Dynamic method of controlling friction losses in the mechanism of converting reciprocating motion into rotary inline piston internal combustion engines

A V Egorov\textsuperscript{1}, A V Lysyannikov\textsuperscript{2}, Yu F Kaizer\textsuperscript{2}, N S Andryuhin\textsuperscript{3}, S V Dorohin\textsuperscript{4}, A V Kuznetsov\textsuperscript{5}, E N Bogdanov\textsuperscript{1} and N N Lysyannikova\textsuperscript{2}

\textsuperscript{1}Volga State University of Technology, 424000, Yoshkar–Ola, 3, Lenin Square, Russia
\textsuperscript{2}Siberian Federal University, 660041, Krasnoyarsk, 82/6, Svobodny Avenu, Russia
\textsuperscript{3}Transneft Upper Volga, JSC, 603950, Russia, Nizhny Novgorod, per. Granite, 4/1, Russia
\textsuperscript{4}Voronezh State University of Forestry and Technologies Named after G.F. Morozov, 394087, Voronezh, 8, Timiryazeva str., Russia
\textsuperscript{5}Krasnoyarsk State Agrarian University, 660074, Krasnoyarsk, 2, Kirenskogo, Russia

E–mail: kaiser171074@mail.ru

Abstract. The task of reducing friction in internal combustion engines is an important task of the development of transport engineering. As the analysis of literary sources shows, the problem of reducing friction losses in relation to internal combustion engines is usually solved for each individual friction pair, for example, a cylinder-skirt of a piston or a cylinder-compression ring. In this case, the measurement of friction is carried out mainly in stationary conditions. However, such approaches do not allow identifying the most critical, in terms of friction in all friction pairs of an internal combustion engine, modes of operation and do not allow to carry out research and control of friction processes of all friction pairs in the internal combustion engines. The developed dynamic methods of control of mechanical parameters of engines of rotational action and drives on their basis allow to synthesize a dynamic method of control of friction losses in the internal combustion engines, the scientific and technical justification of which is devoted to this work. Critical, from the point of view of the developed method, is the calculation of the value given to the axis of rotation of the crankshaft moment of inertia of the parts of the crank mechanism, changing during one revolution of the crankshaft.

1. Introduction

The tasks of reducing friction in internal combustion engines are an important task for the development of transport engineering [1-2]. As the analysis of literary sources shows, the problem of reducing friction losses, as applied to internal combustion engines, is usually solved for each individual friction pair, for example, cylinder-piston skirt or cylinder-compression ring [3-8]. The measurement of friction is carried out mainly in stationary conditions. However, such approaches do not allow identifying the most critical, from the point of view of friction in all friction pairs of an internal combustion engine, modes of operation and do not allow to carry out research and control of friction processes of all friction pairs on transient modes of operation of an internal combustion engine.

The developed dynamic methods for controlling mechanical parameters of rotary engines and drives
based on them [9–10] make it possible to synthesize a dynamic method for controlling friction losses in an internal combustion engine, the scientific and technical substantiation of which is the subject of this work.

2. Development of a dynamic method for controlling friction losses in the mechanism of converting reciprocating motion into rotational in-line piston internal combustion engines

The scheme of implementation of the dynamic method of controlling friction losses in the mechanism of converting the reciprocating motion into rotational inline piston internal combustion engines is shown in figure 1.

Figure 1. The scheme of implementation of the dynamic method of friction loss control in the mechanism of converting reciprocating motion into rotational piston internal combustion engines: 1 - drive motor, 2 - position sensor of the rotor of the drive motor, 3 - coupling, 4 - the studied mechanism of converting reciprocating motion into rotary inline piston internal combustion engines installed in the engine block.

The implementation of the method is preceded by the control of the mechanical parameters of the drive motor experimentally using the moment of inertia of the coupling 3 (figure 2).

Figure 2. The control circuit of the mechanical parameters of the drive motor: 1 - the drive motor, 2 - the rotor position sensor of the drive motor, 3 - coupling.

