ADAPTATION OF CLASSIC COMBUSTION ENGINES TO COMPRESSED AIR SUPPLY

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Abstract: This paper presents the issue of the construction and operation of the pneumatic piston engines. We analyzed different options for design solutions, as well as their applicability. It proposes its own solutions based on reciprocating internal combustion engines JAWA 50 and FIAT 126P, which was obtained during the adaptation of two-stroke engines air. The first attempts were successful operation. We showed the process of adaptation each of engines, their specifications and set the scope for further work related to the improvement of operational characteristics, as well as guidelines for developing a mathematical model of action.

Key words: Mechanical, Compressed Air Engine, the Design

1. INTRODUCTION

Declining resources of the fuel in the ground, tend to search for new fuels or new design of internal combustion engines, which will use the existing fuel liquids, gases or solid fuels.

On the other hand, the gradual reduction of the emission levels of harmful emissions emitted by internal combustion engines, forced the designers to increase the efficiency of energy conversion resulting from combustion into mechanical work, the use of all types of treatment systems as well as the composition of hybrid systems (1999/125/EC.OJ L40, No 2000/303/EC.OJ L100).

In hybrid systems (drive line system, where are working together two different power sources), classically used in internal combustion engines connected to electric generators, which in effect are able to power the electric motors placed on the wheels of the vehicle. At present, internal combustion engines are used independently to generate electricity only, without direct participation in the generation of torque to the wheels (www.elektroenergetyka.org/6/46.pdf).

Hybrid systems can also use the energy contained in compressed air, which through an appropriate system will be processed on the torque driving of the generator. The simplest way to use compressed air is to use the classic internal combustion engine with modifications. The essence of this solution is that the compression of air outside of the external compressor, could occur during vehicle braking by compressor system mounted in the vehicle (recuperation).

2. REVIEW OF EXISTING CRANK SYSTEMS

There are many coverage about use of the working medium which is compressed air. A very large part in this area are structures designed for drive models, especially flying. There are also more advanced constructs used to drive small cars, trucks and small sports vehicles. Below are some constructions of pneumatic engines differ in construction, as well as the degree of sophistication.

2.1. Classic Layout of Crank System

In solutions used in models (Fig. 1), the working medium from source of gas is supplied by ball valve into the cylinder. Conversion of the energy to power is done by work carried out is using classical cranks. In this case, the engine can be considered two-stroke. The advantage is simplicity of construction, disadvantage and the portion of the work lost for combustion residues in air after departure.

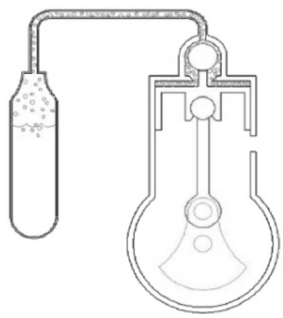

Fig. 1. Classic crank system (www.darmowa-energia.eko.org.pl/pliki/ekoauto/spr_pow.html)

Adaptation of the classic cranks system have got the need to take account of the less energy density at which the compressed air supplies engine, through the ball valve with the specified bandwidth in relation to energy density resulting from the combustion of a combustible mixture inside the cylinder.

Based on the construction shown in Fig. 1, we can duplicate the solution to consecutive cylinders, resulting in the formation for example of the design of 4-cylinder engine, covering smaller fluctuations of speed (Fig. 2).

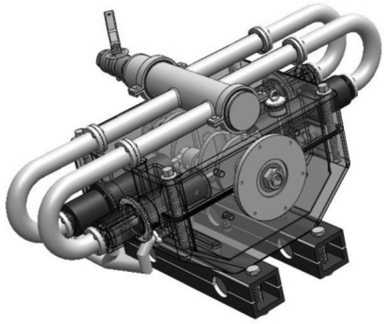

Fig. 2. The boxer engine (Gosk, 2008)

2.2. The Layout with the Split Crankshaft Made by MDI

Because of the considerable differences in the density of energy both sources, which is the compressed air and combustible mixture, constructors attempted to extend time of piston being in “out-crank” position, to enable it to increase the degree of filling the cylinder with compressed air, which is directly converted to work (with minor losses at expansion in relation to the classical crank layout).

The latest solution used in pneumatic piston engines, is the system with split crank made by company MDI also known as Nègre engine (Fig. 3), which provides momentary stop of the piston in the upper extreme point. Drawback of this solution is that the piston and crankshaft doesn’t lie in one plane, which increases the size of the engine and problems with mounting it in cars with small space. Another problem is the presence of significant accelerations during expansion and compression stroke, and thus inertia forces, not leaving without effect on the consumptions cooperating pairs and strength of construction.

