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Streamlining influence on the long-haul trucks with an installed movable roof fairing performance properties teoretical studies

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Influence streamlined elements located on the roof of the tractor main train such as the efficiency of the vehicle with installed no bonnet on it an advanced roof rack, which has the ability to adjust to any trailed warehouse. It has been assumed that it provides high levels of accuracy with respect to analogues due to the possibility of choosing the appropriate geometric parameters, provides ease of use and the ability to adjust the cushion during vehicle movement, prevents probable malfunctions during strong winds or hurricanes due to the strength of the drive management and modern electronic systems mechanical design. On the basis of theoretical studies of the main motor trains various tractors flow, the dependences of power and fuel consumption on the air traffic vehicle coefficient have been established at its movement speeds. It has been proven that it is advisable to use an advanced racing hub on precision drum trucks with small and medium-height cabs.

Key words: main motorway, streamlined, aerodynamic properties, roof fenders, streamlining coefficient.

Теоретичне дослідження впливу обтічності на експлуатаційні властивості магістральних автопоїздів із встановленим рухомим даховим обтічником

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Досліджено вплив обтічного елементу, розташованого на даху тягача магістрального автопоїзда, а саме ефективність роботи безкапотного автомобіля з встановленим на нього удосконаленим даховим обтічником, який має можливість налаштування під будь-який причіпний склад. Було припущено, що відносно аналогів він забезпечує високі показники обтічності за рахунок можливості вибору відповідних геометричних параметрів, забезпечує зручність у використанні та можливість налаштування обтічника під час руху автомобіля, запобігає можливості ймовірних несправностей під час сильних поривів вітру чи буревіїв за рахунок міцності конструкції механічної частини приводу керування та сучасних електронних систем. На основі проведених теоретичних досліджень обтікання різних тягачів магістральних автопоїздів були встановлені залежності потужності та витрати палива від коефіцієнту обтічності автомобіля при прийнятих швидкостях його руху. Було доведено, що удосконалений обтічник доцільно використовувати саме на безкапотних тягачах із малою та середньою висотою кабіни. Теоретичні дослідження проводилися за допомогою прикладного програмного забезпечення Microsoft Exel та SolidWorks за допомогою електронних обчислювальних машин.

Ключові слова: магістральний автопоїзд, обтічність, аеродинамічні властивості, даховий обтічник, коефіцієнт обтічності

Introduction. The truck market is full of proposals for the purchase of tractors - both new and with mileage. In order to choose among all possible options, the buyer needs to evaluate each of them by the key technical, functional and operational qualities, not forgetting about saving.

One of the main factors when choosing a tractor is fuel consumption. In the conditions of operation, the road quality, the vehicle load and the movement speed have a great influence. Therefore, the automobile engine has to work on different load and speed modes.

Aerodynamic experts argue that half the fuel, or perhaps a large part of it, which burns a car at high speed, is spent on overcoming air resistance. Therefore, if it is possible to reduce the dynamic resistance, then the cost of goods delivery can be significantly reduced. Reducing the dynamic air resistance is the shortest way to generate additional profits [1, 2, 3].

Analysis of recent sources of research and publications. Lorries and trains are among the poorly streamlined vehicles. At the same time, if the low traffic velocity of a truck due to its low speed has relatively little effect on its technical and operational performance, then in relation to high-speed main tracks, their influence becomes decisive in the struggle for fuel economy, safety, dynamism, ergonomics and environmental friendliness [4 – 6].

The nature and level of traffic jams of the main train is determined by its shape, structural features and parameters of the air environment. The rectangular shape of the transverse and longitudinal section of modern highway trains bodies, in combination with flat walls, provides the most useful space for placing the cargo in them, but is unsatisfactory fconsidering aerodynamics. At the same time, in the case of on-board trucks, the main component of their frontal projection is cab frontal area, then in the main road trains with high bodies, approximately the same size area above the body front wall cabin is added [4].

