvement and metal consumption reduction of these vehicles, since the cost effectiveness of FPE is higher by 25-30 %, and the metal consumption is lower by 40-50 %. **Originality.** One of the important advantages of the free-piston engines is their simplicity and engine balance. As a result of the crank mechanism absence their construction is much simplified and the vibrations, peculiar to the ordinary engines are eliminated. In such installation the engine pistons are directly connected through the rod to compressor pistons and therefore there are no losses in the bearing bushes. **Practical value.** The free-piston engines are now used only as gas generators and diesel compressors, and the hydraulic transmission is arranged with the ordinary heat-engine, which operates the hydraulic pumps.

Keywords: free-piston engines; engine-and-hydraulic pump; hydrostatical transmission; crank mechanism; free-piston diesel hydraulic pump; engine-and-gas generator; hydraulic cylinder; hydraulic accumulator; power vehicles

Introduction

As a result of fuel price increase and the environmental situation deterioration one should pay special attention to the improvement of technical and economic, as well as dynamic and ecological characteristics of the inner combustion engines (ICE). In Ukraine the number of power vehicles with diesel engines, used in different sectors of national economy increases each year. Diesel engines have higher technical and economic parameters as compared to the gasoline and gas-turbine engines. However, the improvement of technical and economic parameters and design of these engines is still an urgent issue.

Efficiency coefficient (EC) of the modern ICE

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is relatively low: gasoline engines (0.25…0.32); diesel engines (0.33…0.42); gas engines (0.23…0.28). That's why development of the new heat engines design with better indicator and efficiency parameters is a crucial task. These basic parameters of ICE can be significantly increased by the reduction of mechanical losses. The main part of the losses are the friction losses (65…80 %) [1].

Analysis of schemes and designs of free-piston engines

For a long time engine builders have been interesting in the problem of developing free piston engines, which have much bigger coefficient of efficiency (40…80 %) [6]. Such engines don't have the conversion of reciprocating motion for inner combustion engine piston into rotating motion of crankshaft, from which the engine torque is transferred to the power machine transmission. Free-piston engines of inner combustion don't have the crank mechanism (CM) that significantly reduces mechanical losses for friction. Such engines can be used as compressors.

Free-piston engine-compressor is shown on Figure 1.

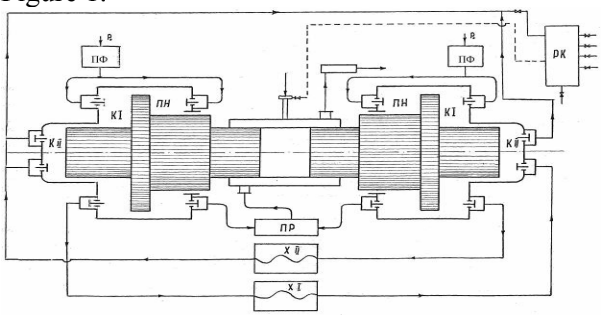

Fig.1. Free-piston engine-compressor:
ПФ – air filter; КІ – first stage of compressor;
КІІ – second stage of compressor; ПР – scavenging receiver; ПН – scavenging pump; Х І та Х ІІ – fridges

Free-piston engine compressor (FPEC) – is a free-piston machine in which energy received from engine's cylinder is being transferred directly to compressor's pistons connected with operational pistons of engine without crank mechanism. Part of the pressed air is being consumed for engine cylinder drain and the other part is going to the consumer.

FPEC have small size and weight, easy and reliable start and are absolutely balanced (no need in understructure). Expenses on 1 m^3 of produced pressed air (or gas) in FPEC are in 1.5-2 times lower than expenses of powered compressors with equal productivity.

Actuating motor – is a gas-diesel with compression ignition. Material consumption of FPEC is in 3.8-6.5 times less than that of stationary electrically driven compressors and mobile compressors with an internal combustion engine [4].

