

# Diagnostic Measurement for the Effective Performance of Motor Vehicles with free acceleration

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**Abstract – Diagnostics means instrumental measurement without dismantling. So measuring the engines on rolling roads is not incorporated in this concept, as this measurement is accomplished on engines taken out from vehicles. During service, it is often necessary to measure the performance of the engines, or to judge the performance projection of some corrections. The new method discussed in this article provides a solution to this problem.**

## I. INTRODUCTION

The measurement of the effective performance of motor vehicles takes place with the aid of bench tests that suggest a dismantled engine. The results of this in case of engines are the usually available so called external or total load characteristics.

In the case of operating vehicles, the possibility to take such measurements is quite rare. During diagnostics and repair work it is necessary more and more frequently to measure the effective moment and performance of the engines.

Some rolling roads possess these kind of skills; however even their prices exceed the budget of the services. Henceforth, I introduce the theoretical background of a new measurement method with accessible instruments and the results of measurements [6].

## II. MEASURING ENGINE PERFORMANCE ON FREE ROLLERS

The principle of the measurement method is to accelerate and decelerate the unloaded drive train of the studied vehicle on free rollers (there is no need for a rolling road). Since we want to measure external characteristics, the measurement must be performed under total load conditions [1], [2].

Let us write the energy equation for the system displayed in Figure 1; according to this equation the temporal change of the introduced work in the system ( $P_e$  – effective engine performance) equals to the temporal changes of the kinetic energy ( $E_k$ ), the potential energy ( $E_p$ ) and the diverted heat ( $Q$ ):

$$P_e = \frac{dE_k}{dt} + \frac{dE_p}{dt} + \frac{dQ}{dt} \quad (1)$$

As the potential energy does not change during the measurement:

$$P_e = \frac{dE_k}{dt} + \frac{dQ}{dt} \quad (2)$$

The kinetic energy change of the system is displayed in the acceleration of the wheel and the rollers, so this element equals to the wheel performance ( $P_k$ ). Though the diverted heat equals to the running loss performance ( $P_v$ ):

$$P_e = P_k + P_v \quad (3)$$

The basic dynamic equation of rotation can be prescribed both for acceleration and deceleration phases:

$$P = M \cdot \omega = (\theta_{red} \cdot \varepsilon) \cdot \omega = \theta_{red} \cdot \frac{d^2\varphi}{dt^2} \cdot \frac{d\varphi}{dt} \quad (4)$$

where:

- $\omega$  the angular velocity of the roller of the rolling road
- $\theta_{red}$  moment of inertia of the drive train of the vehicle reduced to the shaft of the roller of the rolling road

- $\varphi$  angular displacement of the roller
- $\dot{\varphi}$  angular acceleration of the rollers
- $t$  time

The basic equation of the acceleration phase:

$$P_{veszt} = P''_{v,f(M)} + P_{v,f(\omega)} + P_{vpad,f(vg)}$$

$$P_{kerék} = \omega_g \cdot \varepsilon_g^+ \cdot [\theta_{mot,red} + \theta_{jármű,red} + \theta_{pad}] \quad (5)$$

where:

- $f(M)$  the  $f(M)$  index elements are the losses depending on the tractive force
- $f(\omega)$  the  $f(\omega)$  index elements are the losses depending on the velocity
- $g$ -index roller
- $\theta_{mot, red}$  value of the moment of inertia of the engine reduced to the shaft of the roller
- $\theta_{jármű, red}$  value of the moment of inertia of the vehicle reduced to the shaft of the roller
- $\theta_{pad, red}$  value of the moment of inertia of the rolling road reduced to the shaft of the roller
- $+$ -index acceleration
- $-$ -index deceleration

The basic equation of the deceleration phase:

$$P_{veszt} = P'_{v,f(M)} + P_{v,f(\omega)} + P_{vpad,f(vg)}$$

$$P_{fékező} = \omega_g \cdot \varepsilon_g^- \cdot [\theta_{jármű,red} + \theta_{pad}] \quad (6)$$

In the aforementioned equations the alternations of  $P_{v,f(M)}$  value marked with one or two commas refer to a different loss proportion in the acceleration and the deceleration phases, as in the latter phase the engine is separated from the system.

The phases of the measurement are the following:

**1 ACCELERATION PHASE:** The drive train of the vehicle on the bench and the rollers of the rolling road are accelerated, in the studied gear accelerated up to the rated engine speed with full load (on full blast).

**2 DECELERATION PHASE:** By releasing the clutch, leaving the gear at the given position, we let the car decelerate until it stops.

