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AUTOMOTIVE TRANSMISSION EFFICIENCY MEASUREMENT USING A CHASSIS DYNAMOMETER

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ABSTRACT−Automotive transmission efficiency measurements are usually performed on purpose-built rigs. A simple model was developed for calculating the overall transmission efficiency of passenger cars by using a chassis dynamometer. Wheel power and engine output were measured, and these values were used for calculations. The proposed method can only be employed for vehicles with manual drive because it requires constant speed measurements. Two case studies were investigated, with front-wheel and rear-wheel drive passenger cars. The results obtained from using the proposed model are in good agreement with data provided in the literature.

KEY WORDS : Transmission efficiency, Wheel power, Vehicle dynamics, Chassis dynamometer

1. INTRODUCTION

A portion of the power produced by internal combustion engines is lost due to friction in the vehicle's transmission. As a result, the overall powertrain efficiency decreases. Even if considerable advancements were made in the field of automatic (Shinbori *et al*., 2010; Kelling *et al*., 2006) and continuous variable transmissions (CVT) (Saito and Miyamoto, 2010), (Ryu and Kim, 2008), manual drives would still be more efficient, with maximum ratings around 96 % (Schuster, 2000). Studies were conducted to evaluate the benefits of using different lubricants (Wienecke and Bartz, 2001; Kubo *et al*., 1986), and hybrid (Cho *et al*., 2006), epicyclic (Ciobotaru *et al*., 2010) transmissions and models (Kim *et al*., 2010) were developed for new powertrains.

The work developed in this paper aims to asses a simple method for calculating passenger car manual transmission efficiency based on an energy in – energy out approach, similar to the one described in (Schuster, 2000). A chassis dynamometer was used to measure engine output during acceleration and wheel power under steady state operation at full load. These values were used to calculate the overall transmission efficiency for a front- and a rear-wheel drive vehicle.

2. EXPERIMENTAL SETUP

Power measurements were performed on a MAHA LPS 3000 chassis dynamometer with the vehicle secured as shown in figure 1. The tester measures wheel power (P_w), and the software calculates engine output (P_e) by measuring drag power in the additional stage following full load operation. After the vehicle is accelerated at full throttle from 50 km/h up to the maximum engine speed, the clutch is disengaged and the transmission decelerates from the maximum speed down to 50 km/h, while the rig measures drag power. Measuring power with this method ensures increased accuracy of ±2% (Maha Standard Operating instructions and User's Manual).

The dynamometer's settings only allow for full load power measurements during acceleration for engine speed values greater than 1720 rev/min and 1930 rev/min for each of the vehicles with the 4th gear selected because the rig does not measure drag power below 50 km/h vehicle speed. For this reason, steady state measurements were considered, and engine power values for engine speeds below 2000 rev/min were calculated assuming a second degree polynomial drag power variation (figure 2). This drag power measured by the dynamometer is lost power due to friction and the

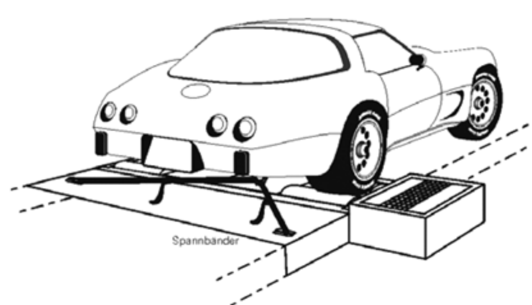

Figure 1. Chassis dynamometer setup (Maha Standard Operating instructions and User's Manual).

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Table 1. Specifications for the FWD passenger car.

Vehicle mass	975 kg
Gear ratios Final drive	3.73:1/2.05:1/1.39:1/1.03:1/0.79:1 4.21:1
Maximum speed	162.5 km/h
Engine power rating	55 kW @ 5500 rev/min
Engine torque rating	112 Nm @ 3000 rev/min
Displacement	1390 cm^3
Bore × Stroke	79.5 mm × 70 mm
Compression ratio	9.5:1

Table 2. Specifications for the RWD passenger car.

Vehicle mass	1265 kg
Gear ratios Final drive	3.95:1/2.19:1/1.39:1/1:1/0.84:1 3.9:1
Maximum speed	187 km/h
Engine power rating	85 kW @ 5200 rev/min
Engine torque rating	170 Nm @ 2600 rev/min
Displacement	1998 cm^3
Bore × Stroke	86 mm × 86 mm
Compression ratio	9.2:1

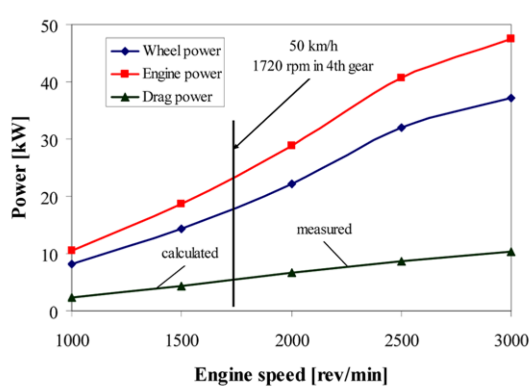

Figure 2. Engine power determined at engine speed below 2000 rev/min for the RWD vehicle.

energy used to accelerate the drivetrain. For this reason, transmission efficiency could not be determined based on acceleration measurements only.