As the constructive analysis shows, the typical for highway trains is the presence of a significant one, reaching 1 m or more, exceeding the body over the cabin, a large (1-2 m) clearance between them (between the bodies), in combination with an uncircumcised or rounded small radius the front edge of the cabin and the body [5]. In addition, there is a considerable distance from the front bumper to the road surface, which, depending on the type and degree of the automobile train loading, ranges from 0.5 to 0.7 m. The influence of the above factors significantly reduces the trains air travel level, as there are large areas of high and low pressure, and because of the boundary layer breakdown on the cabin and the body front edges there are energy-intensive tearing currents that have a pronounced vortex structure. As a result, the trains aerodynamic characteristics significantly deteriorate, its movement resistance is substantially increased, and stability and handling indicators are reduced.

In [4] in detail the complex mechanism of highway trains flow of different layout scheme both oncoming and lateral wind. It negatively affects the trains aerodynamic characteristics. Due to increased pressure resistance and tearing currents, aerodynamic resistance increases and the lifting force acting on the carriageway, which adversely affects trains aerodynamic stability and handling, worsens its course stability. In this case, the aerodynamic resistance intensively increases with an increase in the angle of incidence.

Selection of previously unsettled parts of the general problem. Most authors [7, 8, 9, 10] who are considering improving the aerodynamic properties of road trains, offer theoretical research and modeling with the help of 3D modeling software simply by installing individual rails in different places, both the tractor cab and the trailer link. It is good when designing new equipment, but for the already existing one the question is not solved, although there are enough domestic and foreign production cars used on roads that have not exhausted their resources, but need further modernization for their own competitiveness in the main cargo transportation services market.

Among all the existing inventions, the simplest and most effective remains is the usual fenders, located on the roof and tractor side parts. Its effectiveness is scientifically proven, but the application of one and the same ramp to different semitrailers, trailers, tanks causes a violation of the tractor aerodynamics. Such use is inappropriate and ineffective.

Setting objectives. The article purpose is to conduct a theoretical study of the main trailer aerodynamic properties with the installation of a roof railing on it with the possibility of adjusting to any trailer structure using the 3D modeling software.

Basic material and results. As described in a number of papers [4, 5], the air resistance P_{wis} determined by the friction of the air layers adjacent to the car surface; compressing air with a moving machine; dilution by car; swirling around the car air layers.

When driving the car, the air is located in front, compressed and pushed to the place where the pressure is less, that is, up, down and in the sides. By car there is a relative dilution. This low pressure area is filled with air that goes away. Since the movement of air mass during car movement is associated with a change in air flow direction, there is turbulence formation.

The larger the cross-sectional area, that is, the machine projection area on a plane perpendicular to the longitudinal axis, the greater the amount of air forced to bypass the car. The car largest cross-sectional area is called the front axle. The constituent strength of the air resistance, depending on this area, is called the frontal resistance. It is the main component of air resistance total strength, its share reaches 60% of the total. This resistance is also called resistance form, because its value depends on the body shape. Different shapes bodies investigation[6] on the frontal resistance showed such a dependence on the form, that is, on the edges.

Other components of the air resistance forces:

- internal resistance, created by air flows passing inside the car for body ventilation and heating, for cooling the engine. The share of this component is approximately 10%;
- resistance to surface friction (10%);
- induced resistance (5%) - is caused by the interaction of forces acting in the direction of car longitudinal axis (lifting) and perpendicular to it (lateral);
- additional resistance (15%), created by different protruding parts (headlights, indicators of turning, door handles, license plates).

Given the influence of air resistance all components, this force is determined by the dependence

$$P_w = k_в S V^2 \quad (1)$$

where $k_в$ – the air resistance coefficient, which considers factors that are not dependent on car shape.

$$k_в = 0.5 \beta C_x \rho \quad (2)$$

where β – coefficient which considers additional supports.

The approximate values of air resistance coefficients for different cars are as, $Нс^2м^{-4}$, follows:

sports – 0.13 ... 0.15; cars – 0.15 ... 0.35;
buses – 0.25 ... 0.40; trucks – 0.50 ... 0.70;
trains – 0.55 ... 0.95.

