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ANALYSIS OF PASSENGER VEHICLE CRUISION BY THE MODIFIED METHOD OF CLOSED SPEEDS

Monitoring and diagnosing the technical condition of vehicles is one of the most crucial issues. Recent studies conducted at Kharkiv National Automobile and Highway University (KhNADU) confirm that the condition of transmission aggregates and the chassis of a vehicle can be characterized by the distance traveled during coasting. Several factors influence coasting distance, including operational and design features, as well as the aerodynamic properties of the vehicle and the condition of its transmission and chassis components. The constant improvement of automobiles necessitates a reevaluation of methods for assessing motion resistance, making the modified method for determining approximate speeds relevant. Research has shown that for testing passenger cars, a horizontal road section of over 750 meters is needed for coasting from a speed of 50 km/h to a stop, which is not always available. However, coasting tests can be conducted at different speeds on shorter sections. Changes have also been made to the well-known coasting analysis method, and empirical formulas for air and rolling resistance have been developed, allowing for more accurate calculation of coasting distance and time than the classical method. The results of experiments have improved the method for estimating total resistance when a vehicle is in motion during coasting, dividing it into road and aerodynamic components. Additionally, advancements in vehicle technology underscore the importance of developing comprehensive diagnostic tools and procedures to ensure optimal performance and safety. This includes integrating advanced sensors and diagnostic systems into vehicles to provide real-time feedback on their condition, enabling proactive maintenance and minimizing the risk of unexpected failures.

Keywords: car breakaway, car test, acceleration time, coasting time, tire, car.

INTRODUCTION

The run-out path of a car from a speed of 50 km/h is one of the few road test parameters available to the average user. And even then with reservations: how to measure it? Odometer? How can you detect the start of a run-out? How to simultaneously keep track of the speedometer, maintaining a speed of 50 km/h, the road (this is the column from which you need to start coasting), the odometer - and press the clutch pedal in time... And in the end there remains a rough indication of the path by the odometer - steps of 100 m. Not By chance, we recommended measuring not the path, but the run-out time [1] - in this case, all difficulties are removed and only the time measurement error remains.

ANALYSIS OF LITERARY DATA AND PROBLEM STATEMENT

Many vehicle operating instructions require a run-out distance from 50 km/h of at least 500 m (and in some even 420 m). The corresponding run-down times will be approximately 76 and 64 seconds.

You can find the following information [2]:

> «- the minimum run-out should be ~500 meters
> - normal spread - 450-700 meters
>
> The run-out depends on the tires (inflated - not inflated, studs - slicks), load, type of car... So, for a light car it will be less than for a large single-wheel drive sedan due to different inertia, and for a jeep it will be less than for a large one sedan due to transmission losses.»

The idea of "different inertia" is widespread, but incorrect. This is confirmed by the results of experiments (Table 1).

Table 1 Coasting of passenger cars from 50 km/h (KhNADU experiments)

Automobile	Weight, kg	Time coast down, s	Tires and Cx
DAEWOO Matiz	1111	109,1	ContiEcoContact EP Cx=0,4
DAEWOO Lanos	1360	124,1	Tigar (фил. Michelin) TG621 Cx=0,37
VAZ-2105	1392	94,3	Belshina Бел-103 Cx=0,52
GAZ-31105 ZMZ	1475	86,6	Vredestein SnowTrac 2 M+S Cx=0,461
	1650	87,1	
	1890	88,6	
Chery Tiggo monodrive	1625	143,5	GT Radial Champiro 128 Cx=0,384
BMW 524 TD	1794	101,9	Bridgestone Cx=0,31
Mercedes-Benz E 300 D	2022	141,7	Continental Premium Contact Cx=0,28

AIM AND TASKS OF THE RESEARCH

Contribute changes to the well-known method of coastdown analysis. Derive empirical formulas for air and rolling resistance that will allow calculate the path and run-out time many times more accurately than classical ones.

RESEARCH RESULTS

As can be seen from the table, the decisive role is played not by the weight of the car, but by the quality of the tires. The lightweight DAEWOO Matiz on ECO tires showed a run-down time of 109.1 s - significantly better than the Volga with high inertia, but on all-season tires (86...89 s). On good tires, a Lanos has a 32% longer run-out than a VAZ-2105 of almost the same weight. The Mercedes-Benz E 300 D station wagon demonstrated an absolutely phenomenal roll - but not because of its weight, which is not much more than that of a fully loaded Volga, but thanks to excellent tires (and not new ones, with reduced rolling resistance), excellent aerodynamics and great age - with mileage, the rubbing pairs in the car break in, and the rolling improves (and, probably, thanks to Mercedes quality). The Chery Tiggo runs even better on Indonesian tires made of natural rubber (and weighs 400 kg less). So, even the worst run-down time listed in the table (82 s) turned out to be noticeably better than the value of 76 s, corresponding to a run-out path of 500 meters.

