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A New Method for Control the IC Engine Mechanical Parameters without its Demounting from a Vehicle

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Abstract

The purpose of this paper is to develop and experimentally substantiate a new method to control such internal combustion engine (ICE) parameters as the moment of inertia, the torque, and the power. Existing methods use for these purposes costly brake stands and do not allow determining those parameters without demounting the ICE from a vehicle. This article describes two methods for control the parameters of ICE: by means of an electricity meter, and using a reference body. The latter allows control the mechanical parameters of ICE in dynamic conditions with fewer errors and less financial expenses, so in the experimental part we gave the preference to it. The obtained experimental results showed a sufficient convergence of the values obtained with the developed method and the values indicated in the ICE certificate. Thus, it justifies the applicability of the proposed method, which can be applied in companies producing and operating mechanical systems with internal combustion engines to determine the ICE mechanical parameters without its demounting.

Keywords: Moment of inertia, ICE torque, ICE measurements, reference flywheel, ICE power

Introduction

Improvement of methods for control the mechanical parameters of internal combustion engines (ICE) is made possible due to the wide application of non-brake control methods, which differ less labor- and energy-intensity [1, 2]. These methods do not require a brake tester, and therefore their application significantly reduces material costs for the organization of the test workplace.

Nowadays the problem of non-brake methods for control the mechanical parameters of the ICE mounted on vehicles lies in the need to determine the moment of inertia of the rotating masses of the ICE. Today it can be determined with brake tests, and for this purpose the engine must be demounted from the vehicle, which negates all advantages of the brake method [3 - 6].

Existing non-demounting methods for control the mechanical parameters of ICE do not allow determining the torque and the power of the engine itself, since these parameters are determined by testing with a roller dynamometer [3, 7]. In this case the measured values are determined on the driving wheels of the vehicle and, therefore, the measured values of the torque and the power are the values that are less than the real torque and the power of ICE to the value of losses in transmission mechanisms.

It follows that one of the main objectives of improving the methods of non-brake ICE test is determining the moment of inertia of the rotating masses of ICE and the real values of its torque and power without ICE demounting from the vehicle.

The purpose on this paper is to develop a new non-brake method for control the moment of inertia of the rotating masses of ICE, which does not need its demounting, and with which it is possible to determine the real values of the torque and the power of ICE without the use of expensive equipment.

Materials and Method

From our point of view, the solution of the problem for vehicles equipped with a mechanical gearbox can be found in two ways differing in complexity and cost of the hardware.

Determination of the IC Engine Mechanical Parameters with an Induction Motor

The first way to determine the moment of inertia of the rotating masses of ICE is more labor-intensive and cost-based. The kinematic scheme of the four-wheeled rear-steer vehicle that allows determining the moment of inertia of the rotating masses of the engine is shown in Figure 1.

Figure 1 shows a scheme of the jack mounted vehicle, where the hub of the demounted drive wheel is coupled with a shaft of the drive induction motor, 5, which is powered from the mains through the electricity meter, 6. Other drive wheels remain in their normal locations. Measurements begin after the operating temperature of the transmission oil of the gearbox, engine oil and coolant of ICE brought to the rated values, the direct gear of the gearbox is on and the engine is turned off.

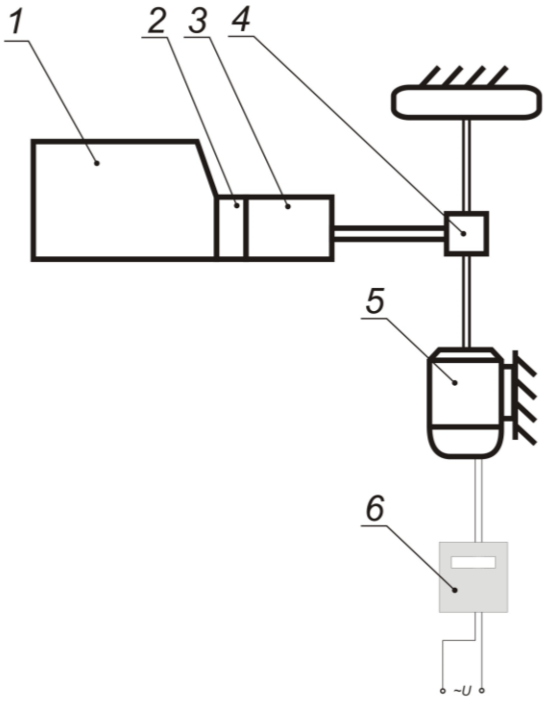

Fig. 1. The kinematic scheme for determining the moment of inertia of rotating masses of the internal combustion engine with an induction motor: 1 is the internal combustion engine, 2 is the clutch 3 is the gearboxes, 4 is the axle drive gear, 5 is the drive induction motor, 6 is the electricity meter

The main objective of the measurements is to determine the value of the active electrical energy consumed by the induction motor to increase the speed of its shaft from zero to the rated value with an electricity meter, which can be an electric power quality analyzer well represented in the world market. The active electrical energy, taking into account the mechanical efficiency (efficiency) of the induction motor, is aimed at an increase the kinetic energy of the rotating masses "induction motor shaft, transmission units, gearbox, ICE".