Constructional diagram of free-piston engine-and-gas generator is shown on Figure 2.

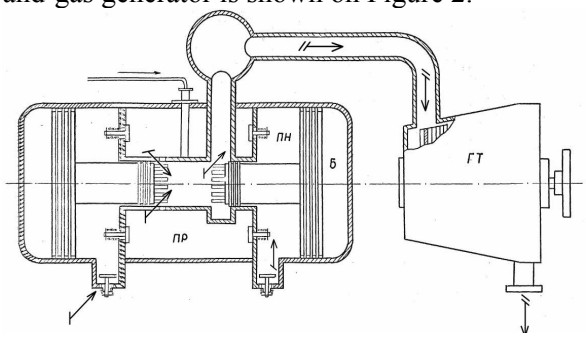

Fig.2. Free-piston engine-and-gas generator:
ПР – scavenging receiver; ПН – scavenging pump;
ГТ – gas turbine; Б – buffer cylinder;

– fuel; – air; – air + gases.

Cylinder of the two-stroke diesel engine with uniflow scavenging is located in the center of the generator; the scavenging port is placed symmetrically relative to the center of diesel sleeve, where the liquid-propellant injector is placed. On both sides the diesel sleeve is directly connected to the piston compressor cylinders, provided by the sucking, air delivery and starting valves. One line of the scavenging ports through the space surrounding the diesel cylinder is connected to the air delivery valve and another line is connected to the pipeline, leading to the receiver and then to the gas turbine. The pistons of generator are double-staged: diesel pistons have smaller diameter and compressor ones have bigger diameter.

The generator's start-up is performed by means of the pressed air from outer source (pressure vessel, reservoir etc.). Pressed air throw the starting valves enters to external spaces of compressor cylinders and moves pistons to center of the engine, compressing the air firstly in the internal compressor spaces and then, when the diesel pistons shuts the scavenging ports, in the engine cylinder. At the end of motion the air pressed in compressors

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through the air delivery valves fill the diesel cylinder. In the center of the diesel pressing is continued, i.e. of air pressure and temperature is increasing. When the temperature of the air exceeds the temperature of the fuel self-ignition, the fuel is injected through the nozzle. The fuel ignites and burns, the pressure rapidly increases and the power stroke starts. Mix of air and fuel combustion products is expanded and makes the pistons move to the different sides. Exhaustion appears in the inner compressor spaces, as result inlet valves are opened and the atmosphere air enters into the compressor. In the external compressor spaces the starting air compression takes place, i.e. air buffers are created. When the diesel pistons open the scavenging ports, combustion products are directed to the receiver and then to the gas turbine blades. Pistons are stopped by the compressed air pressure that makes them start backward running, restarting the operating stroke [3].

The free-piston inner combustion engine (FPICE) with hydraulic power transmission is shown on the Figure 3.

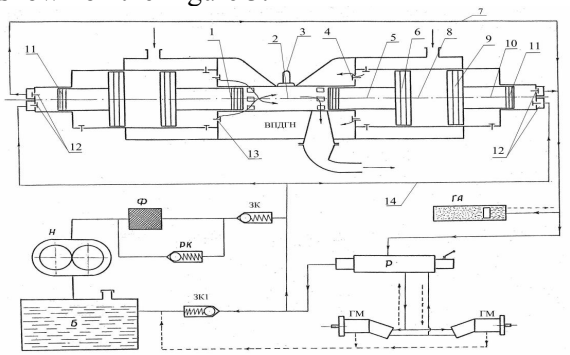

Fig.3. Free-piston inner combustion engine (FPICE) with hydraulic power transmission:
ВПДГН – free-piston diesel hydraulic pump; Р – distributor; ГА – hydraulic accumulator; Б – tank of power fluid; Н – pump; Ф – filter; ЗК – stop valve; РК – air reducing valve; ЗК1 – safety-valve; ГМ – hydraulic motor

The free-piston inner combustion engine (FPICE) with hydraulic power transmission has working cylinder 2 with inlet 4 and exhaust valves 13, nozzles 3, operating pistons 1 with the stocks 5, connected with buffer piston 6. The second buffer piston 9 moves in the buffer cylinder 8 and is connected with the piston of hydraulic pump 11 through the stock 10.

