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VALUATION METHOD FOR OPERATION OF CRANKSHAFT-PISTON ASSEMBLY IN COMBUSTION ENGINES IN ENERGY APPROACH

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Abstract

The paper presents a proposal for evaluation (quantification) of operation of any crankshaft-piston assembly in a diesel engine, in which energy interactions proceed at a defined time. This operation is understood as energy transfer to a receiver at a fixed time during which the energy is converted and transferred in the forms of work and heat. Valuation of operation of crankshaft-piston assemblies in diesel engines, as proposed by the author of this paper, consists in equating the operation of this type of engines to a physical quantity whose the unit of measurement is the joule second [joule×second]. The crankshaft-piston assembly operation leading to execution of a power stroke by piston has been presented with regard to that the piston connected to the engine crankshaft through a connecting rod moves flat.

***Keywords**: operation, energy, crankshaft-piston assembly, diesel engine*

1. Introduction

Operation of diesel engines is interpreted as transfer of energy E in the form of heat and work to a receiver at a given time t [3, 7, 8, 9]. So interpreted operation for this type of engines (in valuation approach) is a physical quantity that is a specific numerical value with the unit of measurement called the joule second [joule ×second].

This interpretation of operation for piston internal combustion engines is a result of applying the analogy method that enables transferring the observations from one object of research (empirical system) to another. The inspiration for the considerations undertaken in this paper were suggestions by P.L. Maupertius and W.R. Hamilton to regard the operation of mechanical systems as a physical quantity that describes a change in mechanical energy at time. In consequence, in classical physics there is known an interpretation for operation as a result of energy changes over time, expressed as a product of energy and time, which makes that the unit of measurement for the operation is the joule second.

This approach considers the operation [12, 13]:

• of a mechanical system, as a result of change in kinetic and potential energy, which is called the Hamilton's operation (D_H) and

• resulting only from a change in kinetic energy of a mechanical system, called the Maupertius' operation (D_M).

A similar interpretation for operation has been adopted to quantum mechanics with reference to the source of electromagnetic radiation [9]. The equivalent to operation in the same sense is here the Planck's constant (h), which is also a physical quantity expressed by a number with the unit of measurement [joule × second].

Achievements in classical physics and quantum mechanics in this regard have led the author to an idea to implement such understood operation also to the technique by providing it with an individual interpretation for particular power systems, including piston diesel engines.

Such engine operation study seems to be useful because consideration of engine power properties, based on analysis and assessment of the way of energy E transfer in the form of work, do not provide full recognition on the engine usefulness for performing a task (work is a form of energy conversion). Such recognition is reached through considering the converted energy and the time of its conversion jointly, so the quantity $D = E{\cdot}t$ that has been called the engine operation. So understood engine operation provides information on how long the energy E is or may be converted. If we narrow down the analysis on energy conversion only to work (L) as a way (form) of energy conversion, simultaneously considering the time of work performance, the engine operation can be defined then as $D_L = L{\cdot}t$. This type of engine operation provides information on how long the work L is or can be performed. This information is equally important as this one provided by engine power (N), which can be determined when knowing the work L and its performance time t. The power, as it is known, provides information on how quickly the work (L) can be done.

In this approach the operation can also be considered for other functional systems in such engines. Undoubtedly, the crankshaft-piston assemblies are ones of the most important functional systems that enable converting the internal energy of exhaust gas into mechanical. The internal energy of exhaust gas is here understood as energy of movement of molecules making up the exhaust gas. It is also called the thermal or heat energy. In this connection interesting may be the issue of analysis and evaluation of so understood operation of this type of assemblies in diesel engines.

The proposed by the author herein interpretation of operation of crankshaft-piston assemblies in diesel engines has the advantage that a descriptive estimation of operation of the systems, eg. the work is good, not too good, worrisome, bad, etc. can be replaced by evaluation resulting from comparison of their operation to the standard operation by using numbers with the unit of measurement which is the joule second.