Thus, equating the work performed by the active current, taking into account the efficiency of the motor, to the total kinetic energy of the rotating masses "induction motor shaft, transmission units, gearbox, ICE" we can determine the moment of inertia of the rotating masses "induction motor shaft, transmission units, gearbox, ICE" according to the equation:

$$A_1 = \eta_{mech} \iiint U_1(t) I_1(t) \cos_1 \varphi(t) dtdtdt = J_1 \frac{\omega^2_{rated}}{2}, \quad (1)$$

Where, $U_1(t)$, $I_1(t)$, $cos_1\varphi(t)$ are the dependencies of voltage, current and $cos\varphi$ on time during the process of increasing the rpm of the induction motor shaft coupled with the system of rotating masses “induction motor shaft, transmission units, gearbox, ICE” from zero to the rated value; J_1 is the moment of inertia of the rotating masses “induction motor shaft, transmission units, gearbox, ICE”; ω_{rated} is the rated angular velocity of the drive induction motor shaft.

Then, after stopping the induction motor and, consequently, the whole system of the rotating masses “induction motor shaft, transmission units, gearbox, ICE” we disengage the clutch and repeat the measurement of the value of active energy consumed by the induction motor to increase the rpm of its shaft from zero to the rated value, i.e. to change the kinetic energy of the rotating masses “induction motor shaft, transmission units, gearbox”:

$$A_2 = \eta_{mech} \iiint U_2(t) I_2(t) \cos_2 \varphi(t) dtdtdt = J_2 \frac{\omega^2_{rated}}{2}, \quad (2)$$

Where, $U_2(t)$, $I_2(t)$, $cos_2\varphi(t)$ are the dependencies of voltage, current and $cos\varphi$ on time during the process of increasing the rpm of the induction motor shaft coupled with the system of rotating masses “induction motor shaft, transmission units, gearbox” from zero to the rated value; J_2 is the moment of inertia of the rotating masses “induction motor shaft, transmission units, gearbox”; ω_{rated} is the rated angular velocity of the drive induction motor shaft.

The moment of inertia of rotating masses of the internal combustion engine “gross” is defined as follows:

$$J_{ICE} = \frac{J_1 - J_2}{k^2_{GB} k^2_{ADG}}, \quad (3)$$

Where, k_{GB} is the transmission ratio of the gearbox; k_{ADG} is the transmission ratio of the axle drive gear.

Determination of the IC Engine Mechanical Parameters with a Reference Body

The second way to determine the moment of inertia of the rotating masses of ICE, less expensive and more efficient, explains Figure 2.

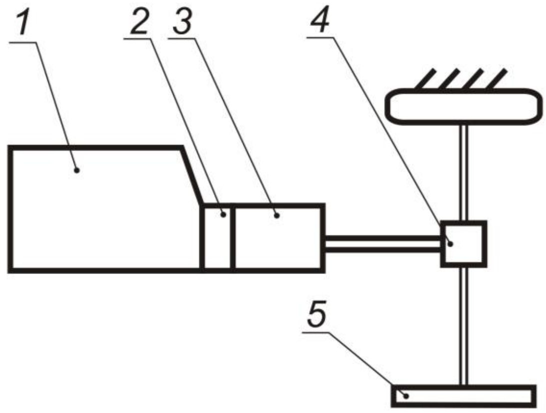

Fig. 2. The kinematic scheme for determining the moment of inertia of rotating masses of the internal combustion engine with a reference body: 1 is the internal combustion engine, 2 is the clutch 3 is the gearboxes, 4 is the axle drive gear, 5 is the reference flywheel

Measurements begin after the operating temperature of the transmission oil of the gearbox, engine oil and coolant of ICE brought to the rated values, and the direct gear of the gearbox is turned on.

