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POMIAR MOMENTU BEZWŁADNOŚCI SILNIKA POJAZDU

MOMENT OF INERTIA MEASUREMENT OF VEHICLE ENGINE

Coraz częściej do pomiaru parametrów eksploatacyjnych pojazdów drogowych wykorzystuje się metody dynamiczne, które stawiają niskie wymagania co do czasu i nakładów pieniężnych. Dynamiczny pomiar parametrów pracy silnika na ogół opiera się na znajomości masowego momentu bezwładności silnika i mechanizmów przekładniowych, włączając w to koła napędowe. Jednakże otrzymanie wskazania odpowiedniego momentu bezwładności nie jest rzeczą prostą. W pracy opisano nową propozycję możliwości pomiaru przeprowadzanego na stanowisku badawczym wyposażonym w luźno osadzone wałki. Wynikiem pomiaru jest moment bezwładności, którego znajomość możemy wykorzystać do pomiaru parametrów eksploatacyjnych, wydajności hamulców, itd.

Słowa kluczowe: *moment bezwładności silnika, parametry eksploatacyjne, stanowisko badawcze wyposażone w wałki.*

The use of dynamic methods for measuring operational parameters of road vehicles begins to increase due to its low demands on time and investment funds. Dynamic measurement of engine performance parameters are generally based on knowledge of the rotating mass moment of inertia of engine and gearing mechanisms including driving wheels. However, it is difficult to obtain an indication of the correct moment of inertia. This paper describes a newly proposed possibility of measurement that is carried on roll test bed with loose rollers. The result of measurement is the moment of inertia, which can also be used in the measurement of performance parameters, brake performance, etc.

Keywords: *moment of inertia of engine, performance parameters, roll test bed.*

1. Introduction

Wide development of the dynamic measurement of operating parameters of vehicles and internal combustion engines in recent years offers new possibilities in the diagnosis. One of many possible applications of dynamic acceleration measurement is the measurement of performance parameters (torque, power) of the combustion engine [4]. Measurements can be made only on the engine itself or on the roll test bed or on the test road [3]. In all cases it is necessary to include the correct value in the calculation of the engine moment of inertia, or the whole vehicle. Effect of moment of inertia is essential when measuring the engine itself.

This article focuses on the description of the possibility of measuring the moment of inertia of the engine by itself. Application for the whole vehicle is quite similar. There are several ways to obtain the moment of inertia of the engine:

- *Obtaining information from the manufacturer* - This is not usually a problem with modern engines, factory diagnostic devices offer the possibility of measuring the performance parameters through the acceleration method. Information about the moment of inertia of the engine should be in the diagnostic tools available. The problem is if there is no factory diagnostics, detailed information about the vehicle, or in the case of obsolete vehicles.
- *Calculation* - Moment of inertia can be determined and calculated from the dimensions and other information of various components. This option is very time consuming and requires precise knowledge of the mechanical design and dimensions of all components [9].
- *With makeweight* - Using makeweight of known moment of inertia can be performed two measurements. One measurement with makeweight and second without it. Then, by comparing the results of both measurements can be calculated moment of inertia of the engine [8].

$$I = \frac{F_A}{d_2 - d_1} \tag{1}$$

where: I – moment of inertia (kg·m^2), F_A – represents added external load (N·m), d_1, d_2 – deceleration rate (rad·s^{-2})

- *New engine* - If there is a new engine for which the manufacturer guarantees performance parameters, acceleration measurements can be carried out. Then it is possible to determine the value of moment of inertia of the engine by return in order to match the performance parameters with the table values.
- *Dynamometer* – Similarly, as a new engine dynamometer can be used [8]. Moment of inertia is assigned to the resulting values of the acceleration measurements in order to correspond to the values measured on the dynamometer.

$$I = \frac{M_D}{\varepsilon_M} \tag{2}$$

where: I – moment of inertia (kg·m^2), M_D – effective torque from rolldynamometer (N·m), ε_M – acceleration (rad·s^{-2})

- *Average* – Exactness of this method assume measurement of large number of vehicles with the same engine and a gradual refining of moment of inertia.