The meaning of such interpretation for operation of crankshaft-piston assemblies in engine and generally in each power mechanism can also be justified by the observation that changes in motion of any body (eg, piston, crankshaft crank, connecting rod) depend on how large the force (F) acts on the body and what the time (t) is of its action. This possibility of body motion is expressed as a product of force and time ($F{\cdot}t$), called the impulse of force [5]. Thus, the unit of the impulse is the newton-second [*newton×second*]. Using the analogy the reasoning can be made as follows: operation ($D = E{\cdot}t$) of a crankshaft-piston assembly in a diesel engine depends on the form into which the energy is transferred by the engine and at what time (t). You can also consider a special case of energy transfer, eg in the form of work (L) and then the reasoning is as follows: operation ($D_L = L{\cdot}t$) of a crankshaft-piston assembly in a diesel engine depends on how big work (L) is performed by this engine and at what time (t).

Presentation of the problem of operation of crankshaft-piston assemblies in this approach is, however, difficult. This follows from the fact that energy is understood in different ways, for example, in classical physics the energy is defined as the only measure for different forms of motion. In thermodynamics, where additionally heat is considered, such definition of energy is not sufficient and therefore the energy is defined as a state function of a thermodynamic system or physical body. In addition, energy can be felt only when it is transmitted. In technique there are known two forms (two ways) of its transfer, namely heat and work. Therefore, operation of crankshaft-piston assemblies will be considered as a transfer of exhaust gas internal energy in the form of work done by a crankshaft-piston assembly and heat lost to the environment.

2. Formulation of the problem of quantification of operation of crankshaft-piston assembly in diesel engine.

Operation of a crankshaft-piston assembly is initiated by work of a piston, which can be considered as transferring the mechanical energy by it, to the other mechanisms of this system. During operation of a diesel engine the chemical energy is delivered to its workspaces as it is contained in the air-fuel mixture produced in these workspaces (cylinders). The energy cannot be assessed until is converted, and this proceeds in the forms of heat and work. Conversion of energy (E) in these forms always runs within a defined time (t). The energy conversion in the way known as heat (in the form of heat} is realized at the time of fuel combustion resulting in creating the internal energy of combustion gases which are the output of the rapid oxidation of combustible components of fuel injected into the cylinder. The combustion runs at a defined time, so the analysis should concern the combustion process which is described the most often by a change in the combustion pressure (p_s) and temperature (T), as shown in Fig. 1. A fuel dose (G_p) and heat release rate ($dq_s/d\alpha$) are often analyzed, too. An example of a graph showing the change in parameters characterizing the combustion process is presented in Fig. 1

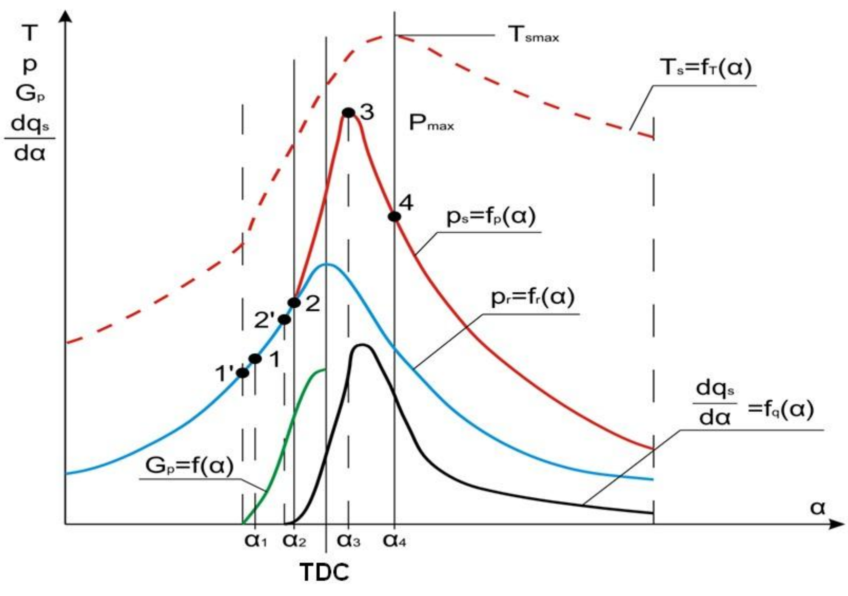

Fig. 1 Graph of changes in pressure and temperature in a diesel engine cylinder:
p - pressure, T - temperature, α - angle of crankshaft rotation, p_{max} - maximum pressure
T_{max} - maximum temperature p_s - combustion pressure, p_r - air pressure in a cylinder at absence of combustion, T_s - combustion temperature, $dq_s/d\alpha$ - heat release rate, G_p - fuel dose,
1 '- beginning of fuel pumping, 1 - beginning of fuel injection, 2' - occurrence of first self-ignition centers, 2 - beginning of fuel combustion in a cylinder, 3 - maximum pressure, 4 - end of combustion process, TDC - top dead centre.