One of the driving wheels of the vehicle is demounted, and in its place the reference flywheel, 5, which has the reference moment of inertia, J_{ref}, is installed. Further, ICE is started and at turned on direct gear, with regulators a certain angular speed of the crankshaft is reached, at which a certain torque is developed. Then, the angular acceleration of rotating masses “the reference flywheel, transmission units, gearbox, ICE”, ε_1, is measured; at this the angular velocity of the ICE crankshaft is changed in the range from ω up to ($\omega + \Delta\omega$). The average torque for a range of angular velocities from ω up to ($\omega + \Delta\omega$) can be defined as follows:

$$\overline{M} = \varepsilon_1 \left(J_1 + \frac{J_{ref}}{k_{GB}^2 k_{ADG}^2} \right), \quad (4)$$

Where, J_1 is the equivalent moment of inertia of the system of rotating masses “transmission units, gearbox, ICE” normalized with respect to the rotation axis of the ICE crankshaft; k_{GB} is the transmission ratio of the gearbox; k_{ADG} is the transmission ratio of the axle drive gear.

Further, with the clutch, 2, disengaged the reference flywheel, 5, is demounted and after the clutch, 2, is engaged the angular acceleration of rotating masses "transmission units, gearbox, ICE", ε_2, is measured; at this the angular velocity of the ICE crankshaft is changed in the range from ω up to ($\omega + \Delta\omega$). The average torque for a range of angular velocities from ω up to ($\omega + \Delta\omega$) can be defined as follows:

$$\overline{M} = \varepsilon_2 \cdot J_1 \quad (5)$$

From the Eq. 4 and Eq. 5 the equivalent moment of inertia of the system of rotating masses “transmission units, gearbox, ICE” normalized with respect to the rotation axis of the ICE crankshaft can be defined as follows:

$$J_1 = \frac{\varepsilon_1 J_{ref}}{(\varepsilon_2 - \varepsilon_1) \cdot k_{GB}^2 k_{ADG}^2} \quad (6)$$

Further, the clutch, 2, is disengaged and the angular acceleration, ε_3, of rotating masses of ICE with the moment of inertia, J_{ICE}, is measured; at this the angular velocity of the ICE crankshaft is changed in the range from ω up to ($\omega + \Delta\omega$). The average torque for a range of angular velocities from ω up to ($\omega + \Delta\omega$) can be defined as follows:

$$M = \varepsilon_3 \cdot J_{ICE} \; . \quad (7)$$

From the Eq. 5 and Eq. 7 the moment of inertia of the system of rotating masses of ICE can be defined as follows:

$$J_{ICE} = \frac{\varepsilon_2}{\varepsilon_3} J_1 . \quad (8)$$

Substituting Eq. 6 in Eq. 8, we can define the moment of inertia of rotating masses of ICE, 1, via the value of the moment of inertia of the reference flywheel, 5, and via the values of the angular accelerations:

$$J_{ICE} = \frac{\varepsilon_2}{\varepsilon_3} \cdot \frac{\varepsilon_1}{\varepsilon_2 - \varepsilon_1} \cdot \frac{J_{ref}}{k_{GB}^2 k_{ADG}^2} \quad (9)$$

Instruments to Control the IC Engine Mechanical Parameters

For experimental justification of the developed method a hardware-software complex (HSC) was used (Fig. 3). It consisted of modified crankshaft position sensor; digital information module (USB-6009) manufactured by National Instuments; laptop Acer Extenca 5210; licensed development environment for virtual instrumentation LabView 7.2 with integrated module Signal Express 2.5.

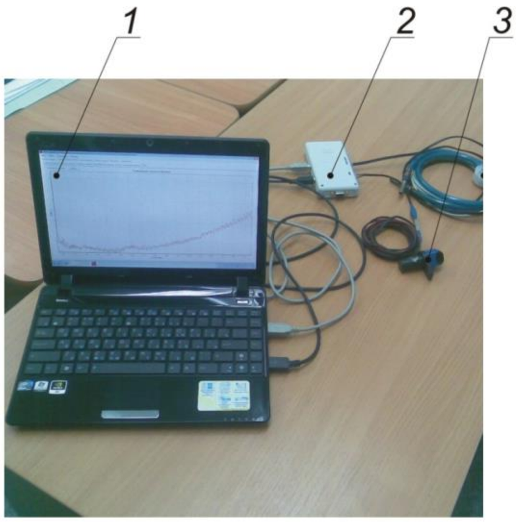

Fig. 3. Hardware-software complex for identification of the performance parameters of the IC engines of the wheeled vehicles: 1 - laptop; 2 - high-speed data acquisition and data processing system; 3 - modified crankshaft position sensor

Modifying the crankshaft position sensor lay in the fact that the two main output leads were connected to two conductors which were in turn connected to the digital information module.

The reference flywheel had the value of the moment of inertia of 0.47637 kg·m^2 at the outer diameter of 0.42 m.

The experimental vehicle is VAZ-2112 (engine capacity is 1500 cm^3, rated power is 89 HP at 5600 rev/min, maximum torque is 128 N·m at 3700 rev/min, the transmission ratio of the main gear is 3.7).

