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Synergetic Properties of the Interaction of the Vehicle with the Element of Road Infrastructure in Urban Driving Modes

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Abstract. In this paper, we analyzed the vehicle's driving modes and opted for the idle mode to save fuel. The synergy of the vehicle with the traffic light depends on many factors and has been studied on the example of the information model of the "Intelligent start-stop system". A vehicle with an "intelligent start-stop system" was saved 8.25 % of fuel during 100 km in urban conditions. In addition, emissions of harmful gases into the environment have been minimized. It was found that an average of 132 liters of fuel was saved when one vehicle traveled 20,000 km per year. Moreover, the idling time of the vehicle's engine was characterized by a reduction of 28–32 % in 100 km of the total test distance. Also included are the concepts of order parameter and flexible parameter on the principles of synergetic by using intelligent transport systems in the local condition.

Keywords: intelligent transport system, intelligent start-stop system, infrastructure, traffic light, drive mode, synergetic, order and flexible parameters.

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Синергетические свойства взаимодействия автомобиля с элементом дорожной инфраструктуры в городских режимах вождения

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Аннотация. В данной работе мы проанализировали режимы движения автомобиля и выбрали режим холостого хода для экономии топлива. Синергия транспортного средства со светофором зависит от многих факторов и изучена на примере информационной модели «Интеллектуальная система старт-стоп». Автомобиль с «интеллектуальной системой старт-стоп» сэкономил 8,25 % топлива на 100 км в городских условиях. Кроме того, выбросы вредных газов в окружающую среду сведены к минимуму. Было установлено, что при пробеге одного автомобиля 20 000 км в год экономится в среднем 132 литра топлива. При этом время работы двигателя автомобиля на холостом ходу характеризовалось сокращением на 28–32 % на 100 км общего пробега испытаний. Также включены концепции параметра порядка и гибкого параметра на принципах синергетики с использованием интеллектуальных транспортных систем в локальных условиях.

Ключевые слова: интеллектуальная транспортная система, интеллектуальная система старт-стоп, инфраструктура, светофор, режим движения, синергетика, порядок и гибкие параметры.

Благодарности. Мы хотели бы выразить благодарность Туринскому политехническому университету в Ташкенте и всем консультантам за практическую помощь в проведении эксперимента в условиях городского вождения. Мы также хотели бы поблагодарить всех участников за их ценное время и обратную связь.

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Introduction

In exploition, the driving of vehicles consists of a complex dynamic variables, which ars provided in accordance with the principles of synergetics in the system "Vehicle – Driver – Road – Pedestrian – Environment".In the system "V-D-R-P-E" mechanic – "Vehicle – road", biomechanic – "Driver – vehicle", "Driver – road", "Pedestrian – vehicler" and "Pedestrian – road", biological – "Driver – pedestrain" systems can be distinguished [1]. In addition, they are integrated into the vehicle's mechatronic systems in intelligent transport systems.Under synergetic principles, the system is characterized by the presence of an open, dynamic unbalance and a nonlinear connection between the parts. The level of data retrieval from infrastructure while driving is limited for the driver.

Every developing society must constantly increase the volume of transport communications, enhance its reliability, safety, and quality.To achieve this, it is important to ensure the interoperability of vehicles and transport infrastructure, as well as the use of intelligent technologies in the field. Because, intelligent transport systems (ITS) and intelligent technologies (IT) are not only the collection of data through automotive mechatronic systems but also the automation of analysis, modeling the processes in real-time, minimizing the "human factor". It is also based on a specific methodological framework that allows for further correction, making it easier to propose or make clear management decisions.

Improvements to modern vehicle design and control of parts with mechatronic systems are aimed at solving various problems in this field.If we consider the vehicle as a complex unified system, then the system, according to the principles of synergetics, adapts to the standards, taking into account internal and external factors through self-regulation.This intelligent approach is based on many parameters. This intellectual approach is based on several factors.

ITS is divided into subsystems consisting of vehicle and infrastructure elements.According to the principles of synergetics, the complex elements of the system are divided into several hierarchical layers, depending on the rate of their change relative to the others.The intellectual elements of a vehicle are a fast-changing group and the intellectual infrastructure elements are a relatively slow-changing group.

1. Literature Review

The development of road infrastructure is the construction of highways, repairing highways, and equipping all elements of traffic safety with modern technologies. Today, they are not fully covered in terms of integration or synergy with the vehicle. As a result, there is a gap between vehicles and infrastructure, and energy consumption, environmental problems, road traffic accidents, and also their consequences are deteriorating.It is necessary to use ITS parts in solving the above problems. Major researchers in the field of traffic management, energy and resource-saving, optimization of automotive electronic control systems in the processes of interaction of the components of ITS with various objects, including B. Mc Queen, G. Nowacki, T. Hasegawa, S. Shaheen, R. Finson, Research work was carried out by I. Kabashkin, O. Katerna, N. Sembaev, N. Stavrova, V. Debelov, D. Morozov and others [2–10].

In addition, the research conducted by R. Nilesh and L. Robert in assessing the impact of ITS is aimed at ensuring road safety in the future [11–12].

M. Sumit, Sh. Khorinov, M. Vanderschuren, N. Parmar and H. Zhang have been used ITS technologies such as GPS, Wi-Fi, and Camera for monitoring traffic. They focused that, assess the traffic conditions of vehicles, prevent congestions and save energy resourcesusing of ITS technologies in their theoretical and practical research [13–17].