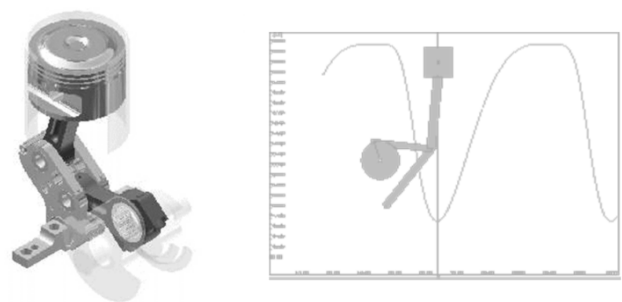

Fig. 3. The layout with the split crankshaft (www.engineair.com.au/development.htm)

MDI company constructed engine in such a way, that it can work in the opposite direction, as a compressor, because the is engine-alternator mounted on gearbox. Composite tanks can be filled by air in two ways: either from the station where is previously compressed air-refuelling is only about 3 minutes, or by plugging the car into electric plug in your wall – then engine-alternator is working as an electric motor and drives pneumatic engine of the car, which is working as a compressor. Such a way of fuelling to full is about 4 h, but this vehicle is not totally dependent on the station with compressed air.

2.3 Angelo Di Pietro Engine

His own concept of pneumatic Wankel engine developed Angelo Di Pietro. The engine he design (Fig. 4) reminds one of the many developed by F. Wankel, except that the working factor here is compressed air, that moves the blade. Originally Wankel foresaw it as internal combustion engine.

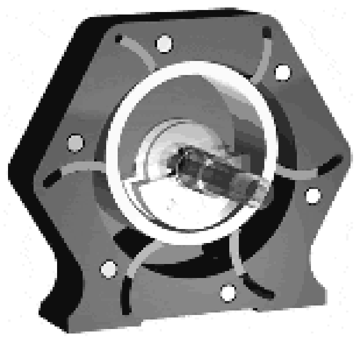

Fig. 4. Angelo Di Pietro engine (www.rexresearch.com/pietro/pietro.htm)

The modernization included also inlet and outlet channels. Di Pietro engine demonstrated significantly less use of components, because there is no combustion and there is less demand for the working factor (compressed air).

2.4. Modified Wankel Engine

In order to adapt the Wankel engine to work on compressed air, the timing system has been redesigned by modifying valve timing and inlet and outlet valve profile (Fig. 5). Presented solution is only a concept that require construction of the prototype and experimental studies.

Opening of the first exhaust window is 6° before closing the intake (Fig. 5e). The chamber is connected to the exhaust channels including by 226° rotation of the engine crankshaft. At the end of the exhaust phase, there is again 5° cover phases of filling and emptying by second outlet window. Exhaust phase was divided in to two parts due to the need to strengthen the head of the engine.

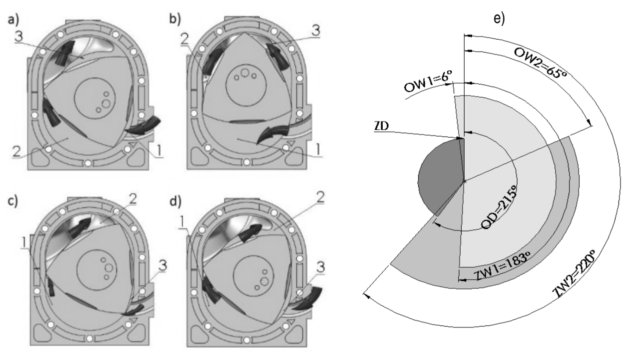

Fig. 5. Modified Wankel engine: a, b, c, i d – phases of load Exchange, e – circular graph of timing phases (Mejlun et al., 2011)

2.5. Crankshaft System with Elongated Expansion Stroke

Another proposal is the design of the engine with elongated expansion stroke (Fig. 6). Its construction is based on the prototype crankshaft system providing temporary immobilization of piston in the upper extreme point, which in the case of using it as energy source of compressed air, it boosts the efficiency of the engine.