Results and Discussion

To determine the reliability of data obtained with developed method for control the mechanical parameters of the internal combustion engine mounted on a vehicle, experiments were carried out. As an experimental engine we chose the engine VAZ-2112 (serial number 0190688) mounted on the wheeled vehicle VAZ-2112 (ID number XTA211200Y0002158), the control unit of which was equipped with software ("firmware") of type J5V05J16 (dynamic).

As a result of experiments, it was found that the moment of inertia of the system of rotating masses “transmission units, gearbox, ICE” is 0.28345 kg·m^2; the moment of inertia of the system of rotating masses of ICE is 0.19715 kg·m^2.

To verify the obtained values of J_{ICE}, a series of experiments were carried out to determine the angular accelerations of a crankshaft in the speed range 1000 - 6000 rev/min.

A diagram of the instantaneous values of torque built using the obtained accelerations values are presented in Figure 4.
After averaging the results obtained we built the speed-torque curve in the speed range from 1000 to 4000 rev/min (Fig. 5).
According to VAZ-2112 certificate, it develops the torque of 128 N*m at the engine speed of 3,700 rev/min (the power is 49.7 kW) using the regular software.
According to the experimental data, the value of the torque at 3,700 rev/min is about 137 N·m. The discrepancy between the experimentally obtained value and the certificate value is approximately 6.5 %. Thus, experimental values of the torque exceed the certificate ones. This can be explained by the fact that the "dynamic" firmware to provide more dynamic conditions of the vehicle motion sends a signal to the injectors to inject some more fuel in comparison with the "standard" firmware thereby providing a more rapid heat release during combustion and the peak torque values as a result.

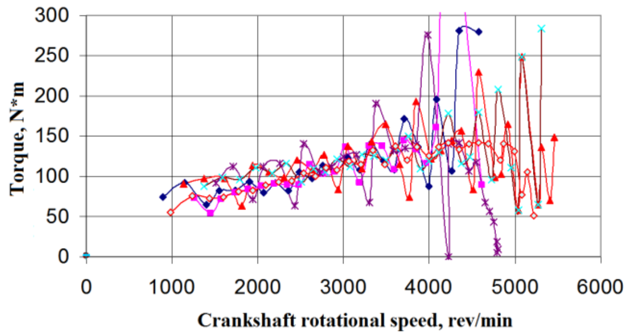

Fig. 4. Instantaneous values of torque of the ICE VAZ-2112

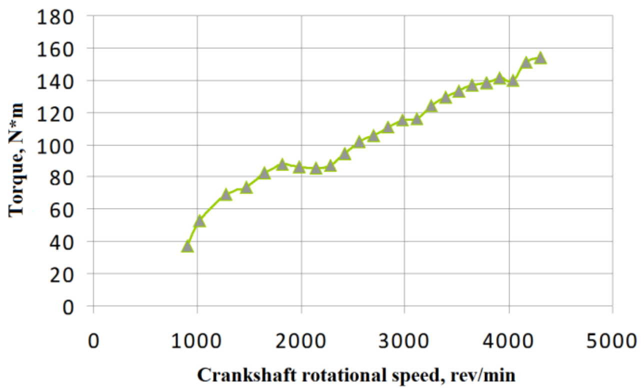

Fig. 5. Speed-torque curve of the ICE of the wheeled vehicle VAZ-2112

Conclusion

Thus, the use of the method proposed for control the ICE mechanical parameters allows with significantly lower financial investments in equipment, lower material and energy costs in comparison with brake methods determining the torque and the power of internal combustion engines mounted on vehicles equipped with manual gearbox without the ICE demounting from a vehicle.

Using the reference flywheel with the known value of moment of inertia, one can also control the moments of inertia and the indicators of speed-torque curves of internal and external combustion engines, electrical, hydraulic and air motors regardless of the size and unit capacity.
For this purpose it is necessary to measure twice the angular accelerations, ε_4 and ε_5, of the motor output shaft (moment of inertia is J_m) within the same angular velocity range with and without the reference flywheel (moment of inertia is J_{ref}), installed on the shaft. Then, from the equation $M = (J_m + J_{ref}) \cdot \varepsilon_4 = J_m \cdot \varepsilon_5$ we find the moment of inertia of the system of rotating masses of the motor $J_m = \dfrac{J_{ref}\,\varepsilon_4}{\varepsilon_5 - \varepsilon_4}$.
Further, we measure the angular acceleration of the output shaft of the motor in the entire rotational speed range $\varepsilon = \varepsilon(n)$. And finally, we determine the dependence of the torque developed by the motor output shaft on the rotational speed: $M=M(n)$.

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