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Fuel Consumption and Gearbox Efficiency in the Fifth Gear Ratio of Roa Vehicle

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Abstract

In this paper, the gear ratio of gearbox in Roa vehicle (An Iranian made car combination of Paykan and Peugeot 405 by Iran Khodro Co.) is computed with considering fuel economy and gearbox efficiency. Firstly, overdrive advantages and its effect on engine rotational velocity have been investigated by consideing road load and engine torque. It is distinguished that in a specified velocity of vehicle, engine speed in overdrive state is very lower than engine speed in fourth gear. It means that noise and fuel consumption and engine wearing and damages will be decreased. The optimized region of engine operation is identified by. Using a geometric progression between automotive gear ratios and entering effective parameters such as specific fuel consumption, minimum mean effective velocity, and etc. in the formula to compute overdrive gear ratio. Finally, the most appropriate overdrive gear ratio and the number ratio of pair gears are chosen and it is functionally the effective automobile operation.

Keywords: Gear ratio, Fuel economy, Gearbox efficiency, Overdrive, Optimized region of engine operation

Nomenclature

A_n	photographed surface of the automobile
C_d	drag coefficient
F_x	propulsive force
N_f	gear ratio of differential
N_t	gear ratio of gearbox
R	resistance force against the automobile movement
RL	resultant torque of the resistance force
T_e	engine torque
T_w	effective torque on the wheels
V	automobile speed
W	automobile weight
n	rpm of the engine
r	radius of the automobile wheel
η_f	differential efficiency
η_t	gear efficiency
θ	angel of the road slope
ρ	air density
μ	revolving friction coefficient of the road

1. Introduction

Automotive designers thought is affected by two main factors including increased value of consumed fuel and the competition market of automobiles, both unit price and supplied facilities are affected. Using the overdrive gear is a necessity to eliminate the first factor, provided that the fuel economy consumption is effectively controlled. The second factor has impelled the automobile manufacturers to produce low cost five-speed gearboxes. To increase output revolution of the gearbox than that of input revolution a heliacal gearbox system can be used. In addition, the revolution can be increased by adding a pair of gears in the gearbox as the fifth gear. Five-speed gearboxes are appropriate alternatives to be replaced as it is concerned with the fuel economy [1], but the disadvantage is that application of the fifth gear depends on the driver and it is just used for high speeds. Overdrive is a device to increase revolution per minute of a low speed engine [1-3]. The device is used in ordinary gearboxes as the fifth gear with lower rates of gear, the engine life increase and its noise is reduced due to the reduced revolution [4-6]. Fuel economy which is very important in automobile manufacturing industry [6,7] has motivated the automobile industry to develop methods to reduce the fuel consumption. Performed studies [1-3] indicate importance of the fuel economy and coordinated gearbox design with the engine specifications.

In this research, a new overdrive gear ratio is introduced for four-speed gearbox of Roa vehicle; the car is a combination of Paykan and Peugeot 405 and a developed version of the Peugeot RD. Engine speed in fourth gear and engine speed in overdrive state are compared. With coordinated gearbox and the engine specification, effective gear rate of the automobile gearbox obtained by the investigators. The optimized region of engine operation is identified.

2. Mathematical model of the automobile gear ratio

Obtained power from the engine fuel ignition is used to overcome the resistance forces such as friction forces of the moving components, revolving resistance of the wheels on the sloped road, and air resistance. When the above mentioned forces have constant effect, for instance, during fast automobile moving on plane roads, the forces are able to move the automobile without any other additional force. With changing the effect of the above mentioned factors and motion from equilibrium, the engine can not produce the required moment itself to move the wheels and the engine torque should be changed to an appropriate rate. Thus, the relation of the engine torque and the effective moment on the wheels is calculated as follows:

$$T_w = T_e . N_{tf} . \eta_{tf} \tag{1}$$

where T_w is the effective torque on the wheels, and T_e is the engine torque; then N_{tf} and η_{tf} are obtained by the following formula:

$$N_{tf} = N_t . N_f \tag{2}$$

$$\eta_{tf} = \eta_t . \eta_f \tag{3}$$

N_t is the gear ratio of gearbox; N_f is the gear ratio of differential; η_t is the gear efficiency and η_f is the differential efficiency. Ratio of the last gear, for instance ratio of the forth gear in four-speed gearboxes is assumed to be 1:1 and the ratio of other gears is obtained by using resistant force (R) based of Fig. 1, since drag force is zero at the starting movement then the following function is used:

$$R = WSin\theta + \mu WCos\theta \tag{4}$$

W is the automobile weight; θ is the angle of road slope; and μ is revolving friction coefficient of the road, when the F_x propulsive force is:

$$F_x = \frac{T_w}{r} \tag{5}$$

r is radius of the automobile wheel; the propulsive force must be equal or more than resistance force:

$$F_x \geq R \tag{6}$$

$$\frac{T_e.N_{tf}.\eta_{tf}}{r} \geq R \tag{7}$$

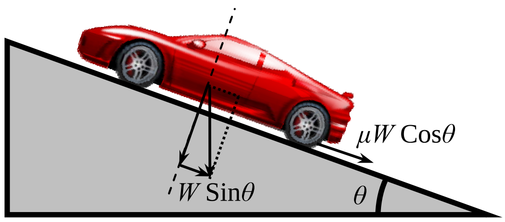

Fig. 1. Resistance force on the road slope

When ith gear ratio of the gearbox is shown by N_{ti} and it is assumed that increased engine moment ($(T_e)_{max}$) is used at the start, then the following formula is used for the mentioned gear of the gearbox:

$$\frac{(T_e)_{\max} N_{ti}.N_f.\eta_{tf}}{r} \geq R \tag{8}$$

then

$$N_{ti} \geq \frac{R.r}{(T_e)_{\max}.N_f.\eta_{tf}} \tag{9}$$

According to the catalogue of the manufacturer, the above mentioned formula of the gearbox is defined as follows [8]:

$$\eta_t = 0.95, \quad \eta_f = 0.98, \quad \frac{r}{N_f} = 0.07197434 \tag{10}$$

To calculate (9) relation, we need to know the increased torque of the engine; when the curve of engine moment has been obtained by changing revolution of the engine Roa; chassis and drive train are similar to the older Paykan but the outer body shell and appearance resemble a Peugeot 405 and it is made by Iran Khodro Co. According to Fig. 2:

$$(T_e)_{\max} = 81\,(\text{lbf.ft}) = 109.82\,(\text{N.m}) \tag{11}$$

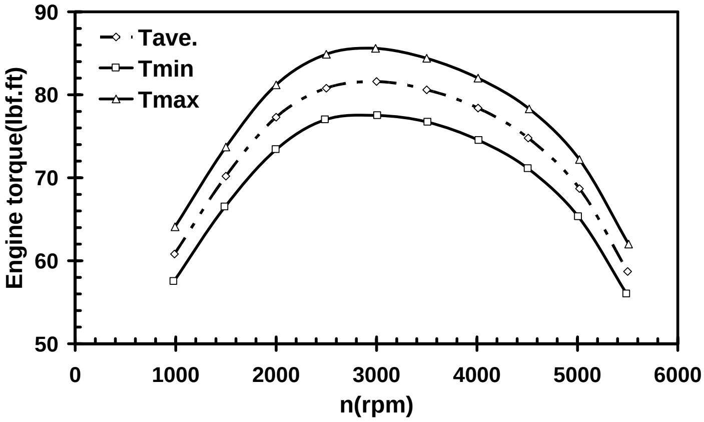

Fig. 2. Torque curve of the Roa automobile engine

If the maximum sine of the road is 33% and allowable weight of automobile is W= 13538 N and revolving friction coefficient of rubber and asphalt is μ=0.0248 [8] according to equation (4) we will have:

$$R = (13538)(0.33) + (0.0248)\times(13538)\times(0.94) = 4783.1\,\text{N} \tag{12}$$

By replacing values from equation (10) and increased torque of the engine from above diagram according to the values of equation (11) and resistant force of equation (12) in equation (9), simplification of N_{ti} is amendable by the following equation:

$$N_{ti} \geq (7.04\times10^{-4})(4783.1) = 3.367 \tag{13}$$

Since the four-speed gear ratio of automobile is 3.353, probably the little difference is due to the primary hypothesis including allowable weight, friction coefficient and so forth.

Some of the researchers believe that gear ratios of the automobile gearbox are calculated by a geometric progression and q modulus [1-3]. According to gear ratios 1 and 4, the progression is defined as follows:

$$N_{t1} = q^3, N_{t2} = q^2,\ \ N_{t3} = q\text{, and } N_{t4} = 1 \tag{14}$$

therefore

$$\begin{aligned} q &= (N_{t1})^{\frac{1}{3}} = (3.353)^{\frac{1}{3}} = 1.4967 \\ N_{t2} &= q^2 = (1.4967)^2 = 2.24 \\ N_{t3} &= q = 1.4967 \end{aligned} \tag{15}$$

Ratio of automobile gears and obtained results of N_{t1}=3.353 and N_{t1}=3.367 are compared in Table 1.