Free-piston diesel hydraulic pump has a system of hydraulic valves 12 and pipelines 14, connecting with the main and secondary devices of the vehicle hydrostatic transmission (disturber; hydraulic accumulator; tank of power fluid; pump; filter; stop valve; air reducing valve; safety-valve; hydraulic motors). The pressure of the power fluid from hydraulic pump pistons 11 through the valves 12 is transferred to the motors of hydrostatical transmission of mobile power vehicle.

Development of free-piston inner combustion engine for hydraulic power transmission

Free-piston inner combustion engines with hydraulic power transmission have simplified construction; they are small due to refusing from crank mechanism, but they require the complex system of pistons movement synchronization. This disadvantage causes the absence of operating constructions of such engines with hydraulic power transmission.

Figure 4 shows a schematic diagram of the free-piston internal combustion engine (FPICE) with the starter [2, 9]. The free-piston inner combustion engine with the hydraulic starter has 4 cylinders 1, with inlet and exhaust valves, nozzles 3, and operational pistons 4 with stocks 5 and plungers 6, inlet and exhaust hydraulic valves 7, cylinders of starting system synchronization 8, 9, pipelines 13.

The starting mechanism of free-piston inner combustion engine consist of starter 19 with elastic clutch 18, clutch 20, connection lever of the clutch 17 with drive gear 16, crankshaft 15, gas distributor shaft gear of the FPICE systems and mechanisms, pistons 12, plungers 11 and shell cases 10.

The starting mechanism of the free-piston inner combustion engine operates as follows. At start of FPICE the starter 19 turns on, so the rotational moment through the elastic clutch 18 and the clutch 20 is transferred to the gear 16 that puts in the motion the crank-shaft 15. The crank mechanism of the FPICE starter sets the reciprocating motion to shell cases 10 plungers 11. Oil pipelines 21 are connected to the shell cases 10 of starting mechanism. By means of oil pipelines the power fluid pressure through the windows 22 is transferred to the cylinders 9, 8. In these cylinders 8, 9 the pressure is changed synchronous that provides work of the free-piston ICE.

The operating pistons 4 work synchronous due to hydraulic connection 23. Work of FPICE is similar

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to the work of four-stroke combustion engine with corresponding mechanisms and systems.

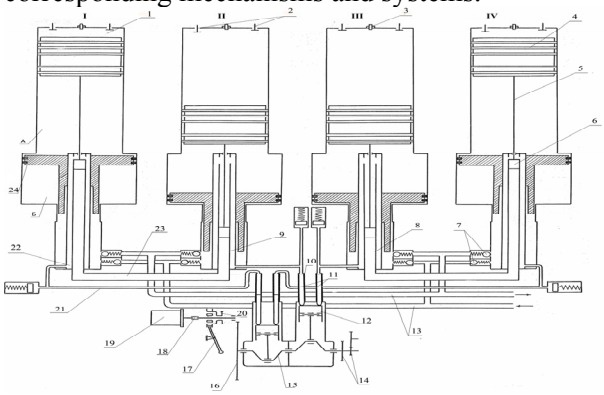

Fig.4. Free-piston inner combustion engine with hydraulic starter [2, 9]: 1 – cylinders; 2 – inlet and exhaust valves; 3 – nozzles; 4 – working pistons; 5 – stocks; 6 – plungers; 7 – exhaust and inlet hydraulic valves; 8, 9 – cylinders of starting system synchronization; 10 – shell cases; 11– plungers; 12 – pistons; 13 – pipelines; 14 – gas distributor shaft gear of the FPICE systems and mechanisms; 15 – crankshaft of the starter; 16 – drive gear; 17 – connection lever of the clutch; 18 – elastic clutch; 19 – starter; 20 – clutch; 21 – oil pipelines; 22 – windows of piston synchronization system; 23 – hydraulic connection; 24 – pump piston; А, Б – capacity of gas drive-gear

The engine consists of four cylinders – I, II, III, and IV, in which the operating pistons 4 with piston rings and stocks 5 perform the reciprocating motion.