The small effect of vehicle mass is easy to understand. If there were no air resistance and transmission losses, the deceleration of the car j (m/s2) would be determined only by rolling resistance:

where Pf is the rolling resistance force, N; ma – vehicle weight, kg; g – free fall acceleration, 9.81 m/s^2; f – rolling resistance coefficient; δ – factor for taking into account rotating masses.

Thus, mass has virtually no effect on deceleration caused by rolling resistance.

On the other hand, air resistance does not depend on mass, but is highly dependent on the shape of the car. A “light car” usually has worse aerodynamics than a large sedan, so the deceleration created by air resistance is higher and the run-out is correspondingly shorter.

The available technical specifications do not indicate the run-out rate. But the user needs this information. In Autoreview experiments, a Civic with an automatic transmission showed a run-out of 631 and 646 m, which corresponds to a time of approximately 96...98 s.

We conducted our experiment on a horizontal road with good coverage [3]. Car – Honda Civic D4 with automatic transmission. Weight with experiment participants – 1705 kg (by weighing). Summer tires ContiPremiumContact_2 205/55 R16 91V.

The registration of the run-out parameters was carried out by video recording the changing readings of the speedometer and the barrier fence, which we used as a road marking.

Video recordings in .mts and .mp4 formats were processed on a computer in the video editing program AVS VideoEditor, in .avi format - in the VirtualDub program: during frame-by-frame viewing, the beginning and end of the indication of the same speed were found and a v(t) diagram was constructed, relating the values speed to the middle of the time segment from the beginning to the end of the display. Using video recordings of the fence, path graphs S(t) were constructed, which were then smoothed using polynomials of the 3rd or 4th degree and then numerically differentiated, obtaining diagrams of the true speed v(t) and deceleration j(v). These are the diagrams used here. After discarding incomplete and unreliable records, eight curves remained (Fig. 1, Table 2). The run-out path in them varied from 591 to 746 m with an average of 658 m. This exceeds the length of horizontal road sections available in our area (350...500 m), so a more detailed analysis was undertaken.

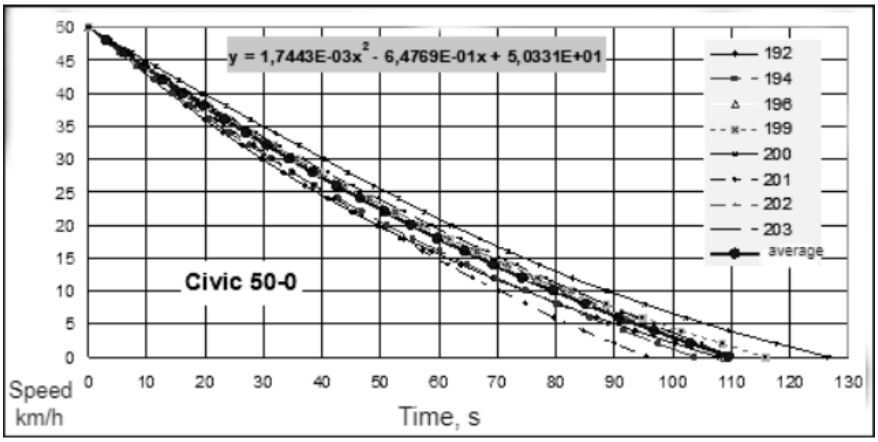

Fig. 1. Rundown diagrams for the Honda Civic D4
from 50 km/h to a complete stop

Table 2 Run time of the Honda Civic D4 from 50 km/h to speed V

Clip	Speed V, km/h				
	40	30	20	10	0
192	13,87	29,70	49,38	74,74	107,63
196	16,69	35,35	56,47	80,66	108,60
199	16,69	35,57	56,96	82,61	115,69
200	19,58	40,23	62,12	88,71	126,74
201	15,40	31,61	49,47	70,23	95,58
202	16,56	35,38	56,96	81,48	108,78
203	17,14	36,56	58,55	83,12	110,05
Average m	16,28693	34,44496	55,1222	79,55868	109,5863
Scope Δ	5,71	10,53	12,74	18,48	31,16
Dispersion D	3,181196	11,74634	21,53607	34,65025	81,28929
Standard off. σ	1,783591	3,427294	4,640698	5,886446	9,016057
Coef. variations v	0,109511	0,099501	0,084189	0,073989	0,082274

It was necessary to find a range of speeds in which the run-out path did not exceed at least 500 m, the time was long enough for reliable measurement during manual notching, and the variation was small enough. The generally accepted sample indicators were assessed - sample mean, range, dispersion, standard deviation and coefficient of variation.