The research work of I. Razi, A. Stevens, E. Dahlman and K. Chai have been learned the communication of vehicle to infrastructure. In this approach the information about oncoming road signs, dengerous turns, railway crossings, etc transmitted to vehicles through short-distance wireless technologies, which have been found to help prevent road accidents in the exploitation conditions [18–21].

Uzbek scientists A. A. Mukhitdinov, A. A. Shermukhamedov, E. Z. Fayzullaev, K. A. Sharipov, J. Sh. Inoyatkhodjaev and others have been achieved significantly positive results such as optimizing mechatronic systems and production processes in the field of exploitation characteristics of vehicles, road parameters, improving energy performance and environmental performance [22–23]. However, the problems of the synergy between vehicle traffic modes with transport infrastructure using ITS capabilities have not been sufficiently addressed. Also, the fact that the level of implementation of these technologies in our conditions remains low, indicates the availability of resources in the field to solve the problem of fuel economy, environmental performance and other issues.

2. Research Methodology

As we know, the movement of vehicles in urban conditions depends on many factors.In such a case, it brings to the increased complexity of movement. In these complexities, we think it is necessary to increase the fuel economy of vehicles and improve environmental performance.

In Boris Kerner's "Three-phase traffic theory", which can be observed during the movement of vehicles under certain operating conditions, the function q = f(ρ) of the flow of vehicles as a function of its density is analyzed [24]. We observe the theoretical hypothesis of the currents F- "free flow", S- "synchronized flow" and J- "traffic in congestion" shown in Fig. 1 in today's real conditions.This means that the level of development of transport infrastructure is important in the regulation of traffic on roads, the elimination of congestion, and other processes.

There are several methods to save fuel. One of these methods is to use the "Intelligent start-stop system (ISSS)" in the component of "vehicle- to- infrastructure" of the ITS in the idling mode of the vehicle.Because saving fuel in this mode has not been researched in our country.

There are different aspects in the coverage of this article. In particular, there is no research on the effect on the engine parts, battery, starter, alternators in the process of turning off the vehicle engine at a red traffic light and restarting it at a yellow or green light in the ISSS.In general, the resource of the related parts can be reduced when the engine is started and turned off several times. However, due to the high level of quality and reliability in the production of mechanical and electronic parts of modern vehicles many violations of them are not observed during the exploitation of vehicles.

The object of the research was a vehicle with a 1,5-liter engine produced by UzAuto Motors. The main objective was to test the vehicle's fuel economy using ISST on the basis of the Chevrolet Nexia engine.

It was analyzed that vehicles equipped with an "auto start-stop system" can save 5–10 % fuel when driving in urban conditions and reduce CO2 emissions by approximately the same [25]. ISSS was tested in the auto polygon, and preliminary fuel savings are estimated to have improved by 7 % in the new European cycle and 5 % in the Tashkent drive cycle.

The efficiency of the ISSS is determined by saving fuel consumed during that time by turning off the vehicle engine more than 10 seconds before the red light of traffic light switches off and restarting it after a certain time.In addition, this system reduces the idling time of the engine and increases its efficiency and resource.

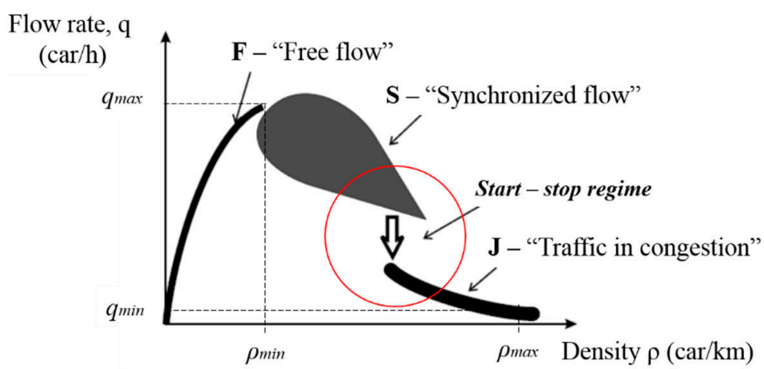

Fig. 1. Kerner's "Three-phase traffic theory" hypothesis

The difference in use of this system compared to others is that it enables mechatronic systems in the vehicle to ensure interoperability with traffic lights on the principles of synergetics.

As a result of research and analysis, the system has been divided into two groups: constructive and synergistic approaches.

In constructive approach, in the "A-D-R-P-E" system, the process is based only on the driver's observation, assessment of the situation and information from reality, stopping the vehicle at red lights of traffic light, traffic jams and other places. In these cases, according to the system conditions, the engine automatically shuts down within 3–5 seconds and after a certain time it is automatically restarted when the driver performs several operations (Fig. 2, a).

In synergistic approach, the vehicle stops also of the above situations. ISSS activates in the designated area. According to the system requirements, several parameters are received and controlled from the vehicle and the infrastructure elements (traffic lights) to decide whether the engine should be shut down or not and restarted after a certain time (Fig. 2, b).

The ISSS is based on as a mechatronic system, such as a mechanical system, a control unit, input signals (sensors) and actuators (actors).

Input parameters from the vehicle:

Input X(t) parameters from the ECM (Engine Control Module);

Input U(t) parameters from the TCM (Transmission Control Module);

Input W(t) parameters from the BCM (Body Control Module);

Input Z(t) parameters from the infrastructure elements to the system.

Output Y(t) parameters from the system.