On the shaft of the drive motor 1 with the moment of inertia $J_{dm}$ set coupling 3 with the moment of inertia $J_c$. With the help of regulators, a certain angular velocity $\omega$ of the output shaft of the drive motor 1 is established, at which a certain torque $M(\omega)$ develops. Then, the angular acceleration $\varepsilon_1$ of the system of rotating masses «drive motor – coupling» is measured, which has an inertia moment when the angular velocity of rotation of the output shaft varies from $\omega$ to $\omega + d\omega$. Torque $M(\omega)$ for the range of
angular velocities from \( \omega \) to \( \omega + d\omega \) is equal to:

\[
M(\omega) = (k_{dn}(\omega)J_{dn} + J_c)\varepsilon_1,
\]

where \( k_{dn}(\omega) \) - coefficient taking into account losses due to friction in the bearings of the drive motor shaft at an angular velocity \( \omega \).

Next, the coupling \( 3 \) is removed, the drive motor starts and the angular acceleration \( \varepsilon_2 \) of the system of rotating masses «drive motor» is determined when the angular velocity of the output shaft changes in the range from \( \omega \) to \( \omega + d\omega \), that is, with the same initial value of torque \( M(\omega) \). Torque \( M(\omega) \) for the range of angular velocities from \( \omega \) to \( \omega + d\omega \) is equal to:

\[
M(\omega) = k_{d,m}(\omega)J_{d,m}\varepsilon_2.
\]

From equations (1) and (2) is determined:

\[
k_{d,m}(\omega)J_{d,m} = J_c \frac{\varepsilon_1}{\varepsilon_2 - \varepsilon_1}.
\]

Next, the installation is assembled according to figure 1, with the drive of all auxiliary mechanisms, the gas distribution mechanism and the cylinder head being removed from the internal combustion engine. The coolant circulation channels that open during this process are hermetically interconnected to ensure the free circulation of coolant. The oil pump and the coolant circulation pump are supplied with independent drives. The circuits of coolant and lubricating oil are supplied with heaters. Then, the temperature and circulation rate of the lubricating oil and coolant in the circulation circuits are brought to the workers, and the temperature of the engine block is also brought to the working one.

Next, the drive motor starts and determines the angular acceleration \( \varepsilon_3 \) of the rotating mass system «drive motor - coupling - mechanism for converting reciprocating motion into rotational piston internal combustion engine» when the angular velocity of the output shaft changes in the range from \( \omega \) to \( \omega + d\omega \), that is, the same initial value of torque \( M(\omega) \). Torque \( M(\omega) \) for the range of angular velocities from \( \omega \) to \( \omega + d\omega \) is equal to:

\[
M(\omega) = (k_{d,m}(\omega)J_{d,m} + J_c + k_{c,m}(\omega)J_{c,m})\varepsilon_3,
\]

where \( k_{c,m}(\omega) \) - coefficient taking into account friction losses in all elements of the mechanism (crank mechanism) for converting reciprocating motion into rotational piston inline engine at angular velocity \( \omega \); \( J_{c,m} \) - the moment of inertia of the mechanism for converting a reciprocating motion into a rotary inline piston internal combustion engine.

Equating equations (2) and (4) taking into account (3) we define:

\[
k_{c,m}(\omega) = \frac{J_{c,m}}{J_c} \frac{\varepsilon_1 - \varepsilon_3}{\varepsilon_2 - \varepsilon_1}.
\]

The coefficient characterizing the mechanical losses in the mechanism of converting reciprocating motion into rotational piston inline engine:

\[
k_{\text{los},c,m}(\omega) = 1 + k_{c,m}(\omega).
\]
To implement the method, it is necessary to determine $J_{c.m.}$, the row piston internal combustion engine under investigation.

The moment of inertia of the disaxial crank mechanism (figure 3), brought to the axis of rotation of the crankshaft, is determined in the same sequence as the moment of inertia of the axial crank mechanism, but has its own characteristics.