Combustion of fuel in the workspace (cylinder) in a diesel engine results in thermal and mechanical loads on it, whereas the most loaded is the crankshaft-piston assembly which is needed in the engine to convert the internal energy of exhaust gas into mechanical energy of the system. This form of energy conversion, as it is known, is called the work. This conversion is accompanied by thermal and mechanical loads on the crankshaft-piston assembly. The mechanical load is a result of the forces and torques acting on the system. An example of a graph of forces acting on the crank system in a trunk engine during fuel combustion in a cylinder is shown in Fig. 2

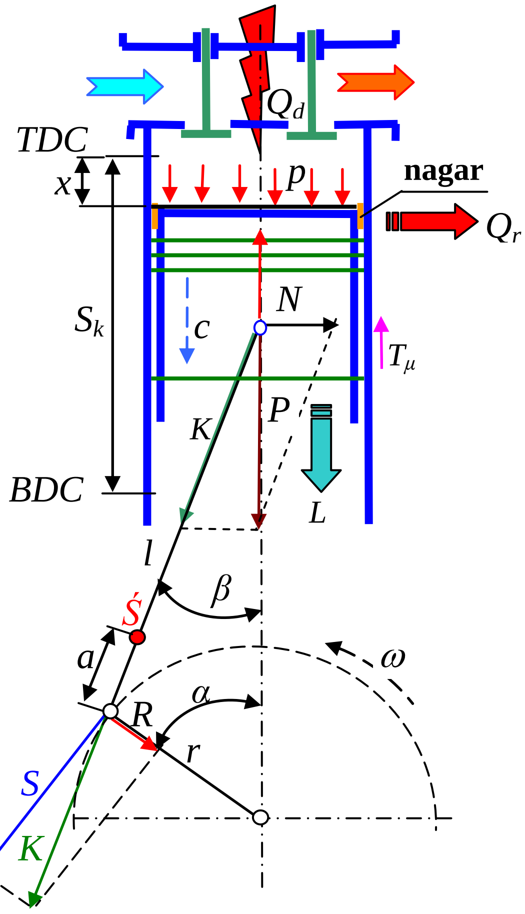

Fig. 2. Diagram of forces acting on an arbitrary crankshaft-piston assembly in a trunk engine: TDC - top dead centre of piston, BDC - bottom dead centre of piston, x - piston displacement depending on the angle of crankshaft position (α), S_k - piston stroke, p - pressure acting on piston crown, c - piston speed, N - normal (lateral) force, K - connecting rod force, S - tangential component of the force K, R - radial component of the force K, P - piston force, l - connecting rod length, ω - crankshaft angular velocity, r - crank radius, β - connecting rod angle, α - crank angle, T_μ - friction force, Q_d - supplied heat, Q_r - dissipated heat, transferred through workspace walls, L - work done by a crankshaft-piston assembly, Ś - centre of mass of a connecting rod, a - distance from the mass centre of connecting rod to the centre of connecting rod big end (centre of crankpin) in engine crankshaft

It should be kept in mind that all the forces enclosed in the diagram of the forces acting on an arbitrary crankshaft-piston assembly in internal combustion engines (Fig. 2) are random quantities, since combustion is a stochastic process. One of its various realizations is shown in Fig. 1 Similarly, heat loads on pistons and bearings are of a random nature. Despite of this, they may sometimes be considered as deterministic quantities [6, 10].

The net force (P), which is the algebraic sum of the gas force and fictitious force (Fig. 2) acts along the axis of the cylinder.

The force acting perpendicular to the axis of the cylinder (P_N) causes piston pressure onto the surface (finishing) of the cylinder sleeve (in case of a trunk engine) and in consequence - friction between the piston and the sleeve, as well as wear of the tribological system.

