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ACTA OF TURIN POLYTECHNIC UNIVERSITY IN TASHKENT

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ACTA TTPU

Preface

Dear readers! I am pleased to announce a new edition of the journal of the Turin Polytechnic University ACTA TTPU. It is the 3rd issue to be published in 2021 year which includes selected articles submitted to the Editors. I appreciate very much our Editorial board for their contribution to improving the quality of our journal and all authors for presented papers. We are always open to any criticism and suggestions to improve the readability and content of the submitted papers published in our journal.

We have developed new website acta.polito.uz for our journal. All articles will be published online there. Moreover, the researchers can submit their paper using this website. I would like to cite Otabeck Akbarov, the ambassador of Uzbekistan to Italy:

> *Turin Polytechnic University in Tashkent, which celebrated its 10th anniversary in 2019, has become one of our country's leading higher education institutions. The famous Juventus Football Academy was created in this University. Based on this positive experience, we strive to expand ties with other academic centers in Italy, particularly with Rome, Milan, Pisa, Campania, Florence, and Venice. Considering Uzbekistan and Italy's academic communities' potential and mutual interest, good prospects for partnership are opening up between the Academy of Sciences of Uzbekistan and the Italian National Research Council. It will mainly aim to develop scientific relations between academic and research groups, mutual use of advanced equipment, exchange of scientific data, and fundamental and applied research experience.*

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THE THERMODYNAMIC FORMALISM FOR CIRCLE MAPS WITH ALGEBRAIC ROTATION NUMBER

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Abstract– In present paper we study the orientation preserving circle homeomorphisms with singularity of break type. Let $T \in C^{2+\varepsilon}(S^1 \setminus \{x_b\})$, $\varepsilon > 0$, be a circle homeomorphism with one break point x_b, at which $T'(x)$ has a discontinuity of the first kind and both one-sided derivatives at the point x_b are strictly positive. Assume that the rotation number ρ_T is irrational and its decomposition into a continued fraction has a form $\rho := \omega_k = [k, k, \ldots, k, \ldots] = \frac{-k+\sqrt{k^2+4}}{2}$, $k \geq 1$. E. Vul and K. Khanin in (21) showed that the renormalization transformation on the space of such circle maps has unique periodic point (F_i, G_i), $i = 1,2$ with period two. Moreover, F_i and G_i) are fractional linear maps. We denote by T_i, $i = 1,2$ the circle homeomorphisms associated by pair (F_i, G_i). Let $B(T_i)$, $i = 1,2$ the set of all circle maps which are C^1 conjugated to T_i, $i = 1,2$. We build a thermodynamic formalism for all maps of $B(T_i)$, $i = 1,2$.

Key words– circle homeomorphism, break point, rotation number, invariant measure, symbolic dynamics, shift map, thermodynamic formalism, renormalization transformation.

I INTRODUCTION

This paper is devoted to the construction of a potential for homeomorphisms of a circle with one break point and the number of rotations equal to $\rho = [k, k, \ldots, k, \ldots]$, $k \geq 1$. In the theory of dynamical systems the thermodynamic formalism was introduced by Ya. G. Sinai (19). Later, thermodynamic formalism was developed in the works of D. Ruelle (18), R. Bowen (2), and others.

E. B. Vul, Ya. G. Sinai and K. M. Khanin in (20), the thermodynamic formalism was used to study an important object of the theory of universality — the Feigenbaum map.

Piecewise-smooth homeomorphisms of the circle is one of the intensively studied fields in the modern theory of dynamical systems. Such maps are a natural generalization of circle diffeomorphisms, as well as an important part of the class of generalized (nonlinear) rearrangements (see (9; 16; 4; 5)). The other hand such maps are interval exchange maps.

It is well known that every orientation-preserving homeomorphism of the circle T with irrational rotation number $\rho = \rho_T$ is strictly ergodic, that is, it has a unique probability T -invariant measure $\mu = \mu_T$ (7). Let the rotation number $\rho = \rho_T$ is irrational. A. Denjoy showed (see (10)) that if $T \in C^1(S^1)$ is circle diffeomorphism with finite $Var(\log T')$ and irrational rotation number then it is topologically conjugated by linear rotation $T_\rho x = x + \rho, \mod 1$ i.e. there exists a homeomorphism Φ such that $\Phi \circ T = T_\rho \circ \Phi$.

The question of the smoothness of the conjugation Φ and the problem of the absolute continuity of the invariant measure μ_T are closely related. Indeed, an invariant measure μ_T is absolutely continuous with respect to the Lebesgue measure if and only if $\Phi(x)$ is an absolutely continuous function. This reasoning was first used by V. I. Arnold (1), where he studied the smoothness of $\Phi(x)$. By now, this problem has been completely solved in a certain sense for diffeomorphisms of the circle. It is well known that for sufficiently smooth maps T with a typical irrational number $\rho = \rho_T$ the unique invariant measure μ_T is absolutely continuous with respect to Lebesgue measure (see (1; 12; 8; 13)).

Piecewise smooth homeomorphisms with breaks are a natural generalization of circle diffeomorphisms. The simplest examples of piecewise smooth maps are piecewise linear (PL) homeomorphisms with two breaks. First, such circle maps were studied by M. Herman (12). M. Herman proved (12) that the invariant PL measure of the homeomorphism h with two breaks and an irrational rotation number is absolutely continuous if and only if both break points lie on the same orbit. For homeomorphisms of a circle with one break point, the character of the invariant measure is very different to the case of diffeomorphisms. A. Dzhalilov and

K. Khanin in (3) proved that for a circle homeomorphism $T \in C^{2+\varepsilon}(S^1 \setminus \{x_b\})$, $\varepsilon > 0$, with one break point x_b and irrational rotation number ρ_T the invariant measure μ_T is singular with respect to the Lebesgue measure λ, that is, there is a measurable subset $A \subset S^1$ such that $\mu_T(A) = 1$ and $\lambda(A) = 0$.

Consider two homeomorphisms T_1 and T_2 with the same irrational rotation number $\rho = \rho(T_1) = \rho(T_2)$ and with one breakpoint $x_0 = x_b$. The question of the regularity of the conjugation Φ between T_1 and T_2 is called the "rigidity" problem. This problem was intensively studied during last 15-20 years by many authors (see for instance (14; 15)).

II Preliminaries

In this section, we will consider all the concepts necessary for formulating the theorem on thermodynamic formalism, including the renormalization group transformation in the space of homeomorphisms of a circle with one breakpoint and with a rotation number ρ (for more details see (21; 14)), dynamic circle partitioning (see (19) for more details), and symbolic dynamics (see (2)).

The renormalization group transformation in the space of homeomorphisms of a circle with breaks and an algebraic rotation number has a periodic orbit (21). We will construct a potential for a periodic trajectory with a rotation number ρ. We denote by X_b the set of pairs of strictly increasing functions ($f(x)$, $x \in [-1,0]$, $g(x)$, $x \in [0,\alpha]$) satisfying the following conditions:

a) $f(0) = \alpha > 0$, $g(0) = -1$;

b) $f(-1) = g(\alpha)$;

c) $f(g(0)) = f(-1) < 0$;

d) $f^{(2)}(g(0)) \geq 0$;

e) $f(x) \in C^{2+\varepsilon}([-1,0])$, $g(x) \in C^{2+\varepsilon}([0,\alpha])$ for any $\varepsilon > 0$.

Conditions a) - c) allow using $(f,g) \in X_b$ to construct a homeomorphism of the circle $[-1,\alpha)$ by the formula:

$$T_{f,g}(x) = \begin{cases} f(x), & \text{if } x \in [-1,0), \\ g(x), & \text{if } x \in [0,\alpha). \end{cases}$$

Homeomorphism $T_{f,g}(x)$ by linear map $l(x) = \frac{x+1}{\alpha+1}$ becomes a homeomorphism of the circle $S^1 = [0,1)$. The rotation number $T_{f,g}(x)$ is defined as the rotation number of the homeomorphism $l \circ T_{f,g} \circ l^{-1}$.

We denote by $X_b(\omega)$ the subset consisting of pairs $(f,g) \in X_b$ such that the rotation number $\rho(T_{f,g}) := \omega = [k,k,\ldots,k,\ldots] = \frac{-k+\sqrt{k^2+4}}{2}$, $k \geq 1$.

We define the transformation of the renormalization group $R_b\colon X_b(\omega) \to X_b(\omega)$ by the formula (see (21; 14)):

$$R_b(f(x),g(x)) = (\tilde{f}(x), \quad x \in [-1,0]; \qquad \tilde{g}(x), \quad x \in [0,\alpha']),$$

where

$$\tilde{f}(x) = -\alpha^{-1} f(g(-\alpha x)), \qquad \tilde{g}(x) = -\alpha^{-1} f(-\alpha x),$$

$$\alpha' = -\alpha^{-1} f(-1).$$

Note that the $(\tilde{f},\tilde{g})$ pair corresponds to the map of the first return in new linear coordinates.

Determine the jump value of the break at the point x=0:

$$c = \sqrt{\frac{f'(-0)}{f'(+0)}}.$$

It is clear that for $c = 1$ we get a smooth map. In what follows, we will assume that $c \neq 1$. In the paper (21) it is proved that for a fixed c the transformation R_b in the subset $X_b(\omega)$ has a unique periodic trajectory

$$\{f_i(x,c_i), g_i(x,c_i), i = 1,2\}$$

of period two. It means that

$$R_b(f_1(x,c_1), g_1(x,c_1)) = (f_2(x,c_2), g_2(x,c_2)),$$

$$R_b(f_2(x,c_2), g_2(x,c_2)) = (f_1(x,c_1), g_1(x,c_1)).$$

Functions $f_i(x,c_i)$ and $g_i(x,c_i)$, $i = 1,2$, have the following form:

$$f_i(x,c_i) = \frac{(\alpha_i + c_i x)\beta_i}{\beta_i + (\beta_i + \alpha_i - c_i)x}, \tag{II.1}$$

$$g_i(x,c_i) = \frac{\alpha_i \beta_i (x - c_i)}{\alpha_i \beta_i c_i + (c_i - \alpha_i - c_i \beta_i)x}, \tag{II.2}$$

where

$$\alpha_1 = \frac{c - \beta_0^2}{1 + \beta_0}, \qquad \alpha_2 = \frac{c^{-1} - \beta_0^2}{1 + \beta_0}, \qquad c_1 = c, \qquad c_2 = c^{-1},$$

$$\beta_1 = \beta_2 = \beta_0,$$

β_0 — unique root of equation

$$\beta^4 - \beta^3 - \beta^2 \frac{(c+1)^2}{c} - \beta + 1 = 0,$$

belonging to the interval $(0,1)$.

Identifying the ends of the intervals $[-1,\alpha_i)$, $i = 1,2$, we obtain the circles S_i, $i = 1,2$. Now, using (f_i,g_i), $i = 1,2$, we define homeomorphisms of the circle $T_i\colon S_i \to S_i$ by the formula:

$$T_i(x) = \begin{cases} f_i(x,c_i), & \text{if } x \in [-1,0), \\ g_i(x,c_i), & \text{if } x \in [0,\alpha_i). \end{cases}$$

Below we describe the properties of the homeomorphism T_1 of the circle S_1. The homeomorphism T_1 has breaks at the points x_0 and $x_1 = T_1(x_0)$, and the product of the magnitudes of the breaks at these points is c_1. We denote the homeomorphism T_1 by T_b. The second homeomorphism T_2 is studied in a similar way.

We denote by $B(T_b)$ the set of all $C^{1+\theta}$ - conjugate homeomorphisms of T_b. In this section, we will construct a thermodynamic formalism for maps belonging to $B(T_b)$. Take an arbitrary homeomorphism $T \in B(T_b)$. The map $T \in C^{2+\varepsilon}(S^1 \setminus \{x_0, T(x_0)\})$, $\varepsilon > 0$, has two breakpoints x_0 and $T(x_0)$, and the rotation number is ω.