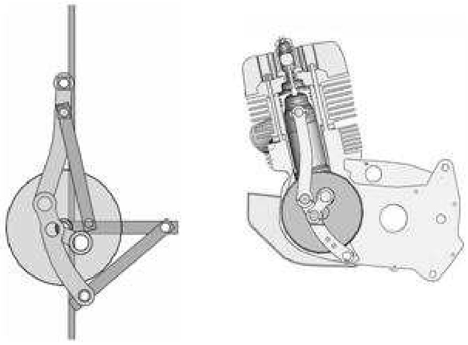

Fig. 6. Crankshaft system with elongated expansion stroke, comparison passes of specific values of concept and classical engine (Jaszuk, 2008)

2.6. Cam Engine

a)

b)

c)

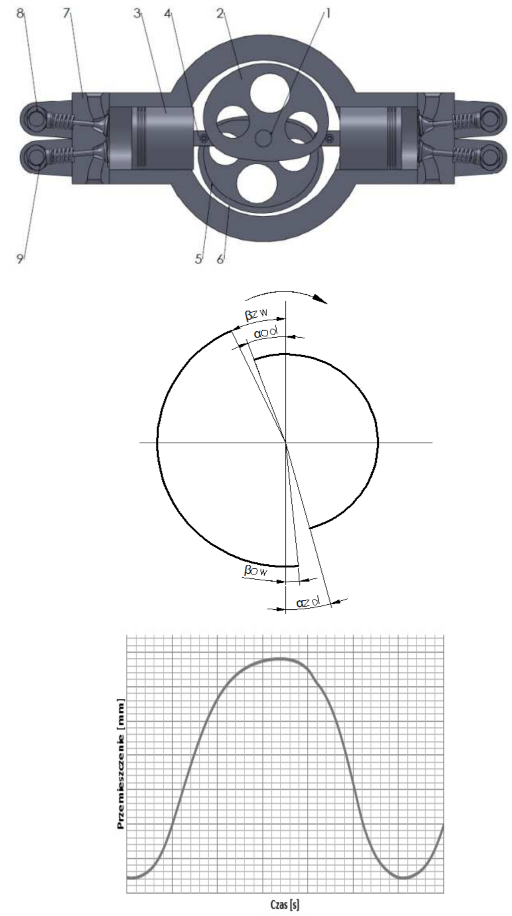

Fig. 7. The concept of cam engine: a – construction schema, b – timing phases: α_{od}=20° – open angle of intake, α_{zd}=15° – close angle of exhaust valve, β_{ow}=5° – open angle of exhaust valve, β_{zw}=25° – close angle of exhaust valve; c – piston movement at function of time (Mejlun et al., 2011)

In the cam engine crankshaft system is replaced by twin-roller cam with the pusher. Similarly, as the Nègre engine (in this case, through appropriate relief camshaft) it is possible to temporary immobilization of piston in the upper extreme point (Fig. 7c).

The conceptual solution (Fig. 7a) is a four-cylinder, double-breasted engine and cylinders in opposite position, where the classic crankshaft was replaced by the shaft with cams (1). Cam (2) drives the special design piston coupled with crankshaft (3) through double-breasted pusher (4). Cam is built with two cams (internal (5) and external (6)), on which roller of pusher moves. Both cams have been designated with different equations. That's because of unchanging position of rollers relative to each other while working. Over the head (7) are camshafts, intake (8) and exhaust ports (9) of cams with different work angle. Such arrangement will be working according to the timing phases shown in Fig. 7b.

3. TECHNICAL CHARACTERISTICS OF THE OBJECTS OF ANALYSIS

In the first place two stroke engine from JAWA 50 has been adapted to work on compressed air. Directory data of engine JAWA 50 is shown in Tab. 1.

The design required a modification of the timing, where in place of the original solution of slot-piston system, appeared intake controlled by ball valve developed within the original devices of the spark plug.

The next design is based on the four stroke engine from the FIAT 126P 650. Technical data is shown in Tab. 2.

Tab. 1. Technical characteristics of the base engine and the modified JAWA 50

Parameter/Indicator	Base	After adaptation
Engine	Two stroke. one cylinder	
Engine capacity	49.9 cm³	
Compression ratio	9:1	-
Maximum power	2.6 BHP	b.d.
Cooling	a free flow of air	
Diameter of cylinder	38mm	
Travel of the piston	44mm	
Rotational speed of idling	1100 rpm	300 rpm
Camshaft system	Slot-piston	Slot-piston + cams

Tab. 2. Technical characteristics of the base engine and a modified FIAT 126P 650

Parameter/Indicator	Base	After adaptation
Engine capacity	652 ccm³	
Operating cycle	4-stroke with spark ignition	2-stroke
Number of cylinder	2	
Diameter of cylinder	77 mm	
Ravel of the piston	70 mm	
Compression ratio	8:1	-
Maximum power	24 BHP	bd
Rotational Speer of idling	850 rpm	120 rpm
Camshaft system	Uppercam system, camshaft mounted In engine block, chain drive	

4. DESCRIPTION OF THE NECESSARY MODIFICATIONS AND EFFECTS

4.1 Adaptation of JAWA 50 Engine

As a base was taken the engine blocked with clutch and gearbox from JAWA 50 engine. Maintained without change gearbox, engine shaft with bearings mounted in gearbox block and connecting rod and cylinder.