The overall height of the sidecar is determined by the trailer couplings height. Their main resistance is created by air, which flows through the cabin and runs into the front wall of the semitrailer. In addition, in the intervals between the automobile train links powerful vortices are formed, which seem to increase the frontal area. Therefore, in various ways to reduce the aerodynamic resistance, rails various designs [6] are used reducing the air resistance.

Area of the front support

$$S = \alpha B_h H_h \quad (3)$$

where α – the factor of filling the area (for cars 0.78-0.8, for freight 0.75-0.9, with more value for heavier cars);

$B_h H_h$ – the overall width and height respectively, m.

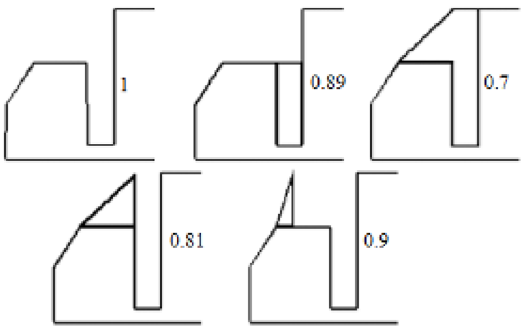

Figure 1 – Ways to improve the vibration of the car by installing the roof rails

It is calculated the roof rails modes and parameters with the ability to adjust for any trailer.

The speed of the car on the horizontal section of the road is determined, as V with its maximum power is equal P. The coefficient of car frontal resistance, and the largest area of intersection in the direction perpendicular to the speed S. The car undergone a reconstruction, the largest area of intersection in the direction, perpendicular to the speed did not change, but the coefficient of frontal resistance decreased to magnitude C'. It is considered the friction force on the surface of the road unchanged, the air density ρ.

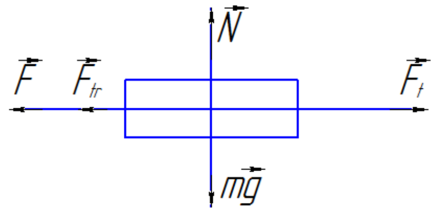

Figure 2 – Conditional application of force to the vehicle

Power car Expressions

$$P = F_t V \quad (4)$$

where F_t – thrust car N.

If the vehicle set on a road flat stretch is set at a constant speed is moved, then according to Newton's second law it is

$$\overline{F_t} + m\overline{g} + \overline{N} + \overline{F_{tr}} + \overline{F} = 0 \quad (5)$$

Formed on a projection the axis of OH it is obtained

$$F_t - F_{tr} - F = 0 \rightarrow F_t = F_{tr} + F \quad (6)$$

The strength of the resistance experienced by the car moving in the air stream is

$$F = \frac{C\rho V^2 S}{2}. \quad (7)$$

Then the power of the car P, kW, can be written

$$P = (\frac{C\rho V^2 S}{2} + F_{tr}) \cdot V \quad , \quad (8)$$

Hence, it is expressed the force of friction F_{tr}, H, the car on the road

$$F_{tr} = \frac{P}{V} - \frac{C\rho V^2 S}{2}. \quad (9)$$

The power expression, but for the changed parameters, is

$$P' = (\frac{C'\rho V^2 S}{2} + F_{tr}) \cdot V, \quad (10)$$

Considering that the force of car friction on the road has not changed

$$P' = (\frac{C'\rho V^2 S}{2} + \frac{P}{V} - \frac{C\rho V^2 S}{2}) \cdot V. \quad (11)$$

Fuel consumption in liters per 100 km of mileage is expressed in the form of the following dependence

$$Q_s = \frac{g_e \cdot P^{/}}{100 \cdot V \cdot \gamma_T}, \qquad (12)$$

where g_e -- specific fuel consumption, g / kWh ˉ;
γ_T – fuel density, for diesel, γ_T = 0,84 kg / l;
V – car speed, km / h.