The force acting along the axis of the connecting rod (K) is transferred by the connecting rod to the crankpin. Its radial component (R) is carried by the crankpin and crank webs to the crank journal. Thus, it loads the crankpin and crank journal. This force is variable as for its value and action direction. It is considered to be positive while clutching the crank webs. The tangential force (S) not only loads the crank and main bearings, but also causes a momentary torque M_o, whose variability is connected with variability of the tangential force, depending on the angle of rotation of the crankshaft (α) . The forces R and S are defined by the formulas [10]:

$$N = Ptg\beta\,,\quad K = \frac{P}{\cos\beta}\,,\quad S = P\frac{\sin(\alpha+\beta)}{\cos\beta}\,,\ \text{and}\ R = P\frac{\cos(\alpha+\beta)}{\cos(\beta)} \tag{1}$$

From the formula (1) follows that the forces N (lateral, normal), R (radial) and S (tangential force) undergo a change depending on angular position of the crankshaft (α). The forces change during operation of the crankshaft-piston assembly in a combustion engine, of which the task is to convert (transform) the internal energy of the exhaust gas into mechanical energy. Considering in general the energy conversion at time t (at assumption that the mass of substrates is equal to the mass of exhaust gas), in accordance with the first law of thermodynamics, the following equation can be written down:

$$U(\mathrm{t}) = L(t) + Q(t) \tag{2}$$

where:

U - internal energy of exhaust gas, L - work, Q - heat loss to the environment

Thus, this formula is valid when assuming that during a power stroke the thermodynamic system being the engine's workspace is closed.

The mentioned internal energy of exhaust gas is a sum of the energy of intermolecular and intramolecular interactions and the energy of thermal motion of molecules [11].

When the crankshaft-piston assembly works, during power stroke the exhaust gas expands in a cylinder from TDC (top dead centre) and the combustion pressure decreases from $p_{\max}$ (Fig. 1) to BDC (bottom dead center).

This operation is a result of exhaust gas pressure on the piston crown, which causes a piston displacement from TDC to BDC. When the piston is at TDC, its instantaneous velocity c is equal to zero (c = 0), which means that at this point the kinetic energy of the piston is equal to zero $E_k = 0$. The piston at TDC position will have a potential (position) energy $E_p = mgS$ with reference to BDC, after reaching which it will return to TDC. This piston movement, however, (from BDC to TDC) will be provided by energy coming from outside (from systems performing work at this time, or from mechanisms which accumulated excess mechanical energy before, eg. from the flywheel). For this reason, this movement is not included in the proposed model of operation of the crankshaft-piston assembly in engine.

During piston displacement from TDC to BDC its speed will increase to the maximum (c_{max}) and along with the speed - the kinetic energy ($E_k > 0$) which at this speed will be maximum ($E_{k\max}$). From this moment the piston speed decreases, and along with the speed - its kinetic energy. In turn, the potential (gravity) energy of the piston along with its movement from TDC to BDC will decrease from the maximum value ($E_{p\max}$) at TDC to the zero value at the taken reference position which is BDC ($E_p = 0$).

Considering the operation of a crankshaft-piston assembly, it should be kept in mind that the internal energy (U) of exhaust gas produced in a cylinder, is converted during transformation into mechanical energy (E_m) of the piston and other components of this system, where the piston performs at this time the work (L) on the distance from TDC to BDC. Also at this time the energy is partially lost due to friction existing in tribological pairs in the crankshaft-piston assembly, while being dissipated in the form (in the way) of heat (Q).

Considering the operation of a crankshaft-piston assembly leading to execution of a power stroke by its piston it should be remembered that the piston connected to the engine crankshaft through a connecting rod moves flat. This results in that the kinetic energy of the crankshaft-piston assembly is as follows:

$$E_k(t) = \frac{1}{2} \cdot I \cdot \omega^2 + \frac{1}{2} \cdot I_k \cdot \left(\frac{d\beta}{dt}\right)^2 + \frac{1}{2} \cdot m_k \cdot \left[\left(\frac{dx_s}{dt}\right)^2 + \left(\frac{dy_s}{dt}\right)^2\right] + \frac{1}{2} \cdot m \cdot \left(\frac{dx}{dt}\right)^2 \qquad (3)$$

where:

I – mass moment of inertia of engine crankshaft with flywheel,
I_k – moment of inertia of connecting rod,
m_k – mass of connecting rod,
m – mass of piston,
x_s , y_s – vertical and horizontal coordinate of mass centre (Ś) of connecting rod (Fig. 2),
x – piston displacement depending on angle of crankshaft position (α)
β – heading *angle between connecting rod and piston axis.*

In the formula (3) the first component represents the energy of engine crankshaft with a flywheel, second - energy of rotational motion of connecting rod, third - energy of its translational motion, and fourth - energy of translational motion of piston. The equation (3) can be written in the simpler form by applying trigonometric relation between quantities shown in Fig. 2*:*

$$\left.\begin{array}{l} x_s = r \cdot \cos\alpha + a \cdot \cos\beta \\ y_s = r \cdot \sin\alpha - a \cdot \sin\beta \\ \sin\beta = \sin\alpha \\ \lambda = \dfrac{r}{l} - ratio \cdot of \cdot connecting \cdot rod \cdot length \\ \alpha = \omega \cdot t \\ x = l \cdot \cos\beta + r \cdot \sin\alpha \end{array}\right\} \qquad (4)$$

where:

ω - angular velocity of engine crankshaft

By applying the trigonometric formulas (4) the equation (3) can be written as:

$$E_k = \frac{1}{2}\left[I + F(\alpha)\right] \cdot \omega^2 \qquad (5)$$

where:

the characteristic function of the system with regard to the crank deflection of the crankshaft F (α) is defined as follows

$$F(\alpha) = I_k \cdot \left(\frac{d\beta}{d\alpha}\right)^2 + m_k\left[\left(r \cdot \sin\alpha + \lambda \cdot a \cdot \sin\beta \cdot \frac{\cos\alpha}{\cos\beta}\right)^2 + (r - \lambda \cdot a)^2 \cdot \cos^2\alpha\right] + m \cdot r^2 \cdot \frac{\sin^2(\alpha + \beta)}{\cos^2\beta}$$

where: other designations are as in Fig. 2 and in formulas (3) and (4).

As a piston starts moving from TDC, the kinetic energy of a crankshaft-piston assembly has an initial value E_{k0} corresponding to the first so-called "dead" position of the crank for $\alpha = 0$ and is described by the equation:

$$E_{k0} = \frac{1}{2}[I + F(0)] \cdot \omega_0^2 \tag{6}$$

where:

$F(0) = I_k \cdot \lambda^2 + m_k \cdot (r - \lambda \cdot a)^2$

where: designations are as in formula (4).

During piston movement to BDC, this energy will be greater than zero. ($E_k > 0$). When the piston is at TDC position the potential energy of the crankshaft-piston assembly calculated with reference to BDC, will be equal to the initial kinetic energy, ie $E_p = E_{k0}$.

Therefore, taking into account at the same time the mechanical energy (E_m) of the crankshaft-piston assembly and the time of its change, the following equation can be written down:

$$D_T(t) = \int_0^t E_m(t)\mathrm{d}t = \int_0^t \left(E_k(t) + E_p(t)\right)\mathrm{d}t \tag{7}$$

where:

$D_T\,(t)$ - piston work, E_m - mechanical energy, E_k - kinetic energy E_p - potential energy,
t - time

During the so-understood operation of a crankshaft-piston assembly at the time of engine power stroke, the kinetic energy (E_k) increases from the value equal to E_{k0} to the maximum value ($E_k = E_{\max}$), when the piston reaches the maximum speed ($c_{\max}$), which takes place in a small distance before the position corresponding to the crank rotation by the angle $\alpha = 90$ ° [10]. Then, this energy decreases to the value E_{k0} at BDC where the piston speed is also zero ($c = 0$). In turn, the potential energy (E_p), is of the greatest value when the piston is at TDC and is being reduced when the piston moves from TDC, until reaches the lowest value at BDC.