We denote by $\frac{p_n}{q_n}$, $n \geq 1$, the n -th fraction of ω. The numbers q_n satisfy the following difference equation: $q_{n+1} = q_n + q_{n-1}$, $q_0 = 1$, $q_1 = 1$. The q_n numbers are called Fibonacci numbers. Take an arbitrary point $x_0 \in S^1$ and consider its orbit

$$\mathbb{O}_T(x_0) = \{x_0, x_1 = T(x_0), x_2 = T^2(x_0), \ldots, x_n = T^n(x_0), \ldots\}.$$

Here and in what follows, T^n denotes the n -th iteration of T. Using the orbit $\mathbb{O}_T(x_0)$, we define the sequence $\{\mathbb{P}_n(x_0), n \geq 1\}$ dynamic partitions of the circle.

The partition $\mathbb{P}_n(x_0)$ is obtained using a part of the orbit of the point x_0: $\{x_i,\ 0 \leq q_n + q_{n+1} - 1\}$. For each $n \geq 1$, we denote by $\Delta_0^{(n)}(x_0)$ the segment connecting the points $x_0\ \ x_{q_n}$.

Let $\Delta_i^{(n)}(x_0) = T^i(\Delta_0^{(n)}(x_0))$, $i \geq 0$. Then the partition $\mathbb{P}_n(x_0)$ consists of the system of segments $\{\Delta_i^{(n)},\ 0 \leq i < q_{n+1}\}$ and $\{\Delta_j^{(n+1)},\ 0 \leq j < q_n\}$ (see (7)). The partition $\mathbb{P}_n(x_0)$ is called the *n - th dynamic partition* of the circle. Note that any two segments of the partition $\mathbb{P}_n(x_0)$ can intersect only by endpoints. When moving from $\mathbb{P}_n(x_0)$ to $\mathbb{P}_{n+1}(x_0)$ all "short" segments $\Delta_j^{(n+1)}(x_0), 0 \leq j \leq q_n - 1$, are preserved, and the "long" segments $\Delta_i^{(n)}(x_0), 0 \leq i < q_{n+1}$, is divided into pairs of segments:

$$\Delta_i^{(n)} = \Delta_i^{(n+2)} \bigcup \Delta_{i+q_n}^{(n+1)}. \tag{II.3}$$

Using the sequence of dynamic partitions $\mathbb{P}_n(x_0)$, one can construct a symbolic dynamics as follows. Let $x \in S^1 \backslash \mathbb{O}_T(x_0)$. Suppose $a_{n+1} := a_{n+1}(x) = a$, if $x \in \Delta_i^{(n+1)}(x_0)$, $0 \leq i < q_n$. Let $x \in \Delta_i^{(n)}(x_0)$, $0 \leq i < q_{n+1}$. Due to (II.3), the point x falls into the segment $\Delta_i^{(n+2)}(x_0)$ or into the segment $\Delta_{i+q_n}^{(n+1)}(x_0)$. We put in the first case $a_{n+1} = 0$, and in the second $a_{n+1} = 1$. Thus, we get a one-to-one correspondence

$$\varphi\colon S^1 \backslash O_f(x_0) \leftrightarrow \{\underline{a} = (a_1, a_2, \ldots a_n, \ldots), \quad a_i \in \{a, 0, 1\},$$
$$\text{wherein } a_{n+1} = a \text{ if and only if } a_n = 0,\ n \geq 1\} =: \Theta_+.$$

Note that in this case, each segment $\Delta^{(n)}$ of the dynamic partition $\mathbb{P}_n(x_0)$ corresponds to a unique word of length n: $(a_1, a_2, \ldots, a_n)$. In particular, the words $(0, a, 0, a, \ldots, 0, a)$ and $(a, 0, a, 0, \ldots, a, 0)$ correspond to the segments $\Delta_0^{(n)}$ and $\Delta_0^{(n+1)}$ respectively. Let $\Delta^{(n)} := \Delta(a_1, a_2, \ldots, a_n)$. The Lebesgue measure on S^1 induces the probability measure λ_0 on Θ_+:

$$\lambda_0(a_1, a_2, \ldots, a_n) := |\Delta(a_1, a_2, \ldots, a_n)|.$$

When passing from the circle S^1 to the space of infinite words Θ_+, the map T goes in $\widetilde{T}\colon \Theta_+ \to \Theta_+$. Using the structure of dynamic partitions, one can easily verify that $\widetilde{T}$ is not a Bernoulli shift.

Now we define another space Ω of one-sided infinite words with the same alphabet $a, 0, 1$:

$$\Omega := \{\underline{a} = (a_1, a_2, \ldots, a_n, \ldots), \quad a_i \in \{a, 0, 1\},$$
$$\text{wherein } a_{n+1} = 0 \text{ if and only if } a_n = a,\ n \geq 1\}.$$

In what follows, by $\vec{a}$ we will denote the vector $(a_1, a_2, \ldots, a_n)$, and by $\underline{b}$ we will denote the infinite word $(b_1, b_2, \ldots, b_n, \ldots)$.

We define the following function

$$\underline{\gamma}(x) = \begin{cases} (a, 0, a, 0, \ldots, a, 0, \ldots), & \text{if } x = a, \\ (0, a, 0, a, \ldots, 0, a, \ldots), & \text{if } x = 0, 1. \end{cases}$$

III A THEOREM ON THERMODYNAMIC FORMALISM FOR HOMEOMORPHISMS OF A CIRCLE WITH BREAKS

Let us now formulate the main result of this paper, the theorem on thermodynamic formalism.

Theorem III.1 *For all maps $T \in B(T_b)$ with one break point and an irrational number of rotations $\rho := \omega_k = [k, k, \ldots, k, \ldots] = \frac{-k+\sqrt{k^2+4}}{2}$, $k \geq 1$, there exists a unique continuous (in the Tikhonov topology) function $U_b : \Omega \to (-\infty, 0)$ with the following properties:*

1) For any $\underline{a} = (a_1, \ldots, a_k, a_{k+1}, \ldots, a_n, \ldots)$ and $\underline{b} = (a_1, \ldots, a_k, b_{k+1}, \ldots, b_n, \ldots)$ the space Ω satisfies the estimate

$$|U_b(\underline{a}) - U_b(\underline{b})| \leq const \cdot q^k,$$

where constant $q \in (0,1)$ - does not depend on $\underline{a}$, $\underline{b}$ and k.

2) Let $\Delta_{s_n}^{(n)} \subset \Delta_{s_r}^{(r)}$, $1 \leq r < n$ $\varphi(\Delta_{s_n}^{(n)}) = (b_1, \dots, b_n)$, $\varphi(\Delta_{s_r}^{(r)}) = (b_1, \dots, b_r)$, *then*

$$|\Delta_{s_n}^{(n)}| = (1 + \psi(b_1, b_2, \dots, b_n))|\Delta_{s_r}^{(r)}| \times$$

$$\times \exp\{\sum_{s=r}^{n} U_b(b_s, b_{s-1}, \dots, b_r, \dots, b_1, \underline{\gamma}(b_1))\},$$

where $|\psi(b_1, b_2, \dots, b_n)| \leq Const \cdot q^r$.

A similar result for homeomorphisms of a circle with one break point and an irrational number of rotations equal to the golden ratio, i.e. $\rho = [1, 1, 1..., 1, ...] = \frac{\sqrt{5}-1}{2}$, was proved in work (6).

Note that the proof of Theorem III.1 essentially uses the method of thermodynamic formalism.

The second statement of Theorem III.1 implies that the potential U_b is uniquely determined as the limit of the ratio of the lengths of segments of dynamic partitions $\mathbb{P}_n$ breakpoints x_0 of the map T. In other words, the dynamics of the singular point x_0 uniquely determines the potential corresponding to T, therefore, only one potential U_b corresponds to the map T.

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ANALYSIS OF REQUIREMENTS FOR WEIGHT AND DIMENSIONAL INDICATORS OF FREIGHT VEHICLES IN THE REPUBLIC OF UZBEKISTAN

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Abstract– In order to ensure the safety of highways, the permissible values of mass, axle loads and dimensions of vehicles have been established. Violations of permissible parameters - the movement of vehicles with excess of the permissible mass or axle loads (with or without cargo), leads to premature destruction of the roadway, the cost of unscheduled repairs, and a decrease in the level of road safety. In the course of business activities, it may be necessary to drive with parameters exceeding the permissible values. Vehicles performing such transportation are called heavy and (or) large-sized vehicles (HLV). The movement of vehicles and the transportation of goods in excess of the permissible parameters without special permission is an administrative offense, liability for which is provided for by law. The system of weight and dimensional control (weight control, dimensional control) is designed to detect the facts of movement of vehicles with excess of the permissible weight and (or) dimensional parameters without special permission in order to attract the owners of such vehicles to administrative responsibility and collect funds in order to compensate for the damage caused to the road. The system of weight and dimension control combines weight control and dimension control of vehicles in one whole. The list of normative and legal documents, on the basis of which the system of weight and size (weight, dimensional) control works, is given. The organization of movement on highways of large and heavy vehicles, as well as their overload on wheel axles, requires attention to ensuring the safety of roads and road safety. In this regard, in world practice, in order to prevent a reduction in the service life of road surfaces and ensure road safety, control and limitation by legislative and regulatory acts of the weight and dimensional parameters of vehicles are provided. The permitted weights of vehicles are given (with or without cargo).

Key words– Cargo transportation, weight and dimension control, heavy and (or) large-sized vehicles, bulky and heavy cargo, weighing, weight and dimension control post, dynamic scales, overload, special permission, highways.

I THE SYSTEM OF WEIGHT AND DIMENSION CONTROL

In order to ensure the safety of highways, the permissible values of mass, axle loads and dimensions of vehicles have been established.[1]

Violations of permissible parameters - the movement of vehicles with excess of the permissible mass or axle loads (with or without cargo), leads to premature destruction of the roadway, the cost of unscheduled repairs, a decrease in the level of road safety.[2] [3] In the course of business activities, it may be necessary to drive with parameters exceeding the permissible values. Vehicles performing such transportation are called heavy and (or) large-sized vehicles (HLV). [1]

The passage of a heavy and (or) large-sized vehicle may be permitted by the Committee on Roads under the Ministry of Transport. [4]

The procedure for permission to travel in excess of the permissible parameters is regulated by the regulatory legal acts of the Government of the Republic of Uzbekistan and the Ministry of Transport.[5][6]

To authorize such travel, the owner of the vehicle shall submit to the Committee for Roads an application in the established form. The Committee for Roads assesses the possibility of passage, approves or denies passage. If agreed, the Committee for Roads issues the owner of the HLV with a corresponding document - a special permit (SP).[5]

The movement of vehicles and the transportation of goods in excess of the permissible parameters without special permission is an administrative offense, responsibility for which is provided for in part two of Article 1251 of the Code of the Republic of Uzbekistan on Administrative Responsibility. In addition, the Committee for Roads may collect a sum of money from the vehicle owner as compensation for the damage caused to the road and its infrastructure in court. [5]

The system of weight and dimensional control (weight control, dimensional control) is designed to detect the facts of movement of vehicles with excess of the permissible weight and (or) overall parameters without special permission in order to attract the owners of such vehicles to administrative responsibility and collect funds in order to compensate for the damage caused to the road. [7][2][3][8][9][10][11][12][13]

In general, the operation of the system of weight and dimension control of vehicles (for example, the Russian Federation) is shown in Fig.1.[11][14]

Fig. 1: The system of weight and dimension control of vehicles (on the example of the Russian Federation)

II WHY DO YOU NEED A WEIGHT AND DIMENSIONAL CONTROL SYSTEM?