When the vehicle stops at a red traffic light, the engine is set for idle. In this mode, engine shutdown by ISSS is dependent on the traffic light that is active and continuous. If the green light is active, according to the system requirements the engine does not shut down. If the red light is active and its duration is more than tr>10 seconds, the system will shut down the engine when other input parameters are ok.The data required by the system program to shut down the engine is analyzed within 2 to 3 seconds. If tr<10 seconds, the system will not shut down the engine. In this prosess traffic lights should equipped with microcontrollers so that the vehicle can receive the necessary information from the traffic lights. The microcontroller in one traffic light acts as a "server", the second traffic light and

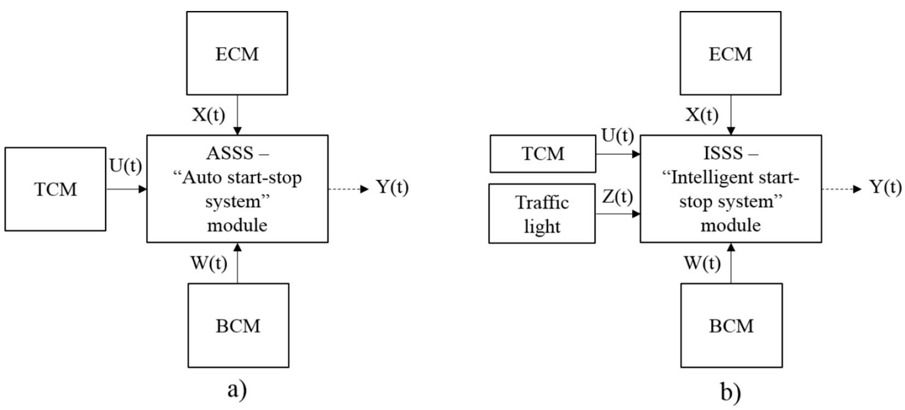

Fig. 2. Information model of the system: a) constructive approach, b) synergetic approach

the microcontroller which is in the vehicle ISSS act as a "client". In the traffic light area, vehicles can receive traffic light signals time continuously each second. Analyzes have shown that in such cases, it is effective to shut down the engine for at least 10 seconds before the vehicle moves in order to use the system.

All parameters included in the model from the vehicle's ECM, TCM and BCM were taken as the X (t) set of the vehicle's construction. The parameters of the set X (t) were determined during the experiment and their correlation values were calculated.As the function of ISSS depends on many parameters, strong connections have been taken. The boundary values of these parameters were determined using measurements (Fig. 3).

As with auxiliary systems in modern vehicles, the driver can use the on-off function of ISSS. If the system is active and the engine is switched off at the red light of traffic light, in case of emergency (an ambulance, fire and other special vehicles) during the red light unchanged state the driver switches off the ISSS with the button and restarts the engine and can drive a vehicle.

We considered that expedient to use the method of measuring fuel consumption by volume during the testing process. Depending on the design capabilities of the test vehicle, fuel consumption is taken from the sensor readings on the tank. Currently, various indicators of fuel consumption are based on vehicle dynamics and are displayed on the on-board computer. It is defined as a standard [26].

On the on-board computer of the Chevrolet Nexia, the display parameters change in the following order: average fuel consumption, current fuel consumption, average speed of the vehicle, odometer mileage, outside temperature, fuel range (Fig. 4).

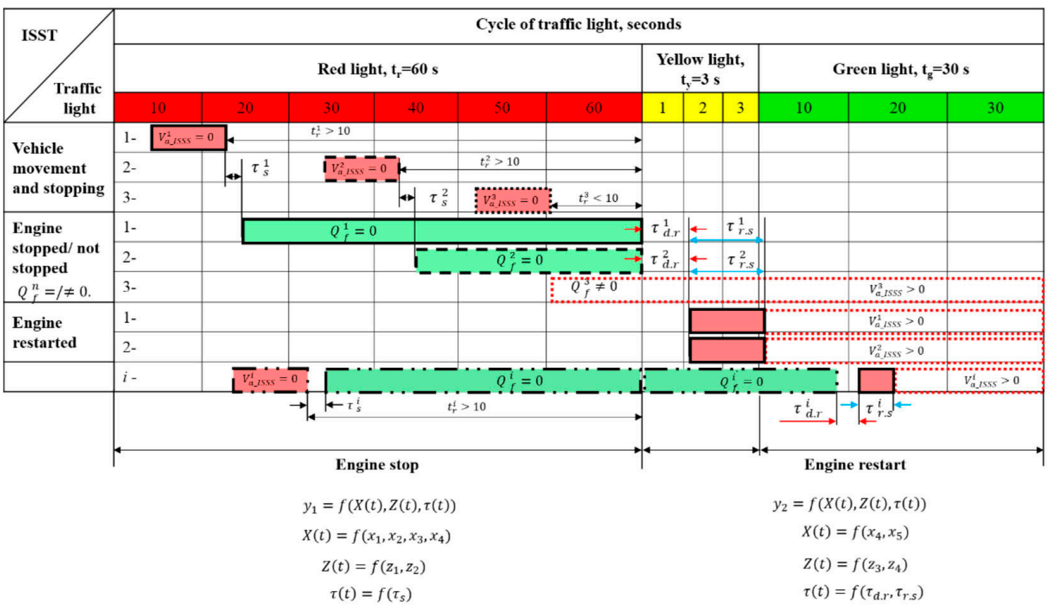

Fig. 3. Gantt model of "Intelligent start-stop system"

where:

x_1 – engine temperature, °C; x_2 – charge level of the battery,% or (V); x_3 – vehicle speed, km/h; x_4 – position of the throttle valve,% or(V); x_5 – position of clutch pedal; z_1 – the traffic light area parameter; z_2 – red light timing, t_r, (s); z_3 – yellow light timing, t_y, (s); z_4 – green light timing, t_g, (s); y_1 – engine stopsignal; y_2 – engine restartsignal; τ_s^n – engine stop time (s); $\tau_{d.r}^i$ – reaction time of driver (s); $\tau_{r.s}^n$ – engine start time (s).