To reduce the requirements for road length, you can measure the run-down not to a stop, but to 20 or 30 km/h. But in the first case, the run-out path still exceeds 500 m, and in the second, the contribution of air resistance is noticeably greater. This makes the test more sensitive to changes in wind speed and less sensitive to chassis and transmission faults. It is better to limit the range from above. Two options look attractive: from 40 to 20 km/h and from 30 to 10 km/h (Table 3).

Table 3 Comparison of two possible speed ranges

Speed range, km/h	From 40 to 20	From 30 to 10
Run-down time, s	38,6	44,9
Run-out distance, m	317,3	242,6
Deceleration range, m/s^2	0,0723	0,0711

Both ranges are comfortable. The average run-out distance is significantly less than 500 m. The average coast-down time is large enough that the error caused by a resection delay, for example, 0.5 s, does not cause an overall error of more than 1.5% (1.3 and 1.1%). The range of deceleration in the sample is almost the same.

The digital speedometer of the Honda Civic car displays the speed in whole km/h, so one value is kept on the display for quite a long time - and a person can note the time both at the very beginning and at the end of the indication period. However, after some training, manual notching turns out to be quite accurate and gives an error from 0 to 0.35 s. The errors in turning the stopwatch on and off have the same sign, so the difference error is small - 0.1...0.2 s. The second feature of the digital speedometer is sporadic omissions of speed values, for example, after 40 immediately 38 km/h, after 33 - 31, etc., which forces you to repeat the measurements.

In the analysis of the experimental results described above, the average value f = 0.01124 (for a speed of 20 km/h) was obtained. This is close to 0.01130 - at the lower limit of the field of possible values for tires of categories S and T. The highest possible values of f (the upper limit of the field for H, V and other high-speed tires) are 1.237 times higher, the smallest (the lower limit of the field for ECO tires) – 0.756 times. Omitting calculations, we present the obtained values of the path and run-down time for the considered speed ranges.

Table 4 Estimated standard values of parameters "Coasting time" and "Coasting distance" of the vehicle Honda Civic D4

Rolling resistance option	Parameter	Speed range			
		from 50 to 0	from 40 to 20	from 30 to 10	from 40 to 10
worst	Time, s	90,6	32,4	37	52,3
	Path, m	554,1	266,8	200,6	348,7
average	Time, s	106,2	37,3	43,2	60,7
	Path, m	639,2	306,7	233,6	403
best	Time, s	129,4	44,2	52,3	72,8
	Path, m	760	362,6	281,3	480,3

So, the recommended modes for checking a Honda Civic D4 with ECO tires and the standards for these modes have been established.

However, for other types of tires the standards will be different. Not being able to repeat the experiment with all tire options, we tried to calculate these options based on generally accepted models of vehicle resistance to movement. However, no combination of a constant value of Cx and the dependence f(v) produced a deceleration curve j(v) approaching the experimental one.

All that remained was to accept the version of the inconstancy of Cx and try to find fairly simple methods for calculating the parameters of the run from 50 km/h, taking into account this inconstancy. It is convenient to study the nature of the dependence Cx(v) using the method described, for example, in [4]: select two points close in speed on the experimental curve j(v) and make the assumption that, due to the small difference in speeds, the resistance values at both points are the same. Next, they create a system of two force balance equations for these two points and solve it. Then they move on to the next pair of speeds - and so on until the end of the range under study. We call this procedure the “near speed method”, CSM.