Plungers 6 of the hydraulic synchronization mechanism, installed in double-acting cylinders are fastened on the stocks.

Lower space of synchronization mechanism is connected with similar space of pair-connected cylinders (I with II and IV with III) by means of the oil pipeline 21.

Top space of the hydraulic cylinder synchronization mechanism is connected with the plunger 11 shell case 10 of crank mechanism 15 of the distributing shaft, ventilator and other auxiliary systems through the ring space between synchronization cylinder shell case and the lower pump body, and then through the starting oil pipeline

Gas piston 4 during operation of engine hydraulic pump makes reciprocating motion in the cylinder 1 and by means of stock 5 is connected with plunger 6 of synchronization system.

A-volume is located in cylinder between operating piston 4 and the piston 24. It creates the interpiston space of gas shaft and is used for force transfer from piston 1 to gas piston 24. The lower part of piston 24 is used as hydraulic pump, which through the valves 7 forces the power fluid into the hydrostatical transmission of power vehicle. Stroke of gas-oil piston 24 depends on pressure of the power fluid forcing.

B-volume under the gas piston is used for returning of the gas-oil piston 24 in initial position. During this operation, the volume vacated by the pump piston is filled by the power fluid, which comes from the hydraulic transmission line throw the inlet valves 7.

During the lowering piston movement 24 the volume of power fluid through the air delivery valves 7 gets into the high-pressure line 13 of hydraulic system transmission and moves to hydraulic motors of the locomotive.

The use of the free-piston engines-hydraulic pumps as the power-transmission plants of power vehicles (diesel locomotives, combine harvester, tractors, automobiles and other mobile and stationary power installations) with the continuously variable transmissions allows cost effectiveness improvement and reduction in metal consumption of these vehicles, since the FPE cost effectiveness is higher by 25-30%, and metal consumption is lower by 40-50% in comparison with those of the modern diesels. Free-piston combustion engine developed by the authors can be used for hydrostatic power transfer for power vehicles on railway transport.

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СВОБОДНОПОРШНЕВОЙ ДВИГАТЕЛЬ-ГИДРОНАСОС ДЛЯ ЖЕЛЕЗНОДОРОЖНОГО ТРАНСПОРТА

Цель. Разработать свободнопоршневой дизельный двигатель-гидронасос для бесступенчатой гидростатической трансмиссии мобильного энергетического средства. **Методика.** Двигателестроителей давно интересует проблема создания свободнопоршневых двигателей, которые имеют значительно больший КПД (40...80 %). В таких двигателях нет превращения возвратно-поступательного движения поршня ДВС во вращательное движение коленчатого вала, от которого крутящий момент двигателя передается трансмиссии энергетической машины. Свободнопоршневые двигатели внутреннего сгорания не имеют кривошипно-шатунного механизма (КШМ), что существенно уменьшает механические потери на трение. Такие двигатели используются в качестве компрессоров. Свободнопоршневой двигатель-компрессор (СПДК) – свободнопоршневая машина, в которой энергия, получаемая в цилиндре двигателя, непосредственно отдается поршням компрессора, связанным с рабочими поршнями двигателя без кривошипно-шатунного механизма. Часть сжатого воздуха расходуется на продувку цилиндра, а другая большая часть сжатого воздуха поступает к потребителю. **Результаты.** Использование свободнопоршневых двигателей гидронасосов в качестве