When the piston finds at TDC, additionally at this position it is affected by the internal energy of compressed fresh charge and small internal energy of exhaust gas generated just after self-ignition, at the beginning of the so-called period of flash fire. It can be expected that if the rotational speed n of the crankshaft was then equal to zero, the internal energy of the compressed fresh charge (U_{SL}) and potential energy of the piston, would not be able to set this system in motion. They would not be able because then their energy would be insufficient to overcome the motion resistance of the system. Motion of the crankshaft-piston assembly is possible only when the conversion of chemical energy of fuel (E_{chpl}), into internal energy of exhaust gas (U), proceeds in continuous manner. Then, part of this energy will cause the piston motion, giving to it the energy E_k. The rest of energy U is dissipated according to the equation (2).

The work of external forces acting on the crankshaft-piston assembly, corresponding to an increment in its kinetic energy, is defined by the equation:

$$L(\alpha) = \int_0^\alpha (S - R_A) \cdot r \cdot d\alpha = P \cdot r \cdot (1 - \cos\alpha) + \frac{r}{2 \cdot \lambda} \cdot \arcsin\left(\lambda^2 \cdot \sin^2 \alpha\right) + R_A \cdot r \cdot \alpha \tag{8}$$

where:

S - tangential force (Fig. 2) acting on the crank web of engine crankshaft,
R_A - utility resistance (power receiver) in engine

The equation (8) shows that operation of a crankshaft-piston assembly is a function of crankshaft rotation angle α and causes a change in its kinetic energy.

The relationship between energy and work for the flat motion [11] being performed by the mentioned system, can be written as:

$$\frac{1}{2}[I+F(\alpha)]\cdot\omega^2+\int_0^\alpha (S-R_A)\cdot r\cdot d\alpha = E_{k0} \tag{9}$$

In the formula (9) designations have the same interpretation as in the previous formulas.

In practice, the precise equation expressing the relationship between the kinetic energy and work (9) is replaced by an approximate one:

$$\frac{1}{2}\cdot I\cdot\left(\omega^2-\omega_0^2\right)=\int_0^\alpha (S-R_A)\cdot r\cdot d\alpha-\frac{1}{2}\cdot\omega_{śr}^2\cdot[F(\alpha)-F(0)]=G(\alpha) \tag{10}$$

where:

$G(\alpha)$ – characteristic function of the system.

The angular velocity for engine crankshaft is derived from the equation (9), obtaining the following formula:

$$\omega=\frac{d\alpha}{dt}=\sqrt{\frac{2\cdot(E_k)_0-2\cdot L(\alpha)}{I+F(\alpha)}} \tag{11}$$

In the formula (11) designations have the same interpretation as in the previous formulas.

The angular velocity of engine crankshaft reaches the values $\omega_{\max}$ or $\omega_{\min}$ for the values of the crankshaft rotation angle α,, which correspond to maximum and minimum of the function $G(\alpha)$. Values $G_{\max}$ and $G_{\min}$ are calculated on the basis of indicator diagram by taking into account the tangential force S (*Fig. 2*) which is a function of the angle α and afterwards the motion resistance force (R_A) of the engine crankshaft-piston assembly (utility resistance) is determined from the condition:

$$\int_0^\alpha (S-R_A)\cdot r\cdot d\alpha = 0 \tag{12}$$

The motion resistance force can also be derived by differentiating the equation (9) as follows:

$$[I+F(\alpha)]\cdot\frac{d^2\alpha}{dt^2}+\frac{1}{2}\cdot\frac{dF(\alpha)}{d\alpha}\cdot\omega^2+(R_A-S)\cdot r=0$$

hence (13)

$$R_A=S-\frac{1}{r}\cdot\left\{[I+F(\alpha)]\cdot\frac{d^2\alpha}{dt^2}+\frac{1}{2}\cdot\frac{dF(\alpha)}{d\alpha}\cdot\omega^2\right\}$$

Therefore, taking into account the dynamics of the crankshaft-piston assembly [6, 10], its operation during the power stroke can be (in general terms) defined as follows:

$$D(t)=\left[P\cdot r\cdot(1-\cos\alpha)+\frac{r\cdot\arcsin\left(\lambda^2\cdot\sin^2\alpha\right)}{2\cdot\lambda}\right]\cdot t-r\cdot R_A\cdot\omega\cdot t^2 \tag{14}$$

where: designations are as in the previous formulas.