Initial system of equations:

$$\begin{cases} P_{f1} + P_{xx.mp1} + kF\cdot v_1^2 = \delta\cdot m_a\cdot j_1; \\ P_{f2} + P_{xx.mp2} + kF\cdot v_2^2 = \delta\cdot m_a\cdot j_2, \end{cases} \quad (2)$$

where Pf is the rolling resistance force, N; Pxx.tr – transmission idle resistance force, N; k – streamlining coefficient, $N\cdot s^2\cdot m^{-4}$; $k = 0{,}5\cdot\rho\cdot C_x$ (ρ·– air density, kg/m^3; Cx – aerodynamic drag coefficient); F – frontal area of the car, m^2; v_1, v_2 – selected close velocities, m/s; j_1, j_2 – decelerations at these speeds.

As stated above, it is assumed that at sufficiently close velocities the resistances are equal. However, a preliminary assessment using the example of a Honda Civic shows that the sensitivity of the three components to changes in speed is different (Table 5, Fig. 2).

Table 5 Dependence of the coasting resistance of a Honda Civic on speed (air resistance - according to the standard formula at ρ=1,208 kg/m^3, C_x=0,31, F=2,1 m^2; rolling resistance at m_a=1703 kg, f – at the lower limit of the field of possible values for tires of categories S and T [1]; Pxx – based on measurement results [5])

v	0	5	10	15	20	25	30
Pw	0,0	0,8	3,3	7,3	13,0	20,4	29,3
Pf	189,4	189,0	188,8	188,8	188,8	189,0	189,3
Pxx	0,052	0,704	1,05	1,37	2,64	3,85	4,81

v	35	40	45	50	55	60	65
Pw	39,9	52,2	66,0	81,5	98,6	117,4	137,8
Pf	189,6	190,2	190,8	191,5	192,4	193,4	194,5
Pxx	5,72	6,78	8,07	9,46	10,85	12,4	15,1

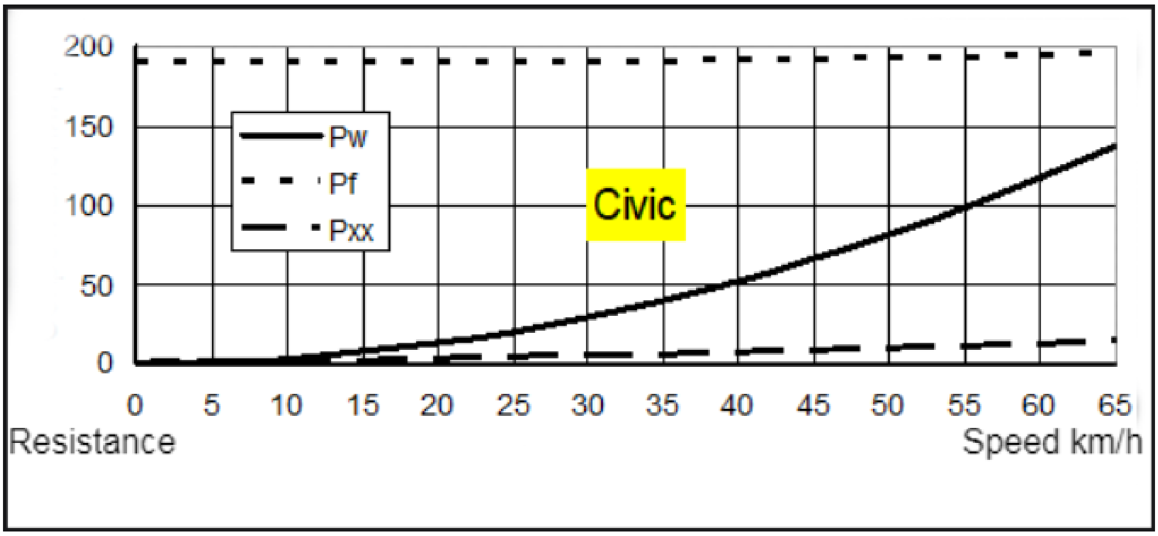

Fig. 2. Dependence of the Honda Civic coasting resistance on speed

Rolling resistance is the least sensitive; it can be considered constant in the selected speed range from v_1 to v_2 without compromising accuracy. ($P_{f1}=P_{f2}=P_f$).The other two resistances are speed dependent. It is convenient to combine them in the form $kF^*\cdot v^2$. Then:

$$\begin{cases} P_f + kF^*\cdot v_1^2 = \delta\cdot m_a\cdot j_1; \\ P_f + kF^*\cdot v_2^2 = \delta\cdot m_a\cdot j_2. \end{cases} \quad (6)$$

