SIMULATIVE COMPARISON OF THE TRACTION PROPERTIES OF DAEWOO LUBLIN 3 MI VAN WITH PARTICULAR TYPES OF GEARBOX

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Abstract

A problem of comparing the traction properties of Daewoo Lublin 3 Mi van with respective types of gearbox has been taken up in the paper. There were three gearbox types: TS5-21, PD.97 and ZF. These properties were concluded based on vehicle traction graph. They included: reaching the reserve driving force in respective gears, obtaining accelerations, overcoming the resistances to motion (rolling resistance, air resistance and grade resistance) as well as achieving the maximum speed.

Vehicle traction diagram has been made based on the torque curve of Andoria 4CTi90 engine external characteristics obtained on engine test bed in a direct way using an AVL eddy current brake. The engine was supplied with a complete fuel dose and loaded with the resistance torque produced by engine brake. The characteristics was performed every 200 rpm from 1000 rpm to maximum revolutions and the other way from maximum revolutions to 1000 rpm every 200 rpm. The torque characteristics points were determined as a mean value obtained from these two measurements. After considering the data from engine external characteristics, vehicle information (including, among others, respective gear ratios and final drive ratio, under-the-bonnet power loss coefficient, and dynamic wheel radius) and the resistances to motion, a vehicle traction diagram of Daewoo Lublin 3 Mi van was made for three types of gearboxes. Based on this, the authors found that a Daewoo Lublin 3 Mi van equipped with ZF gearbox is the best from the point of view of traction properties.

Keywords: *traction characteristics of a vehicle, theory of motion, combustion engines, external characteristic of an engine, power transmission system*

1. Introduction

Traction properties are very important features which describe the behaviour of a vehicle. They allow determination of vehicle accelerations in respective gears, speeds being achieved by a vehicle and possibility of overcoming the resistances to motion. Traction diagram allows observation of certain dependencies between the driving force and the linear velocity of a vehicle. Not only the vehicle engine itself but also the selection of appropriate power transmission system is of considerable importance in obtaining the above mentioned properties. One of the subassemblies of that system is a gearbox which, as a set of selectable gear ratios, allows us to adjust a vehicle to required traffic conditions. This is not only about obtaining a range of certain speeds but also about specific accelerations, which can be of great importance in traffic. This is them which allow, for instance, making an overtaking manoeuvre in a smooth way without unwanted endangering oneself and other traffic participants.

Appropriately selected gear ratios allow not only making the above mentioned manoeuvre but also hill-climbing without gear reduction.

This is of even larger importance in case of a delivery van which has a maximum load (3.5 tonnes). Acceleration is directly proportional to the driving force on wheels but inversely proportional to vehicle weight. It can be seen therefore how a good selection of gear ratios in a gearbox may affect this parameter.

This paper takes up the problems of using an appropriate gearbox in a Daewoo Lublin 3 Mi van from the point of view of vehicle traction properties.

2. Study objective

The study objective was to compare in a simulative way the traction properties of Daewoo Lublin 3 Mi van, a combi 6-seater version, type 3N, variant 524, for three types of gearboxes, i.e. TS5-21, PD.97 and ZF.

3. Test bed

Examinations were carried out on engine test bed. It enabled determination of real engine parameters such as, for instance, engine horsepower or torque.

Depending on the needs, the scope of tests could vary considerably: from rough horsepower and fuel consumption measurements to complex scientific examinations according to the equipment of engine test bed.

The tests were performed on a test bed at the Department of Automotive Vehicles Operation presented in Figure 1.

One of the more important elements on test bed was a brake loading ANDORIA 4CTi90-1BE6 combustion engine (Tab. 1) with smooth adjustment of the value of set load. During the tests, AVL Dynoperform 160 eddy current brake was being used.
In Table 1 below, the technical data of ANDORIA 4CTi90-1BE6 engine given by its manufacturer are presented.