To determine and construct a mathematical model, several tractors were given in Table 1. The results of the parameters are given in Table 2.

Due to the many tests, it was determined that the size of the propulsion coefficient strongly depends on the vehicle shape e and the attachment. The tests results are in Table 3.

Further calculations are presented in Table 4 and presented in the form of charts in Figures 3 and 4.

Table 1 – Constructive features a sidecar tractor constructions in terms of overall dimensions

Car make	Cabin	Height, mm	Width, mm	Lenght, mm	Wheel base, mm	Power, kW
MAN	average	3600	2500	6100	3600	265
MAN	low	2900	2500	5800	3600	300
Renault	average	3600	2400	5900	3700	320
Renault	low	3100	2500	6100	3600	315
DAF	average	3500	2500	5900	3700	335
DAF	low	2600	2400	6800	3600	300
VOLVO	average	3600	2500	6800	3800	280
VOLVO	low	2800	2400	5900	3600	280
SCANIA	average	3400	2500	6500	3600	310
SCANIA	low	3100	2500	5900	3600	300

Table 2 – Average tractor parameters are given

№	Height of the cab	Length, mm	Width, mm	Height, mm	Engine power, kW	Fuel consumption, *l* / 100km
1	Average	6200	2500	3500	300	19 - 21
2	Low	6200	2500	2900	300	20 - 22

Table 3 – Change of the frontal load resistance from the car and ramp parameters

№	Height of the cab	Flying	Location	Frontal resistance coefficient C_x
1	Average	No	-	1,08
		Ordinary	Behind	0,77
		Improved		0,52
2	Low	Missing	-	1.09
		Normal	Behind	0.85
		Improved		0.57
		Improved	AheadWe	0.87

$$P^{/} = (\frac{0.52 \cdot 1.2041 \cdot 25^2 \cdot 10}{2} + \frac{300000}{25} - \frac{1 \cdot 1.2041 \cdot 25^2 \cdot 10}{2}) \cdot 25 = 254.85$$

$$Q_s = \frac{510 \cdot 254.85}{100 \cdot 90 \cdot 0.84} = 17.19$$

Table 4 – Estimated power and fuel consumption, depending on the change in the strain coefficient

№	Cabin height	Roof Fairing	Position	C_x	P_{90}	Q_{90}	P_{60}	Q_{60}	P_{40}	Q_{40}
1	Middle	Absent	–	1 – 1.09	300 - 308.8	20.2 – 20.8	162.5 - 167.8	16.7 – 17	99.7 - 100.4	15.13 - 15.24
2		Ordinary	–	0.77 – 0.86	278.36 - 286.8	18.8 – 19.3	158.8 - 161.3	16.06 - 16.3	97.8 – 98.5	14.84 - 14.95
3		Improved	Backward	0.52 – 0.61	259 – 268	17.5 – 18.1	151.8 - 154.3	15.36 - 15.6	95.7 - 96.45	14.5 - 14.64
4	Low	Absent	–	1.05 – 1.14	304.7 - 313.2	20.55 - 21.1	166.86 - 17.1	16.86 - 17.1	100.1 - 100.8	15.2 – 15.3
5		Ordinary	–	0.85 – 0.94	285.9 - 294.35	19.3 – 19.9	16.3 – 16.5	16.3 - 16.5	98.4 – 99.2	14.94 - 15.05
6		Improved	Backward	0.57 – 0.66	254.8 - 263.3	17.2 – 17.8	15.5 – 15.8	15.5 - 15.8	96.1 – 96.9	14.6 – 14.7
7		Improved	In front	0.87 – 0.96	287.7 - 296.2	19.4 – 20	16.35 - 16.6	16.35 - 16.6	98.6 – 99.3	14.97 - 15.07