Table 1. Comparison of current gear ratios of Roa automobile and calculated amounts in the study

	N_{t1}	N_{t2}	N_{t3}	N_{t4}
Ratio of automobile gears	3.353	2.141	1.392	1
Ratio of gears by using N_{t1}=3.353	3.353	2.24	1.497	1
Ratio of gears by using N_{t1}=3.367	3.367	2.246	1.498	1

The above mentioned results have been computed by a geometric progression and when N_{t1}=3.353 is used, the gear ratio is increased five times:

$$N_{t5} = \frac{1}{q} = \frac{1}{1.4967} = 0.66 \tag{16}$$

The gear ratio is modified by considering some parameters such as the specific fuel consumption and by changing minimum effective speed. Firstly the above mentioned parameters are defined and then the concerning curves are drawn. According to the equation (4), primary air resistance force is assumed to be zero and then the resultant forces are calculated based on the following formula:

$$R = WSin\theta + \mu WCos\theta + \frac{1}{2}\rho C_d A_n V^2 \tag{17}$$

V is the automobile speed; ρ is the air density; C_d is the drag efficiency; A_n is the photographed surface of the automobile, if the road load (resultant torque of resistance force) is shown by RL, according to equations (7) and (17), the formula would be:

$$RL = r \times \frac{R}{\eta_{tf}.N_{tf}} = \frac{r}{\eta_{tf}.N_{tf}} \times (WSin\theta + \mu WCos\theta + \frac{1}{2}\rho C_d A_n V^2) \tag{18}$$

The torque of automobile is reduced when $RL \geq T_w$, but it is increased when $RL < T_w$ and it is remained constant when $RL = T_w$, that are clearly shown in Fig. 3.

Accordingly engine torque depends on the drag coefficient and according to equation (18); the increased speed of the automobile is contrary to the drag coefficient.

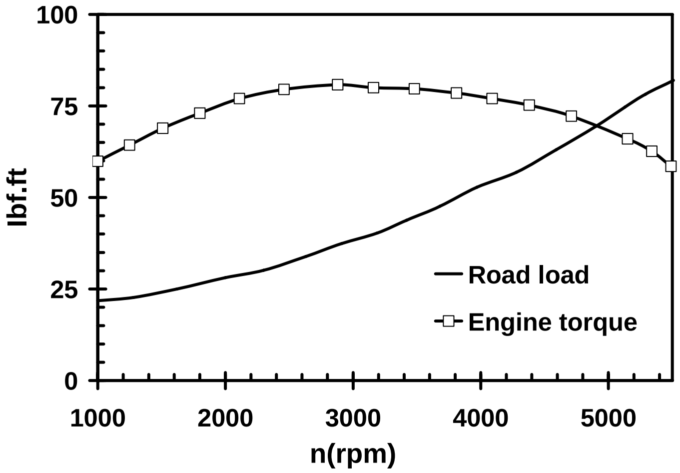

Fig. 3. Confluence curve of the road load and engine torque

3. Effective operation limit of the automobile

Effective operation limit of the automobile depends on the following items:

- According to Fig. 3, the increased speed of the automobile is contrary to the drag coefficient, thus the coefficient is possibly decreased with effective aerodynamic.
- According to this Figure, since the road load and the engine torque are increased where the two curves are intersected but then the engine torque is decreased, it is an indication of a limited speed.
- According to Fig. 4, if engine torques of A and B are considered the same respectively before and after the increased engine torque, every preventing factor may reduce speed of the automobile, but the torque is increased at B to defuse the effect of preventing factor, thus speed and revolution of the engine must be located after the increased torque of the engine.
- According to Fig. 4, it must be approached to the increased power of the engine.
- According to the above mentioned items, the best operation limit is almost the difference of increased engine torque and increased power of the engine.