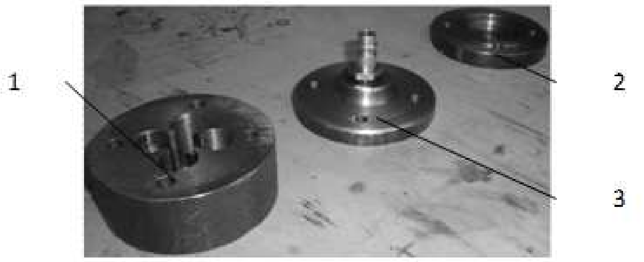

Fig. 8. Modified head of JAWA 50 engine: 1 – middle part, 2 – base, 3 - cover

In the course of modification, the fundamental change is the head of the engine (Fig. 8) with innovative timing layout, which, in the lower part is matched to the original cylinder of JAWA 50 engine. At the top there is a socket for a steel ball, acting together with the valve controls the intake of compressed air. The middle part (1) is a tray for compressed air just before returning it to the cylinder. There is also a spring which pushes the ball to the base (2). Spring has its mainstay in the basis (2) and the cover (3). In addition, there is universal connector mounted to the lid (3) to the power cord.

Fig. 9. Modified piston from JAWA 50 engine

The original piston have been modificated (Fig. 9). In the center of the piston now there is the spindle, which during filling, raises a steel ball and the compressed air is injected into the cylinder to perform work.

The cycles of this one cylinder JAWA engine is shown by using the model engine (Fig. 10).

When the piston is at the top position (Fig. 10a) its spindle opens the ball valve, the compressed air fills the space of cylinder. The air exerts pressure on surface of the piston, causing its movement down and rotate the crankshaft (Fig. 10b). The valve closes when piston is moving down, but the air is still expanding and exerts a force on the piston. In the lower turning point (Fig. 10c) piston is opening outlet window and releasing air outside. The shaft is starting to move by inertia (Fig. 10d) then pushes the piston to the top and closing the off window. In the cylinder are small amounts of air, so the piston moves upwards until it will again open the ball valve and the cycle repeats.

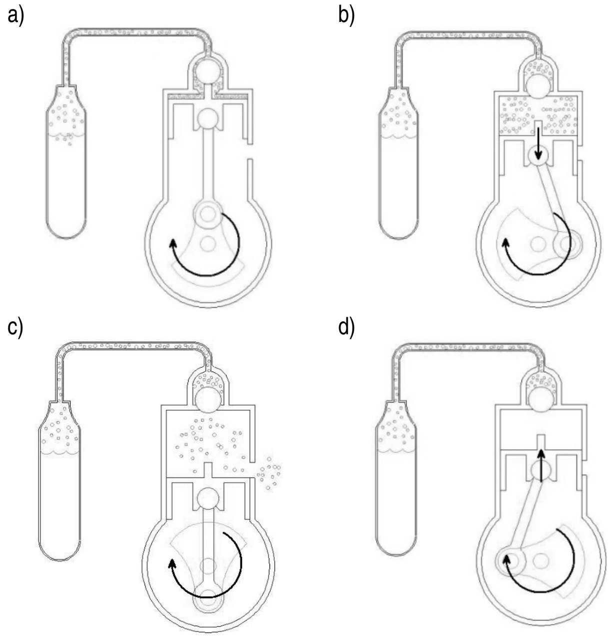

Fig. 10. Work of the model pneumatic engine (www.darmowa-energia.eko.org.pl/pliki/ekoauto/spr_pow.html)

After the prototype was made, there were few initial starts of an engine, which ended successfully. When air pressure approx. 4 bars, there were noticeable sounds of air escaping between the individual parts of the head, which require additional seals. It needed also regulation eject of mandrel mounted on top of piston. After the fixes and reconnecting compressed air, there were achieved speeds in a wide range of work, less vibration against a variant of combustion engine resulting from the absence of cyclic explosions in the combustion chamber.

4.2 Adaptation of FIAT 126P 650 Engine

As the base of the next adaptation was used the engine from the FIAT 126P with engine capacity of 650cm ^{3} (Fig. 11).

