TESTING OF MODERN VEHICLES ON A 2WD ROLLER TEST BENCH

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SHRNUTÍ

Pro zkoušení většiny vozidel s jednou poháněnou nápravou je základní provedení vozidlových dynamometrů s jednou dvojicí válců plně vyhovující. Problém při měření však může nastat v případě netolerantnosti moderních asistenčních systémů (ESP, ASR), které kvůli neotáčejícím se kolům nepoháněné nápravy, neumožní rozjezd vozidla. Tato situace je typická zejména u vozidel s hybridním pohonným ústrojím. Článek popisuje úpravu vozidlového dynamometru s jednou dvojicí válců tak, aby bylo možné zajistit otáčení kol nepoháněné nápravy simultánně s poháněnými koly. Zařízení bylo úspěšně vyzkoušeno při měření automobilu s hybridním pohonným ústrojím v paralelním uspořádání. V textu jsou zároveň uvedeny některé poznatky získané z měření.

KLÍČOVÁ SLOVA: ZKOUŠENÍ VOZIDEL, VOZIDLOVÝ DYNAMOMETR S JEDNOU DVOJICÍ VÁLCŮ, FREKVENČNÍ MĚNIČ

ABSTRACT

Most roller test benches are designed for two-wheel drive vehicles. However, modern vehicles with sophisticated assistance systems such as ABS, ESP and ASR can require rotation of the non-driven wheels. A typical example of such modern vehicle is a hybrid vehicle with one driven wheel axle, where the sophisticated control of the vehicle doesn't allow normal operation without rotation of the non-driven wheels. The paper describes equipment which upgrades a 2WD roller test bench for the testing of modern vehicles. The new equipment was successfully tested on a hybrid vehicle, and results of the experimental work are also introduced in this paper.

KEYWORDS: TESTING OF VEHICLES, ROLLER TEST BENCH FOR TWO-WHEEL DRIVE, FREQUENCY CONVERTOR

1. INTRODUCTION

The testing of a vehicle on a roller test bench is a standard procedure to simulate desired conditions, which may be difficult to consistently replicate on a road. It enables analysis of the longitudinal characteristics of vehicles and can investigate the energy parameters within a wide range of different test cycles. A roller test bench is also used for vehicle type-testing, where the vehicle must undergo a predefined cycle (NEDC). The CO₂ content in the exhaust gases is one of the results of this testing and is used for determination of the official vehicle fuel-consumption. Not only a standard cycle such as NEDC, but any procedure can be driven on this test rig.

Typically, only two-wheel drive roller test benches were used in laboratories in former times. This type of testing equipment was

sufficient in most cases and a problem only occurred for vehicles with a higher number of driven axles. However, control systems in vehicles have evolved from simple to very complex systems in recent years [1]. As the complexity of vehicle control systems increases, so the amount of information required by them has also increased. This type of precise vehicle control system requires all monitored data in a given range and therefore it doesn't allow the operating of a 2WD vehicle without rotation of the non-driven wheels. In particular, this behaviour is very typical for hybrid vehicles [2]. A common 2WD roller test bench is not suitable for testing vehicles with sophisticated control systems. One possible arrangement of the roller test bench will be described in the next chapter.

The main goal of the work is to upgrade the roller bench with equipment which provides rotation of non-driven wheels synchronously with the driven wheels. This allows testing of a vehicle which requires rotation of all wheels to drive properly.

2. 2WD ROLLER TEST BENCH – INITIAL STATE

Figure 1 shows the layout and basic technical parameters of the roller test bench used in the author's laboratories. The roller test bench is equipped with a set of variable flywheels for the simulation of different vehicle weights. The range depends on the used gear ratio and varies from 780kg to 10 700kg. Simultaneously the selected gear ratio changes the ratio between achievable maximum roller speed and maximum brake torque. Maximum speed is within the range 73 to 235 km/hour.

3. 2WD ROLLER TEST BENCH – UPGRADE

The goal of this project was to secure rotation of non-driven wheels simultaneously with the driven wheels. Two main concepts were considered. The first concept is based on the simulation of the wheel speed signal to the ECU. This concept has a disadvantage in that the type of the signal can differ from vehicle to vehicle and it may not always be possible to find out this information. Furthermore, it can also be a problem to access the sensor wiring without damaging them. Therefore, the second concept was chosen.