Weight and dimension control is a topic in which, in our country, both the Committee for Roads - an authorized body, state authorities of republican, regional and local significance, as well as freight carriers, owners of trucks, drivers.[3][12]

For the former, the most important thing is to ensure the integrity and safety of their roads, in accordance with numerous regulations, as well as to ensure road safety for all stakeholders. The second is interested in transporting cargo from one point to another as quickly as possible, with minimal costs and safely. Vehicle owners also want their cars to drive on quality, level roads. [3][15][16]

It is clear that if an overloaded truck is driving, which puts a load on the road more than it can withstand, then the road will collapse. Weight control is designed to detect such intentionally or not intentionally overloaded vehicles in order to stop them, stop their movement, force drivers and (or) owners to move part of the cargo to another vehicle, or obtain a special permit to travel. A special permit will be issued by a specialist who will take into account all the parameters of the car with the load, the characteristics of the roadbed and decide how to drive such a car most quickly and safely, without prejudice to each of the countries. For the organization of weight control, the so-called "weight control framework" is established, mobile or stationary points (posts) of weight control are organized.[17][18]

Let's consider another situation. A cargo vehicle with bulky cargo, which exceeds all permissible norms, is moving along the road, often protrudes beyond its lane, even touching the oncoming lane. Drivers of other vehicles have limited visibility; it is difficult to overtake a car with bulky cargo. A nervous emergency situation is created on the road. Reduced traffic safety. Dimensional control of vehicles is designed to check the compliance of vehicle dimensions with the standards of safe travel. Dimensional control can also be carried out by weight control frames. Dimensional control can be performed by specialists of the Committee for Roads in conjunction with inspectors from the State Traffic Safety Inspectorate.[2][19]

The system of weight and dimension control combines weight control and dimension control of vehicles in one whole.

List of normative legal documents of the Republic of Uzbekistan, on the basis of which the system of weight and size (weight, dimensional) control works:

1. Law of the Republic of Uzbekistan dated October 2, 2007, no. Law of the Republic of Uzbekistan -117 "About automobile roads"[4];

2. Resolution of the Cabinet of Ministers of the Republic of Uzbekistan dated December 26, 2011 no. 342 "On measures to organize and ensuring safety on highways in the territory of the Republic of Uzbekistan"[5];

3. Resolution of the Cabinet of Ministers of the Republic of Uzbekistan dated May 28, 2020 no. 337 "On measures to introduce control of weight and dimensional parameters of vehicles", provide for a ban on the movement of heavy and large-sized vehicles on public roads[6].

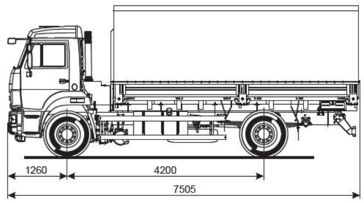
However, due to the lack of a weight and dimensional control system, road carriers manage to bypass the legal requirements.

The organization of movement on highways of large and heavy vehicles, as well as their overload on wheel axles, requires attention to ensuring the safety of roads and road safety. In this regard, in world practice, in order to prevent a reduction in the service life of road surfaces and ensure road safety, control and limitation by legislative and regulatory acts of the weight and dimensional parameters of vehicles are provided[15][16][17][18][19]. Automobile weight control is carried out by determining the vertical forces of the impact of the wheel axle (group of axles) on the roadway[20][21].

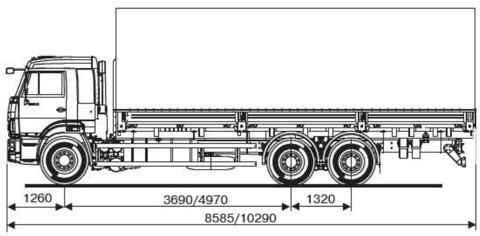
In accordance with the Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 342 dated December 26, 2011, Appendix 2 "Rules for ensuring the safety of road transport when transporting bulky and heavy cargo "in which the permitted masses of vehicles are given (with or without cargo)[5]:

Single vehicles

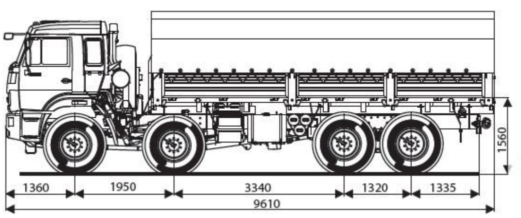
- biaxial: permitted weight 18 tons;



- triaxial: permitted weight 26 tons;

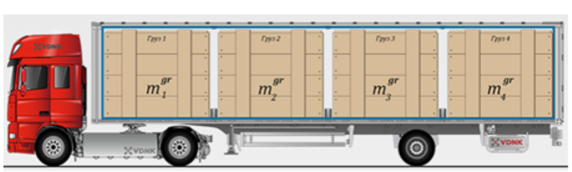


- four-axle: permitted weight 32 tons.

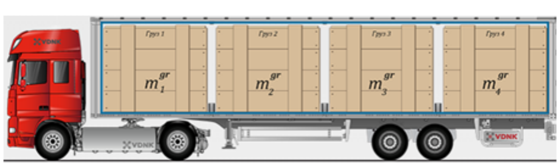


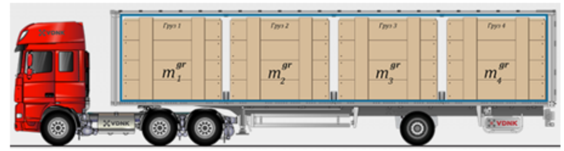
Trailed and semitrailer automobiles

- three-axle: permitted weight 28 tons;

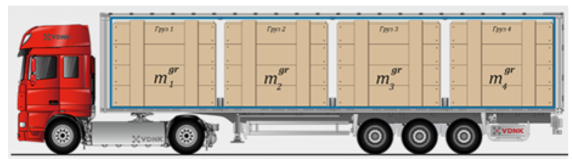


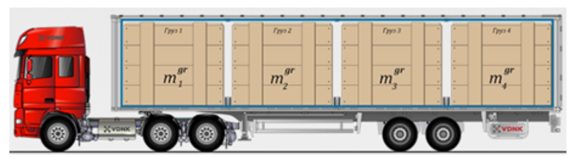
- four-axle: permitted weight 36 tons



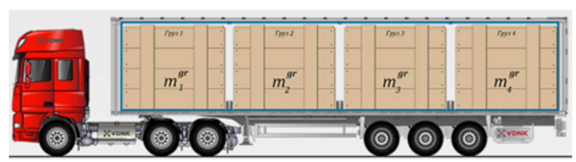


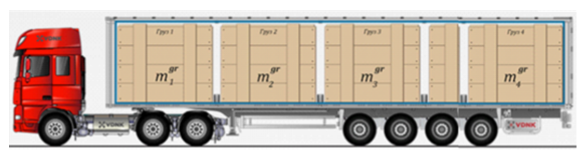
- five-axle: permitted weight 40 tons



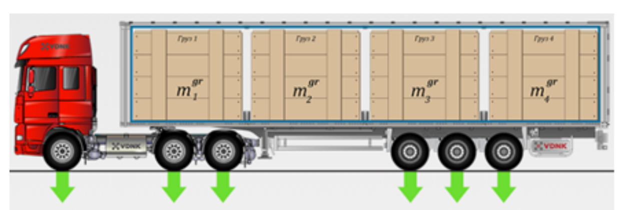


- six and more axles: permitted weight 44 tons





Permissible axle loads of a motor vehicle, while observing the total permissible mass of a motor vehicle, must be no more than 11.5 tons on a single drive axle, and no more than 10 tons on other axles.: **Six-axle automobile (example)**



Total weight :
6397+3128+3128+10309+10309+10309 = 43580 kg < 44000 kg

Single drive axle: 3128 kg < 11500 kg

Other axles: 10309 kg > 10000 kg

According to the second part of Article 125[1] of the Code of the Republic of Uzbekistan On administrative responsibility for driving without a special permit with a load exceeding the norm on motor roads, it entails the imposition of a fine on citizens in the amount of ten times the basic calculation or deprivation of the right to drive a vehicle for up to six months[5][1].

In the case of transportation of indivisible goods, a heavy and (or) large-sized vehicle is issued by the Committee for Roads with a special permit[5].

Indivisible cargo - cargo that cannot be divided into several parts without causing damage to it and which cannot be transported by any other mode of transport or returned to its original state after it is divided into separate parts; reinforced concrete intermediate devices for bridges and other structures, separate technological blocks (modules); welded (riveted) bridges and other technical and industrial structures; no more than two large diameter pipes; heavy trucks; construction equipment; agricultural machinery and equipment; truck cranes; lathes; industrial transformers, furnaces, generators, prefabricated factories; furnaces, generators, prefabricated mills; tank trucks with liquid chemicals; refrigerators; containers (reactors) for breweries, sugar producers and refineries; trams; ships (boats), airplanes; sea containers; railway cars; tunnel-digging shields, starters; military equipment; perishable foodstuffs; other cargoes based on a feasibility study. *(Clause 3 "Regulations on the procedure for monitoring the weight and volumetric parameters of vehicles" approved by the Resolution of the Cabinet of Ministers of Uzbekistan dated May 28, 2020 No. 337, Appendix 1.)*[5][1].

III Conclusion

The organization of movement on highways of large and heavy vehicles, as well as their overload on wheel axles, requires attention to ensuring the safety of roads and road safety. In this regard, in world practice, in order to prevent a reduction in the service life of road surfaces and ensure road safety, control and limitation by legislative and regulatory acts of the weight and dimensional parameters of vehicles are provided.

Legal restrictions on the weight and size parameters of vehicles in the Republic of Uzbekistan are given.

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TECHNIQUE OPTIMIZATION THE LOCATION OF SOME NETWORKS OF SERVICE INSTITUTIONS

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Abstract– Mathematical models, algorithms and programs for optimizing the location of some networks of service institutions have been investigated and developed, both in urban development and in rural areas, i.e. a toolkit for optimization for organizing a network of objects and service institutions (taking into account the existing planning structure of development).

Key words– Service objects (SO), service institutions (SI), power, optimal solution, service areas (SA), single-level and multi-level, mathematical models (MM), outpatient clinics and polyclinics, multidisciplinary hospitals, schools, methods, algorithms, programs.

I Introduction

Improving the planning of the sectors of the public service should be guided by the long-term aims of social development of society, and the network of service institutions should be based on a long-term scientifically grounded concept of systems of populated areas and the location of the country's productive forces. All this necessitates scientific forecasting of the system of public service institutions, such as a network of health care institutions, individual vehicles, a network of schools, etc., which performs the most important problem of further socio-economic development of our society.

The socio-economic zoning of the republic, based on which various settlement systems are distinguished, made it necessary to fundamentally new approaches to the formation of a network of service facilities and institutions, and to improve the methods of their territorial planning.

Any complex systems that include collectives of people, information management systems are considered by many as a universal tool that guarantees a modern level and high quality of management. Serious attention is paid to the accelerated development of industrial and civil construction in the CIS, since not only the growth of national wealth depends on its effectiveness, but also the solution of many socio-economic issues. These industries provide both the reproduction of fixed assets in all sectors of the production and non-production areas, and their own development.

Everyone knows that the high value of the agricultural lands surrounding the cities of Central Asia is due to its high productivity, exceeding, for example, 15-25 times the analogous indicators of Belarus and the Baltic states.

The sprawl of urban areas leads to additional capital and operating costs due to:

- lengthening of transport and engineering communications;
- increasing the rolling stock of public transport;
- growing loss of time of the population for transport movements;
- compensation due to the withdrawal of additional agriculturally valuable lands, etc.

An alternative to this process is, firstly, an increase in the density of development (construction of high-rise buildings, an increase in the capacity of objects of cultural and public services, etc.). Secondly, the rejection of the construction of single-storey garages (creating zones in residential buildings that are unfavorable from the sanitary-hygienic and criminogenic points of view, not representing architectural and aesthetic value), occupying significant areas of micro districts (more than 5% of the area of the micro district) and the construction of multi-storey garages.

In the context of the scientific and technological revolution and progress in the field of construction production, the scope of activities of an architect and urban planner is becoming more complex and expanding. Methods of architectural design and solving urban planning problems require the improvement of the feasibility study of design problems, allowing to analyze complex urban planning problems as a whole, to ensure the strengthening of the complexity and target orientation of design and planning decisions.