**Figure 3.** Diagram of a disaxial crank mechanism single cylinder engine engine: $r$ - the crank radius; $l$ - the length of the connecting rod; $l_0$ - the distance from the axis of the crank pin to the center of gravity of the connecting rod; $b$ - the distance from the center of gravity of the connecting rod to the axis of rotation of the crankshaft; $b_1$ - the distance from the center of gravity of the piston pin to the axis of rotation of the crankshaft; $b_2$ - the distance from the center of gravity of the piston to the axis of rotation of the crankshaft; $c$ - the projection on the vertical axis of the distance from the center of gravity of the piston pin to the axis of rotation of the crankshaft; $c_0$ - the distance from the center of gravity of the piston pin to the center of gravity of the piston; $a$ - disaxial; $\alpha$ - the angle of deviation of the axis of the connecting rod from the axis of the cylinder; $\beta$ - the angle between the crank and the connecting rod; $\phi$ - the angle of rotation of the crank, counted in the direction of rotation of the crank from its vertical position; $\gamma$ - the angle between the horizontal and the segment $b_1$.

The angle of deviation of the axis of the connecting rod from the axis of the cylinder we find from the relationship $r \sin \phi = l \sin \alpha$:

$$\alpha = \arcsin \left( \frac{r \sin \phi - a}{l} \right).$$

Angle $\beta$ is $\beta = 180 - \alpha - \phi$.

Distances $b$ and $b_1$ determine by the cosine theorem:

$$b = \sqrt{r^2 + l_0^2 - 2rl_0 \cos \beta},$$

$$b_1 = \sqrt{r^2 + l^2 - 2rl \cos \beta}.$$
\[ c = r \cos \phi + l \cos \alpha . \]  

(11)

The angle \( \gamma \) is determined from the expression

\[ b_1 \cos \gamma = a \]

\[ \gamma = \arccos \frac{a}{b_1} . \]  

(12)

where \( a \) - disaxial.

The distance \( b_2 \) is determined by the cosine theorem

\[ b_2 = \sqrt{b_1^2 + c_0^2 - 2b_1c_0 \cos(90 + \gamma)} . \]  

(13)

The moment of inertia of the piston mass \( m_p \), taking into account the mass of the compression and oil wiper rings relative to the axis of rotation of the crankshaft is equal to

\[ J_p = m_p b_2^2 + J_{p0} , \]  

(14)

where \( J_{p0} \) - the moment of inertia of the piston relative to its central axis.

The moment of inertia of the piston pin relative to the axis of rotation of the crankshaft

\[ J_{p.p} = m_{p.p} b_1^2 + J_{p.p.0} , \]  

(15)

where \( J_{p.p.0} \) - the moment of inertia of the piston pin relative to its central axis.

The moment of inertia of the connecting rod relative to the axis of rotation of the crankshaft

\[ J_{c.r.} = m_{c.r.} b_1^2 + J_{c.r.0} , \]  

(16)

where \( J_{c.r.0} \) - the moment of inertia of the connecting rod relative to its central axis.

Assuming that the moment of inertia of the crankshaft \( J_{\text{crankshaft}} \) is constant and does not depend on the position of the crankshaft, we determine the moment of inertia of the axial crankshaft engine of the inline piston internal combustion engine in the form

\[ J_{c.m.} = J_p + J_{p.p} + J_{c.r} + J_{\text{crankshaft}} . \]  

(17)

The results of mathematical modeling of the disaxial crank mechanism under \( r/l = 0.3 \) and changing the ratio \( a/r \) in the range \( a/r \in [0:1] \) of single-cylinder internal combustion engines show that as the ratio increases \( a/r \), a harmonic change occurs in the dependence of the crank shaft inertia moment on the crank mechanism rotation angle \( \phi \) (figure 4).
Figure 4. The effect of the size of the disaxial on the nature of the change in the moment of inertia of the crank mechanism single-cylinder engine for one rotation of the crankshaft.

Mathematical modeling data show that the moment of inertia of parts of a crank mechanism, which is reduced to the axis of rotation of the crankshaft, changes during one revolution of the crankshaft. The dependence of the crankshaft moment of inertia of the crankshaft axis driven to the axis of rotation changes from the angle of rotation of the crankshaft rotation is crucial for the implementation of the described method.

3. Conclusion

- Control of the mechanical parameters of the mechanisms for converting reciprocating to rotary motion in in-line piston internal combustion engines in a wide range of speed, temperature and transient modes of operation with high accuracy is possible by a dynamic method.
- The value of the moment of inertia of a crank mechanism connecting to the axis of rotation of the crankshaft, which changes during one revolution of the crankshaft, is crucial for the implementation of the developed dynamic control method.

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