The consideration of road longitudinal slopes in automobile fuel consumption rationing

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Abstract. Nowadays the consideration of longitudinal slope when rationing automobile fuel consumption is hardly taken into account, and it is received just impliedly when paying attention to the area relief. Along with this, the influence of slopes of flat and slightly hilly terrain on fuel consumption is not taken into consideration at all. This article presents an easy calculation approach to the consideration of the quantitative effects of road slope angles (rise and descent) on the final fuel consumption of a vehicle on real routes. The notion of a reduced slope angle is introduced, a substantial increase of fuel consumption on descents in comparison with rises is ascertained.

Keywords: fuel consumption, fuel consumption rationing, the problems of rationing, road slope.

In Russia longitudinal slopes of roads (rises and descents) are taken into account in the rationing system of automobile fuel consumption impliedly, by means of adequate allowances when calculating the operational rate of fuel consumption [1,2].

Thus, in July 1, 1960 in the USSR recommendatory regulatory document “Standard quotas of liquid fuel consumption for cars” became effective, it was approved by the USSR Council of Ministers Resolution on March 5, 1960 No. 252 “On quotas of liquid fuel consumption for cars”, according to which:

- when working on roads in mountain areas (more than 1,500 meters above sea level) or on roads with a difficult plan (having an average 1 km track with more than five curves with the radius less than 40 meters):
  - in the summer time - up to 10 percent and in the winter time - up to 20 percent;

Besides turnings, the term “complex road scheme” in the document implied longitudinal slopes, which can be found on the vast majority of mountain roads. However, no recommendations for specific allowances taking slope rate into consideration, when fuel rationing, were meant. It should be pointed out, that such recommendations didn’t appear in all the subsequent regulatory documentation on the automotive fuel rationing.

Later on, the Decree of the Ministry of Transport of the Russian Federation dated March 14, 2008 No. AM-23-p “Automotive fuel and lubricants consumption quotas” fixed the following allowances, which also took longitudinal slopes on the routes into account only impliedly:

- operation of vehicles on public roads (categories I, II and III) in the mountains, including cities, towns and suburban areas, at an altitude above sea level:
  - from 300 to 800 m - up to 5% (lower mountains);
  - from 801 to 2000 m - up to 10% (mid mountains);
  - from 2001 to 3000 m - up to 15% (high mountains);
  - over 3000 m - up to 20% (high mountains);
The operation of vehicles on public roads of categories I, II and III with a complex area relief (outside cities and suburban areas), where an average 1 km track has more than five curves with the radius less than 40 meters (or per 100 km ways - about 500) - up to 10%, on public roads of categories IV and V - up to 30%.

This regulatory document doesn’t take proper account of longitudinal slopes on roads in flat and slightly rolling country (reliefs P1 and P2 with heights above sea level up to 200 m and from 200 to 300 m respectively) in fuel consumption rationing.

The latest regulatory adjustment in the sphere of automotive fuel and lubricants consumption rationing was made on May 14, 2014 by the Decree of the Ministry of Transport of the Russian Federation No. NA-50–r “Alteration of recommended practice “Automotive fuel and lubricants consumption quotas “attached by the Ministry of Transport of the Russian Federation Decree on March 14, 2008 No. AM-23-p”, and then it became operative with the Ministry of Transport of the Russian Federation Decree on July 14, 2015 N HA-80-p, according to which new models with corresponding basic standards were added to the list of vehicles. No other changes were made, including adjustments for considering longitudinal slopes of the roads in automotive fuels rationing.

Factors affecting fuel consumption make up the so-called fuel balance of a car [1,3]. It includes the following components: mechanical, thermal and pumping losses in the engine \( Q_{\text{м}} \); mechanical losses in transmission \( Q_{\text{т}} \), as well as everything regarding road resistance. Road resistance is composed of rolling resistance \( Q_{\text{r}} \), aerodynamic resistance, i.e. air resistance \( Q_{\text{w}} \) and inertia overcoming \( Q_{\alpha} \). The listed factors affecting fuel consumption are also taken into account in rationing methods, determining the basic (linear) fuel consumption rate, or are taken into account by the corresponding fixed allowances. Among other components in the fuel balance, there is one that determines losses on road longitudinal slopes overcoming \( Q_{\alpha} \). These losses are not taken into account in regulatory documents on automotive fuel consumption rationing. Thus, even fuel balance analysis suggests that the standards for automotive fuel consumption rationing need revision and completing.

In this regard, the Department of "Automobile Transport" NSTU named after R.E. Alekseev has been carrying out research on of longitudinal slopes effect on automotive fuels consumption, aimed at revealing quantitative relationships between these factors.

Such interdependence is recognized by some scientists of the sphere, but despite a wide range of scientific works, textbooks, teaching aids and other technical documentation, this fact is not reflected in the system of automotive fuel and lubricant consumption rationing.

The fuel consumption when a vehicle is moving on slope is increasing due to gravity \( F_{\text{i}} = G_{\alpha} \sin \alpha \), called lifting resistance [4], counter- or co-directional (respectively, positive grade - rise and negative grade - descent) to movement (Fig. 1).

To study the quantitative relationships between the slope angle and fuel consumption, a GAZelle Next car of class N1 (up to 3.5 tons) model A21R22 with a Cummins 2.8 ISF engine and a 5-speed manual gearbox GAZ was taken.