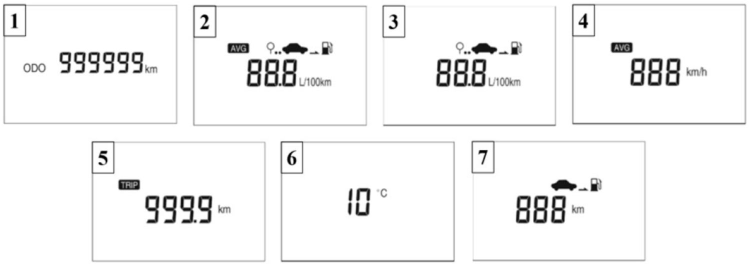

Fig. 4. On-board computer system of Chevrolet Nexia

The fuel pump of the Chevrolet Nexia is manufactured at the Uz-SaeMyung Co company. In accordance with the requirements of technical specification TSh 64–16464049–13: 2016, in accordance with paragraph 3.2.1, the sensor parameters of the fuel tank are calibrated relative to the volume of the tank and marked with reference indicators. The measurement accuracy of the sensor is 1 in 100. The sensor shows the residual fuel in the fuel tank (l), the sensor voltage (V), the fuel reserve in the tank (%) and the resistance of the sensor resistor (Om).

According to the Situational Center of the Tashkent City Traffic Police, more than 900000 vehicles are moving on the streets of Tashkent city every day. Based on this, the city of Tashkent was specified as the test object. For the test requirement, it is necessary to select the direction including 45–50 traffic lights at a distance of 25–30 km. Based on this requirement, the inner central streets of the small ring road of the city of Tashkent were selected (Fig. 5).

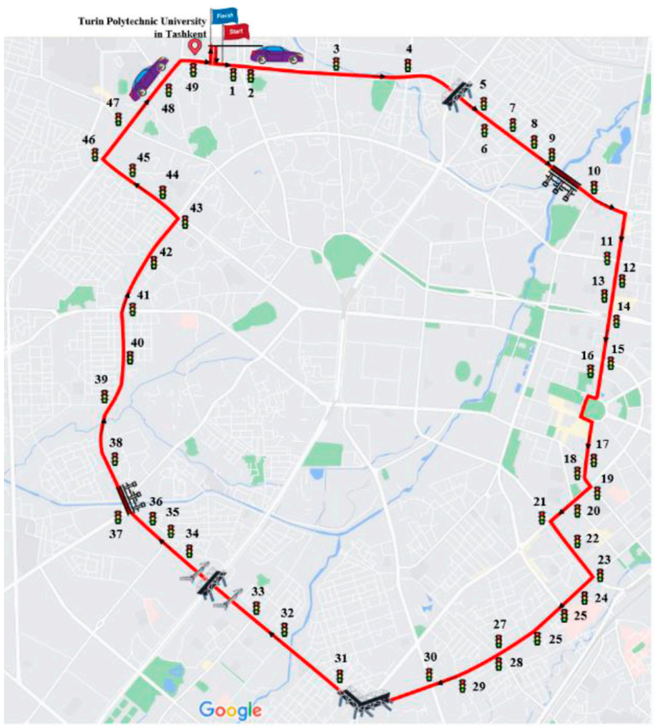

Fig. 5. Geo-map of the test direction in the Tashkent city

According to the test method, the results obtained from the electronic control unit (ECU) of the engine are analyzed through the Scanmatic diagnostic device during the testing of the vehicle. Because all sensors of the vehicle are improved. This device receives data from more than 90 sensors of the vehicle using the onboard diagnostic system which is recorded on a computer using the software of Scanmatik.

3. Results

The dynamic variability of vehicle movement in an urban drive cycle depends on a several of factors.These factors are characterized by the width of the roads, the proximity of the distances between intersections, number of vehicle, the loss of a lot of time at traffic lights, traffic jams, and so on. As a result, fuel consumption increases [27].

The idling mode of the vehicle on the driving modes of the city of Tashkent was analysed separately in the experiment.

If the instantaneous speed of vehicle is $V_{a_i} = 0$, it is assumed to be in idle mode or stop mode [28].

$$V_{a_i} = V_c^n = 0 \tag{1}$$

where: n – number of idle mode or stop mode.

In theory, it is possible to save fuel in idle mode. That is,

$$\text{If, } V_a = 0;\ \varpi_e = \varpi_{i,m} > 0; S = 0; t > 0 \text{ is } Q_f = 0 \tag{2}$$

The engine fuel consumption per hour in idle mode is usually determined experimentally with special equipment. The fuel consumption measurement was used DFL 3X-5 device in the trial department of the Engineering Products Department of UzAuto Motors JSC (Fig. 6).