This concept deals with external equipment which mechanically rotates the non-driven wheels. Some of the considered solutions are shown in Figure 2. It was very important to minimize construction work in the test room itself, but not to reduce the versatility of the developed equipment. The final solution is therefore based on an electric motor which is coupled directly with the wheel hub [3]. The electric motor has a maximum power of 3 kW. The connecting flange has an arrangement of holes for the wheel bolts with the most commonly used pitch circle diameters, so it can be used for various vehicles. The electric motor is mounted on a frame which is fixed to the test cell mounting base. Such a solution makes it easy to adapt the device for any vehicle. The required wheel hub height is achieved by adjustable supports placed under the vehicle axle. Potential misalignment between the electric motor and the wheel hub is compensated for by use of a double cardan joint. Figure 3 shows the equipment installed on two different types of vehicle.

The speed of the electric motors is governed by converters, which are controlled by a newly developed software application in LabVIEW [4] to achieve the same speed as the driven wheels. The feasible difference between these speeds has a certain limit. The limit value depends mainly on an algorithm used in

FIGURE 1: 2WD roller test bench

OBRÁZEK 1: Vozidlový dynamometr s jednou dvojicí válců

FIGURE 2: Proposals for equipment to power non-driven wheels:

a) Pair of rollers driven by test bench rollers using belt drive, b) Roller with adjustable position driven by electric motor, c) conveyor belt driven by electric motor, d) Wheel hub driven by electric motor

OBRÁZEK 2: Návrhy zařízení pro pohon kol nepoháněné nápravy:

a) Dvojice válců poháněná řemenovým převodem, b) Válec s nastavitelnou polohou poháněný elektromotorem, c) běžící pás poháněný elektromotorem, d) Pohon náboje kola elektromotorem

FIGURE 3: New equipment to power non-driven wheels installed on two types of car

OBRÁZEK 3: Realizace otáčení kol nepoháněné nápravy na dvou různých automobilech

FIGURE 4: Scheme of the roller test bench
OBRÁZEK 4: Uspořádání měřicího stanoviště

the vehicle control system. In practice, the speeds should be as close together as possible. The scheme of the roller test bench is shown in Figure 4.

4. VEHICLE TESTING

The main goal of the hybrid vehicle testing is to prove the new roller test bench equipment that ensures rotating of non-driven wheels at the same speed as the driven wheels. This allows the testing of vehicles which require rotation of all wheels to drive. The Toyota Prius hybrid vehicle is an example of such a modern sophisticated vehicle.

First of all, the roller test bench has to be adjusted according to the tested vehicle [5]. There are two main setup procedures to be performed in order to simulate driving on a common road. Firstly, the dynamic forces coming from the acceleration and deceleration of the vehicle; this load is simulated by additional flywheels on the shaft between the rollers and dynamometer. The

second setup is the adjustment of roller resistances depending on the vehicle speed. A torque calculation based on the vehicle speed is implemented in the dynamometer SW. This relationship is expressed by the quadratic polynomial:

$$M = k_2 \cdot n^2 + k_1 \cdot n + k_0 \quad (1)$$

where M is torque, n is roller speed and k₀, k₁, k₂ are coefficients of vehicle resistances. One of the methods for determining the coefficients k₀, k₁, k₂ is driving the vehicle on a real testing road and perform a coast down, acceleration and maximum speed test. Then these tests are repeated several times on the roller test bed and the coefficients are changed until the same patterns of tests are achieved. For the hybrid vehicle it is important to consider the state of the battery during these tests. Significantly different results can be achieved with a fully charged battery and with an empty battery at the beginning of a test. All tests

FIGURE 5: Coasting and acceleration test for the tested vehicle. Patterns measured on a real road (red) and on the roller bench (blue)
OBRÁZEK 5: Dojezdová a akcelerační zkouška měřeného vozidla na zkušební trati (zobrazeno červeně) a na vozidlovém dynamometru (zobrazeno modře)

FIGURE 6: Acceleration test on roller bench, new equipment inactive (red), active (blue)

OBRAZEK 6: Akcelerační zkouška na vozidlovém dynamometru bez (vyneseno červeně) a s aktivovaným (vyneseno modře) zařízením pro pohon kol nepoháněné nápravy

were performed with a fully charged battery for the purposes of roller bench adjustment.

Figure 5 shows the coasting and acceleration test for the tested Toyota Prius vehicle.

The red dashed line in the graph in Figure 6 shows what happens if the non-driven wheels stay still during acceleration (new roller bench equipment inactive). The vehicle starts to accelerate up to 20–30 km/h, then emergency mode is switched on (indicated by a control lamp of brakes on the dashboard) and power is lost and the vehicle no longer accelerates.

The blue line shows the same acceleration with the new equipment activated. The vehicle can be driven normally as on the real road and can be accelerated up to maximum speed.