After the simplest transformations we get:

$$kF^* = \frac{\delta\cdot m_a\cdot(j_1-j_2)}{(v_1^2-v_2^2)},\quad C_x^* = \frac{2\cdot\delta\cdot m_a\cdot(j_1-j_2)}{\rho\cdot F\cdot(v_1^2-v_2^2)} \quad (7)$$

or, if the speed is expressed in km/h,

$$C_x^* = \frac{25{,}92\cdot\delta\cdot m_a\cdot(j_1-j_2)}{\rho\cdot F\cdot(v_1^2-v_2^2)}. \quad (8)$$

It is easy to find the rolling resistance coefficient.

$$\begin{cases} P_f + kF^*\cdot v_1^2 = \delta\cdot m_a\cdot j_1; \;\| \;\times v_2^2 \\ P_f + kF^*\cdot v_2^2 = \delta\cdot m_a\cdot j_2, \| \;\times v_1^2 \end{cases}$$

$$f = \frac{\delta\cdot(j_1\cdot v_2^2 - j_2\cdot v_1^2)}{g\cdot(v_2^2-v_1^2)}. \quad (9)$$

If we accept the hypothesis that the exponent n is not constant [1], then the picture will change somewhat:

$$C_x^* = \frac{2\cdot\delta\cdot m_a\cdot(j_1-j_2)}{\rho\cdot F\cdot(v_1^{n_1}-v_2^{n_2})};\quad f = \frac{\delta\cdot(j_1\cdot v_2^{n_2} - j_2\cdot v_1^{n_1})}{g\cdot(v_2^{n_2}-v_1^{n_1})}. \quad (10)$$

As an example, we took the run-down data of the Mitsubishi Lancer 2.0 sedan (weight 1555 kg, δ=1,0373, $r_{к}$=0,318 m; using [1] the values were calculated C_x=0,364, f=0,0117) and processed in two versions: with the classical description of air resistance with a constant exponent at speed n=2 and with a variable exponent *n(v)* according to D.V. Nikitin (Fig. 3). In Fig. 4 and 5 show the calculated dependences of the aerodynamic drag coefficient C_x and the rolling resistance coefficient *f* as a function of speed.

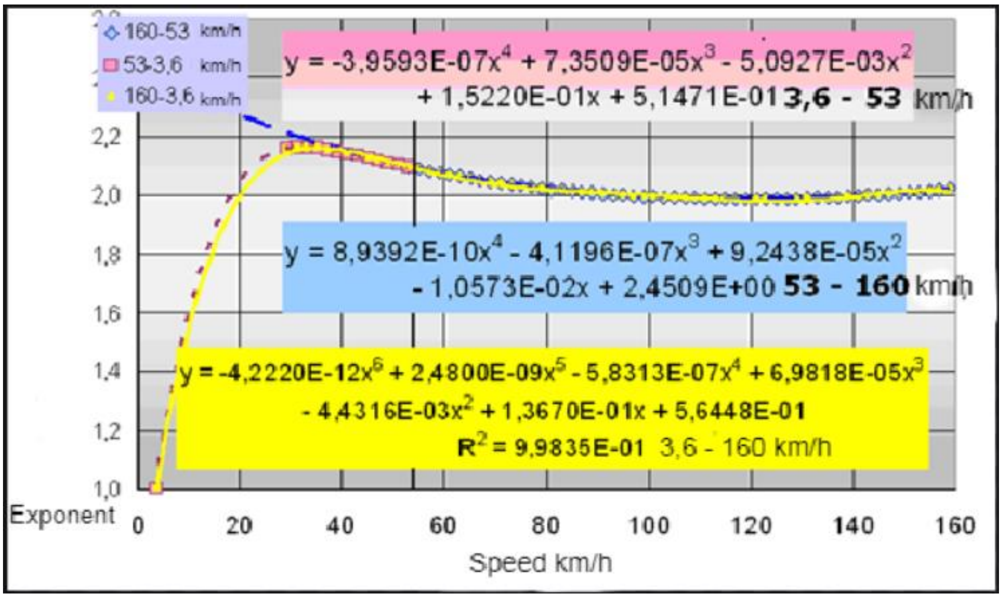

Fig. 3. Dependence of the exponent n on speed – averaged over 84 different types of passenger car models