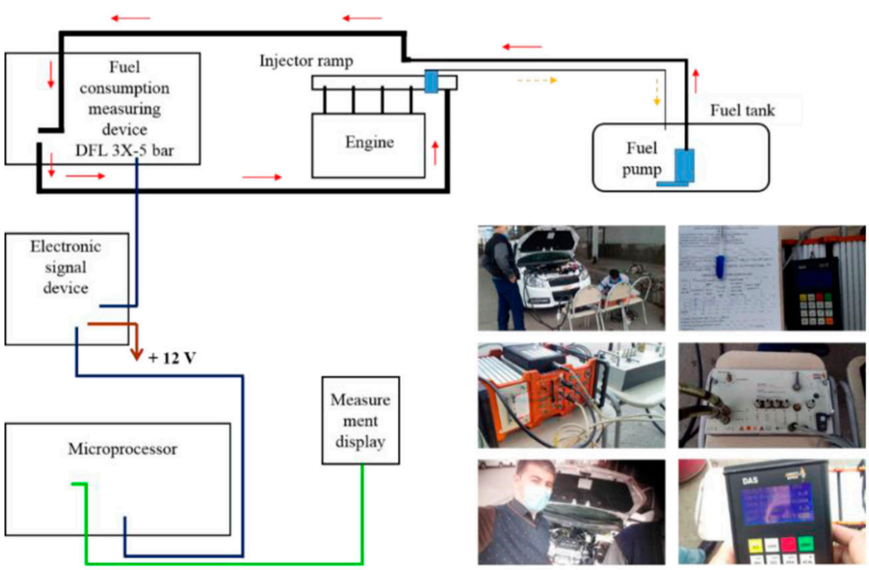

Fig. 6. Schematic and process for determining fuel consumption per hour while idling the Chevrolet Nexia engine using the DFL 3X-5

The measuring device is connected to the fuel supply system to determining the engine fuel consumption per hour in idle mode. To make the measurement process more accurate, the experiment was performed 3 times and the arithmetical average of the detected values was calculated. The engine capacity of the Chevrolet Nexia was 1,5-liter, and the engine fuel consumption per hour in idle mode was $\Delta Q_{i.m\_h} = 0{,}7782\ (L/h)$ [29].

One of the considerations when using the method for determining fuel consumption by volume is the degree of accuracy of the sensor in the fuel tank. This aspect determines how much fuel is saved when ISSS has been used. The engine fuel consumption per hour in idle mode was determined using the Scanmatic device and $\Delta Q_{f.s.i\_i.m\_h} = 0{,}817\ (L/h)$. So, the ratio of the values obtained from the fuel sensor through the Scanmatic device to the value determined on the DFL 3X-5 device was calculated as follows with its error rate $\Delta_{f.s}$.

$$\Delta_{f.s} = \frac{\Delta Q_{f.d.i} - \Delta Q_{f.s.i}}{\Delta Q_{f.d.i}} * 100\% \tag{3}$$

$$\Delta_{f.s} = \frac{0{,}817 - 0{,}7782}{0{,}7782} * 100\% = 5\%$$

where:

$\Delta Q_{f.d.i}$ – DFL 3X-5 device indicators in fuel consumption per hour in idle mode in, (l/h);

$\Delta Q_{f.s.i}$ – Scanmatik device indicators in fuel consumption per hour in idle mode in, (l/h).

This analysis showed that, based on the fuel sensor indicators recommended above, its error rate was experimentally determined to be $\Delta_{f.s} = 5\%$.

The movement of a vehicle which has been used and has been not used ISSS was analyzed on the city driving mode in Tashkent. The city driving mode of the vehicle was carried out during the morning, noon and evening at peak times of the day. During these times, the vehicle was determined at random stopping times at a red light of traffic lights in the specified direction (Fig. 7).

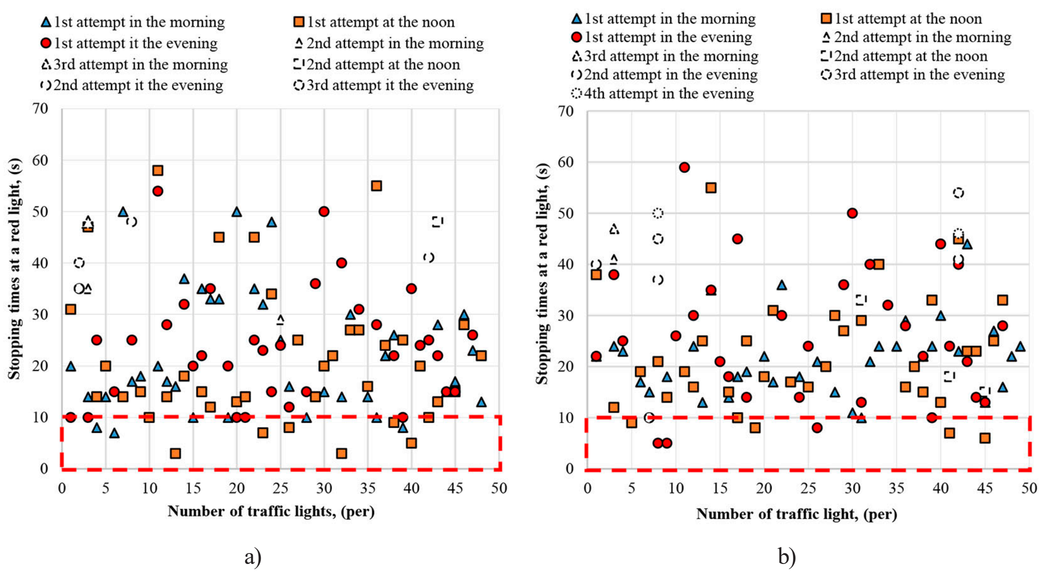

Fig. 7. Graph of random stopping times of vehicle at a red light of traffic lights: a) Standard vehicle, b) Vehicle with ISSS

These values were randomly determined in the example of the city of Tashkent in the framework of a cycle of variability tr = 18 ÷ 90 seconds at the standard minimum and maximum illumination period (tact) of the red light of traffic lights.

