Effect of high-speed traction gearbox ratio on vehicle fuel consumption

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Summary. This paper presents the effect of high-speed traction gearbox ratio on vehicle mileage fuel consumption. Relation was determined for constant linear velocities of a motor vehicle being reached on more than one gearbox ratio. The characteristic curve was prepared based on an engine's torque-speed relationship for respective mileage fuel consumption being obtained when using given gears. Experiments were carried out based on engine standards, according to which the points of external and partial characteristic curves for an engine's torque and its fuel consumption were established by measurement.

It was demonstrated in conclusions that fuel consumption of a motor vehicle increases together with an increase in the value of high-speed traction gearbox ratio.

Key words: high-speed traction gearbox ratio, mileage fuel consumption, energy consumption of vehicle motion.

INTRODUCTION

Mileage fuel consumption is an important parameter characterising a motor vehicle in terms of economy and ecology. It is the clearest characteristic for a potential user, the value of which has been constantly reduced over the years. It can be described by the following relation [2,7]:

$$Q = \frac{G_e \cdot 100}{\gamma \cdot v} \tag{1}$$

where:
Q - mileage fuel consumption [dm^3/100 km],
G_e - hourly fuel consumption [kg/h],
γ - fuel specific gravity [kg/dm^3],
v - vehicle's linear velocity [km/h].

Gearbox ratios are important for fuel consumption. The larger value has the ratio, the accordingly higher is fuel consumption curve located. Engine has to make a larger number of work cycles so that a motor vehicle could cover a specific road section. Then, the most important parameter affecting mileage fuel consumption when moving with a constant speed is high-speed traction gearbox ratio (ratio of engine crankshaft angular velocity ω_S to vehicle linear velocity v or a ratio of power transmission system's overall gear ratio i_C to dynamic wheel radius r_d) [10]:

$$i_S = \frac{\omega_S}{v} = \frac{i_C}{r_d}. \tag{2}$$

Then, the relationship (1) assumes the following form:

$$Q = \frac{G_e \cdot 100 \cdot i_S}{\gamma \cdot \omega_S}. \tag{3}$$

The foregoing considerations being referred to have determined that 5-speed mechanical gearboxes are frequently used in motor vehicles, of which the last gear is an economic one (lowest fuel consumption) but also an overdrive gear (gearbox ratio is less than one) [10].

High-speed traction gearbox ratio is thus an effective indicator of the impact of engine elements' motion mechanics (engine crankshaft speed) on the energy consumption of vehicle motion expressed as fuel consumption.

RESEARCH OBJECTIVE AND METHODS

The objective of this research project was to determine the effect of high-speed traction gearbox ratio on vehicle fuel consumption.

The methods of carried out research are in conformity with standards [15,16,17]. Experiments were conducted according to the requirements specified in them, using an engine test bench. Test points were prepared for feeding an engine with a full fuel dose (external characteristics) and partial fuel doses (25%, 50 % and 75%), i.e. partial power characteristics for Fiat 1.3 JTD Multijet engine. Based on the presented graphs, a full load characteristics was prepared. The final stage was to establish a relationship between mileage fuel consumption and high-speed traction gearbox ratio.

TEST BED

The test bed consisted of the following components:

a) eddy current brake EMX 100 manufactured by Elektromex (Poland);
b) Fiat 1.3 JTD Multijet engine, i.e. a compression-ignition, four-stroke, turbo-supercharged, direct fuel injection engine with fuel feed system of the Common Rail type. Fuel injection was controlled electronically with air supercharging by turbo-supercharger and air cooler. The engine was controlled by means of electronic high pressure injection system designed by Magneti Marelli [14].

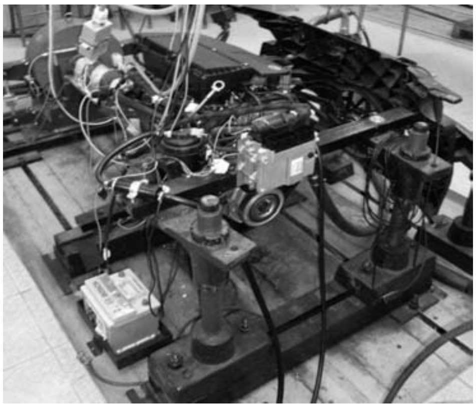

Fig. 1. The view of Fiat 1.3 JTD 16 V Multijet engine connected with eddy current brake EMX 100 by means of drive shaft

Engine details are given in Table 1 below according to manufacturer's data.