![Fig. 1. The model of car motion on the slope:](image)

\[ a – \text{acceleration; } V_{a} – \text{speed; } F_{i} – \text{lift resistance; } \]
To reveal this relationship the fuel consumption was calculated on the horizontal section \(L_1 + L_2\) and the corresponding sections of rise and descent. According to construction regulations 2.05.02-85, the maximum road slope grade \((i = \tan \alpha = H / L)\) is 0.03-0.07, particularly complex relief areas, slope rise 0.02 is allowed. The maximum admissible (in road construction) slope is 0.07-0.09, which corresponds to 4.2-5.5° (the value \(\alpha = 5.5°\) is taken in this work). The movement in both cases will be characterized by different values of the power \(P_\psi\) needed to overcome total road resistance.

Obviously, there are several options for the expected result (output):
1. The power expended in overcoming rise and descent resistance is equal, i.e. the increase in power losses on the rise is compensated by their equivalent decrease on the descent. In this case, the total fuel consumption will be equal to the consumption when driving on a horizontal road section, and the relationship cannot be observed. This is exactly how the present fuel rationing system works for roads in flat and slightly hilly terrain, and therefore road slopes are not taken into account in regulatory documents on fuel rationing.
2. The powers expended in overcoming rise and descent resistance are not equal, and which is more, their sum is positive. In this case, the total consumption will be greater than that on horizontal road, and the “rise-descent” model comes to “rise” movement with a smaller angle (it can be designated as the reduced angle of the road).
3. Similarly, the powers are not equal, but their sum is negative. The final consumption will be less, and the desired model comes to “descent” movement with negative reduced slope angle.

As is known [3, 4], the total road resistance \(\psi\) takes into account the rolling resistance (in the form of the coefficient of rolling resistance \(f\)) of a wheel on supporting surface and the angle of the road longitudinal slope \(\alpha\) through the expression \(\psi = f \cdot \cos \alpha + \sin \alpha\) (for horizontal roads \(\psi = f\)). In these research, asphalt covered roads are meant, for horizontal profiles with \(\psi = f_{\psi \alpha} = 0.008-0.015\) [3].

Power expended in overcoming road resistance is determined by the expression \(P_\psi = F_\psi \cdot V\), where \(F_\psi = F_f + F_a = G_a \cdot f \cdot \cos \alpha + G_a \cdot \sin \alpha\) is the resistance to movement. For horizontal roads, these power losses will amount to \(P = 6.3\) kW. In this article we use the value of the coefficient \(f\) obtained in the course of research work carried out by students of the MA course at the Department of Automobile Transport, Nizhny Novgorod State Technical University. R.E. Alekseev, it was calculated for the road conditions of N.Novgorod and forms \(f_{\psi \alpha} = 0.011\). This value was obtained as a result of several measurements with the help of a car weeling-out method, using the expression \(f = \frac{|a|}{g}\), where \(a\) is the deceleration when weeling out, modulo [1,3].

Using the steady-motion fuel consumption equation at a speed of \(V_{\text{a}} = 60\) km / h, the fuel consumption of a GAZelle Next car with a total mass of 3.5 tons will be \(Q_s = 9.33\) l / 100 km (according to official data from the manufacturer of the GAZ car the fuel consumption for the specified car of laden mass at the appropriate speed will be \(8.5\) l / 100 km).

Further calculations showed that the average fuel consumption of the vehicle in the “rise-descent” sections is \(18.35\) l / 100 km, provided that the requirements for road safety are met, which appeared primarily in inadmissibility of inertial motion (without gear) when descending. Thus, part of the engine power released on the descent will be almost completely dissipated through the car braking mechanisms [5,6]. Mostly this determines a significant increase in fuel consumption for overcoming slopes in general compared with driving along horizontal sections of the road.

Hence, if rise and descent characteristics are equal \((\alpha_1 = \alpha_2)\), the calculated values testify to the second variant of the above conclusions or expected results. This allows us to reduce the rise – descent model (Fig. 1) to the “rise” model and to determine the slope angle at which the fuel consumption will correspond to the fuel consumption in the “rise – descent” model. In this work, it is convenient to designate this calculated angle as \(\alpha_n\) - reduced slope angle (Fig. 2).

Calculations have proved that for the above conditions of the problem with \(|\alpha_1| = |\alpha_2| = 5.5°\) the rise – descent model can be reduced to the “rise” model with a given angle \(\alpha_n = 1.134°\). And the total fuel consumption will be the same.

In the practice of fuel consumption rationing, when routes have many slopes with different characteristics (height and length) a general expression for calculating the reduced slope angle can be derived, it can be either positive or negative and, accordingly, will increase or decrease the final value of fuel consumption.
For the entire route having many slopes it is necessary to summarize their values somehow, by the values of the angles. In this case, a final angle, most likely, should be called accumulated reduced angle of the slopes. At present it will not be particularly difficult to put this idea into practice with the help of the software available that uses satellite navigation data (for example, the GoogleEarth program), which ensures that slope characteristics can be determined with any resolution.

**Figure 2.** The slope angles calculation model for fuel consumption rationing:

\[ \alpha_n \text{ – reduced slope angle.} \]

The output of the research described is a mathematical model of accumulated reduced slope angle for automotive fuel consumption rationing considering all the factors that influence fuel consumption, including losses for road slopes overcoming.

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