The most common infrastructure element in the city's road network is a traffic light. The operation of the ISSS in conjunction with the traffic light is required to determine the order parameter based on the principles of synergetics. The following filtering was performed on the detected main sets based on the ISSS efficiency when the red light off time is more than 10 seconds ($t_{r>10}$):

$$t_{r>10} = \sum_{i=1}^{m} t_{r.n} - \sum_{i=1}^{m} t_{r<10.n}, \tag{4}$$

where: $t_{r.n}$ – the total number of stop times at red lights, (pcs); $t_{r<10.n}$ – the total number of stopping times at red lights of traffic lights less than 10 seconds, (pcs); m – number of experiments, (pcs).

In synergetics, it is important the speed of processes. Synergetics adapts existing technologies based on local conditions through ITS to solve problems of transport systems. In any multicomponent system are controlled by qualitative changes as called the order parameter.In the formation of the order parameter, the system is characterized by the presence of an open, dynamic imbalance and a nonlinear connection between the parts.

The order parameter is a slow variable that is related to the length, width, signs, and other infrastructure elements of the road.The flexibility parameter is a fast variable that includes vehicle speed, movement flow and other dynamic objects.

The flexibility parameter is characterized group of fast changing parameters in synergetics. This ensures interoperability between the existing intelligent systems in the vehicle and the elements of the infrastructure.

At a certain value of the order parameter, the movement of vehicles on existing roads is subject to the specified direction, speed and similar control parameters. It is variable in the range between 0 and 1 (0 <k <1).

So, we define the order parameter k as follows:

$$k = 1 - \frac{\sum_{i=1}^{m} t_{r>10}}{m \cdot N}, \tag{5}$$

where:

$t_{r>10}$ – the total number of stopping times at red lights of traffic lights more than 10 seconds, (pcs); N – the number of traffic lights in the experiment, (pcs).

Using Equation (5), we determine k in the example of the Tashkent city driving mode:

$$k = 1 - \frac{236 - 32}{6 \cdot 49} = 1 - 0{,}69 = 0{,}31$$

This defined k represents the value of the order parameter is depending on the traffic light as an element of infrastructure.Its value approaching 0 means that the traffic light corresponds a lot to the red light. If it is close to 1, it is explained by the fact that the traffic light corresponds to the green light.

The function of the ISSS depends on the microcontroller installed on the traffic light. During an experiment in an urban condition, stopping and restarting the engine when the vehicle stopped at a red traffic light was imitated by the driver.

The calculation of fuel consumption for the test Q_{f_ISSS} is shown in the following equation:

$$Q_{f\_ISSS} = FC_{base} - FC_{ISSS}, (L/km) \quad (6)$$

$$FC_{base} = \frac{\sum_{i=1}^{n} fc_{base}^{n}}{n}, (L/km) \quad (7)$$

$$FC_{ISSS} = \frac{\sum_{i=1}^{n} fc_{isss}^{n}}{n}, (L/km) \quad (8)$$

where:

FC_{base} – fuel consumption of vehicle in, (*L/km*);

FC_{ISSS} – fuel consumption of vehicle with ISSS in, (*L/km*);

n – number of experiment.

Given the error-index of the fuel sensor calculated above, Equation (6) has the following changes:

$$Q_{f\_ISSS} = (FC_{base} - FC_{base} * \Delta) - (FC_{ISSS} - FC_{ISSS} * \Delta), (L/km) \quad (9)$$

In the conditions specified in the driving mode, the fuel consumption at each restart of the ISSS engine after shutting it down is taken into account. This is found using Equation (10).

$$Q_{fuel\ cumulative} = Q_{f\_ISST} - Q_{\frac{fuel}{restart}} * N_{\frac{fuel}{restart}}, \left(\frac{L}{km}\right) \quad (10)$$

where:

$Q_{fuel/restart}$ – fuel consumption at engine restart in, (*g/s*);

$N_{fuel/restart}$ – number of engine restarts.

During the test, the parameters from the sensor in the fuel tank do not allow to determine how much fuel is consumed during engine restart. To do this, the recommended fuel consumption Q_f in *L/s* can be calculated as follows [30].

$$Q_f = \frac{M_e * n_e * Q_{TS}}{3{,}6 * 10^9 * \rho_{gas}}, (L/s) \quad (11)$$

where:

M_e – torque of the engine in, (*N*m*);

n_e – number of revolutions of the engine crankshaft in, (*rpm*);

ρ_{gas} – is the density of gasoline, whose value is 0,725 *L/kg* at the temperature of 20 °C;

Q_{TS} – fuel consumption rate in technic specification of vehicle in, (*l/100 km*).

The engine power, torque and fuel economy are determined by what vehicle it is installed on. The fuel consumption rate of the engine can be regarded as a function of engine torque and engine speed if the engine dynamics are neglected. Then, the fuel consumption rate can be expressed as follows [30].

$$Q_{TS} = f_e(M_e, n_e), \quad (12)$$

Such a connection can be constructed by theoretically calculating the external speed characteristic graph of the engine and conducting a practical experiment (Fig. 8).

Considering M_e and n_e, determined by both methods, the fuel consumption according to equation (11) is calculated in *L/s*. For example:

Theoretically $Q_{f.T\_800} = 0{,}00035\ (L/s), Q_{f.T\_1200} = 0{,}00056\ (L/s)$ etc.