Table 1. Engine details according to manufacturer's data [14]

Make: FIAT		Type: 1.3 JTD 16 V Multijet
Work cycle		4-stroke
Cylinder diameter	[mm]	69.6
Piston travel	[mm]	82
Compression ratio		18.1
Number of cylinders		4
Arrangement of cylinders		in-line
Injection sequence		1-3-2-4
Engine capacity	[cm^3]	1248
Maximum power	[KM/kW]	70/51
Rotational speed at maximum power	[min^{-1}]	4000
Maximum torque	[Nm]	145
Rotational speed at maximum torque	[min^{-1}]	1750

VEHICLE INFORMATION

In order to be able to draw a relationship of fuel consumption-high-speed traction gearbox ratio, certain information were necessary, such as – for instance – power transmission system efficiency, kinematic wheel radius and gearbox and final drive ratios. These data are presented in Tables 2 and 3.

Table 2. Basic vehicle and motion resistance data

Element	Value	Unit	where (comment):
η_{UN}	0.9	-	power transmission system efficiency (for passenger cars)
r_k	0.27	[m]	kinematic wheel radius

In Table 3 below, vehicle gearbox and final drive ratios are being considered.

Table 3. Basic C514R gearbox and final drive ratios [14]

I gear	3.909
II gear	2.158
III gear	1.345
IV gear	0.974
V gear	0.766
Final drive	3.438

COURSE OF TESTS AND RESULTS

The graphs made on the basis of measurements were the full power characteristics (external characteristic curve) as well as partial power characteristics (characteristic curves for feeding the engine with 25%, 50 % and 75 % fuel dose). The most important parameters were engine torque and fuel consumption. The collected measurement results are presented in Tab. 4 and Figs 2 and 3:

where: *n* – engine speed, *Ttq25%* – corrected engine torque (fuel feed with 25% nominal dose), *Ttq50%* – corrected engine torque (fuel feed with 50% nominal dose), *Ttq75%* – corrected engine torque (fuel feed with 75% nominal dose), *Ttq100%* – corrected engine torque (fuel feed with 100% nominal dose), *B25 %* – engine fuel consumption (fuel feed with 25 % nominal dose), *B50 %* – engine fuel consumption (fuel feed with 50 % nominal dose), *B75 %* – engine fuel consumption (fuel feed with 75 % nominal dose), *B100 %* – engine fuel consumption (fuel feed with 100 % nominal dose)

Table 4. Measurement results for engine parameters

	n	Ttq25%	Ttq50%	Ttq75%	Ttq100%	B25%	B50%	B75%	B100%
Item	[rpm]	[Nm]	[Nm]	[Nm]	[Nm]	[g/s]	[g/s]	[g/s]	[g/s]
1	1000	12.0	13.1	35.7	71.4	0.23	0.25	0.35	0.59
2	1500	18.4	20.1	62.2	124.4	0.50	0.60	0.84	1.39
3	1700	18.0	19.9	69.8	139.6	0.50	0.55	1.01	1.65
4	1900	19.5	24.2	71.2	140.1	0.57	0.70	1.08	1.78
5	2000	20.2	24.3	70.1	138.1	0.63	0.86	1.12	1.85
6	2200	19.1	25.1	68.9	137.7	0.59	0.91	1.23	2.01
7	2400	18.4	24.3	67.6	135.2	0.72	0.85	1.25	2.08
8	2500	17.1	24.6	67.2	134.4	0.64	0.93	1.33	2.20
9	3000	18.8	26.8	67.3	134.6	0.74	0.99	1.66	2.75
10	3500	18.5	32.9	68.1	124.2	0.95	1.23	1.87	3.08
11	4000	25.0	44.4	70.2	115.1	1.16	1.34	2.09	3.38
12	4500	14.4	43.3	60.3	94.6	1.25	1.50	1.95	3.25