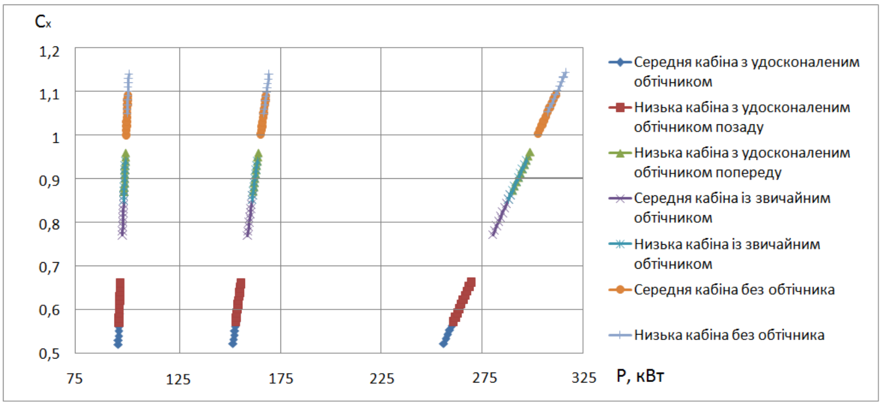

Figure 3 - Dependence of power consumption on the air flow coefficient at speeds 40 - 90 km / h

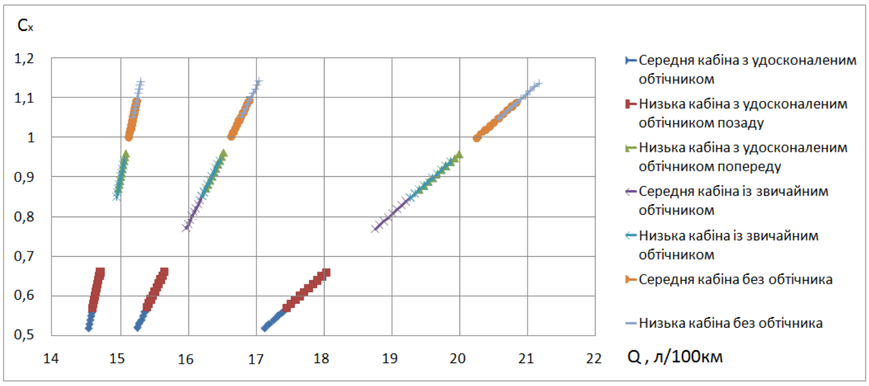

Figure 4 - Dependence of fuel consumption on the coefficient of airworthiness at speeds 40 - 90 km / h The

Graph (Figure 3) represents the ratio of power to the vehicle speed. The larger the coefficient of frontal resistance C_x is, the worse the car overcomes the air masses. All sharp edges, protruding surfaces, and streamlined elements affect the car airiness. The graph shows various trains with and without their improvements. The sloping lines correspond to the car speeds 40, 60 and 90 km/h, respectively. From the graph, it is evident that at speed of 40 km/h, a carriage train with or without a racing gun spends almost the same power on overcoming a given speed. At speed of 60 km/h, the difference between good and bad traffic trains starts to appear. At a speed of 90 km/h, there is a strain significant influence on power car. It is due to the fact that when speed increases, the required power increases to overcome the resistance forces that can stop the auto-train.

The graph (fig. 4) shows the change in the amount of fuel consumed by the trains traction. On the graph, sloping lines correspond to speeds of 40, 60, 90 km/h, respectively. As in Figure 3, there is a tendency to increase the speed ratio to the amount of fuel consumed. With the increase in the speed of different tractors, the expired power increases, and therefore, the fuel amount consumed per 100 km of road increases.

The relative economy of a tractor with a low cabin and an improved ramp is 16.3% of the tractor without an outboard and 10.9% of the fitted with a conventional racing gun. For the average cab with improved racing, the figures are 13.4% and 7.1% respectively.

5-10 shows the increase in the amount of fuel consumed from the increase in car power at speeds of 40, 60 and 90 km / hr, respectively, for trains with different improvements and different corduroy. With low speed and even motion, the car spends the smallest amount of fuel and power. With an increase in speed up to 60 km/h, the car spends approximately 2 times more power in support of a given speed. With increase in speed up to 90 km/h, the power increases almost 3 times. It is due to the fact that the motionvelocity has a quadratic function and a parabolic character.