During the measurement, as there is no external load, the engine has to accelerate the moments of inertia indicated

in Figure 1. During the deceleration we separated the moment of inertia of the engine, so with this exemption the rest of the moments of inertia decelerate the system.

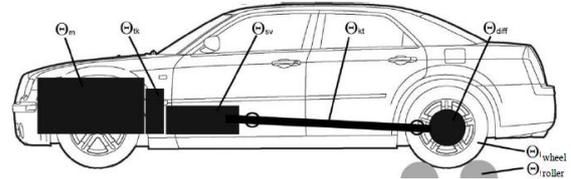


Fig. 1. Vehicle drive train on free rollers.

According to the aforementioned measurements diagram displayed in Figure 2 can be recorded.

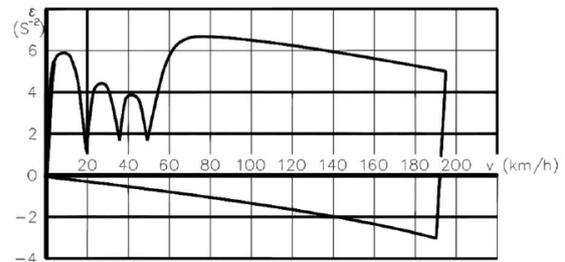


Fig. 2. Characteristic curve recorded during the measurement.

### III. EVALUATION OF THE MEASUREMENT RESULTS

The main condition for evaluating the results of the measurement is to know the moment of inertia indicated in the Figure 1. Although these values are not available, their shortage can be eliminated with an adequate measurement procedure.

### IV. VALIDATING THE EXTERNAL CHARACTERISTIC CURVE OF THE ENGINE BY ROLLER BENCH TEST

If we possess not only rollers but our measuring rollers are the rollers of a vehicle bench pad, we have to find the velocity value ( $v^*$ ) that belongs to the local maximum of the acceleration phase indicated in Figure 3 [3], [4].

As a next step we choose the load characteristics of constant velocity on the roller bench, we set the  $v^*$  velocity, and then we measure the wheel performance with full load (Figure 4).

With these steps the values appear in kW even on the vertical axis of Figure 3, i.e. the effective performance curve of the engine is available.

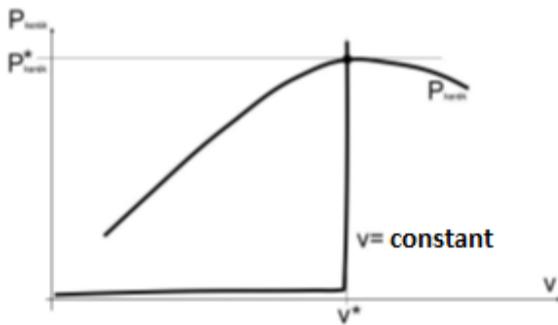


Fig. 3. Performance proportionate characteristic curve recorded during the measurement

The flaw in this method is that the scales of the diagram phases of the acceleration and deceleration are not equal, as in one case we should take into consideration the (unknown) moment of inertia of the engine, while in the other case it is not needed. This fact can be considered only with a correction factor defined empirically (generally 10%).

#### V. VALIDATING THE EXTERNAL CHARACTERISTIC CURVE OF THE ENGINE WITHOUT ROLLER BENCH TEST (NEW MEASUREMENT METHOD)

The main point of the measurement method which I elaborated is the following:

If we do not possess a rolling road, just a roller bed, we need to conduct two free acceleration measurements.

##### 1st Measurement

Actually, this is equal with the previously mentioned measurement method.

Equations:

$$\begin{aligned} P_{k,1} &= (\theta_{engine,red} + \theta_{drive\ train,red}) \cdot \varepsilon_1 \cdot \omega_1 \\ P_{v,1} &= \theta_{drive\ train,red} \cdot \varepsilon_1 \cdot \omega_1 \end{aligned} \quad (7)$$

##### 2nd Measurement

In this case we tie an additional flywheel to the shaft of the rollers, which enhances the total reduced moment of inertia calculated for the shaft of the roller.

$$\begin{aligned} P_{k,2} &= (\theta_{engine,red} + \theta_{drive\ train,red} + \theta_{flywheel,red}) \cdot \varepsilon_2 \cdot \omega_2 \\ P_{v,2} &= (\theta_{drive\ train,red} + \theta_{flywheel,red}) \cdot \varepsilon_2 \cdot \omega_2 \end{aligned} \quad (8)$$