Experimentally $Q_{ё.э\_800} = 0{,}00025\ (L/s), Q_{ё\_1200} = 0{,}0004\ (L/s)$ etc.

The adequacy ratio between them was 0,71.

In the experiment, the polynomial equations of fuel consumed in a vehicle which has been used and has been not used ISSS can be determined using the Lagrange interpolation formula.

$$L_n(x) = \sum_{i=1}^{m} y_i \, l_i(x); \qquad (13)$$

where: $l_i(x)$ – m level basic polynomials.

$$l_i(x) = \frac{(x-x_0)\ldots(x-x_{i-1})(x-x_{i+1})\ldots(x-x_n)}{(x_i-x_0)\ldots(x_i-x_{i-1})(x_i-x_{i+1})\ldots(x_i-x_n)}; \qquad (14)$$

Depending on the number of points given the fuel consumption values, i.e. m = 3, the above Lagrangian interpolation formula can be written as:

$$L(x) = y_0 \frac{(x-x_1)(x-x_2)}{(x_0-x_1)(x_0-x_2)} + y_1 \frac{(x-x_0)(x-x_2)}{(x_1-x_0)(x_1-x_2)} + y_2 \frac{(x-x_0)(x-x_1)}{(x_2-x_0)(x_2-x_1)}; \qquad (15)$$

The following is known for a situation where ISSS has been not used:

$x_0 = 37{,}1;\ x_1 = 35;\ x_2 = 33.$

$y_0 = 35;\ y_1 = 33;\ y_2 = 30{,}8.$

$$L_f(x) = 35 \frac{(x-35)(x-33)}{(37{,}1-35)(37{,}1-33)} + 33 \frac{(x-37{,}1)(x-33)}{(35-37{,}1)(35-33)} + 30{,}8 \frac{(x-37{,}1)(x-35)}{(33-37{,}1)(33-35)}.$$

$$L_f(x) = 0{,}04x^2 - 1098{,}02x + 47{,}08.$$

The following is known for a situation where ISSS has been used:

$x_0 = 30;\ x_1 = 28;\ x_2 = 26.$

$y_0 = 28{,}1;\ y_1 = 26{,}2;\ y_2 = 24.$

$$L_{ISSS\_f}(x) = 35 \frac{(x-28)(x-26)}{(30-28)(30-26)} + 33 \frac{(x-30)(x-26)}{(28-30)(28-26)} + 30{,}8 \frac{(x-30)(x-28)}{(26-30)(26-28)}.$$

$$L_{ISSS\_f}(x) = 0{,}63x^2 - 790{,}05x + 388{,}72.$$

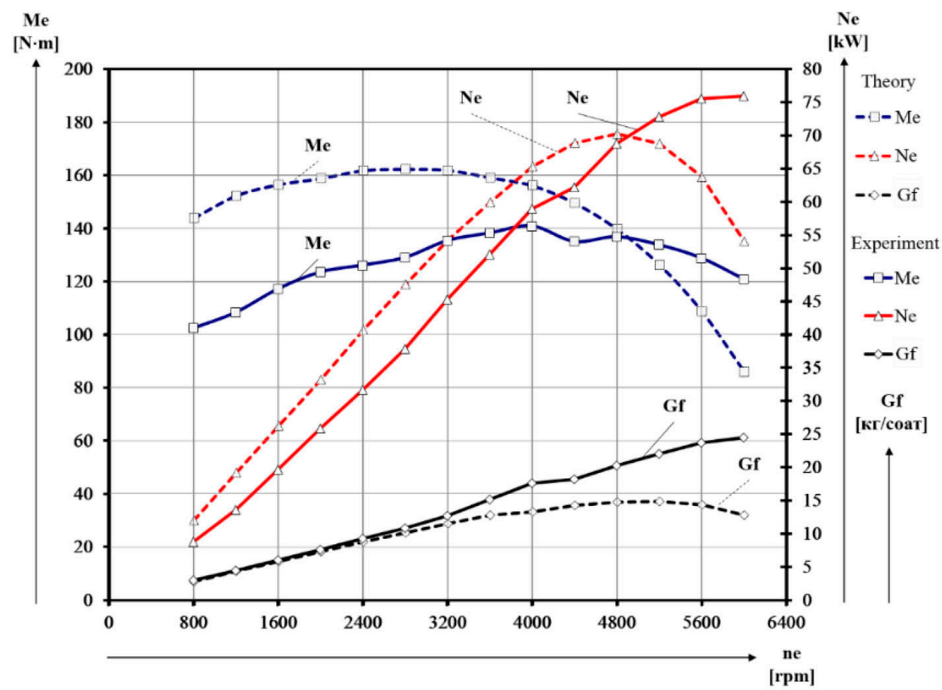

Fig. 8. The external speed characteristic graph of the engine (Chevrolet Nexia B 15D 2)