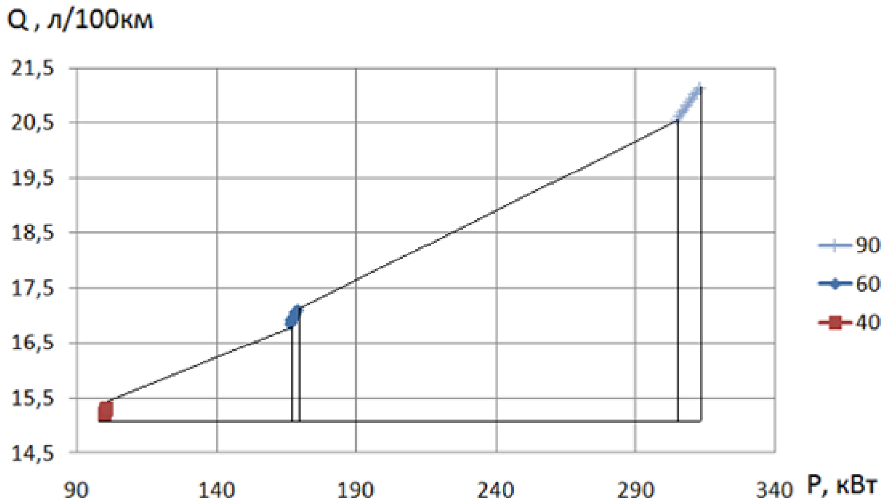

Figure 5 – Power dependence on the amount of fuel consumed by the low cab without a rudder

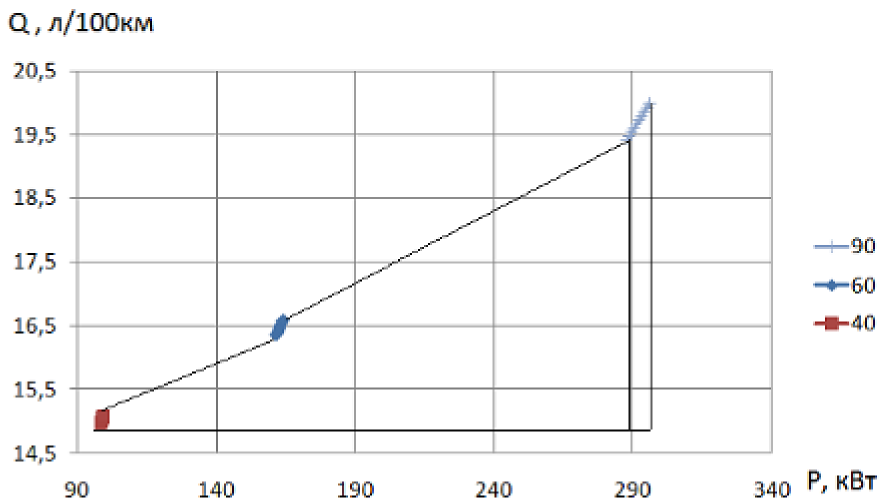

Figure 6 – Power dependence on the amount of fuel consumed by the lower cabin with improved ramp ahead