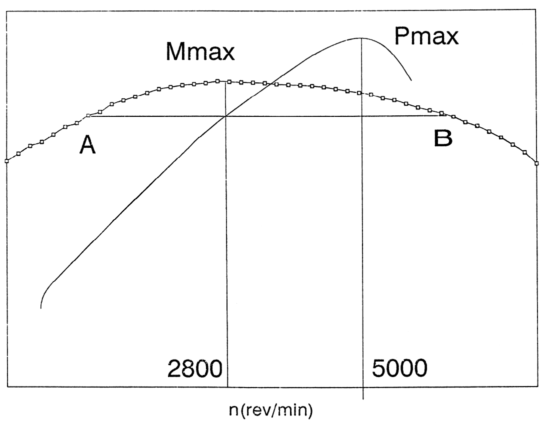

Fig. 4. The effective operation limit of the automobile

4. Results and Discussion

Automobile velocity (V, km/h) is based on the engine n (rpm) of the fourth gear when the overdrive gear ratio is 1:1 and the gear ratios are 0.81 and 0.84, they are shown in Fig. 5. The curve has indicated the important advantage of the overdrive.

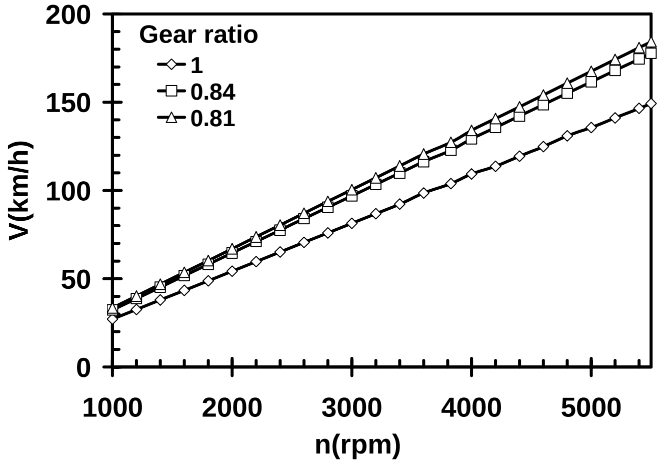

Fig. 5. Diagram of engine velocity change (*V*, km/h) in n (rpm) of the fourth gear with 1:1 gear ratio and 0.81 and 0.84 overdrive ratio

If we study a specific output velocity of an engine, for instance in 120 km/h, then the fourth rpm is 4600 but with 0.81 and 0.84 overdrive gear ratios it is respectively 3530 and 3600 rpm that is almost 1000 rpm lower than that of the forth gear that results in noise reduction and friction reduction of the engine.

Fig. 6 shows road torque diagram based on different overdrive gear ratio and the force gear. The mid point of the road torque curve and the engine torque curve will be the same as the cars limited speed. It is obvious from diagram that with reducing of round gear ratio, cars limited speed reduces (under design condition).

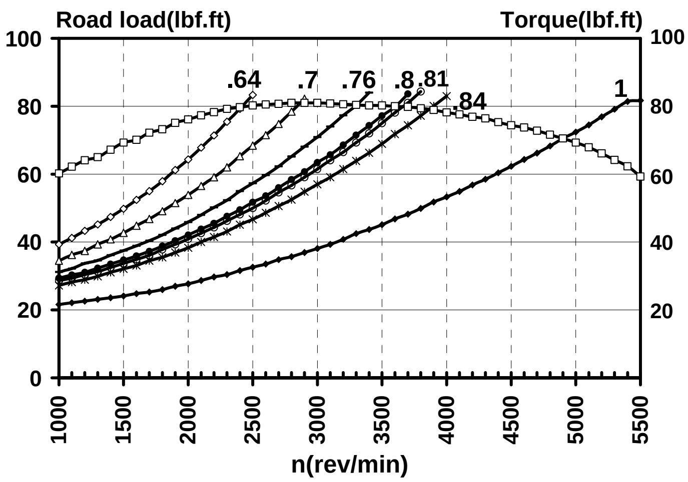

Fig. 6. Road torque diagram based on different overdrive gear ratios and the fourth gear

Table 2 depicts the maximum and minimum output velocity of the automobile with different overdrive gear ratios. According to the data, the minimum velocity increases when the gear ratio is decreased, and in gear ratio of 0.71 and less, the ratio of maximum velocity is decreased that is an indication of impossible overdrive use. Besides, Table 2 is an indication of appropriate gear ratio of the pair gears, when the appropriate gear is selected according to the Table. Fig. 7 shows the arrangement of the designed and developed models of gearbox.