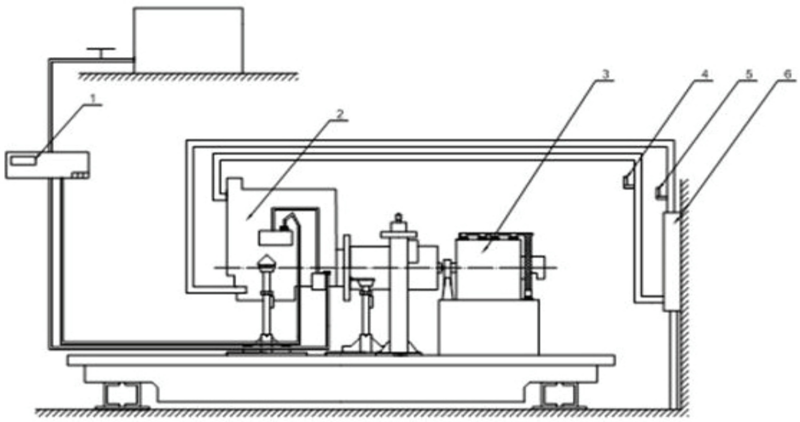

Fig. 1. Schematic diagram of test bed with ANDORIA 4CTi90 engine: 1 – AMX212F gauge, 2 – 4CTi90 engine, 3 – Dynoperform 160 brake, 3 – dynamometer, 4 – engine temperature sensor (inlet), 5- engine temperature sensor (outlet), 6 – cooling fluid exchanger

Tab. 1. Manufacturer's technical data of ANDORIA 4CTi90-1BE6 engine [10]

Item	Parameter	
1	2	3
1	Engine type	Compression-ignition, four-stroke engine with indirect injection to turbulence chamber
2	Timing gear type	Overhead-valve timing gear with camshaft placed within cylinder head
3	Cylinder number and arrangement	4, vertical
4	Piston stroke	95 mm

1	2	3
5	Cylinder diameter	90 mm
6	Displacement volume in cm^3	2417
7	Compression ratio	21.1
8	Compression pressure (in a new engine)	3 MPa
9	Power rating	66 kW (90 KM) according to ISO 1585
10	Rotational speed at rated power	4100 rpm
11	Maximum torque	205 Nm
12	Rotational speed at maximum torque	2000 – 2500 rpm
13	Minimum rotational speed at idle running	800 rpm

4. Vehicle basic information

Vehicle basic information is presented in Table 2 below.

Tab. 2. Vehicle basic information

Parameter	Value	Unit	where:
G_c	34335	[N]	vehicle weight
f_t^0	0.01	-	basic rolling resistance coefficient
A	0.00005	-	additional rolling resistance coefficient
c_x	0.7	-	dimensionless air resistance coefficient
k	1.1	-	filling factor
B	1.94	[m]	vehicle width
H	2.34	[m]	vehicle height
F	4.99	[m^2]	vehicle frontal area
η	0.88	-	mechanical efficiency of power transmission system
σ	1	-	under-the-bonnet power loss coefficient
r_k	0.34	[m]	wheel kinematic radius

Basic assumptions referring to the selection of values for a given vehicle are as follows (adopted according to [1] and [11]):

- it was assumed that a vehicle has a maximum load, hence its weight (G_c),
- the value of basic rolling resistance coefficient f_t^0 was assumed for smooth asphalt pavement type,
- the value of additional rolling resistance coefficient A was assumed for most applied pavements,
- the value of dimensionless air resistance coefficient c_x was assumed for a van,
- the value of filling factor k was assumed for motor trucks,
- the value of vehicle width and height was assumed for a Daewoo Lublin 3 Mi van, a combi 6-seater version, type 3N, variant 524, according to [12],
- vehicle frontal area was calculated based on a dependence $F=kBH$,
- the value of mechanical efficiency of power transmission system was assumed for motor trucks of low and medium load capacity,
- the value of under-the-bonnet power loss coefficient was assumed for a vehicle running at 0 m a.s.l.,
- wheel kinematic radius resulted from tyre size (filled with air under the pressure given by manufacturer) and wheel band size allowing for static loads.

In Table 3 below, basic gear ratios for gearboxes TS5-21, PD.97 and ZF are presented. Also the ratio of final drive is included.

Tab. 3. Basic gear ratios for three type of gearboxes and final drive [11]

Gears	Gearbox TS5-21	Gearbox PD.97	Gearbox ZF
Gear I	4.38	4.185	4.99
Gear II	2.48	2.371	2.59
Gear III	1.57	1.432	1.52
Gear IV	1.00	1.000	1.00
Gear V	0.87	0.867	0.78
Reverse gear	3.83	4.130	4.50
Final drive	4.77		

5. The course of tests and basic dependencies

During the tests, the external characteristics of Andoria 4CTi901BE6 engine was made on engine test bed. This was obtained by using AVL eddy current brake (connected to the engine via a shaft) which loaded the engine with a specific resistance torque necessary for making the characteristics of that type.