For the construction of research objects, it is necessary to develop projects for organizing their networks, providing for the solution of the following interrelated problems:

- determination of the minimum required number of objects;
- optimization of their location on the territory of the city, residential buildings;
- identification of service areas and the capacity of each of them,
- moreover, taking into account a complex of serious limitations and factors (described further in the work).

The solution of the set problems is largely associated with the use of mathematical methods and CAD, which in turn increases the quality and validity of design decisions, reduces the time and labor intensity of projects. All this determines the significance and relevance of the study.

The aim of the study are formalization, mathematical modeling and creation of a system for optimizing the planning and location of a number of networks of service institutions (SI) in rural areas and cities of the Republic. The mathematical and software support of the system has developed to solve a wide range of problems for organizing an SI - analysis of existing SI networks, their reconstruction, development and design of a new network.

This aim made it necessary to solve the following problems:

- analysis of mathematical models for the location of institutions and facilities from various groups of the service institutions;
- classification of problems solved when organizing networks of service institutions;
- development of a concept for the implementation of the problems of optimizing the network of the city's SI
- development of synthesis algorithms for options for organizing networks of the investigated service objects;
- experimental testing of algorithms for the implementation of problems, using the developed and existing software tools, on specific examples of organizing a network of educational institutions in order to confirm the basic theoretical prerequisites and the effectiveness of the proposed approach.

The scientific novelty of the research consists in the creation of a toolkit for generating options for organizing a network of educational institutions in the development of a city or in rural settlements, taking into account the existing planning structure of development; in the formalization of problems and the development of a new concept for the implementation of the stated problems, the creation of effective algorithms using as an optimizer the method of determining the smallest externally stable set of a graph, the method of random search for the global extremum of multi-parametric multi-criteria functions, as well as multi-criteria evaluation of the generated variants of SI networks to identify the best one.

As you know, the service industry is broadly divided into five main groups: administrative and public, cultural and educational and entertainment, health and fitness and physical culture and sports, retail and household and mass recreation.

The structure and composition of institutions and enterprises of the public service network is determined by the specifics of this type of service, the requirements for the development of the system as a whole, the specific features of the life of the local population, the size and architectural and planning structure of populated areas.

The networks of service establishments, according to the specifics of their functioning, are divided into:

- one-tier service;
- tiered service.

Peer-to-peer service networks include a wide class of institutions and service facilities. For example, in healthcare - pharmacies, ambulances, specialized hospitals, maintenance facilities - gas distribution stations and gas distribution points, boiler houses, temporary buildings and structures on a construction site, buildings and structures of railway stations, multi-storey car parks, trade enterprises, etc.

Multilevel service networks include the following institutions: outpatient clinics and polyclinics, multidisciplinary hospitals, rural schools, etc.

Although the design of networks of service establishments solves the same type of problems, but due to the need to take into account the specifics and functioning, it is not possible to reduce them to one or a number of mathematical models.

On the basis of studying the processes of functioning of the studied networks of educational establishments (multi-level outpatient-polyclinic and school networks in rural areas; single-level - a network of multi-storey garages for individual vehicles, a network of fuel stations [1], a network of innovative type pharmacies - "Univerpharm" [2]), a mathematical apparatus is proposed generation of options for organizing networks of the SI, which is implemented by a triune problem (determination of the optimal number, locations, service areas and capacity of the SI at each service level), typical for this class of problems. Although it differs depending on the considered SI (the algorithm for determining the smallest externally stable set of a graph, the simplex method of linear programming, a random search algorithm, the method of potentials, etc.), in all cases, the pivotal algorithm is the algorithm for determining the smallest externally stable set of a graph [1][3][4][2], a modification of which was developed for this class of problems.

In the general case, the problem of locating the network of the SI is reduced to the following: it is necessary to determine their optimal number at each service level, service area and capacity (bandwidth and location).

II The mathematical formulation

of problems in this class is reduced to the following.

Many settlements (micro districts) are set $\{a1, a2, \ldots an\} = A$, many residents in these $\{q1, q2, \ldots, qn\} = Q$, road network with distances between nodes [L]mn, possible locations of service objects $\{m1, m2, \ldots, mn\} = M$, number of settlements n. It is necessary to determine the number of service objects ξ, location of these objects xi*yi*, service areas by each object

$$\{a_1, a_2, \ldots an\} = A, A_1 \subset A,$$

$$\{a_m + 1, a_m + 2, \ldots, a_k\} = A_2, A_2 \subset A,$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$\{a_s + 1, a_s + 2, \ldots, a_n\} = A_\xi, A_\xi \subset A,$$

service objects capacity (OO) – W_i.

The criterion is Φ=f(A, Q, M, V, L), where V – the need for this type of service. That is, the problem is usually multicriteria. So, when designing an outpatient-polyclinic network, the criteria are:

- capital expenditures for the construction of outpatient clinics and polyclinics of all service levels, taking into account equipment;
- total annual path of the population to visit polyclinics of all service levels;
- annual cost of maintaining the staff of polyclinics.

The problems limitations are as follows:

$$P_{min} \leq P_i \leq P_{max};$$

$$A_j = \begin{cases} 1, & \text{if the microdistrict is entered in the Service Zone,} \\ 0, & \text{otherwise.} \end{cases}$$

$$L_{ji} \leq R, \text{and others,}$$

where P_{min} and P_{max} — minimum and maximum allowable capacity of SI; L_{ji} – distance from j -th micro district to i -th SI, R — allowable service radius.

III PROBLEM SOLUTIONS.

Problems have been formalized, mathematical models, algorithms and software have been developed that allow interactively generate options for organizing a two-level school network in rural areas, both with high and low population density [3].

The structure was developed and the database of the system was filled, which is the basis for the generation of school and outpatient-polyclinic networks in rural areas. It collects and systematizes materials on modern projects of schools, outpatient clinics and clinics (capacities, capital costs for their construction, annual operating costs for staff, equipment cost, etc.), a digital model of the road network of a rural area, tariffs for transportation of the population by buses, standards for the number of visits by the population per year to outpatient clinics and polyclinics of all service levels, demographic structure of the population, SNiP standards, etc.

A mathematical model, algorithms and software for generating a multilevel outpatient network in a rural area have been developed. One of the criteria for the considered multi-level network is the socio-economic criterion - the annual volume of population movements to polyclinics of all service levels, the algorithm of which is proposed in [4].

IV Conclusion

The developed tool for multi-level multi criteria evaluation of indicators of options for organizing networks of educational institutions and determining the best of them, including: evaluation of a set of indicators of options according to a number of optimality criteria (Wald, Hurwitz, Laplace, Savage criteria) with the involvement of qualimetry methods to evaluate the quality indicators; evaluation of indicators of options by an additive criterion, which is one of the methods of convolution of a vector criterion; evaluation of options for a number of integral ratings [3] has shown its high efficiency.

In the studied SI networks, the problem of optimization of the "Univerpharm" nertwork of stores stands out in particular [2]. Here, for economic reasons, the population in the service area of the store must live at least a predetermined number of people. Therefore, their required number is determined by the population of the city (town). They need to be optimally located on the area of an existing city, which creates a number of algorithmic and computational problems.

The main theoretical prerequisites of the research, the efficiency and technological rationality of the developed software are confirmed by the results of the problems implemented on the materials of the 2 regions of the Republic of Karakalpakstan, implementation acts and copyright certificates of the Intellectual Property Agency of the Republic of Uzbekistan. The results of the study are the basis of the object-oriented instrumental system of the designer of the networks of the SI.

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CRITICAL REVIEW OF THE PERFORMANCE OF THE BATTERY ELECTRIC VEHICLE AVAILABLE ON THE MARKET.

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Abstract– The paper analyses the battery electric vehicles available on the market. The data for more than 80 models of such vehicles are collected. The vehicles' performance is compared with different power requirements. The electric motor power, battery capacity and vehicle driving range are analysed to fulfil such requirements. Based on the results of the critical analysis the future possible activities in the field of Battery Electric Vehicles (BEVs) performance improvement are defined.

Key words– Battery Electric Vehicles, driving cycle, power required, acceleration performance, battery capacity

I Introduction

Recent trend toward the zero emission mobility lead to increased number of BEVs in the market over the last 10 years. Accordingly, sales of BEVs in commercial markets have grown. In the world, the number of vehicles with electrified powertrains on the road in 2010 were about 17000 while in 2019 this number has increased to 7.2 mln. The main share of this value comes to China [1]. European countries' BEV market have grown to the second largest overcoming the United States. Fig.1 below shows the world electrified vehicle sales between 2012 and 2019. It is evident that 0.11 mln. electric cars were produced worldwide in 2012 and 4.79 mln. by the end of 2019. Plug-in Hybrid Electric Vehicles (PHEVs) are type of hybrid electric vehicles with possibility to recharge it from external grid. They are characterized by smaller capacity of the battery, which should be enough for 50 km of pure electric range [2].An in-depth analysis of the technical characteristics of BEVs, allow gaining more information about them. Thus, this paper aims to analyse the specifications of the existing BEVs on the market and draw general conclusions to understand the current state-of-the art in sizing the powertrain components. Furthermore, the paper gives an overview about how the existing BEVs are located with respect to main performance requirements. To fulfil the objective, the technical data for more than 80 BEVs were collected from the sources [3] [4] [5] and the manufacturers' websites.

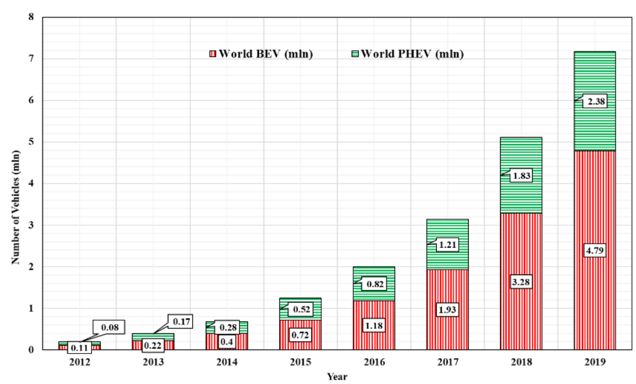

Fig. 1: The growth dynamics of the number of electrified vehicles between 2012 - 2019 [1]

II Critical analysis of the BEVs available in the market

The vehicle performance depends mainly on the power of traction source and the vehicle weight. To determine the category of the vehicles where BEVs are wide spread, the analysis of the BEVs in the weight range of 1000 and 2750 kg were performed. Fig.2 shows that almost 56 percent of BEVs are located in the weight range of 1500 to 2250 kg. These corresponds to C and E categories according to the European car classification [6]. Vehicles in the SUV category make up a large percentage of about 22 percent, as this category holds the highest share in the current new vehicle sales [7].

The maximum power of the traction source of BEVs highlights the transient performance (acceleration, regenerative braking etc.) of such vehicles. Instead, the continuous

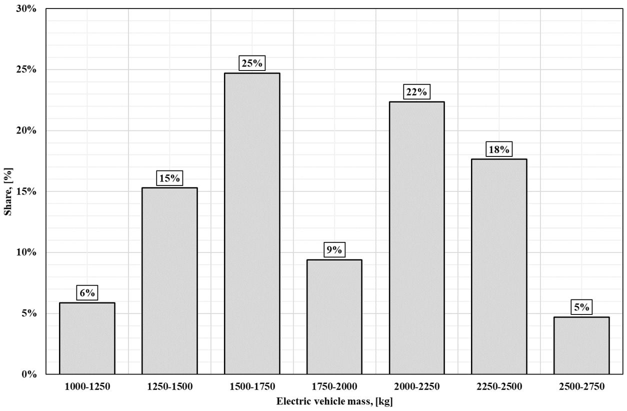

Fig. 2: The weight distribution of BEVs available on the market

power indicates the vehicle steady-state performance such as maximum or constant speed, gradeability and others. Therefore, based on the data collected the maximum power of the electric motors of the BEVs were arranged in Fig.3. It shows that the most of the available BEVs have the electric motors in the range of 100-400 kW. Almost 70 percent of BEVs in the market have the electric motor power in this range. This means the particular design of the electric motors and their inverters are required to satisfy the required electric motor power output. This could be the main reason why the permanent magnet electric motors are widely used in BEVs use to high power outputs for a given geometrical dimensions [8]. BEVs with power below 50 kW and above 600 kW are rarely used. These high-power BEVs mainly belong to Tesla models. Another important indicator is the specific power that is calculated as a ratio between maximum power and the vehicle weight. Higher specific power indicates the better acceleration and overtaking performance of the vehicle.