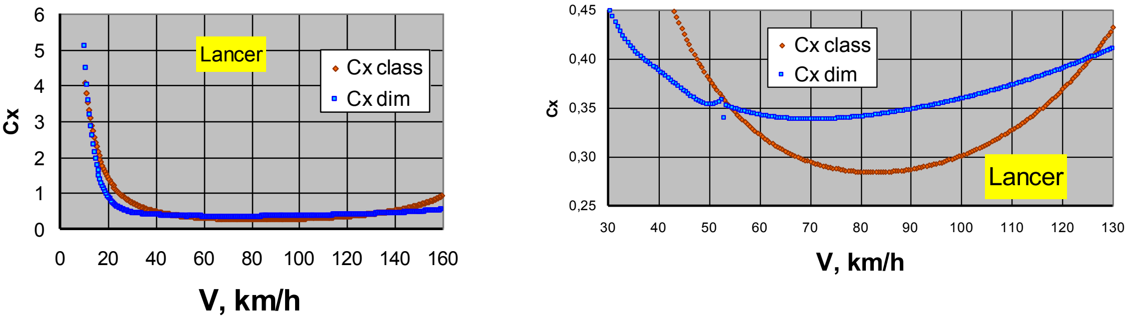

Fig. 4. Calculated dependence of the aerodynamic drag coefficient Cx on speed, obtained by the close speed method, in full (left) and operating speed ranges

DISCUSSION OF THE RESEARCH RESULTS

What is unexpected is the decrease in rolling resistance to zero at the beginning and, especially, at the end of the diagram. A sharp drop in f at speeds below 20 km/h has already been described in the works of KhNADU [1], but it was not noted for high speeds. Most likely, this is a consequence of the imperfection of the model. However, for this study this issue is not important: coast-downs are studied here from a speed of 50 km/h.

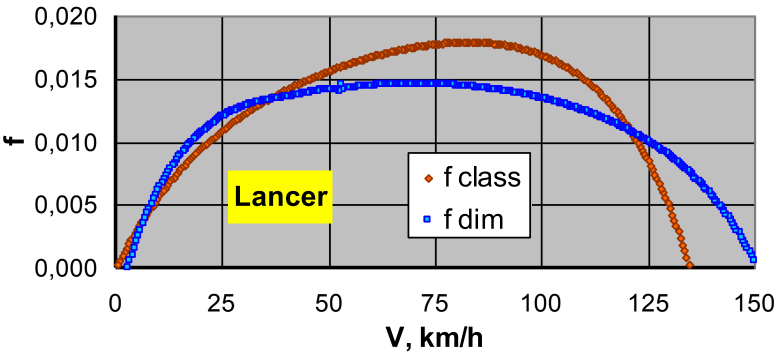

Fig. 5. Calculated dependence of the rolling resistance coefficient on speed, obtained by the close speed method

As can be seen from these diagrams, in the version with a variable exponent, CSM gives slightly more stable results. The resulting average value for the operating speed range C_x = 0,3656 quite close to the value calculated by the method [1] 0.3639, and the value f = 0,011748 practically coincides with f = 0,011706 (at a speed of 23.75 km/h, at which it is calculated f method [1]).

The question arose: to what power should the speed be raised at this value C_x, to get the same air resistance that it gives CSM? The result of the calculation turned out to be useless: the curve of this conditional exponent (n′ m/s in Fig. 6) in the low-speed zone noticeably departs from the initial one (n), rushes to infinity and forms a gap near 3.6 km/h. This operation gave a more practical result when substituting the speed in km/h. Curve n′ km/h in Fig. 6 goes more flatly in the range of operating speeds; in the area from 90 to 30 km/h this figure is almost constant (1.4135), and in the range from 50 to 20 km/h 1.418 can be taken. True, at lower speeds the calculation of air resistance at C_x=0,3639 и n′=1,418 gives an increasing error, but against the background of other resistances it is insignificant, and the calculation itself is based on CSM not ideal.

Similar calculations for cars with sharply different aerodynamics: Toyota Land Cruiser 200 SUV (C_x=0,5063) and Honda Civic D4 sedan (C_x=0,3092) gave close values n′=1.4396 and n′=1.4228. The average of the three is 1.427.