Steady state measurements were conducted at constant speed operation to measure wheel power for 1000-6000 rev/min engine speeds. These measurements were used to determine the actual power that propels the vehicle. All measurements were conducted at relatively constant ambient conditions, with the engine at a nominal working temperature. Therefore, it can be safely assumed that the gearbox lubricating oil temperature was practically constant during all measurements.

Besides the power lost in the transmission, additional energy is necessary to cover rolling resistance at the contact point of tire and dynamometer rollers. This loss cannot be measured; therefore, equation (1) was used to calculate it:

$$P_r = \mu_r \cdot m_v \cdot g \cdot w_v \tag{1}$$

where P_r is lost power due to rolling resistance, measured in W, μ_r rolling friction coefficient, m_v is the vehicle mass in kg, g is the gravitational acceleration in m/s^2 and w_v is the vehicle speed measured in m/s.

Losses such as the power lost due to tire flexing, were not considered because they are insignificant.

After measuring engine power throughout the entire rpm range, transmission efficiency was calculated using equation (2):

$$\eta_t = \frac{P_w + P_r}{P_e} \tag{2}$$

where η_t is the efficiency of the transmission, P_w is the wheel power measured in W and P_e is the engine power in W.

Two vehicles were used for measurements: one with front-wheel drive (FWD) and the other with rear-wheel drive (RWD). These case studies were not chosen for comparing two drivetrains, but rather to confirm the method's validity in more than one case. Both passenger cars were equipped with spark ignition engines. Specifications for these vehicles are given in table 1 and table 2, respectively.

Given that the experimental rig measures engine power with a ±2 % accuracy, a similar error level can be expected to occur during transmission efficiency measurements. Additional errors are induced using equation (1) but are not that significant. A brief analysis of the measured values shows that over 86% of the points for the FWD passenger car (figure 5), and over 88 % of the points for the RWD vehicle (figure 6) are within a ±2% range of the values given by the polynomial fits. All deviations, calculated as the measured values compared to the corresponding polynomial fits were within a ±5% range.

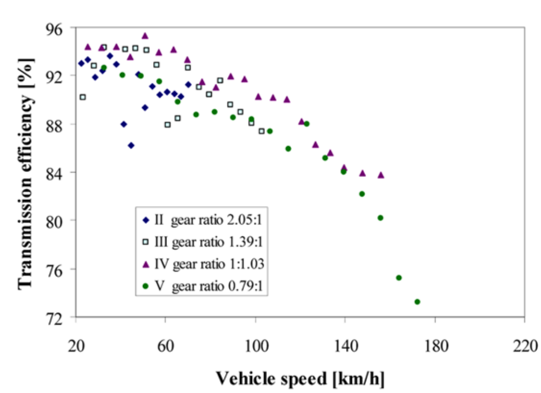

Figure 3. Transmission efficiency for the FWD vehicle.

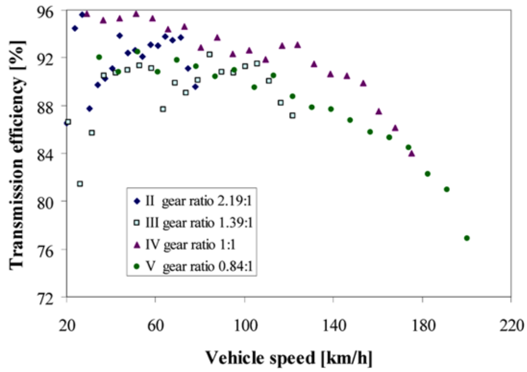

Figure 4. Transmission efficiency for the RWD vehicle.

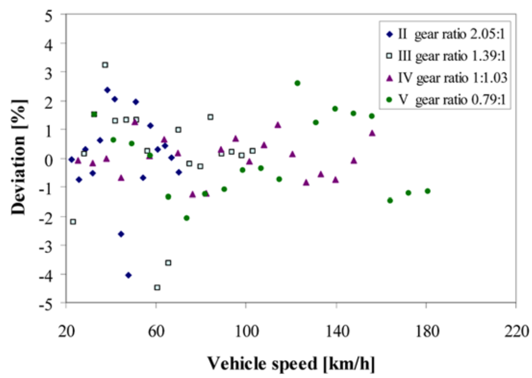

Figure 5. Deviation of measured points from the polynomial fits for the FWD vehicle.