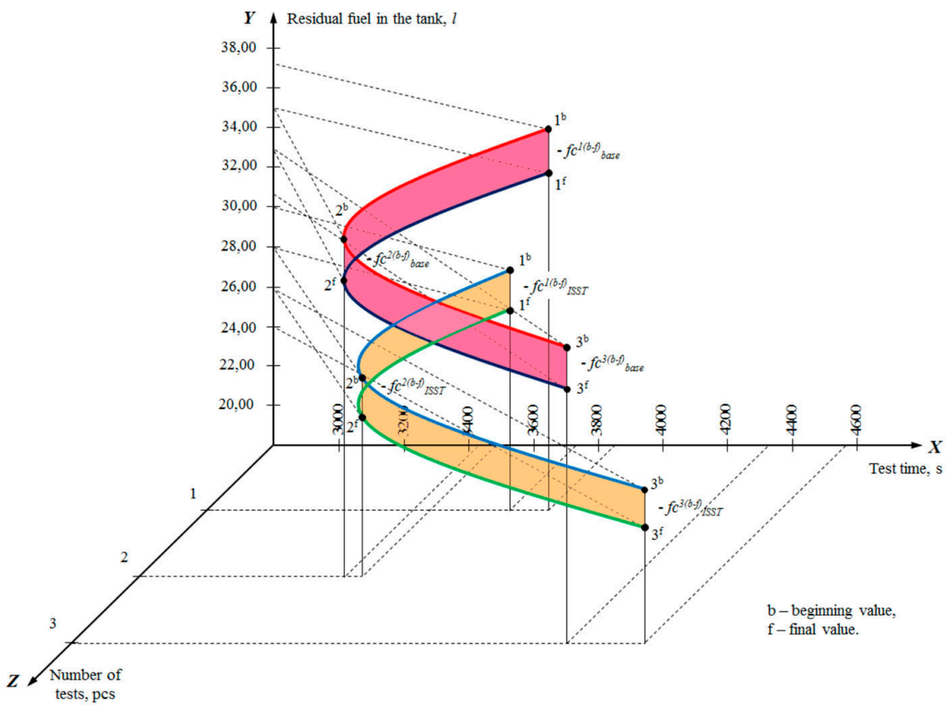

Fig. 9. Graph of residual fuel in the tank during the test, depending on the test procedure and time

In cases where ISSS has been used and not used, the vehicle's fuel consumption has been shown to significantly reduce fuel consumption using ISSS by comparing the residual fuel values at the start and end of the test in the tank (Fig. 9).

In both cases, the polynomial equations determined from the Lagrange interpolation formula represent the spatial appearance of the fuel consumed during the experiment on the X, Y, and Z axes.

The calculated values were compared with the controlled fuel consumption per 100 km given in the linear norm according to the technical characteristics of the vehicle. It also showed that the fuel consumption in a vehicle with ISSS was saved as a percentage (%) or in liters (l) of the calculated values.

Voltage values from the power supply system of the Chevrolet Nexia were measured in the driving modes of Tashkent (Fig. 10). These values indicated the ability of the existing parts in the vehicle to work in ISSS. The results were analyzed using practical-analytical methods to ensure compliance with the values specified in the technical description of vehicle parts.

The fuel consumption of the ISSS vehicle was calculated in *L/km* and the results are given in Table 1.

When ISSS is used in the conditions of the autopolygon, the vehicle saved 7 % of fuel per 100 km on the NEDC and 4.78 % on the driving mode of Tashkent [31–32].

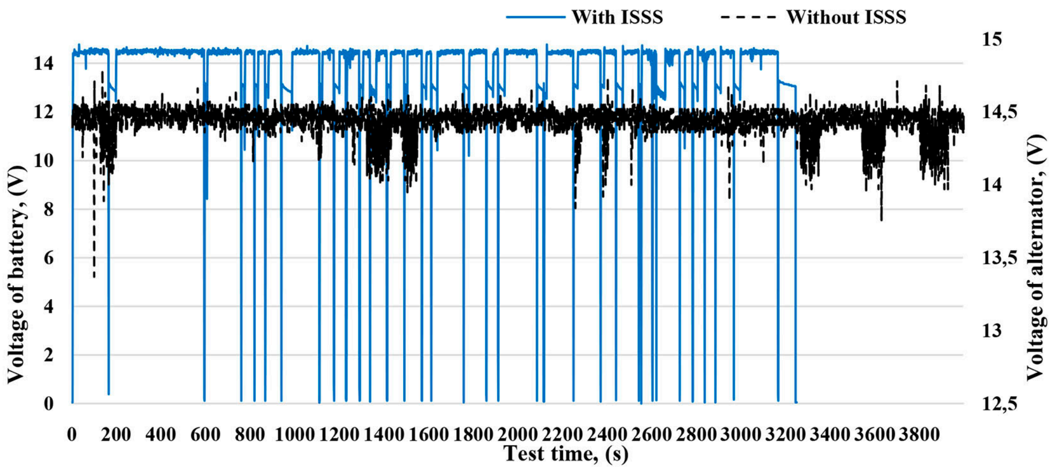

Fig. 10. Status of the vehicle power supply system in urban driving modes

Table 1. Fuel consumption indicators of the vehicle in urban driving modes

Vehicle model	According to technical description, *L / 100 km*	Fuel consumption according to experiment in, L/75 km		According to the description of the experiment in, L/100 km		Difference, +/-, L/100 km		Percentage of fuel saved in, % (L/100km)
		Stan-dard	With ISSS	Stan-dard	With ISSS	Stan-dard	With ISSS	
Chevrolet Nexia	8	5,99	5,52	7,98	7,32	- 0,02	- 0,658	8,25

4. Conclusions

According to the above practical-analytical calculations, in urban conditions, a vehicle with ISSS saved 8.25 % of fuel per 100 km.Emissions of harmful gases into the environment have also been minimized by about the same percentage. It was found that an average of 132 liters of fuel was saved when one vehicle traveled 20,000 km per year. Moreover, the idling time of the vehicle's engine was characterized by a reduction of 28–32 % in 100 km of the total test distance.

Furthermore, many kinds of research have shown that the start-stop system saves an average of 5–10 % of fuel in an urban condition and it is consistent with the values that we obtained from the experimental results.

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