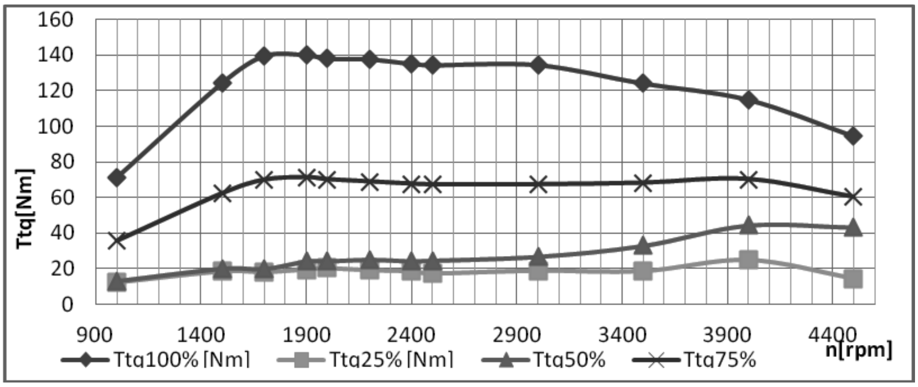

Fig. 2. Partial characteristic curves for engine torque

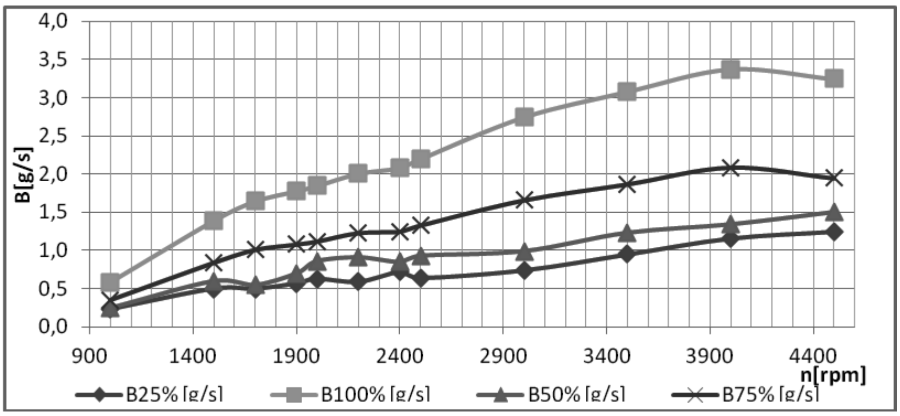

Fig. 3. Partial characteristic curves for fuel consumption

The presented graphic relations allowed for the establishment of the full load characteristics as a fuel consumption-engine torque relationship and transposition of the axes of that characteristics together with the replacement and conversion of hourly fuel consumption into mileage fuel consumption according to relation (1)

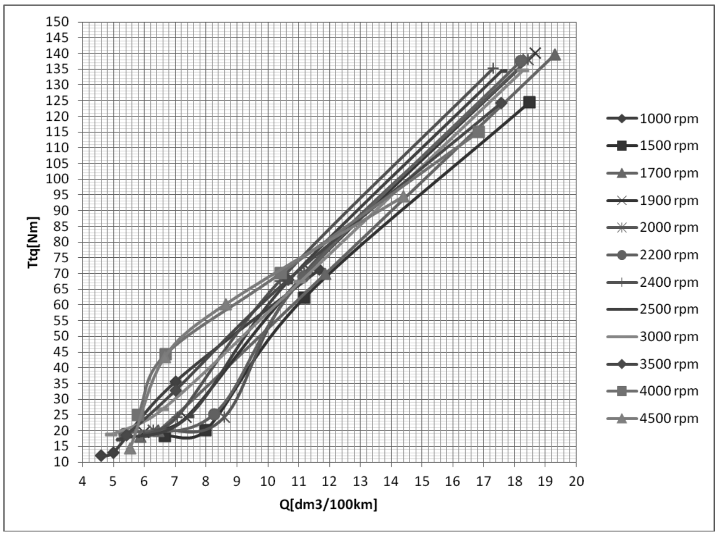

Fig. 4. Engine torque-mileage fuel consumption relationship for the third gear

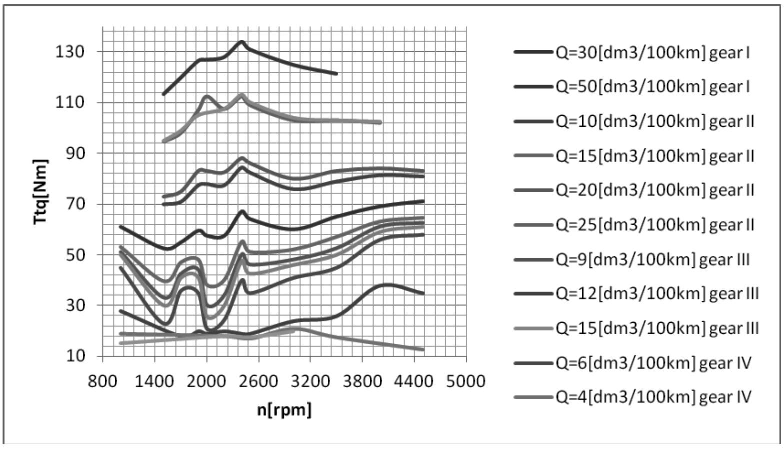

Fig. 5. Relation between engine torque and its speed allowing for sample mileage fuel consumption curves for individual gears