Fig.4 shows the distribution of the specific powers for

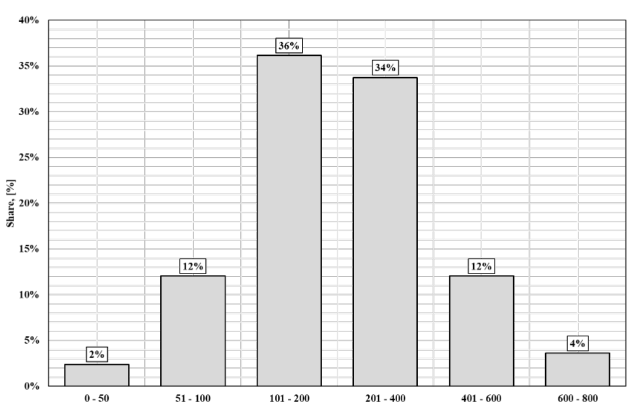

Fig. 3: The distribution of BEVs electric motor power

the considered BEVs. The most common specific power has been found to be in the range of 50 - 150 W/kg and it accounts for almost 75 percent of all BEVs. The specific power required to accelerate to 100 km/h from a standstill in 12 s is around 40-50 W/kg [9].

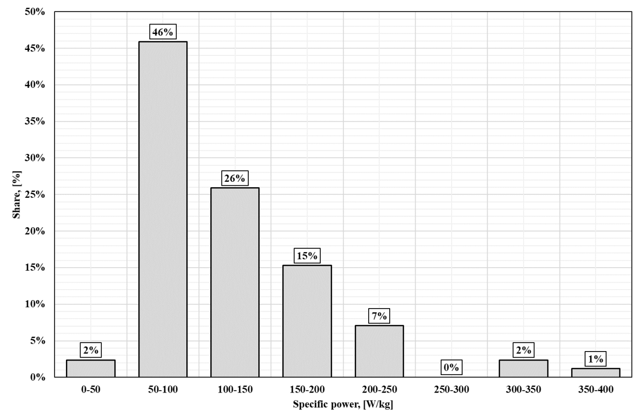

Fig. 4: The distribution of BEVs electric motor's specific power

This means that the BEVs currently available on the market have acceleration performance superior to the minimum acceleration requirement set by Partnership for a New Generation of Vehicles [10]. As the share of BEVs on the roads increases, the city traffic will consist of mixed performance vehicles (conventional and BEVs). Therefore, the performance of the BEVs has to meet minimum requirements set to conventional vehicles. In this work, the following performance requirements are considered: acceleration time to reach 100 km/h, maximum speed, overtaking performance and gradeability. As it was mentioned before, the main performance requirements sued in the paper are listed in PNGV. The analysis of technical characteristics of considered BEVs are summarized as a plot of total power available at the wheels vs. vehicle weight (Fig.5).

The points indicated as BEV are collected data points of total electric motor power. The lines Z60-8 and Z60-12 represent power values required to accelerate from 0 to 60 mph (96 km/h) in 8 and 12 s, respectively. The line Vmax = 137 km/h shows the power required to drive the vehicle with given weight at maximum speed of 85 mph (137 km/h). The line WLTC represents a maximum power values required to accomplish a WLTC homologation cycle. It can be indication of the power required in daily usage of the vehicles. Fig.5 shows that the most of the considered BEVs have enough power to accelerate to 96 km/h in less than 8 s.

The electric motor maximum powers can satisfy the power

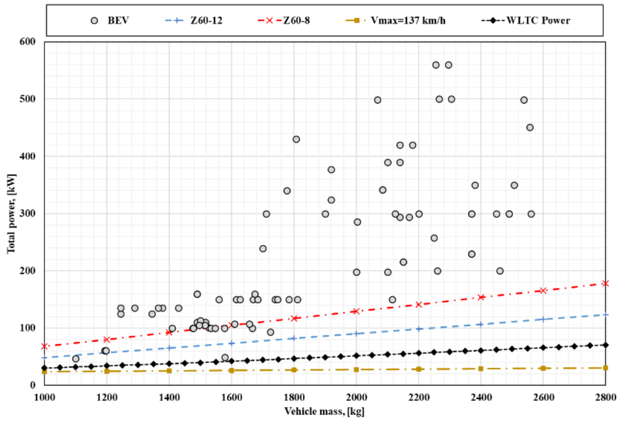

Fig. 5: The data points for electric motor total power vs. BEV weights

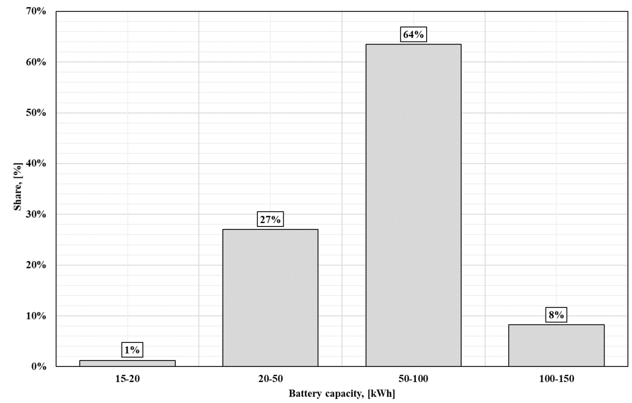

Fig. 7: Distribution of battery capacity of BEVs available on the market

requirement of WLTC driving cycle. As can be seen from the graph, the power of all the BEVs analysed are sufficient to reach a maximum speed of 137 km/h. It should be noted that the most of the BEVs have the electric motors that are oversized in terms of power. In daily usage, most of the time these vehicles do not utilize all the rated power they have. It is known that the electric motors have lower efficiency at low torque regions.

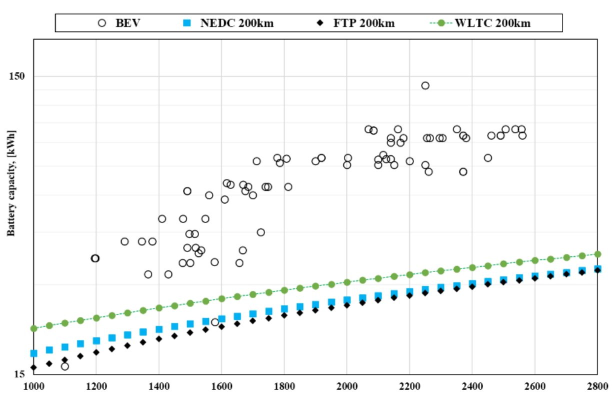

Fig. 6: Battery capacity analysis for the BEVs available on the market

Therefore, this oversizing of the electric motor could result in higher losses during the daily driving scenarios. The driving range of BEVs depends on the battery capacity as it is only source of energy in such vehicles. Therefore, the battery capacities were analysed. Fig.6 shows a dependency of the battery capacity of existing vehicles from the vehicle weight.

It is evident that as the mass of vehicle increases the battery capacity increase, as well. Three lines indicate the battery capacities required to fulfil the required driving range on different homologation cycles. In this analysis, driving range of 200 km and such homologation cycles as FTP, NEDC, and WLTC are considered. Fig.6 shows that most of the BEVs can run more than 200 km. As it can be seen from the figure, the battery capacity should be at least 30 kWh to accomplish this driving range depending on the vehicle weight. Fig.7 summarizes that the existing BEVs have a battery capacity in the range of 50-100 kWh. The share of these range accounts for almost 65 percent of the total available BEVs on the market.

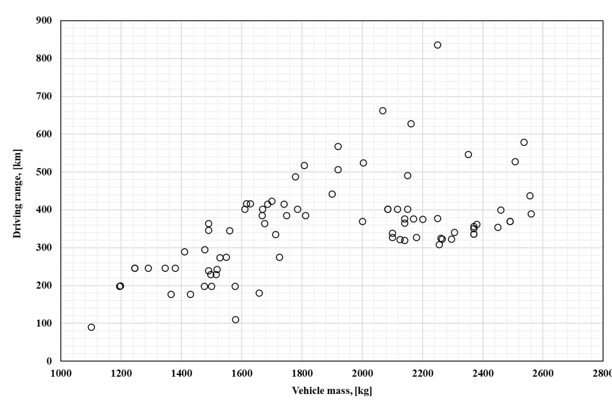

Fig. 8: Driving range analysis for the BEVs

The technical specifications include the data for the driving range, which is shown in Fig.8. Moreover, the figure shows that the majority of the BEVs can have driving range more than 200 km as it was predicted from the battery capacity installed on them (Fig.6). Fig.9 shows the distribution of the driving range for the considered BEVs. Almost 87 percent of existing BEVs have a driving range more than 200 km. However, more than half (57 percent) of the vehicles have a driving range of 200-400 km. One of the main advantages of the BEVs over conventional petrol fuelled vehicle is the possibility of recharging it at home or during the parking. This gives additional freedom in reducing the capacity of the battery, as most of the daily travels do not exceed 200 km.

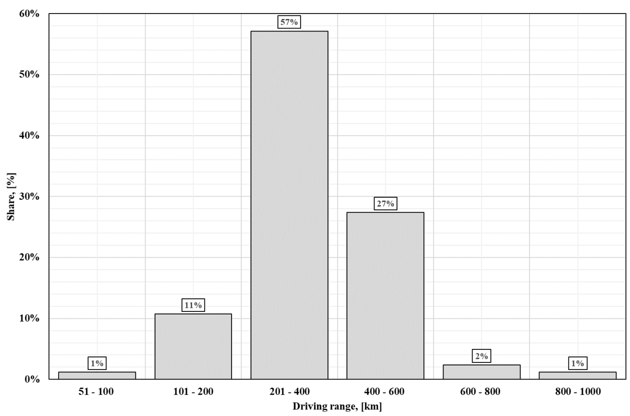

Fig. 9: Driving range distribution of BEVs

III CONCLUSIONS AND FUTURE WORK

This paper present analysis of BEVs available on the market, by collecting the technical data for more than 80 BEVs. As the share of BEVs on the roads increases, the city traffic will consist of mixed performance vehicles (conventional and BEVs). Therefore, the performance of the BEVs has to meet minimum requirements set to conventional vehicles. It was found that almost 75 percent of electric motor specific power of existing BEVs are in the range of 50-150 W/kg, which is enough to satisfy the minimum acceleration requirement. It should be noted that the most of the BEVs have the electric motors that are oversized in terms of power. In daily usage, most of the time these vehicles do not utilize all the rated power they have. It is known that the electric motors have lower efficiency at low torque regions. Therefore, this oversizing of the electric motor could result in higher losses during the daily driving scenarios. It would be interesting to understand the influence of having the same total rated power but with two or more electric motors. This might allow using two smaller electric motors with the feature of deactivation of one when low torque is needed. One of the main advantages of the BEVs over conventional petrol fuelled vehicle is the possibility of recharging it at home or during the parking. Therefore, the influence of sizing the battery based on daily trip length could be investigated.