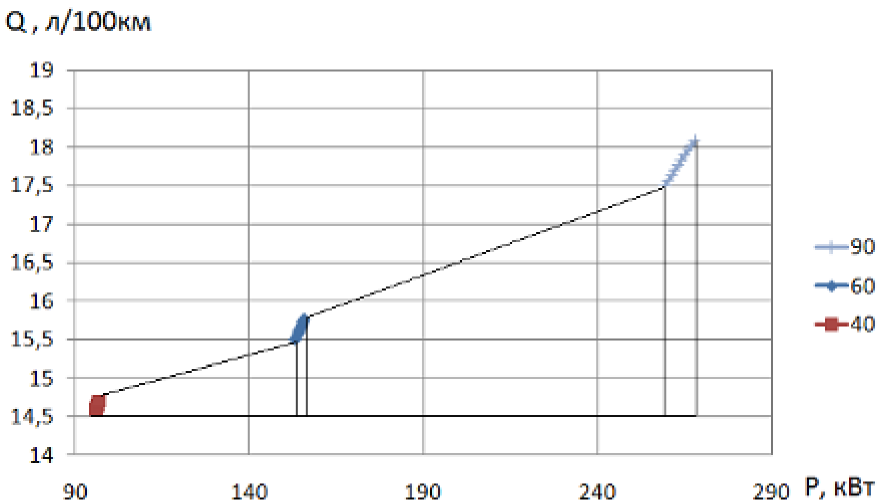

Figure 7 – Power dependence on the amount of fuel consumed by the low cabin with improved ramp behind

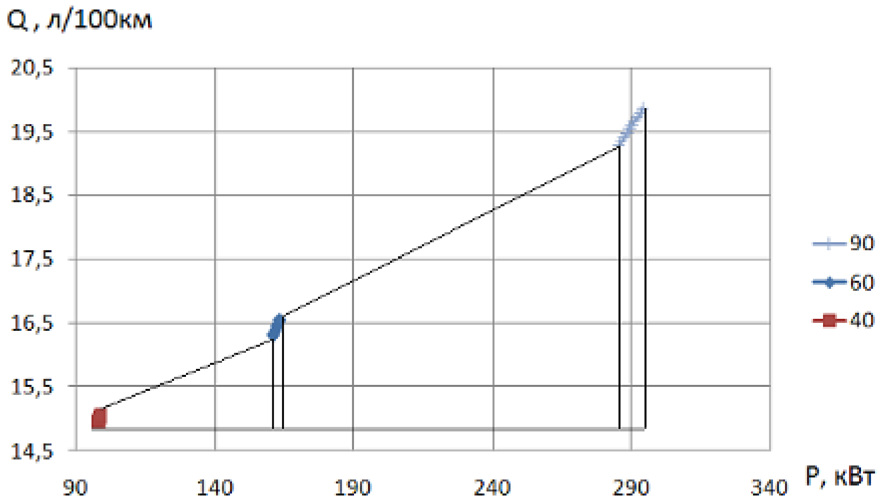

Figure 8 – Power dependence on the quantity consumed fuel of a low cabin with a normal riviera

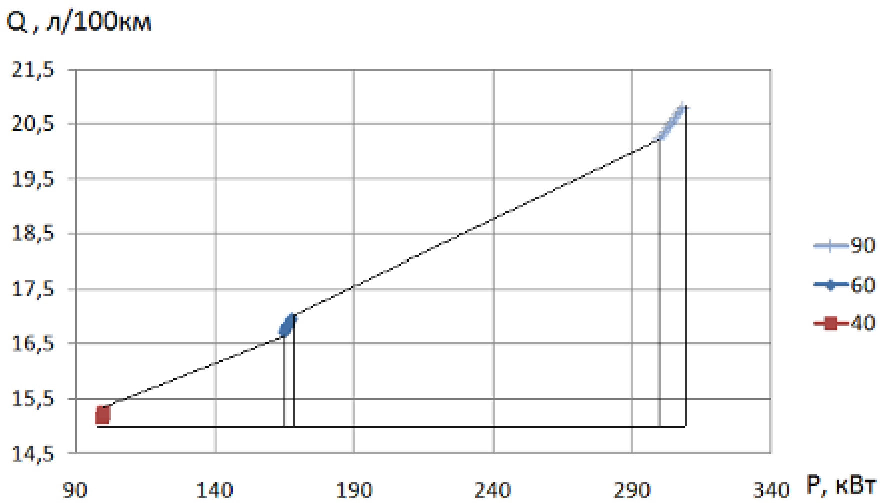

Figure 9 – Power dependence on the amount of fuel consumed in the average cabin without a ramp