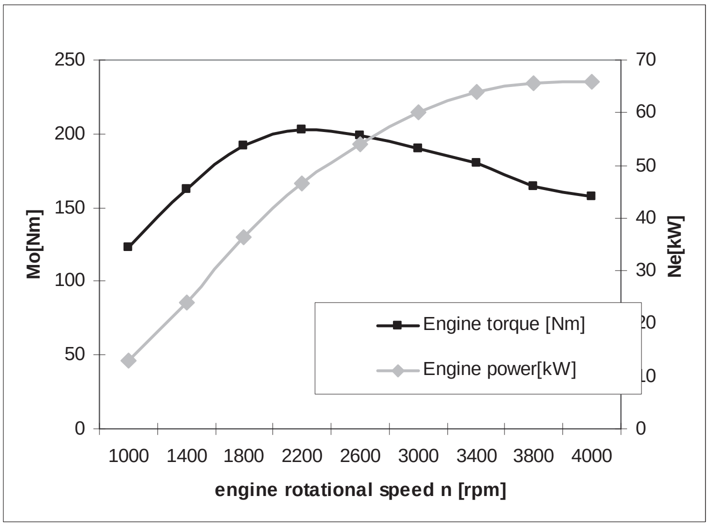

Fig. 2. The external characteristics of Andoria 4CTi901BE6 engine

Below is presented the full power speed characteristics (external characteristics), and therefore a dependence of engine torque and its power output on rotational speed when feeding the engine with a maximum dose of fuel.

Tab. 4. Engine torque and horsepower depending on its rotational speed

Engine rotational speed n [rpm]	Engine torque [Nm]	Engine power [kW]
1000	123.2	13
1400	162.7	24
1800	192.3	36.5
2200	202.7	46.5
2600	199	53.9
3000	190	60
3400	180	64
3800	164	65.7
4000	157	66

Based on the above mentioned characteristics, a traction diagram was made next, using the formulas available in literature and the data referring to the vehicle.
Vehicle traction diagram was a dependence of the driving force on vehicle wheels on the linear velocity. It was determined based on the dependencies given below.
The driving force on wheels was calculated based on the following formula:

$$P_k = (\mathrm{M}_s \sigma \eta_m i_c \ ) / r_k, \tag{1}$$

where: P_k – driving force on wheels [N], M_s – engine torque [min^{-1}], σ – under-the bonnet power loss coefficient, η_m – mechanical efficiency of power transmission system, i_c – total gear ratio of power transmission system, r_k – wheel kinematic radius [m].
The total gear ratio of power transmission system was calculated based on the following dependence:

$$i_c = i_{bi} i_g, \tag{2}$$

where: i_{bi} – gear ratio of the present gear of gearbox in which the vehicle moves (selectable gear ratio), i_g – final drive ratio (constant gear ratio).

The vehicle speed was described by the following dependence:

$$V = (0.38 n_s r_k) / i_c, \tag{3}$$

where: V – vehicle linear velocity [km/h], r_k – wheel kinematic radius [m], n_s – engine rotational speed [min^{-1}], i_c – total gear ratio of power transmission system.
A very important aspect of the traction diagram was to mark the resistances to vehicle motion on it. They were as follows: rolling resistance, air resistance and grade resistance.

Rolling resistances were described by the following dependence:

$$W_t = f_t^0 \left(1 + AV^2\right) G \cos\alpha, \tag{4}$$

where: W_t – rolling resistance [N], f_t^0 –basic rolling resistance coefficient, A – additional rolling resistance coefficient [s^2/m^2], V – vehicle speed [m/s], G – weight loading vehicle wheels [N], α – gradient [$^\circ$].
It was assumed that a vehicle would not move on elevation and therefore cos 0° = 1.
Finally, the formula assumed the following form:

$$W_t = f_t^0 \left(1 + AV^2\right) G, \tag{5}$$

Air resistances under regular conditions (air density 1.226 kg/m^3) were described by the following dependence:

$$W_p = 0.613\, c_x\ F V^2, \tag{6}$$

where: W_p – air resistance [N], c_x – dimensionless air resistance coefficient, F – vehicle frontal area [m^2], V – vehicle speed [m/s].

$$F = k\ B\ H, \tag{7}$$

where: k – filling factor, B – vehicle width [m], H – vehicle height [m].

Grade resistances

$$W_w = p\ G, \tag{8}$$

$$p = h / l\,100\%, \tag{9}$$

where: p –road grade percentage, where: h – road height [m], l – 100 meters of road length.