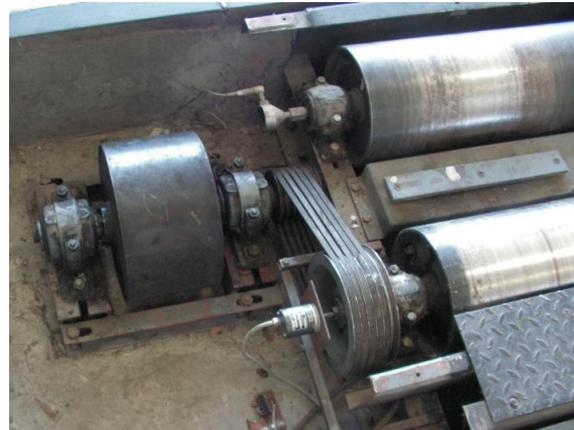


Fig. 4. Roller bench with the rotating mass

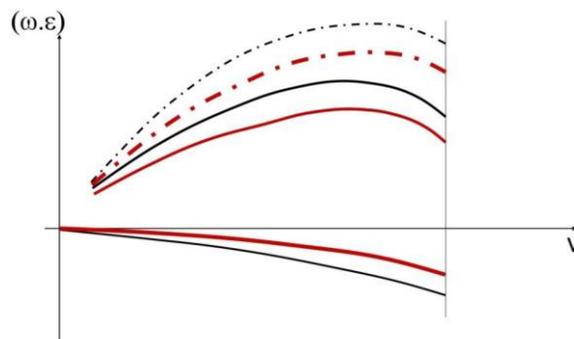


Fig. 5. Diagrams of two subsequent measures

Although in both of these cases the inertia and naturally the acceleration and deceleration of the system are diverse, by calculating the performance the performances through the wheel and the performance loss must correspond with each other, since the engine that accelerates the system and the drive train that has losses are unaltered.

Consequently, in the case of the 1st and 2nd measurements, the equations of the wheel performance and the drive train loss can be equated in couples:

$$\begin{aligned} (\theta_{engine,red} + \theta_{drive\ train,red}) \cdot \varepsilon_1 \cdot \omega_1 \\ = (\theta_{drive\ train,red} + \theta_{flywheel,red}) \cdot \varepsilon_2 \cdot \omega_2 \end{aligned} \quad (20)$$

$$\theta_{drive\ train,red} \cdot \varepsilon_1 \cdot \omega_1 = (\theta_{drive\ train,red} + \theta_{flywheel,red}) \cdot \varepsilon_2 \cdot \omega_2 \quad (9)$$

Thus the following is derived from the 2nd equation:

$$\theta_{drive\ train,red} = \frac{(\varepsilon_1 \cdot \omega_1 - \varepsilon_2 \cdot \omega_2)}{\theta_{flywheel,red} \cdot \varepsilon_2 \cdot \omega_2} \quad (10)$$

In the above equation the numerator is measured, and the denominator is a datum known from the construction. On

the basis of this, with the help of the 1st equation, even the moment of inertia of the engine can be determined. All of this process is naturally controlled and calculated with the aid of adequately elaborated measuring software. Consequently, the end result will be an external characteristic curve of torque and performance defined by exact values.

## VI. MEASUREMENTS

There are measurements going on (Figure 4.) to validate the theoretical calculations and to be able to compare the results with the roller bench test.

The first measurements have been done at Széchenyi István University in Győr. The bench was designed to be able to measure effective performance with the help of an electric motor. The bench is also equipped with an additional rotating mass connected to the rollers with belt drive, so it is able to test with the free acceleration measuring method. The electric motor was disengaged to not to have any effect on the measurement.

The measurement system contained 2 sensors to measure to rotation speed which is the only necessary signal that must be recorded to be able to analyze the properties of the engine.



Fig. 6. Ncoder type sensor

One of the sensors was an incremental sensor (Fig. 6) and the other was a tachometer (Fig. 7) Both of them were the original equipment of the bench, so there was no need to connect new sensors.



Fig. 7. Tachometer

The DAQ system was based on an HBM QuantumX mx 840A with 8 channels possibility with integrated ncoder input module (Fig. 8).



Fig. 8. DAQ system for the measurements

The measurements were done at 200 Hz with 10 Hz Butterworth filter to reduce the unreal waves that belongs to the measurement system, not the physical phenomenon. The tested car was an Opel Tигра with C16SE GM engine close to stock performance (Fig 9.). This means that the max. performance of the engine was expected to 110-115 HP.



Fig. 9. The measured vehicle

The first measurements were done with the additional rotating mass (Fig 4). The angular speed of the rollers was measured and the data have been converted into Matlab file.

The other measurements were done without the rotating mass (Fig 10). All the data were converted into Matlab files to be able to process the measured values to the effective properties of the engine.