Several tests were performed to prove this new equipment and verify correct function. One of the test sets is presented in this paper – the NEDC emission test [6]. Several NEDC tests were run with different starting conditions. The pattern of speed, power, engine speed and position of the throttle for one NEDC test are shown in Figure 7.

5. MEASUREMENT RESULTS

An overview of the test conditions and results is shown in Table 1. Five NEDC tests are presented. One of them (test no. 3) was with a cold start – engine temperature around 28 °C, another with hot start – engine temperature around 90 °C. The Prius as a hybrid vehicle does not have a conventional gearbox. The driver can just select from three driving modes:

D – normal forward driving

B – forward driving with engine braking during each deceleration

R – reverse driving.

All tests except one (no. 4) were driven in the mode D. Table 1 also shows the state of the battery at the beginning and at the end of each test. An interesting parameter is the percentage time of engine running during the test. It can be observed in graph 6 that the engine does not run all the time. There are parts of the test where only the electric motor powers the vehicle and the combustion engine is still. The fuel consumption is presented as the final information in the table. There are two values, one is calculated during the urban part of the NEDC, and the second value is calculated during the whole NEDC test. This fuel consumption was obtained from the vehicle on-board computer and represents the average fuel consumption in litres per 100 km, which is also presented by the vehicle's producers. As could be expected, the highest fuel consumption was recorded in test no. 3 with a cold start and with low charged battery at the beginning. Correspondingly, the rate of combustion engine use is also the highest. On the other hand, the lowest consumption was achieved in test no. 6, with hot start and also low battery charge at the beginning. Even the fully charged battery at the

FIGURE 7: Data record from the NEDC test cycle

OBRAZEK 7: Záznam z NEDC jízdního cyklu

TABLE 1: Tests conditions and results of different NEDC tests

TABULKA 1: Zkušební podmínky a výsledky různých NEDC jízdních cyklů

test no.		2	3	4	5	6
Eng. temp. at start		–	HOT	COLD	HOT	HOT
Driving mode		–	D	D	B	D
Time of engine running	(%)	44.3	59.2	56.5	43.4	42.2
Battery	at start	(%)	75	12.5	75	87.5
state	at end	(%)	87.5	87.5	37.5	75
Fuel	urban part	(l/100 km)	4.9	6.5	5.4	4.5
consumption whole test	(l/100 km)	5.6	6.5	5.8	5.5	5.4

beginning of the test (as in test no. 5) does not represent the best conditions and the fuel consumption is little higher. The presented experimental data very well illustrates the complexity of the control system for a hybrid vehicle, but they are not sufficient for establishing any general conclusions about the behaviour of the vehicle control system.

Thus these results of the NEDC cycles can be taken just as preliminary results. The fuel consumption is significantly higher than the values presented by the producer of this vehicle type. There are several reasons why the same results couldn't be achieved. First of all, the tested Toyota Prius was 6 years old and had already run around 271 000 km. This probably means that neither the combustion engine nor the battery are in as good a condition as a new one. Secondly, during the testing it was determined that the rear brakes were in bad condition and added extra losses during the driving. This negative phenomena was repaired, but the testing of the vehicle on the real road, used for the roller bench adjustment, was performed with this additional load. This means that the roller bench simulated a higher load than it should have for this type of vehicle. Also, there isn't any accurate measurement of the fuel consumption. As mentioned above, the fuel consumption was obtained from the vehicle on-board computer. The accuracy of this measurement is unknown. However, all tests were carried out successfully and no errors were apparent due to different speed of the driven and non-driven wheels.

6. CONCLUSION

This contribution deals with the testing of modern vehicles with sophisticated systems (such as ABS, ESP, ASR, ...) on a roller test bench. Such modern vehicles need rotation of all wheels for proper driving, even if they are only 2WD. The testing of such a vehicle is not possible on the standard 2WD roller test bench. A new equipment upgrade of the existing 2WD roller bench is presented. It powers the non-driven wheels synchronously with the driven wheels. Several sets of tests were performed and some NEDC tests are presented as an example. The vehicle can be driven as on a real road without any fault message caused by different speed of the driven and non-driven wheels. Testing of the vehicle was successful and correct function of the new roller bench equipment has been verified.

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LIST OF NOTATIONS AND ABBREVIATIONS

ABS	Anti-lock Brake System
ASR	Anti-Slip Regulation
ECU	Electronic Control Unit
ESP	Electronic Stability Program
M	Torque [N.m]
n_eng	Engine speed [1/min]
NEDC	New European Driving Cycle
P_Dyno	Dynamometer power [kW]
ped_pos	Gas pedal position [%]
v_dyno	Dynamometer speed [km/h]
WD	Wheel Drive

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