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DEVELOPMENT OF A HIGHLY EFFICIENT MACHINE FOR DEHYDRATION OF MOISTURE-SATURATED MATERIALS

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Abstract– A technological machine for the dehydration of moisture-saturated materials is developed. In the design of the machine, moisture-saturated materials (for example textile fabrics, leather, and paper) are sequentially drawn between two roller pairs located one above the other by a chain conveyor and a base plate. At that, the base plate is composite, with rollers at the ends, along which the processed wet material moves a certain distance from its initial position, due to friction forces with the lower working rollers. As a result, the untreated strip fold over the base plate is transferred to the sidewall and additionally processed by the upper working roller. Consequently, the area and quality of treating the processed material between the pairs of rotating working rollers increase.

Key words– vertical roller machine; moisture-saturated material; composite base plate, roller pair; dehydration; chain conveyor; processing area

I Introduction

One of the problems with vertical roller machines for mechanical dehydration is poor or insufficient removal of moisture from the fold zone of moisture-saturated sheet materials on the base plate by means of a feeding conveyor chain with vertical feeding between the working rollers. This problem makes it impossible for the multilayer mechanical dehydration of moisture-saturated sheet materials. Therefore, the elimination of excess water from the fold zone of moisture-saturated sheet materials is relevant for science and production.

II Review of literary sources

The reference [1] describes the control of the process of hot rolling of bar and wire, with control of the required clearance between the rollers. The results of that study can be used in improving the design of roller machines for processing sheet materials with variable thickness and surface [2][3][4]. The study in [5] presents the results of the analysis of factors affecting the power consumed by the drive of the roll module. The authors of [6] proposed a universal conveyor with a concave bearing belt surface for handling operations in leather production and loading raw materials into vehicles. The authors of [7] experimentally determined the costs of power and moment of resistance spent in the contact zone of the rollers of the modules under the strain of their coatings and the processed material. In [8], a dynamic analysis of the rollers of textile machines was conducted on the basis of a numerical method. An algorithm was developed for studying roll modules with an arbitrary number of rollers. In [9], the coefficients of static friction and sliding were experimentally determined for various materials. The dependences of the friction coefficients on the rotation frequency and the values of roller friction were obtained. Study in [10] describes the process stages and materials used in traditional leather tanneries in Ghana, and the scientific principles underlying each process. Traditional and modern processes of leather production were compared, and studies in the field of handicraft leather production were identified and studied. In [11], 39 peer-reviewed articles were reviewed, of which 30 were published over the past 6 years. The publications were subdivided into 4 groups: 1) production process, 2) individual stages of the production process, for example, mechanical processing of materials, 3) waste recycling and 4) long-term strategies in the leather industry. The importance of scientific and practical knowledge for the improvement and implementation of technological operations for the processing of raw materials was noted.

In [12], the author has analyzed existing and new technologies of pressure treatment and revealed signs that determine the complex local loading of the strain zone. A mathematical model of metal forming processes with complex local loading of the strain zone was developed. The stress-strain state and the pattern of plastic flow of the material in the strain zone were determined. The author of the study given in [13]

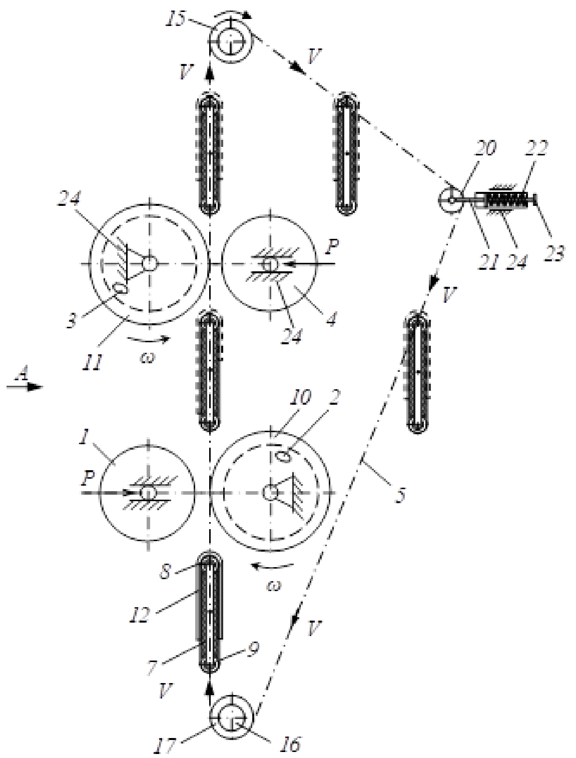

Fig. 1: Schematic diagram of pulling-in of the processed material between pairs of working rollers (a side view) 1, 2 - lower working rollers, 3, 4 - upper working rollers 5, 6 - conveying chains, 7 - base plate with rollers 8, 9; 10, 11, 15, 17, 18, 19 - sprockets, 12 - sheet material, 24 – bed frame

has investigated the relationship between stresses, strains, and density for cases of a stressed state arising in rolling and drawing of powder materials, which made it possible to increase the accuracy of calculating the stress-strain state during the aforementioned technological operations. The influence of the shape, material and thickness of the shell on the geometric characteristics of the strain zone was established. The influence of the thickness and material of the flux-cored strip shell on the energy-power parameters of the flattening process was established. In [14], an improved method for modeling the elastic strains of sheet mills rollers was developed, based on a three-dimensional finite element model of a roller unit. A new analytical method was developed for calculating the elastic strains of six-roller stands and it was revealed that in the production of cold-rolled strips it is more efficient to use six-roller stands than four-roller ones. In [15], a roller machine for squeezing wet fibrous materials was developed, which ensures uniform removal of excess water in all topographic sections of the material of non-uniform thickness and surface. In [16], the design of the pressure device between the working rollers was improved, for the significant thickness of the processed materials. In [17], new types of base plates of a vertical roller machine were developed and the most rational options were recommended to improve the technological process of pressing wet sheet materials. In the current study, the device and the principle of operation of a roller machine for mechanical dehydration of moisture-saturated sheet materials were developed and described. The advantage of the proposed device is evident in the fact that the feed of moisture-saturated sheet material with a base plate to the machining zone of roller pairs, and the operation of the drive of rigidly fixed working rollers with sprockets at both ends, are simultaneously performed by chains (Figures 1 – 5).

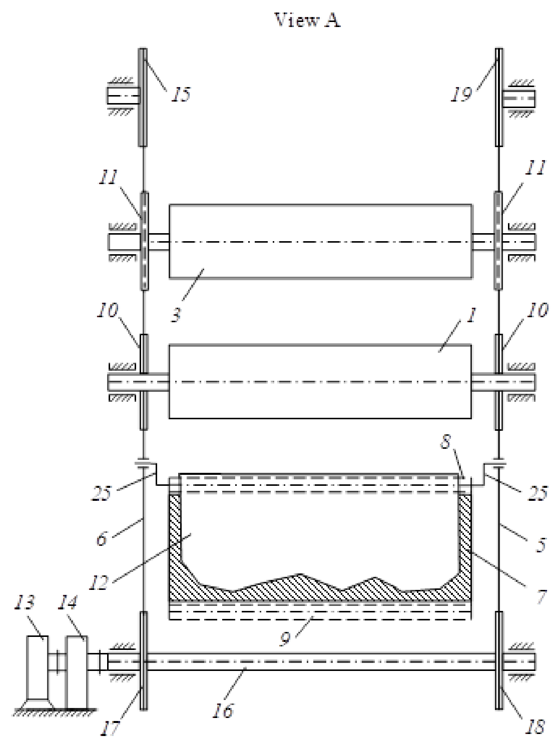

Fig. 2: View A of the chain conveyor and base plate with the processed material (front view) 1, 2 – lower working rollers, 3, 4 – upper working rollers, 5, 6 – conveyor chains, 7 – base plate with rollers 8, 9; 12 – sheet material, 10, 11, 15, 17, 18, 19 – sprockets, 13 – electric motor, 14 – gearbox, 16 – roller

III THE DEVICE AND THE PRINCIPLE OF OPERATION OF THE MACHINE

The proposed machine eliminates the problems mentioned and consists of two pairs of rollers 1 and 2, and 3 and 4, located one above the other. Between these pairs, there are two pairs of chain conveyors 5 and 6, on which the base plate 7 is located. Moreover, the base plate 7 consists of a rotating roller 8, on which plate 9 is suspended. On the lower roller pairs 1 and 2 on the right side on both ends of the axis of roller 2, the sprocket 10 is installed, which is in contact with conveyor chains 6 and 7. A similar sprocket 11 is installed on the upper pair of rollers 4 and 5 on both ends of the axis of roller 3. Roller 1 does not have a drive but rotates due to contact with the left-hand vertical plane of the moisture-saturated sheet material 12. Roller 4 rotates due to contact with the right-hand plane of the moisture-saturated sheet material 12. To drive the transporting chains 5 and 6 above the upper pair 3 and 4, on the left-hand side, there is an electric motor 13 and a gearbox 14 at the outlet end of which sprocket 15 is installed. Under the lower pairs of the working rollers, there is roller 16 at the end of which sprockets 17 and 18 are installed. Above the upper rollers 3 and 4, at the horizontal level of sprocket 15, sprocket 19 is installed, which is in contact with sprocket 18. For tensioning of conveyor chains 5 and 6, two tensioning devices are installed as roller 20 of rod 21 of spring 22 and rod 23. The working rollers 2 and 3 are fixed on bed frame 24. The working rollers 1 and 4 have the possibility of horizontal motion along the guides on bed frame 24. Rotating roller 8 is mounted on crankshaft 25 and has the ability to displace the vertical axis of base plate 7 with sheet material 12 relative to the vertical axis of motion of chains 5 and 6. This makes it possible to machine sheet material 12 of different thicknesses.

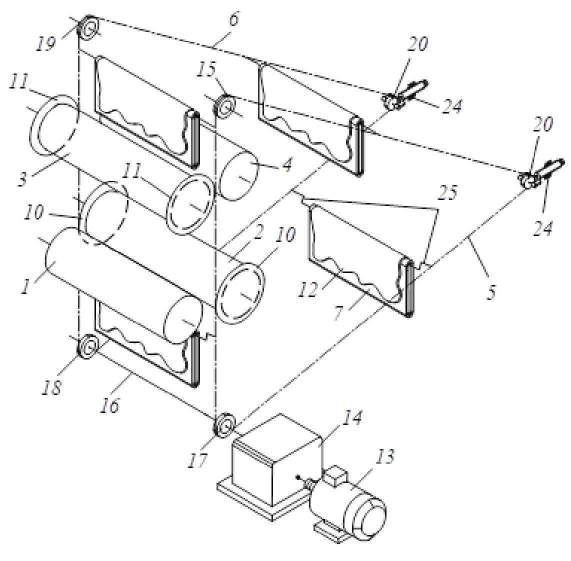

Fig. 3: General view of the roller machine (a perspective view) 1, 2 – lower working rollers, 3, 4 – upper working rollers, 5, 6 – conveyor chains, 7 – base plate with rollers 8, 9; 12 – sheet material, 10, 11, 15, 17, 18, 19 – sprockets, 13 – electric motor, 14 – gearbox, 16 – roller, 20 – tension roller

The roller machine works as follows. When electric motor 13 is turned on, the rotation through gearbox 14 is transmitted to sprockets 10, 11, 15, 17, 18 and 19, and rotates working rollers 2 and 3. Chains 5 and 6 transfer base plate 7 with rollers 8 and 9 and when it moves under working roller 2, then the left plane of the moisture-saturated sheet material 12 contacts working roller 1 by rotating it. The velocity of roller 2 is greater than the velocity of roller 1, and the velocity of roller 1 at the beginning of contact with the sheet material is zero. This leads to the fact that working roller 2 transfers the length of sheet material 12. Since the velocity of chain conveyors 5 and 6 is higher than the velocity of working roller1, then the moisture-saturated sheet material 12 does not pile up in the transition zone of processing and transfers part of the length to the left side of base plate 7 by rotating roller 8. When base plate 7 with roller 8 is under the pairs of working rollers 3 and 4, the opposite happens, and the original moisture-saturated material returns to its initial place.