But sometimes it is impossible to get to the actual moment of inertia with any of described ways [10]. For example, because there is no dynamometer or a new vehicle or the manufacturer's information and it is not possible to mount the make-weight of known moment of inertia. In such cases, there are suitable several other ways, such as measuring of vehicle acceleration on the road or on roll test bed with loose rollers or on the roll test bed itself.

This paper describes the possibility of determining the moment of inertia using modified roll test bed. Authors of the paper invented this method and applied for its patent. It is possible to use proposed method in order to realize dynamic measurement of power parameters [2]. Based on behaviour of power parameters there can be determined technical state and potential faults of engine [7]. Such approach can contribute to better economy and primarily to ecology of vehicle utilization [1, 5].

2. Material and methods

Structural adjustment of roll test bed, originally designed only to check the brakes, consisted in the removal of gearbox and connecting electric motors to frequency converters (this is not strictly necessary). Detail of the test bed adjustments is shown in the figure 1, frequency converters are shown in the figure 1B. Angular velocity and angular acceleration of the vehicle engine are calculated from the time recorded data of incremental rotating speed sensor. The sensor (figure 1A) gives 1024 pulses per revolution (with time accuracy within 20 nanoseconds) at this described specific application. The sensor is attached to the rollers of test bed. Required values of vehicle's engine are defined by reduction of measured values in the overall speed ratio between vehicle's engine and rollers of test bed.

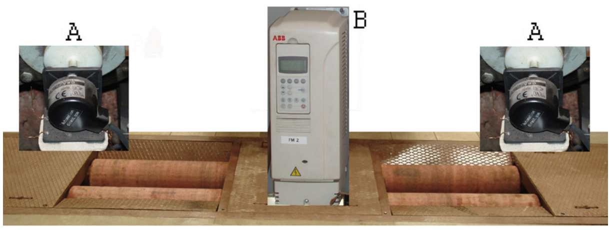

Fig. 1. Roll test bed: A - Incremental sensor of roller's revolution, B - Frequency converter

Possibilities of utilization of roll test bed are extensive and include dynamic measurement of performance parameters of engines of vehicles, measurement of transmission ratios, measuring the dynamic braking forces, etc. Data collection is carried out with eight-channel collector, which ensures online data preprocessing and passes data to the operating computer type PC which is connected through the USB port.

Procedure finding moment of inertia of the vehicle engine is implemented in three steps, which are logically connected and, if necessary, it is possible to print a protocol.

1) The first step is to measure gear ratio between the engine and rollers of test bed for each vehicle. Revolutions of roller test bed measured by an incremental sensor and revolutions of engine measured by the other external sensor are compared. To measure the revolutions of the vehicle engine, it is most suitable to use the diagnostic plug OBD. For instance, if a motor vehicle has 820 rpm, and rollers of test bed have 265 rpm, then the overall gear ratio is 3,094.
2) The second step is to measure all inertial mass, i.e. the mass of engine, transmission and wheels of the vehicle and rolls and other rotating masses of test bed, reduced to the circumference of rollers. Frequency converters controlled by electric motors are used to measure and it is possible for them to change the performance of approximately 15 to 30 kW (according overload set on converter). Given procedure, in view of the performance characteristics of electric motors roll test bed, is different for engines of vehicles with low inertia mass (lower stroke volume, approximately up to 1,4 dm^3) and for vehicles with engines higher inertia mass (higher stroke volume more than 1,4 dm^3 and diesel engines).
   a) Measurement of inertial mass of smaller engines is simpler. The vehicle‘s engine is running at idling speed revolution, there is geared up chosen gear speed (recommended is the second). Rollers of test bed are driven by vehicle's wheels and these wheels are spinning with revolutions according idle revolution of engine. After that the electric motors of roller test bed are connected; the frequency converters are set higher speed revolutions than speed revolutions that correspond to idle revolutions of the vehicle. All rotating mass are accelerated by virtue of known power of electric motors. During the acceleration are measured values of the immediate velocity and acceleration, which is calculated from the mass inertia of the rotating mass, reduced with the circumference of rollers.
   b) For vehicles' engines with larger inertial mass it is not enough electric power to accelerate the testing of all the rotating mass of the idling speed revolutions. At first the vehicle on the rollers is started by using its own engine to a speed of about 50 km/h and then electric motors are connected. Gas pedal is fully released and all the rotating mass starts to decelerate. The performance of the electric motors which drives rollers of test bed slows down this deceleration. During deceleration, there are again measured values of instantaneous velocity and acceleration (i.e. deceleration) of them is again calculated inertial mass of the rotating mass, reduced with the circumference of rollers.
3) In the third step is necessary to determine the inertial mass of all rotating parts except the engine and the relevant parts of the gearbox. The procedure is the same as in the second step, but is no gear shifted.