From the formula (14) follows that at the operating time of piston performing a work, the kinetic energy obtained from the internal energy of exhaust gas is consumed. Therefore, when the piston is under operation the energy is converted into work, which consists in changing a part of the internal energy of exhaust gas into kinetic energy of the piston. Additionally, the potential energy which the piston owns being at TDC, takes also part in the conversion.

The time (t) of piston operation can be determined on the basis of the following reasoning. During piston motion from TDC to BDC, which enables execution of work by a piston force *P* made above the piston while travelling the distance S (piston stroke), the piston moves at subsequent moments by a defined value x dependent on the angle (α)) of the crankshaft position (Fig. 2) [10].

Integrating the equation (11) gives the formula for the motion, from which the time of piston operation is calculated as follows:

$$t = \int_0^\alpha \sqrt{\frac{I + F(\alpha)}{2 \cdot \left[(E_k)_0 - L(\alpha)\right]}} \cdot d\alpha \tag{15}$$

where: designations are as in the previous formulas.

By applying the given formulas, the following difficulties arise: although the forms of the functions $F(\alpha)$ and $L(\alpha\}$ are known we do not know the values E_{k0} because unknown is the angular velocity ω_0 corresponding to the initial energy E_{k0}. These difficulties are solved by adopting the average value of angular velocity ω_0 and applying the equations from which the velocity ω_0 is derived:

$$\begin{gathered} \frac{2\pi}{\omega_{śr}} = \int_0^{2\pi} \sqrt{\frac{I + F(\alpha)}{[I + F(0)] \cdot \omega_0^2 - L(\alpha)}} \cdot d\alpha \\ \omega_{śr} = \frac{2\pi}{T} \end{gathered} \tag{16}$$

where:

T – period of one rotation of engine crankshaft.

The presented proposal of analysis and valuation of operation of a crankshaft-piston assembly during piston motion from TDC to BDC at the time of power stroke, can be applied when the assumption can be accepted that the combustion process is not a stochastic process. If this assumption cannot be accepted, the statistical methods need to be applied.

The internal energy provides motion of the piston from TDC to BDC, during which is converted in the form of work into mechanical energy of a crankshaft-piston assembly. However, only a part of this energy is converted to mechanical energy of CPA (according to the second law of thermodynamics), the rest is dissipated to the environment as energy being lost due to friction in its tribological pairs and the energy loss because of existing differences in temperature between exhaust gas and CPA components and the ambient temperature.

From the considerations follows that only a part of the internal energy of exhaust gas makes motion of PCS' components and the rest undergo dissipation as different types of energy.

Operation of crankshaft-piston assemblies over time will require more and more internal energy of exhaust gas, because the energy losses will increase due to:

• increase in exhaust gas flow between the piston and the cylinder liner into the under piston space because of wear of rings or their immobilization in the grooves as a result of occurrence of exhaust carbon,

• increase in friction between the piston and the sleeve and bearings of the crankshaft and the piston pin bearing, if the piston is connected to the connecting rod through a pin,

• scuffing of the piston in the cylinder liner.

This results from wear of the mentioned tribological pairs in engine crankshaft-piston assemblies and from aging lubricating oil.

The technical diagnostics is needed to be applied in order to obtain information on the process of the exhaust gas flow as well as friction and wear in specific tribological pairs of crankshaft-piston assemblies in a combustion engine.

3. Remarks and conclusions

The proposed interpretation for operation of crankshaft-piston assemblies (CPA) in engine is the first such attempt, presented in general terms. However, it requires more precise defining, which will not be easy because of the need for detailed identification of all energy types which undergo conversion at the time of CPA operation.

The proposed evaluation method for operation of a crankshaft-piston assembly leading to execution a power stroke by its piston, reflects the observation that the piston connected to the engine crankshaft via a connecting rod performs a flat motion.

Certainly, the provided considerations on CPA operation have cognitive advantages, but at this moment it is difficult to determine how much important to science. In turn, the utilitarian values are difficult to be assessed because of problems with implementation of relevant empirical research.

CPA operation requires defining a change in not only energy but also time of its conversion. Both the amount of converted energy which manifests itself in the ways (forms) of its conversion, as well as the operating time of CPA operation, during which the energy conversion proceeds, depend on the technical state of its components, particularly a piston which is the most loaded mechanism. Thus, quantification of the operation requires application of an adequate measuring technique.

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