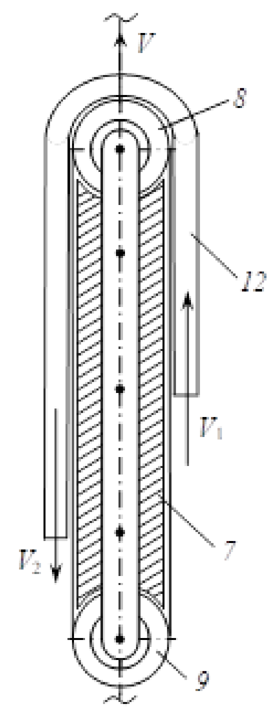

Fig. 4: Composite base plate 7 – base plate, 8 – upper roller, 9 – lower roller, 12 – sheet material

If necessary, the composite base plate 10 can be additionally equipped with a rotation lock (stop) on rollers 2 and 3; this stop will control and ensure the rotation of the roller at a required angle. Significant differences of the developed machine from the existing designs of roller machines consist in the simultaneous operation of the feed and drive mechanisms of working rollers, through the operation of continuous chains installed parallel to each other. Another feature consists in using the effect of the difference in linear velocities between the working rollers and the motion of the moisture-saturated sheet material to one or another side plane of the composite base plate without additional drive devices, sprockets, gear wheels or racks, thereby greatly simplifying the design of the device, and reducing the overall material consumption of the machine.

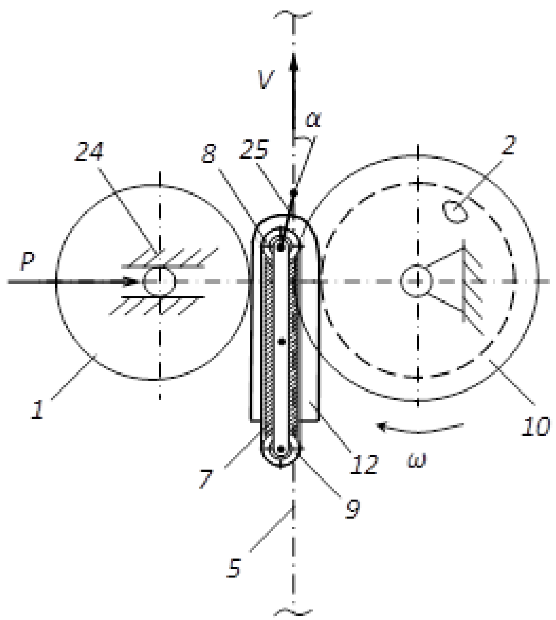

Fig. 5: Displacement of the base plate from the conveyor chain at an angle () depending on the variable thickness of the sheet material 1, 2 – working rollers, 5 – conveyor chain, 7 – base plate, 8 – upper roller, 9 – lower roller, 10 – sprocket, 12 – sheet material, 25 – crankshaft

IV Conclusion

The advantages of the proposed design of technological machines in comparison with similar machines are obvious since the proposed design performs a set function in a simpler way and using simple mechanisms. The design of the machine is simplified, providing uniform processing over the entire area of the wet sheet material, including the fold section at the nose of the base plate. The uniform moisture content in all areas of the processed sheet material (for example, textile fabrics, leather) contributes to improving the quality, reducing defects in subsequent technological operations. The proposed design of a machine for mechanical dehydration of sheet materials, in comparison with other existing machines, increases productivity by several times due to dehydration of sheet multilayer materials folded over the base plate. The results of experimental studies showed [2] that it is possible to remove excess water from wet sheet materials with a pressing force of the working roller equal to 32 kN/m and a feed rate of 20 m/min, which shows the process acceleration in comparison with known machines. This will increase the productivity of the technological process of squeezing the moisture from wet sheet materials by 200%, in comparison with existing roller squeezing machines.

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STRESS AND DEFORMATION ANALYSIS OF THE BRAKE PEDAL USING FINITE ELEMENT METHOD.

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Abstract– Brake pedal is one of the most crucial components of the braking system of all types of vehicles.During the design phase it is of vital importance to make sure that the pedal is able to withstand the loads exerted by the driver during the deceleration process. Moreover, the pedal must be "ready" to withstand large loads in a hard braking process. This article describes the static stress and deformation analysis of the brake pedal with the help of Finite Elements Method (FEM). The paper summarises that a safe region of stress and deformation is achieved even when a force of 1100 N is applied at the brake pedal.

Key words– brake pedal, FEM, Finite Elements Method, stress analysis, strain analysis

I Introduction

Currently there are two main factors that encourage the development of already existing braking systems and development of new components and technologies: legislation and consumers. Speaking of automotive components and brake components in particular, one can highlight that their design has to include the considerations of not only safety, but also comfort.However, the scope of the article covers only the safety point of view.Before implementing a component, the analysis of its performance has to be carried out. A proper analysis of brake pedals allows to develop the product not only for real vehicles which will be realised in the global market, but also provides necessary concepts to develop components for brake pedal force simulators. Modern advancements of computer technologies make it possible to perform the analysis of complex systems and components using highly efficient software packages. The implementation of the Finite Elements Method is carried out in Solidworks software (Dassault systems). The Finite Element Method (FEM) is best used when analytical methods are difficult or impossible to use. This method allows the calculation of deformations and loads with high accuracy when the constraints, forces are set correctly[1][2].

Table 1: Information on the brake pedal

Parameters of the system	Property
Material used	steel AISI 4340 normalized at 870°C
Yield strength $R_{p0.2}$	710 MPa
Ultimate strength R_m	1100 MPa
Young modulus E	205 GPa
Poisson's ratio ν	0.29

Table 2: Mesh characteristics of the pedal

Mesh type of the system	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	16
Maximum element size	1mm
Minimum element size	0.33 mm
Mesh quality	High
Remesh parts with incompatible mesh	Off

II Method

As a first approximation, an assumption for the pedal statics has to be introduced. The point is that the brake pedal has limited stroke and it reaches the limit condition in a quick manner. Besides, there is a feedback force from the hydraulic circuit of the braking systems which opposes the motion and diminishes inertia effects.The brake pedal will be analyzed in tandem to the idler shaft which is often used in clutch and brake systems(Figure 1). The reason is these parts are the most stressed during the braking operation. Basically the Finite Element Method analysis in Solidworks consists of the following steps [3]:

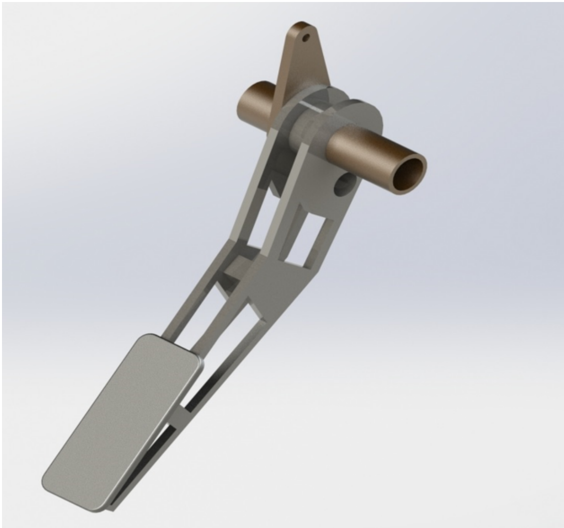

Fig. 1: CAD model of the brake pedal

- Material definition;
- Applying proper connections and boundary conditions;
- Meshing the structure;
- Defining the loads acting on the system;
- Simulation;

The information on material properties is listed in Table 1. The material is supposed to be linearly elastic and homogeneous.

The next step is to apply the proper fixtures and boundary conditions to the system under investigation. .Since the static analysis is to be performed, the shaft has to be fixed on both ends (Figure 2). Due to the complexity of the system, a 3D analysis will be carried out and, therefore, the next step becomes to do discretisation of the system by creating a proper mesh. For the scope of the problem curvature-based mesh will be used and an h-adaptive method for mesh convergence will be introduced. In h-adaptive method the software uses iterative procedures and with each loop it decreases the mesh size in the high stress-areas. As far as loads are concerned, there is only one force applied- the force exerted on the brake pedal. In these studies it is equal to 1100N which is a good representative value of a force during a heavy braking operation.It can be highlighted that in general the braking force is not applied over the whole pedal area, but over a certain region. Finally, the simulation of the system takes place once the previous steps have been done.

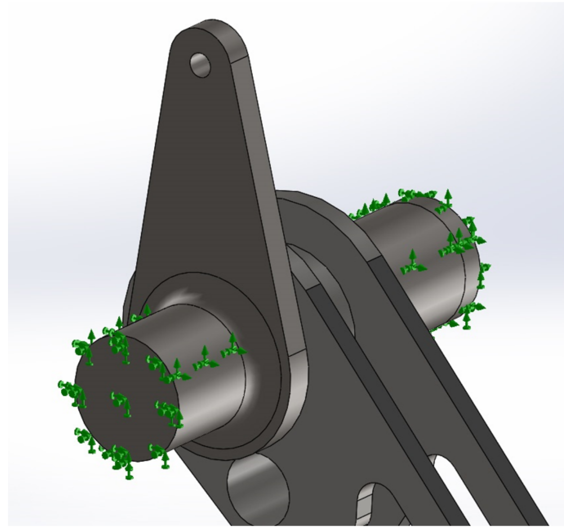

Fig. 2: Fixed geometry

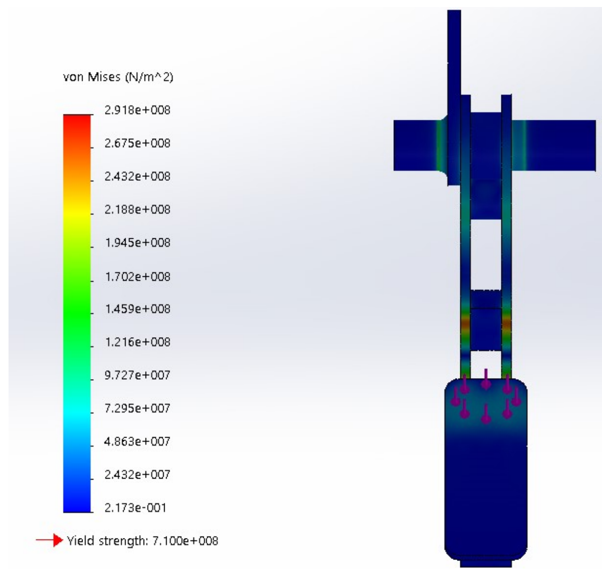

Fig. 3: Von-Mises equivalent stress distribution

III ANALYSIS OF THE RESULTS

Interpreting results starts from understanding if a proper meshing has been done for the system. As can been in the Figure 2, the mesh maximum size is 1mm, the type is curvature based. The mesh quality is high, more than 99 per cent of elements have an aspect ratio lower than 3. The obtained mesh is quite fine.As was mentioned before, an h-adaptive method was used. The characteristics of the method are presented in Table 3. According to the simulation data, one can conclude that the structure consisting of brake pedal and brake pedal idler shaft is able to withstand the maximum load under investigation regardless of the pedal inclination.