Fig. 11. The modified engine FIAT 126 650cm^3

Many of serial parts has been dismantled, making the engine lighter and smaller. It was necessary to make a modifications in key parts of the engine. In the engine, circulation of the compressed-air was inverted, outlet channels became the inlet and inlet channels became outlet ones. Also camshaft has to be changed (Fig. 12). The angle between the axis of the inlet and outlet cam in the serial camshaft is 120°. In the compressed-air engine inlet and outlet cam are placed opposite each other, so the angle between them is 180°.

Fig. 12. The modified camshaft with cams placed opposite

As a result of the modifications, it was necessary to transit the cycle of engine from 4-stroke to only two-stroke, hence the use of 1:1 ratios in the drive shaft timing (Fig. 13).

a)

b)

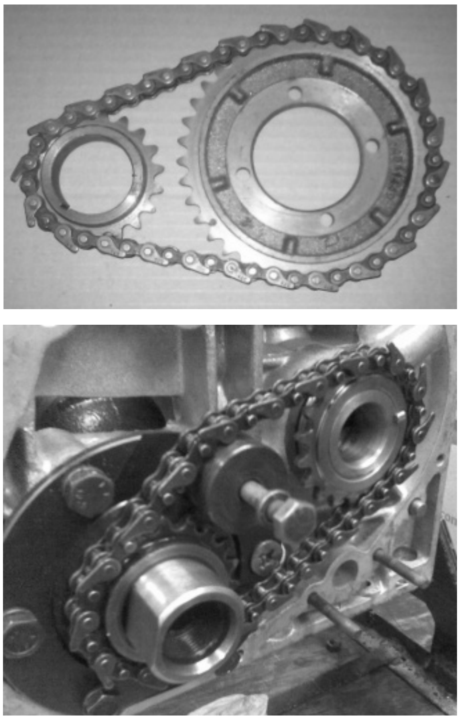

Fig. 13. Drive shaft timing system: (a) original, (b) modified

The operating cycle of the modified engine FIAT 126 is following. Compressed air through the open intake valve (originally outlet) is filling cylinder and pushes the piston down, doing the work. At the end of work stroke air goes out through the outlet valves (originally inlet) on the outside of the engine.

The first tests have shown that the engine is running from the air pressure of 2 bars. Maximum air pressure on which engine worked was 8 bars. Rotating speed of crankshaft, in this case, as like in JAWA engine is regulated by ball valve for regulating flow of mass air to intake. Engine oil system remained unchanged. Interesting is the fact that in the case of compressed-air engine it's possible to get the air conditioning system based on process of expansion in air from the exhaust and the associated pressure drop.

5. APPLY OF THE MODIFY FIAT 126P 650 ENGINE

The first vehicle, in which the modified FIAT 126 engine was provided to be assembly is the tube type vehicle SAM (Fig. 14).

The first tests have shown that the modifications was correct. There are works going on with mounting tank with compressed air and the necessary equipment in the vehicle.

After the tests and road trials will be completed, the engine will be dismantled and its parts taken to verification in order to designate their consumption. This will allow further modifications to increase the usage possibilities.

Further provides for the examination of the engine on rolling road (or dynamometer) to determine the values of the external indicators at variable pressure, indicating the area of the modification phases of timing.

a)

b)

Fig. 14. Vehicle type Buggy in which will be mounted an engine on the compressed air

In parallel with the experimental, will be build a mathematical model of functioning pneumatic engine in Matlab-Simulink. During process of modeling will be used finite element method proposed by Miatluk and Avtuszko (1980) and have been successfully used with modeling of pneumatic braking systems (Miatluk, 2003), and air supply systems of internal combustion engines (Szpica, 2008; Szpica, 2009). To describe the phenomena will be used the descriptions set out in (Bossel, 2010), and verification will be a function of flow Miatluka-Avtuszko against the commonly-used.

As the end result is planned to verify the mathematical model with the results of the experimental in the pressure area changes in the cylinder in different conditions of loads.

6. APPLICATIONS

By making the necessary modifications it is possible, as it has been shown in the article, to adopt classic engines to work in the two-stroke cycle on compressed air. In addition, the use of compressed air as a source of energy, due to the absence of explosions of combustible mixture, as it's in the combustion engine, results in smaller vibrations power unit, which however would reflect negatively on the values of generated torque. Proposed guidelines for the construction of a mathematical model describing work of the pneumatic engine, which intends to be present in subsequent publications.

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