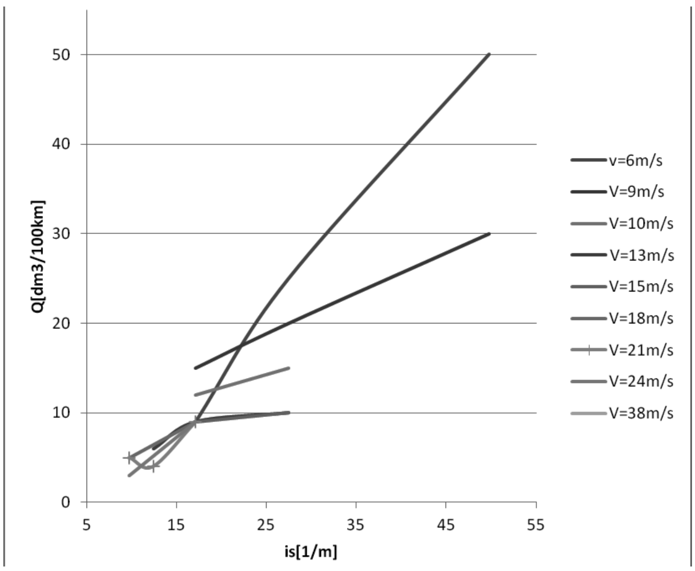

Fig. 6. Effect of high-speed traction gearbox ratio on mileage fuel consumption

Table 5. Constant value of high-speed traction gearbox ratio for first gear

n	*n*	*ω*	*v*	*v*	i_S
[rpm]	[rps]	[rad/s]	[km/h]	[m/s]	[1/m]
1000	17	104.67	7.570	2	49.77
1500	25	157.00	11.355	3	49.77
1700	28	177.93	12.869	4	49.77
1900	32	198.87	14.383	4	49.77
2000	33	209.33	15.140	4	49.77
2200	37	230.27	16.654	5	49.77
2400	40	251.20	18.168	5	49.77
2500	42	261.67	18.925	5	49.77
3000	50	314.00	22.710	6	49.77
3500	58	366.33	26.495	7	49,77
4000	67	418.67	30.281	8	49,77
4500	75	471.00	34.066	9	49,77

Table 6. Sample fuel consumption for specific high-speed traction gearbox ratios (constant vehicle linear velocities)

	i_S	*Q*	[dm³/100km]							
	[1/m]	*v*=6m/s	*v*=9 m/s	*v*=10 m/s	*v*=13 m/s	*v*=15 m/s	*v*=18 m/s	*v*=21m/s	*v*=24 m/s	*v*=38 m/s
i_{sI}	49.77	50	30							
i_{sII}	27.48	25	20	15	10	10				
i_{sIII}	17.13	9	15	12	9	9	9	9	9	4
i_{sIV}	12.40				6			4		
i_{sV}	9.75						5	5	3	5

for each engine speed and for linear velocity ranges for each total ratio (being a product of selectable gearbox ratio and constant final drive ratio) (Fig. 4).

From the graph presented above, sample mileage fuel consumption values were selected (for each gear) and engine torque values corresponding to them were read. This allowed attainment of fuel consumption curves for individual engine speeds (which allowed further replacement into vehicle linear velocities for specific total ratios of power transmission system).

The converted values of high-speed traction gearbox ratio were identical within the whole range of rotational speeds for individual gear ratios (see an example in Tab. 5).

For successive gears, the following values of high-speed traction gearbox ratio were obtained together with specific values of mileage fuel consumption for constant vehicle linear velocities (Tab. 6 and Fig. 6).

CONCLUSIONS

High-speed traction gearbox ratio is an important parameter characterising the ratio of engine angular speed to linear velocity of vehicle wheels. It has a greater value for lower gears, whereas a smaller one for higher gears. Mileage fuel consumption for specific linear vehicle velocities increases with increasing values of high-speed traction gearbox ratio but also decreases for smaller values of high-speed traction gearbox ratio.

The reported arguments allow for the conclusion that the most economical driving (and at the same time the most ecological one) is that one where vehicle speed values are high (over 18 m/s in Fig. 6) and high-speed traction gearbox ratio values are low. Then the mileage fuel consumption is the lowest.

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WPŁYW PRZEŁOŻENIA SZYBKOBIEŻNOŚCI NA ZUŻYCIE PALIWA POJAZDU

Streszczenie. Publikacja prezentuje wpływ przełożenia szybkobieżności na przebiegowe zużycie pojazdu. Relację określono dla stałych prędkości liniowych samochodu osiąganych na więcej niż jednym przełożeniu skrzyni biegów. Charakterystykę wykonano na podstawie zależności momentu obrotowego silnika od jego prędkości obrotowej dla poszczególnych przebiegowych zużyć paliwa uzyskanych przy wykorzystaniu danych biegów. Eksperymenty zostały wykonane na podstawie norm silnikowych, według których przez pomiar utworzono punkty charakterystyk zewnętrznych oraz częściowych momentu obrotowego silnika oraz jego zużycia paliwa.

We wnioskach wykazano, że wraz ze wzrostem wartości przełożenia szybkobieżności rośnie konsumpcja paliwa pojazdu samochodowego.

Słowa kluczowe: przełożenie szybkobieżności, przebiegowe zużycie paliwa, energochłonność ruchu pojazdu.