Table 2. Ratio selection procedure of the overdrive gear

N_t	1	0.84	0.81	0.8	0.79	0.76	0.7	0.64
Velocity	Specific fuel consumption							
80	0.272	0.268	0.270	0.272	0.273	0.276	0.285	0.293
90	0.270	0.270	0.267	0.267	0.268	0.268	0.273	0.282
100	0.268	0.272	0.272	0.272	0.271	0.270	0.267	0.272
110	0.268	0.269	0.270	0.271	0.271	0.272	0.270	0.268
120	0.273	0.267	0.271	0.269	0.269	0.270	0.272	0.270
Max. Velocity	131	124	123	122	120	118	112	102
rpm of the Engine	4900	3850	3700	3600	3500	3350	2900	2450
Min. Velocity	75.97	90.45	93.80	94.97	96.17	99.97	108.5	118.7

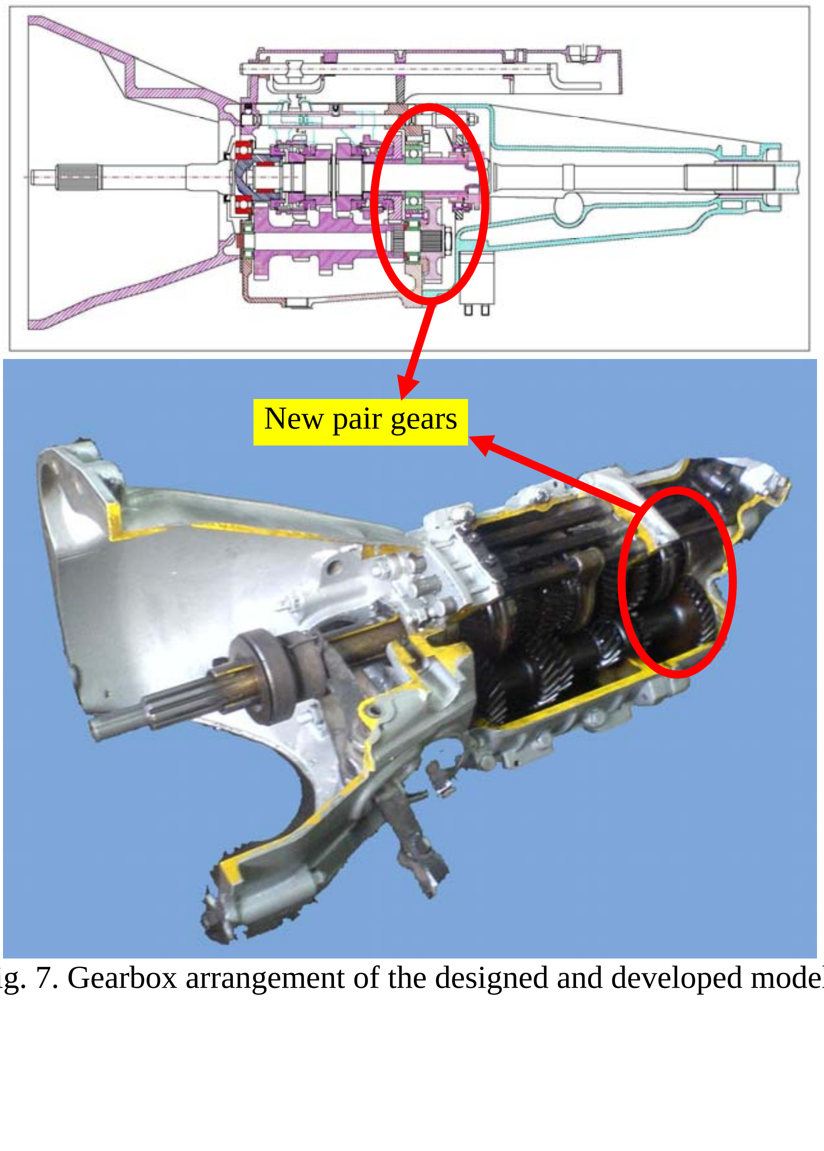

Fig. 7. Gearbox arrangement of the designed and developed models

5. Conclusion

A new overdrive gear ratio is introduced for four-speed gearbox of Roa (An Iranian made car combination of Paykan and Peugeot 405 by Iran Khodro Co.). If the engine works with lower ratios or 0.79, we notice that the consumption of specific fuel is increased compared with 0.8 to 0.84. According to the above mentioned results the appropriate gear ratio must be 0.8 to 0.84. Based on the minimum engine rpm, 0.8 is the appropriate gear ratio. Number of 0.8 (0.64-1) gear ratios and appropriate pair gears were studied according to Table 2 with trial and error procedure; the general effect of fuel economy parameters were evaluated; minimum engine velocity, the difference of maximum and minimum effective velocity of the engine were studied to specify 0.81 as the most appropriate engine ratio, finally the number ratio of pair gears are 19 to 34, and it is functionally the effective automobile operation.

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