There are some parameters that were need to be measured because they were input parameters to the evaluation:

- the inertia of the additional rotating mass
- the ratio between the additional rotating mass and the bench roller speed
- the ratio between the engine and the bench roller speed



Fig. 10. The disengaged rotating mass

The evaluation process, that is described by the equations 3-10, based on a Matlab script that can provide universal solution for different type of vehicles.

First, the angular acceleration of the bench roller was created as the derivative of the speed which was measured. The angular acceleration is in connection with the torque of the engine. The positive acceleration is regarding to the “braking torque” and the negative acceleration is regarding to the “loss” torque (Fig. 11).

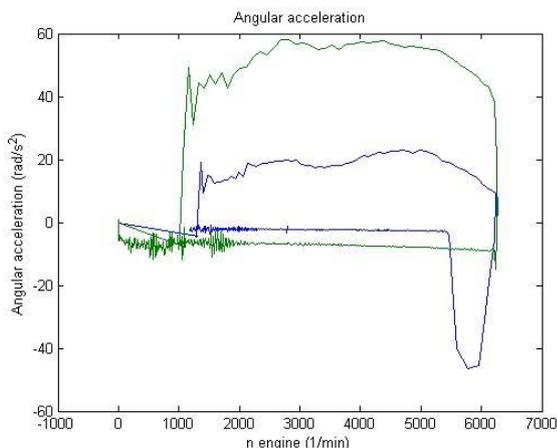


Fig. 11. Angular acceleration with 2 subsequent measurements

It is nearly the same with the performance which is connection with the multiplication of the angular acceleration and the angular speed. Both braking and loss performance can be evaluated (Fig. 12).

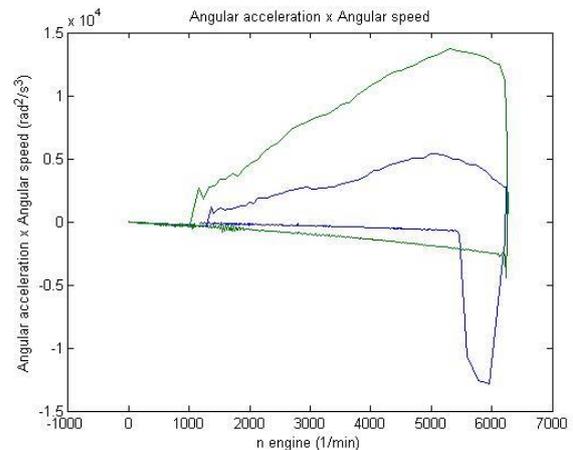


Fig. 12. Angular acceleration multiplied with angular speed with 2 subsequent measurements

To be able to scale the diagrams not just the inertia of the drivetrain + bench and the engine must be determined but the values must be put to the equations so the correct performance and torque diagrams can be determined.

The max. performance can be calculated, which in the case of the Opel Tigra was 119 HP. In this calculation the effectiveness of the belt drive was 97% which is a usual value, have not measured on the bench yet.

Further evaluation processes are under preparation and validation to show the measurement results properly.

## VII. RESULTS

The measurements have shown that the bench has many disadvantages for this type of measurements.

The first problem is the belt drive between the additional rotating mass and the bench rollers. As it can be seen in Fig.11 and Fig 12. there is a high deceleration at that point when the clutch is released. It is caused by the tension change of the belt.

The belt drive has an other disadvantage: the effectiveness of the belt highly depends on the torque of the engine. When a car with high torque is measured, the belts have high slip that can be heard near the bench.

There was a measurement made with a car over 200 HP and it comes out, that in that case we measured more the 10% higher values than the real torque and performance of the car.

## VIII. FURTHER DEVELOPMENTS

Most of the disadvantages that have been listed above can be eliminated with the development of the test bench and the measuring system.

The belt drive should be eliminated and a gear drive should be used instead. In that case there would be no slip, so there would be no difference in the angular acceleration of the

rollers and the additional rotating mass. With the gear drive there would be no overshoot in the measurement. If the mechanical design cannot be changed the angular speed of the additional rotating mass should be measured to be able to calculate the slip properly in every time step. The electrical wires and connectors should be also renewed with shielded ones to minimize the noise during measurement and to make DAQ-process easier.

#### IX. SUMMARY

There are several advantages to elaborating a new measuring system [5]:

1 There is no need for a rolling road, and therefore simpler and cheaper measuring devices can be developed.

2 The measurement is more precise, since it defines everything on the basis of measuring excluding empirical correction factor.

The described new method provides an available opportunity for professional services, as it is able to define the diagnostic performance of the engine with required accuracy if the bench is designed properly for this measurement process.

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