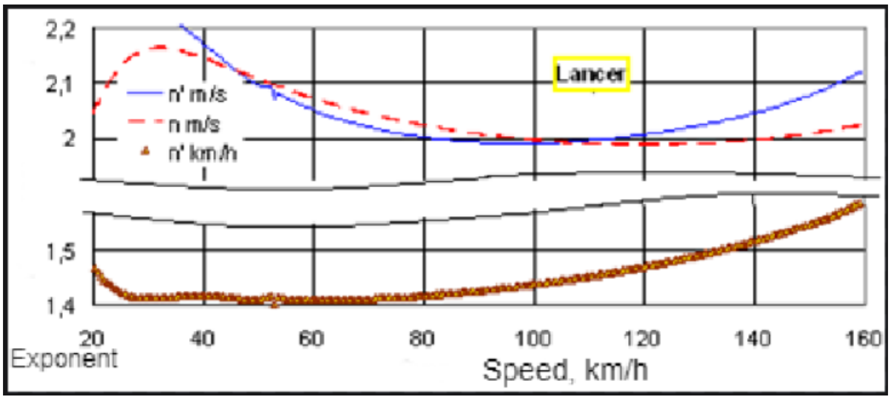

Fig. 6. Conditional exponent when calculating with C_x=0,3639

Selection of empirical formulas for calculating the rolling resistance coefficient f also relied on the results of the analysis of the Mitsubishi Lancer run-down using CSM with a variable exponent. The resulting diagram f(v) is shown in Fig. 7. It was approximated by a logarithmic function, but the curve at speeds below 2 km/h went into the negative region, which has no physical meaning. Therefore, the function was adjusted by shifting the argument by 1.7 km/h.

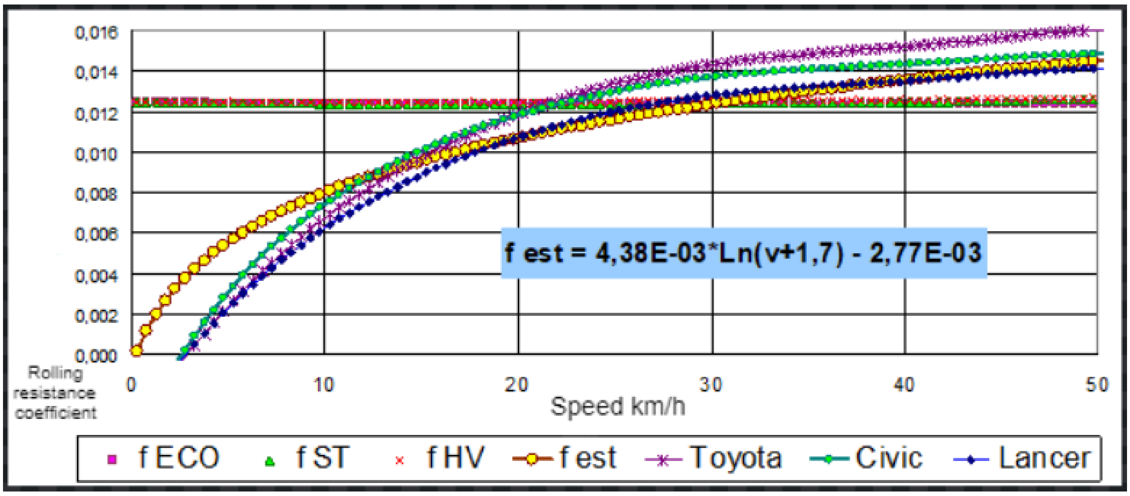

Fig. 7. Dependence of the rolling resistance coefficient f on speed, calculated by the close speed method with a variable [n(v)] exponent, reference for three groups of tires [f ECO, f ST, f HV], three cars [Lancer, Toyota, Civic] and accepted for calculation [f est]

For the other two cars considered, the shape of the fitting curve is the same, but the ordinates are higher or lower in accordance with the properties of the tire. It is convenient to correct this by the scale factor C_i/C_L, where C is the free term in the approximating expression for the dependence of the rolling resistance coefficient f on speed [1]; i – index of the car in question; L – Lancer car index. Meaning C_L for the Lancer sedan it is taken along the center line for SR-TR tires (0.012467), for a Toyota SUV along the top line for HR-VR tires (0.0140095), for the Civic sedan along the center line for HR-VR tires (0.013261). The choice of C was determined by the speed category of the tire, taking into account the value ψ, obtained by processing the run-down diagram according to [1].

CONCLUSIONS

The results of calculating the coasting parameters for three cars are presented in Table 6 with natural values and deviations from the experimental data as a percentage (ε, %).