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силовых агрегатов энергетических средств (тепловозов, комбайнов, тракторов, автомобилей и других мобильных и стационарных энергоустановок) с бесступенчатой передачей позволяет повысить экономичность и снизить металлоемкость этих средств, так что экономичность КПД является высшей, чем экономичность современных дизелей на 25-30 %, а металлоемкость – ниже на 40-50%. **Научная новизна.** Одним из важных преимуществ свободнопоршневых двигателей является их простота и полная уравновешенность. Вследствие отсутствия кривошипно-шатунного механизма значительно упрощается их конструкция и ликвидируются вибрации, присущие обычным двигателям. В такой установке поршни двигателя непосредственно соединены через шток с поршнями компрессора, и поэтому потери в подшипниках отсутствуют. **Практическая значимость.** Свободнопоршневые двигатели пока используются только как генераторы газов и дизель-компрессоры, а гидрообъемная передача сегодня компонуется с обычным тепловым двигателем, который приводит в движение гидронасосы**.**

Ключевые слова: свободнопоршневые двигатели; двигатель-гидронасос; гидростатическая трансмиссия; кривошипно-шатунный механизм; свободнопоршневой дизель-гидронасос; двигатель-генератор газа; гидроцилиндр; гидроаккумулятор; энергетические средства

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ВІЛЬНОПОРШНЕВИЙ ДВИГУН-ГІДРОНАСОС ДЛЯ ЗАЛІЗНИЧНОГО ТРАНСПОРТУ

Мета. Розробити вільнопоршневий дизельний двигун-гідронасос для безступеневої гідростатичної трансмісії мобільного енергетичного засобу. **Методика.** Двигунобудівників давно цікавить проблема створення вільнопоршневих двигунів, які мають значно більший ККД (40…80 %). У таких двигунів немає перетворення зворотно-поступального руху поршня ДВЗ в обертовий рух колінчастого вала, від якого крутящий момент двигуна передається до трансмісії енергетичної машини. Вільнопоршневі двигуни внутрішнього згоряння не мають кривошипно-шатунного механізму (КШМ), що суттєво зменшує механічні втрати на тертя. Такі двигуни використовуються в якості компресорів. Вільнопоршневий двигун-компресор (ВПДК) – вільнопоршнева машина, в якій енергія, що отримується в циліндрі двигуна, безпосередньо віддається поршням компресора, пов'язаним із робочими поршнями двигуна без кривошипно-шатунного механізму. Частина стисненого повітря витрачається на продування циліндра двигуна, а інша більша частина стисненого повітря поступає до споживача. **Результати.** Використання вільнопоршневих двигунів гідронасосів у якості силових агрегатів енергетичних засобів (тепловозів, комбайнів, тракторів, автомобілів та інших мобільних і стаціонарних енергоустановок) з безступеневими передачами дозволяє підвищити економічність та знизити металоємність цих засобів тому, що економічність ВПД є вищою економічності сучасних дизелів на 25-30 %, а металоємність – нижчою на 40-50 %. **Наукова новизна.** Однією з важливих переваг вільнопоршневих двигунів є їх простота і повна врівноваженість. Внаслідок відсутності кривошипно-шатунного механізму значно спрощується їх конструкція і ліквідуються вібрації, властиві звичайним двигунам. У такій установці поршні двигуна безпосередньо з'єднані через шток із поршнями компресора, і тому втрати у підшипниках відсутні. **Практична значимість.** Вільнопоршневі двигуни поки що використовуються тільки як генератори газів та дизель-компресори, а гідрооб'ємна передача сьогодні компонується зі звичайним тепловим двигуном, який приводить в рух гідронасоси.

Ключові слова: вільнопоршневі двигуни; двигун-гідронасос; гідростатична трансмісія; кривошипно-шатунний механізм; вільнопоршневий дизель-гідронасос; двигун-генератор газу; гідроциліндр; гідроакумулятор; енергетичні засоби

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