Note: If the engine power has to be measured, according to the procedure described above is supplemented by the action acceleration of the vehicle on the rollers at the full fuel supply. The result is a course of torque and power depending on speed. Figure 2 describes an example of the number of performance characteristics of combustion engine of a car Skoda Fabia 1,4 (55 kW) [6].

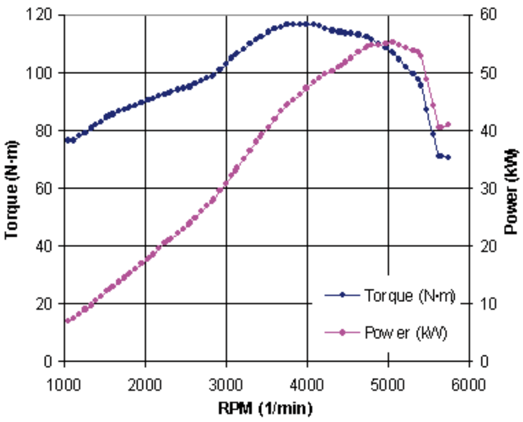

Fig. 2. Performance parameters - Skoda Fabia 1,4

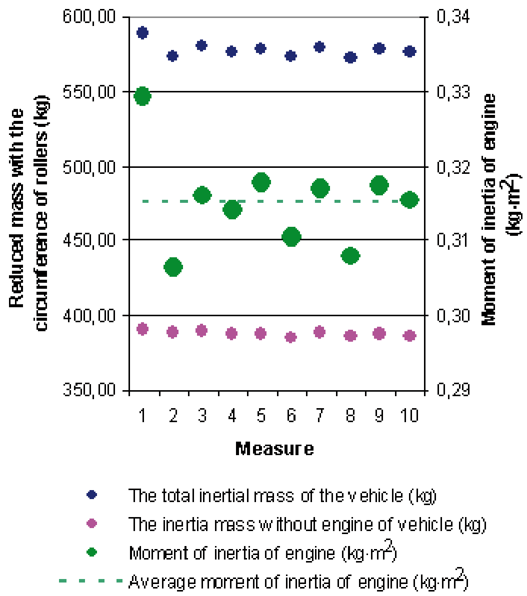

Fig. 3. Results of repeated measurement of inertial mass and moment of inertia of engine

3. Results

The method of measuring the moment of inertia the engine was applied to the vehicle Skoda Octavia II 2,0 TDI (103 kW). It is a vehicle that belongs to the category 2b - engines with higher mass of inertia. The resulting measured and calculated values are in the table 1, where the columns listed in the overall gear ratio between motor vehicles and the roll test bed, the total inertial mass of the rotating mass of vehicle reduced the circumference of rollers, the rotating mass inertia weight without motor vehicles reduced the circumference of a roller the resulting moment of inertia of the rotating mass of the vehicle engine.