An increased scatter of measured points was observed at low speed, below 60 km/h (figures 3 and 4). As previously mentioned, the chassis dynamometer measures engine power only above 50 km/h vehicle speed during acceleration trials.

Therefore, below this speed threshold, the experimental rig most likely cannot ensure the increased accuracy. Above 60 km/h, over 93% of the measured values were within a ±2 % deviation from the polynomial fits. An increase of the deviations was observed for higher gear ratios (II and III), most likely caused by the high wheel torque transmitted. This explanation also seems to be supported by the impossibility of conducting measurements in 1st gear for either of the vehicles. Because of the very low wheel speed and high torque, the dynamometer simply could not maintain a constant speed when 1st gear (3.73 for the FWD vehicle and 3.95 for the RWD car) was selected. The dynamometer's brake most likely cannot generate enough power to maintain a constant speed with such high wheel torque at very low rotational speeds. This relationship is also suggested by the deviation analysis. These values drop from ±5 % at 20 km/h vehicle speed, down to ±2 % above 60 km/h (figures 5 and 6).

3. RESULTS AND DISCUSSIONS

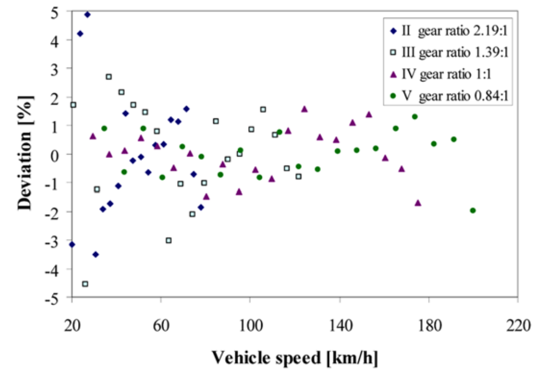

Figure 6. Deviation of measured points from the polynomial fits for the RWD vehicle.

Friction losses increase with increasing rotational speed. Thus, the efficiency is at its maximum for low speeds and decreases as top engine speed is approached (figures 7 and 8). The efficiency variation with higher gear ratios for the RWD passenger car (II and III) suggests that this observation is not valid for these cases. This phenomena can be partially explained by the variation of lubrication oil churning losses. High gear ratios allow for the input and output shafts to rotate at significantly different speeds, most likely an unfavorable hydrodynamic state was present, compared to the case of lower gear ratios (IV and V). This could result in increased churning losses at certain levels of rotational speed and cause a change in the efficiency variation trend. It must be mentioned, however, that measurements performed at low wheel speed should be analyzed knowing that the accuracy is much lower below 60 km/h vehicle speed. Given that the efficiency curves for the 4th and 5th gears share similar trends for both vehicles (figures 7 and 8), it can be concluded that this measurement method can be used with great accuracy,

Table 3. Results for the FWD vehicle, 4th gear selected.

n (rpm)	P_w (kW)	P_e (kW)	P_r (kW)	η_t (%)
1000	7.40	8.70	0.81	94.33
1500	11.90	13.90	1.21	94.33
2000	16.70	19.20	1.62	95.40
2500	21.70	25.25	2.07	94.14
3000	25.40	30.41	2.42	91.49
3500	29.10	34.71	2.83	91.98
4000	31.70	38.72	3.23	90.21
4500	36.90	45.01	3.63	90.06
5000	36.70	47.22	4.04	86.28
5500	35.10	46.86	4.44	84.39
6000	34.70	47.20	4.85	83.78

Table 4. Results for the RWD vehicle, 4th gear selected.

n (rpm)	P_w (kW)	P_e (kW)	P_r (kW)	η_t (%)
1000	9.8	11.50	1.20	95.68
1500	16.10	18.60	1.81	96.28
2000	23.60	27.10	2.41	95.98
2500	33.80	38.90	3.02	94.64
3000	38.80	45.29	3.62	93.65
3500	45.00	53.13	4.22	92.63
4000	51.90	61.01	4.82	92.97
4500	57.60	68.92	5.42	91.44
5000	63.20	76.53	6.03	90.46
5500	62.20	78.68	6.63	87.48
6000	55.00	74.12	7.23	83.96

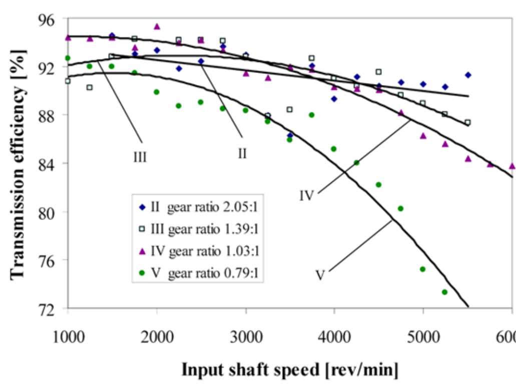

Figure 7. Transmission efficiency for the FWD vehicle.