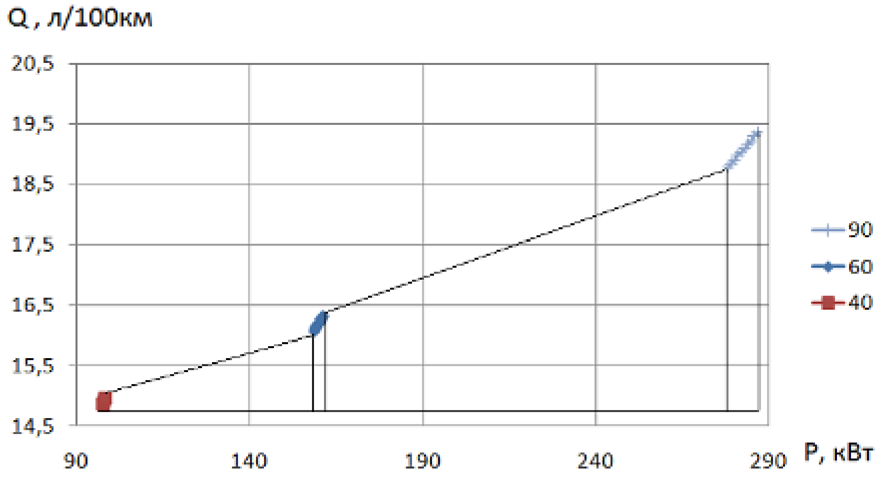

Figure 10 – Dependence of power relative to the amount of fuel consumed by the average cabin with a conventional rampramp

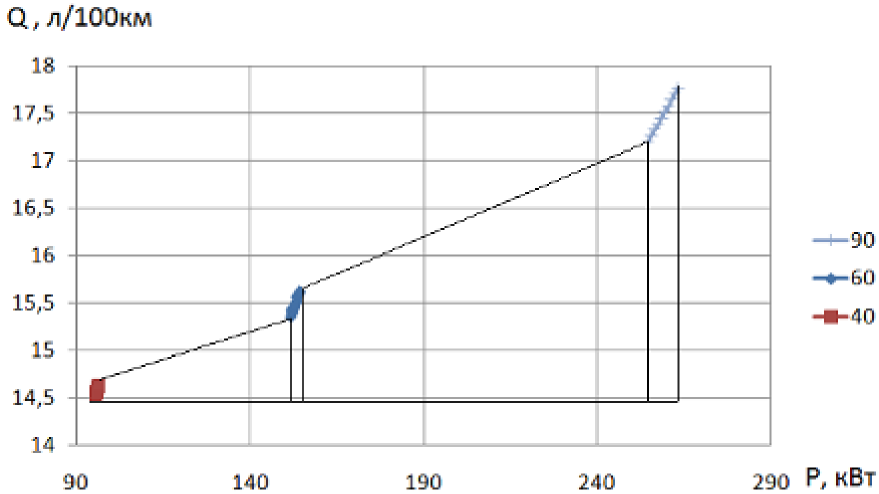

Figure 11 – Power dependence on the amount of fuel consumed in the average cabin with an improved figure

Conclusions The theoretical study of the strain influence on the main motor tracks performance enables to achieve the following results:

– after analysis the existing flow elements installed on the main train trailer and the ramps revised large number installed directly on its roof, it was substantiated the expediency of installing a movable rope on the tractor roof, which can change the angle of airflow trailing link with the combination of two movements - vertical and horizontal;

– the method of calculation and the calculations of power and quantity of fuel consumed for various types of booths and their possible improvements by the proposed moving ramp are proposed;

– an imaginary main motorway is divided into the air flow zone with its flow in the road projection and determine the air velocity in these zones.

The next step of the research is the development of a schematic diagram and the roof ramp design, a hydraulic system for changing the parameters of the roof rack with the possibility of adjusting for any trailer structure, as well as possible options for connecting and adjusting its parameters.

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