6. Results

Exemplary conversion of external characteristics values into driving force values and vehicle linear velocity (traction diagram) for first gear for gearbox TS5-21.

Tab. 5. Total transmission ratio for first gear calculated exemplarily and the conversion of engine external characteristics values into traction diagram according to dependence (1), (2) and (3)

gear I	**icI**	20.8926	
n [rpm]	**Mo[Nm]**	**V[km/h]**	**Pk1[N]**
1000	123.2	6.18	6662.04
1400	162.7	8.66	8798.00
1800	192.3	11.13	10398.62
2200	202.7	13.60	10961.00
2600	199	16.08	10760.92
3000	190	18.55	10274.24
3400	180	21.03	9733.49
3800	164	23.50	8868.29
4000	157	24.74	8489.77

Exemplary air resistance values for selected speeds for a Daewoo Lublin 3 Mi van.

Tab. 6. Example of air resistance calculations

V[km/h]	***Wt[N]***	***Wp[N]***	***Wt+Wp***	***Wt+Wp+Ww 5 %***	***Wt+Wp+Ww 10 %***
5.00	343.38	4.13	347.52	2064.27	3781.02
10.00	343.48	16.53	360.02	2076.77	3793.52
15.00	343.65	37.20	380.85	2097.60	3814.35
20.00	343.88	66.13	410.01	2126.76	3843.51
25.00	344.18	103.33	447.51	2164.26	3881.01

V[km/h]	***Wt+Wp+Ww 15 %***	***Wt+Wp+Ww 20 %***	***Wt+Wp+Ww 25 %***	***Wt+Wp+Ww 30 %***	***Wt+Wp+Ww 35%***
5.00	5497.77	7214.52	8931.27	10648.02	12364.77
10.00	5510.27	7227.02	8943.77	10660.52	12377.27
15.00	5531.10	7247.85	8964.60	10681.35	12398.10
20.00	5560.26	7277.01	8993.76	10710.51	12427.26
25.00	5597.76	7314.51	9031.26	10748.01	12464.76

The traction diagram after calculations for three types of gearboxes is as follows:

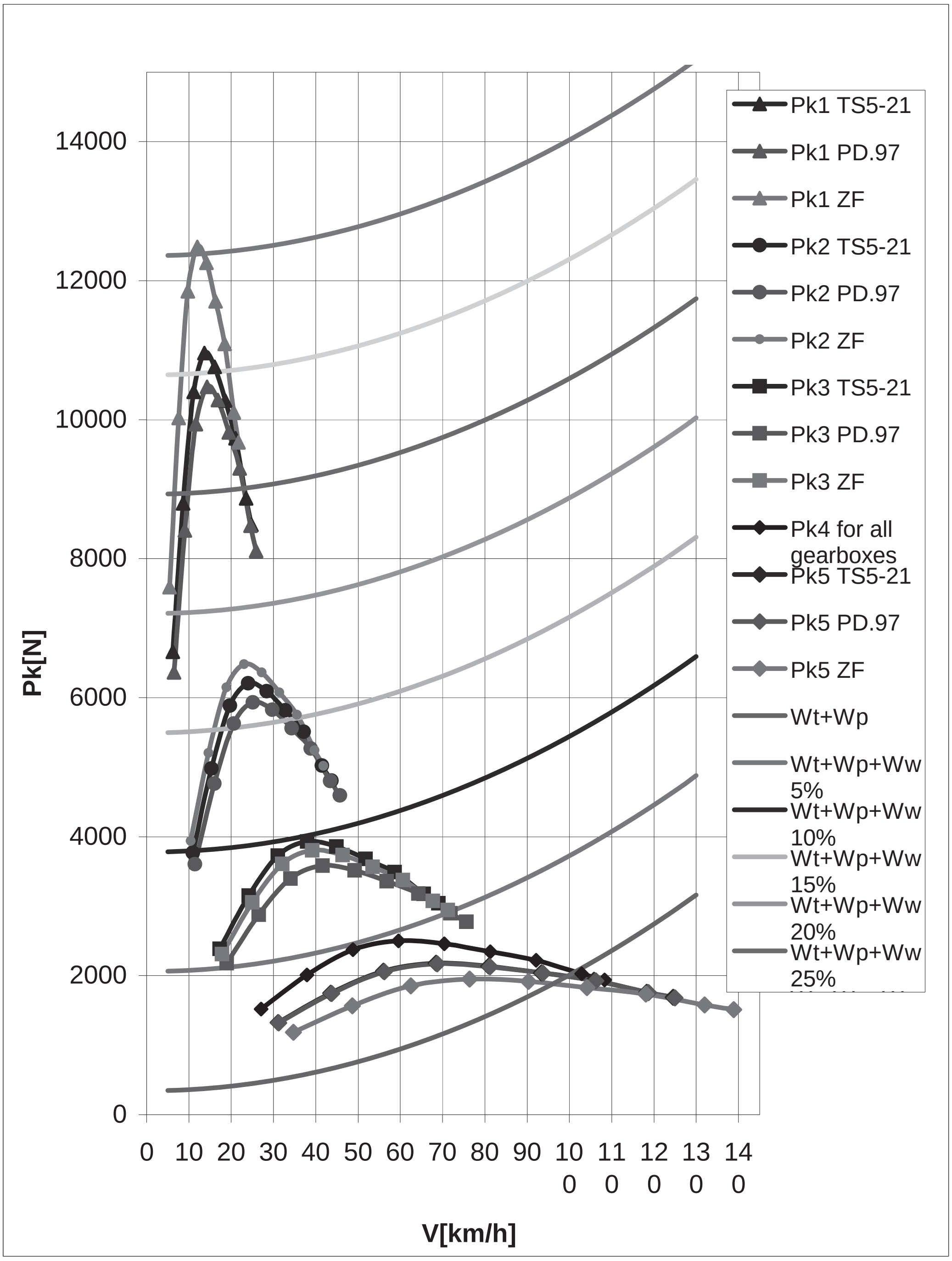

Fig. 3. Traction diagram for Daewoo Lublin 3 Mi van with three types of gearboxes: TS5-21, PD.97 and ZF

Maximum driving forces and accelerations in respective gears are as follows:

Tab. 7. Driving forces and accelerations in respective gears

	Gearbox TS5-21		Gearbox PD.97		Gearbox ZF	
	Pk[N]	a[m/s^2]	Pk[N]	a[m/s^2]	Pk[N]	a[m/s^2]
Gear I	10961	3.13	10473.01	2.99	12487.53	3.57
Gear II	6206.23	1.77	5933.45	1.70	6481.5	1.85
Gear III	3928.94	1.12	3583.59	1.02	3803.82	1.09
Gear IV	2502.51	0.72	2502.51	0.72	2502.51	0.72
Gear V	2177.18	0.62	2169.68	0.62	1951.96	0.56

7. Conclusions

The driving force in first gear is the largest (of which the largest reserve driving force results) for gearbox ZF (largest acceleration) and it allows overcoming the resistances to motion on 30% elevation in this gear, whereas gearbox PD.97 mounted in a vehicle is not able to get over such an elevation and gearbox TS5-21 copes with it not before the maximum torque has been reached. Owing to that, there is a possibility to accelerate a vehicle as fast as possible in first gear. The largest reserve driving force in second gear also speaks in favour of gearbox ZF.

The situation looks in a slightly different way as far as third gear is concerned. In this case, gearbox TS5-21 behaves the best. When it is in use, a vehicle accelerates in the fastest way. This is of enormous importance for driving a vehicle in urban traffic where third gear is used for the most part and most frequently.

Fourth gear is an indirect gear and therefore its gear ratio is equal to 1. This gear is applied to all types of gearboxes.

The last gear determines the reaching of maximum vehicle speed and the possible flexibility of a vehicle (reserve driving force in that gear). Gearboxes TS5-21 and PD.97 (values of the curves overlapped on diagram) determine larger maximum vehicle speed (after overcoming the rolling and air resistances) and vehicle flexibility. A vehicle can drive with a speed of approximately 100 km/h (for gearbox ZF it is about 95 km/h) and has larger reserve driving force in the last gear.

It is difficult to choose decidedly the best gearbox out of the ones mentioned above since each presented its advantages and disadvantages. The worst solution seems to be gearbox PD.97 when compared to other two types.

The authors acknowledged that the most reasonable solution, from the point of view of traction properties, would be to use gearbox ZF (it was the last gearbox mounted in a Daewoo Lublin 3 Mi van). This choice was substantiated by reaching maximum accelerations and driving forces and possibilities of overcoming larger elevation in lower gears (gears I and II). Difference in the maximum speed being achieved (disadvantage of about 5 km/h when compared to gearboxes TS5-21 and PD.97) was not a deciding factor since the vehicle intended use was not of the racing car type.

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