The required result is the moment of inertia of the rotating masses of engine. To verify the accuracy of the method there were carried of a number of repeated measurements. The results are shown in figure 3.

The average value of moment of inertia of the vehicle engine Skoda Octavia II 2,0 TDI (103 kW) is 0,3152 kg·m². A greater deviation from the average (4.5%) for the first measurement is probably due to the fact that the engine was before heated to operating temperature, but the transmission was cold. The differences are negligible in the individual measurements after the temperature stabilization of the engine and gearbox.

Table 2 describes an example of measured moment of inertia of chosen vehicles. Besides moment of inertia there is

Tab. 1. Results of measurement of vehicle Skoda Octavia II 2,0 TDI

Measurement	Gear ratio (-)	The total inertial mass of the vehicle (kg)	The inertia mass without engine of vehicle (kg)	Moment of inertia of engine (kg·m²)
1.	3,07	589,31	390,62	0,329
2.	3,07	573,12	388,32	0,306
3.	3,07	580,64	389,94	0,316
4.	3,07	576,84	387,36	0,314
5.	3,07	579,14	387,43	0,318
6.	3,07	572,89	385,61	0,310
7.	3,07	579,21	388,04	0,317
8.	3,07	572,22	386,48	0,308
9.	3,06	578,47	387,07	0,317
10.	3,06	576,78	386,55	0,315

Tab. 2. List of vehicles – an example of measured moment of inertia

Producer	Vehicle model	Year of production	Fuel type	Engine volume (dm³)	Power (kW)	Moment of inertia of engine (kg·m²)
Hyundai	i20	2008	gasoline	1,2	57,2	0,0961
Peugeot	107	2008	gasoline	1,0	50	0,0741
Peugeot	308 SW	2008	diesel oil	1,6 HDI	80	0,2082
Škoda	Octavia II	2006	diesel oil	2,0 TDI	103	0,3152
Škoda	Octavia II	2004	gasoline	2,0 FSI	110	0,3293
Škoda	Favorit	1991	gasoline	1,3 carburetor.	46	0,1317
Škoda	Octavia	2005	gasoline	1,6 MPI	75	0,1882
Škoda	Roomster	2007	diesel oil	1,4 TDI	59	0,2619
Škoda	Felicia	1998	gasoline	1,3 MPI	50	0,1361
Škoda	Felicia	2000	gasoline	1,4 Sport	100	0,1556

also nominal power of engine (according producer), volume of engine, type of fuel, year of production, producer and vehicle model.

4. Discussion and conclusion

Moment of inertia is one of the necessary input data for diagnostic non-assembling acceleration measurement. The correct and accurate detection is usually the main problem of these measurements. There are several options for finding moment of inertia, however, there are not always easily feasible.

Moment of inertia of all parts (rotating with the engine in neutral) can be obtained by the procedure described above. This is not a moment of inertia of the engine by itself, but for the purposes of measuring the acceleration performance parameters is not misleading. These are precisely those masses which are accelerating during the acceleration measurement.

Method proposed by authors is suitable for cases where it is available roll test bed, even with low power. The method provides a specific value of moment of inertia of the rotating mass of the vehicle engine and immediately after provides its basic performance characteristics.

The method was experimentally verified on the vehicle Skoda Octavia II 2,0 TDI (103 kW) using a roll test bed with electric motor with mere output (7,5 kW) of one pair of rolls. The moment of inertia for the vehicle was set 0,3152 $kg \cdot m^2$. This value seems very likely correct. The first practical measurements of chosen vehicles were launched after an experimental validation of the method. An example of results is given in table 2.

Known value of moment of inertia can be used for dynamic measurements of the engine of entire vehicle, both in measuring the performance parameters as well as the performance of automotive brakes.

There are still other methods applicable to the measurement of the roll test bed or the test section of the road, except that the proposed method of finding the moment of inertia of the engine of vehicle.

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Paper was created with the grant support - CZU 31190 / 1312 / 313121 - Accuracy of measurement of performance parameters on the roll test bed.

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