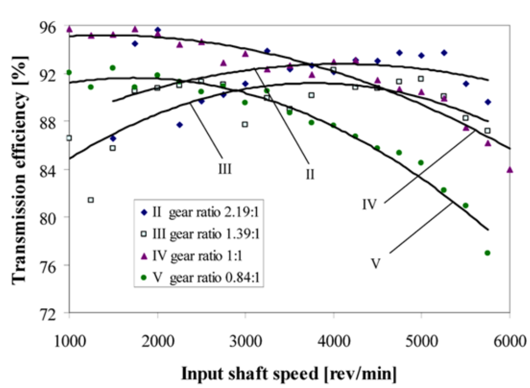

Figure 8. Transmission efficiency for the RWD vehicle.

better than ±2%, only for gear ratios that cover a 60-200 km/h vehicle speed interval, throughout the engine's rpm range. If a different dynamometer, with a higher accuracy at low wheel speed is used, error levels should be expected to decrease, even during low speed measurements.

Even though load and rotational speed are very important factors that influence transmission efficiency, measurements were not taken at partial load engine operation because as transmission input power cannot be determined with the proposed experimental setup. Therefore, this method can only be used to determine transmission efficiency with the engine at full load.

Transmission losses are influenced by transmitted torque. However, considering that the values obtained at low engine speeds with the 4th and 5th gears selected, are very close to maximum efficiency levels given in the literature, one can conclude that transmitted torque influences friction only at high rotational speeds. Because high engine speed is usually associated with high load, the results obtained using this method are highly relevant for powertrain simulations. Measured results as well as calculated values are presented in tables 3 and 4 for the two passenger cars at full load, with the 4th gear of the transmission selected. Multiple runs were conducted, all with the engine at nominal operating temperature. Presented values are the averaged results of numerous trials. Ambient temperature ranged within a narrow interval, with a minimum value of 29.1ºC and a maximum of 32.9ºC. Air pressure also featured a slight variation between 1014.1 mbar and 1021.4 mbar. As proper ventilation was ensured, no overheating episodes were encountered. All engine power measurements were well within the parameters given by the manufacturers, and no malfunctions occurred during the experimental trials.

An interesting result is that the RWD vehicle features a higher transmission efficiency throughout the engine's rotational speed range, in 4th and 5th gears. Maximum calculated efficiency is 96.28 % for the RWD vehicle (table 4), while top value for the FWD car is 95.4 % (table 3), both with the 4th gear selected. These results are very close to generic values given in the literature. One reason for the higher power losses in the FWD vehicle could be that the input shaft has a higher rotational speed compared to the RWD transmission, for the same input power. This relationship occurs because the FWD powertrain is equipped with a smaller engine that produces the same power as the larger engine on the RWD vehicle, at a higher rotational speed. Also, a substantial difference in maximum speed was noticed for the two passenger cars used in the case study. Further studies involving vehicles with similar power ratings would provide a more accurate conclusion when comparing FWD with RWD solutions.

4. CONCLUSIONS

A simple methodology for measuring passenger car transmission efficiency using a chassis dynamometer was developed and validated. By employing the entire vehicle rather than just the transmission mounted on purpose-built rigs, the proposed method ensures results obtained in conditions very close to real world operation conditions of automotive powertrains.

As the results obtained following the experimental trials are close to the values given in the literature, the proposed methodology can be used to determine manual transmissions efficiency with the engine operating at full load, without using purpose-built rigs. Given that a chassis dynamometer is used when employing this method, measurement accuracy depends on the experimental rig's settings. Very good accuracy was obtained with the setup used in this work, only for gear ratios that cover a 60-200 km/h vehicle speed range. One disadvantage of this setup is that measurements were limited to vehicle speed higher than ~20 km/h and good accuracy was obtained only at wheel speed values higher than 60 km/h. At values lower than 60 km/h wheel speed, the errors were below ±5%, while in the 60-200 km/h speed range, the accuracy was much improved, with values ranging between ±2% deviation.

Being a simple model based on an energy in – energy out approach, it can be easily integrated into powertrain simulations and can be used for calculating engine efficiency without having to resort to dedicated dynamometer rigs where the motor is decoupled from the transmission. Also, it is highly relevant in simulations because it covers operating situations encountered in real world situations.

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