Table 6 Coasting parameters of passenger cars, calculated by classical and proposed empirical methods, in comparison with experimental data

Data source	Speed range							
	50-1		50-20		40-20		30-10	
	Time, s / ε, %	Path, m / ε, %	Time, s / ε, %	Path, m / ε, %	Time, s / ε, %	Path, m / ε, %	Time, s / ε, %	Path, m / ε, %
sedan Mitsubishi Lancer 2,0								
Experiment	154,96	654,81	50,11	470,21	35,90	293,02	46,35	243,92
Class. calculation	101,92	667,12	56,96	540,51	40,13	330,66	61,90	240,21
ε, %	-34,23	1,88	13,68	14,95	11,79	12,85	33,57	-1,52
Empirical calculation	151,93	656,17	50,85	474,92	36,79	299,65	47,48	250,63
ε, %	-1,96	0,21	1,48	1,00	2,47	2,26	2,45	2,75
SUV Toyota Land Cruiser 200								
Experiment	141,91	583,95	44,30	415,06	31,83	259,54	41,65	218,58
Class. calculation	89,04	579,89	49,41	468,75	34,82	286,79	53,89	209,28
ε, %	-37,26	-0,70	11,53	12,94	9,39	10,50	29,39	-4,25
Empirical calculation	134,04	573,66	44,32	413,73	32,09	261,25	41,64	219,51
ε, %	-5,55	-1,76	0,03	-0,32	0,80	0,66	-0,04	0,43
sedan Honda Civic D4								
Experiment	136,91	628,58	49,33	465,50	34,98	286,44	43,27	229,77
Class. calculation	103,02	680,53	58,22	554,23	40,73	336,07	62,43	241,28
ε, %	-24,75	8,26	18,01	19,06	16,44	17,33	44,27	5,01
Empirical calculation	146,05	640,92	49,93	467,42	35,97	293,38	45,89	242,72
ε, %	6,68	1,96	1,23	0,41	2,85	2,42	6,05	5,63

As can be seen from the table, the proposed empirical method is much more accurate than the generally accepted classical method.

1) 1) measuring the run-down parameters of passenger cars from a speed of 50 km/h to a complete stop is possible only if there is a straight horizontal section of road more than 580...750 m long;

2) 2) the smallest variation in the run-down deceleration of the Honda Civic D4 is observed in the range from 20 to 30 km/h, the largest – from 10 km/h to a stop and from 50 to 40 km/h;

3) 3) depending on the length of the accessible straight horizontal section of the road, it is recommended to measure the coasting parameters of a passenger car in the speed ranges from 40 to 10, from 40 to 20 or from 30 to 10 km/h; approximate values of the Honda Civic D4 vehicle run-down standards in the specified speed ranges - according to table. 4;

4) 4) the travel distance and run-down time standards should be calculated using the method described here.

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***Ю.В. Зибцев, П.А. Ворошилов.* Аналіз вибігу легкового автомобіля модифікованим методом близьких швидкостей**

Контроль та діагностика технічного стану автомобілів є однією з найбільш важливих проблем. Недавні дослідження, проведені в ХНАДУ, підтверджують, що стан агрегатів трансмісії та ходової частини автомобіля можна оцінити за величиною шляху по вибігу. На цей шлях впливає безліч факторів, включаючи експлуатаційні та конструктивні особливості, а також аеродинамічні властивості та стан агрегатів. Стійке вдосконалення автомобільної техніки вимагає постійного оцінювання опору руху, що робить модифікований метод визначення близьких швидкостей актуальним. Дослідження показали, що для перевірки легкових автомобілів на вибігу зі швидкості 50 км/год до зупинки потрібна горизонтальна ділянка дороги довжиною понад 750 м, що не завжди доступно. Однак на коротших ділянках можна проводити вибіги з інших швидкостей. Також були внесені зміни в відомий метод аналізу вибігу, розроблені емпіричні формули для опорів повітря та кочення, що дозволяють розрахувати шлях і час вибігу набагато точніше, ніж за класичним методом. Результати експериментів дозволили удосконалити метод оцінки сумарних опорів при русі автомобіля по вибігу, розподіливши їх на складові: дорожні і аеродинамічні опори. Крім того, прогрес у технології транспортних засобів підкреслює важливість розробки комплексних діагностичних інструментів і процедур для забезпечення оптимальної продуктивності та безпеки. Це включає в себе інтеграцію передових датчиків і діагностичних систем у транспортні засоби для надання зворотного зв’язку про їхній стан у реальному часі, уможливлення проактивного технічного обслуговування та мінімізації ризику несподіваних збоїв.

Ключові слова: Вибіг автомобіля, тест автомобіля, час розгону, час руху накатом, шина, автомобіль.

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