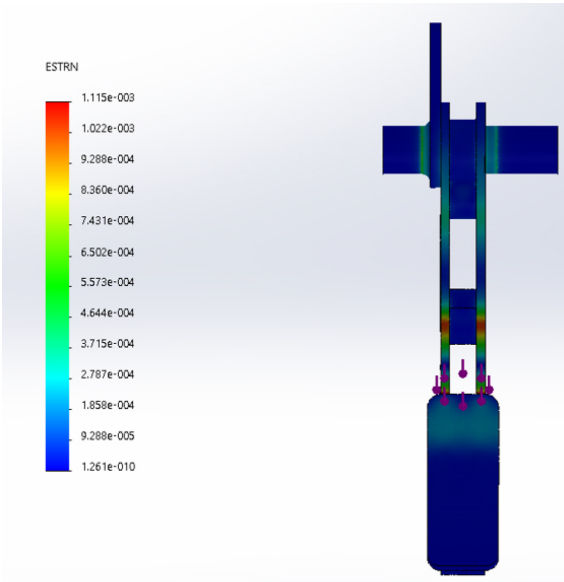

Fig. 4: Strain distribution

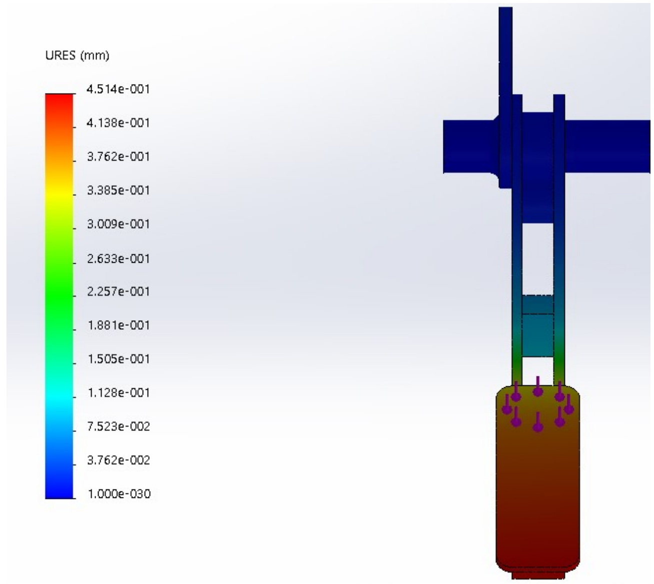

Fig. 5: Transverse displacement distribution of the brake pedal

TABLE 3: MESHING RESULTS

Total nodes	1657958
Total elements	1141705
Maximum Aspect ratio	8.3561
Share of elements with Aspect ratio <3 (percent)	99.8
Share of elements with Aspect ratio >10 (percent)	0
Share of distorted elements (percent)	0
Time to complete mesh (hh:mm:ss)	00:00:51

From the stress plot (Figure 3) showing the equivalent stress according to the Von-Mises failure criterion, it becomes evident that the maximum generated stress does not exceed the value of the yield stress which implies that no yielding will occur under the force of 1100 N. Moreover, basing on the results of the stress distribution it is possible to evaluate the safety factor:

$$F_s = \frac{R_{p0.2}}{\sigma_{eq}^{max}} = \frac{710MPa}{291.8MPa} = 2.43 \qquad (1)$$

The obtained value of the safety factor is considered good for ductile materials [4]. According to the strain plot, the maximum value corresponding to the strain is in the region corresponding to the largest stress (Figure 4). This is justified by Hooke's law for linearly elastic and homogeneous materials:

$$[\varepsilon] = \frac{1}{E}[\sigma] \qquad (2)$$

As far as the transverse displacement is concerned, the maximum value corresponds to the pedal region (Figure 5). It is quite clear that the amount of displacement is relative small (approximately 0.45mm) to affect the change of geometry of the braking system.

IV CONCLUSION

The results of the article claim that the structure consisting of the brake pedal and the idler shaft is able to withstand an extremely large load without yielding. Moreover, the amount of displacement caused by the load is considered acceptable from engineering point of view. The deformation due to the applied load does not produce significant geometrical changes to the system. The performed foundation serves as a good first approximation of the overall analysis. However, some improvements can be done by taking into account the kinematics and dynamics of the brake pedal during the deceleration process.

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ON THE PARAMETERS INFLUENCING THE BRAKE PEDAL "FEEL" IN PASSENGER CARS

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Abstract– Nowadays there exist two driving forces that impose the development of already existing braking systems and development of new components and technologies: legislation and consumers. Alluding to automotive components and brake components in particular, it is noteworthy mentioning that their design has to include the considerations of not only safety, but also comfort for users. “Brake pedal “feel” is of equal significance for both safety and comfort.Consumers expect a good “feel” of braking for easier driving and to fulfill the driver’s intention of deceleration so that to ensure confidence in the sense of personal safety and comfort.

Key words– Brake pedal, brake pedal feel, pedal characteristics, brake comfort, brake safety

I Introduction

Braking effectiveness is generally determined by vehicle’s ability to decelerate in a timely manner or stopping distance, pedal travel and pedal force [1]. Driver’s intention is to possess full control over vehicle during deceleration by sensing how much force he applies to actuate the braking system and also how much the pedal travels because of the actuated force. Effectiveness of the braking system has a connection with the brake pedal “feel”. Moreover, this effectiveness is important to drivers because there exists a relationship between the stopping distance and the perception quality of the braking process that the driver possesses. Figure 1 presents the definition of brake pedal “feel”. According to this figure, the brake pedal “feel” can be defined in 6 categories [2]. The figure claims that in principle both the conventional braking system and brake-by-wire system may affect the perception of a driver during braking. As a result, the outputs of a good pedal “feel” form customer satisfaction (evaluated from driver’s subjective point of view), comfort and safety. After taking all the above mentioned categories together, one can try to represent parameters which will be able to describe objectively the conditions for a good brake pedal "feel" [2].

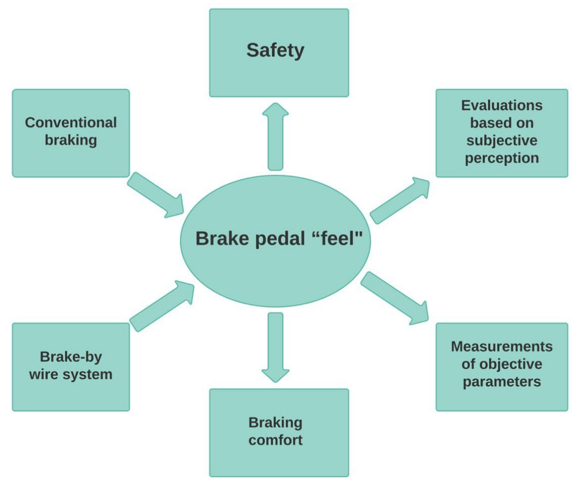

Fig. 1: Definition of brake pedal feel

II Method

Besides, when working with braking system, we have to consider factors which will influence the brake pedal “feel”. Below is presented a short summary of the parameters and factors influencing the feeling that the driver perceives during deceleration:

1. **Brake pedal.** During the design phase of braking systems and brake simulators it is crucial to keep in mind a direct connection between the force the driver applies on the brake pedal and the vehicle deceleration . Hence, a proper selection of the lever ratio of the pedal is necessary since too high force can lead to a vehicle instability whereas an insufficient amount of force may not fully stop the car. A typical brake pedal in passenger cars has a lever ratio from 2.5:1 to 5:1. Moreover, the brake pedal has a high importance to “feel” because it serves as a medium transmitting a force feedback to the driver from the braking system.

2. **Influence of the Tandem Master cylinder on the pedal "feel".** A master cylinder is a "must have" device in conventional braking systems.The main function of the Master cylinder is to transform and amplify the force applied by the driver into a hydraulic force [3]. As a requirement of legislation, the master cylinder has to guarantee a safe and reliable vehicle deceleration even in case the Vacuum Booster fails to work. Moreover, recent advancements in the development of braking systems make master cylinders work in cooperation with such systems as ABS (anti-lock braking system), EBD (electronic brake force distribution)[4]. The geometrical dimensions of the master cylinder play a vital role in the whole braking process. So that to make a good braking at high pressure, it is required to reduce the bore size of the cylinder. On the other hand, the reduction of the bore size leads to the increase of the piston stroke, which, in turn, will increase the pedal stroke.In this regard the geometry of the Master cylinder has to be managed as well in order to comply with dimensions of the whole system. The most common brake system layout for modern passenger cars comprises 2 separate circuits for passenger cars is the diagonal 'split', where each circuit controls one wheel at the front and another at the diagonally opposite rear wheel, e.g. left front and right rear wheels.

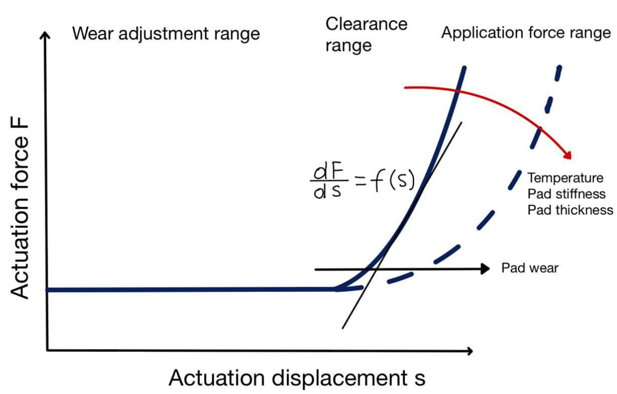

Fig. 2: Force-displacement relationship during the braking process

3. **Effect of Vacuum Booster on brake pedal "feel".** The idea of fitting a vacuum booster to passenger cars and light commercial vehicles originated from the global market demand for the reduction of the brake force that drivers have to apply and a high level of efficiency. The brake vacuum booster increases the input force from the brake pedal and transmits it through the master cylinder to the brake calipers through the hydraulic circuit and reduces the pedal effort during braking operation. Earle [5] stated the best trade-off between brake pedal effort and braking effort transmitted to the calipers from cost effectiveness point view can be achieved given that the vacuum booster is designed properly. It can be mentioned that in order to provide a good brake pedal "feel" for the driver, the pedal lever ratio and hydraulic ratio should have a correspondence to the characteristics of the brake vacuum booster. The brake booster must be able to enhance the performance of braking, and the force amplified by the booster can provide positive feedback of brake pedal 'feel' by diminishing the pedal effort and pedal stroke. In other words, the braking performance of a vehicle is highly dependent on the capabilities of brake booster [6].

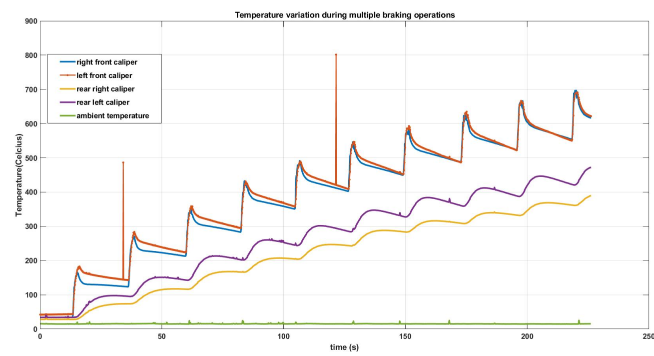

Fig. 3: Temperature of brake calipers during multiple sequential braking operations

4. **The influence of brake calipers on the brake pedal "feel".** In addition the pedal lever ratio and the hydraulic ratio, the proper selection of materials for the braking system is of significant importance since they will affect the feelings the driver perceives during braking. Especially this is concerned with the friction material used. According to Day and Shilton [7], the functional requirements of a brake friction material are as follows:

   - To provide consistent and reliable friction force.
   - To be durable, the effective life must be equivalent to the manufacturer's service target.
   - To be mechanically and thermally strong to withstand the load applied.
   - To minimize the noise and vibration issues.
   - To be environmentally friendly.
   - To be cost effective in design, manufacturing,maintenance and use.

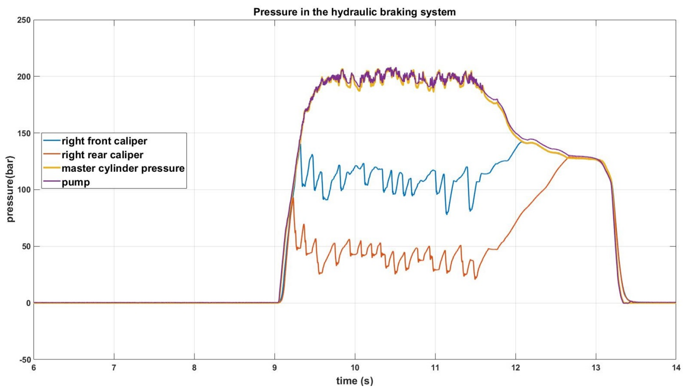

Fig. 4: Pressure dynamics during a hard braking

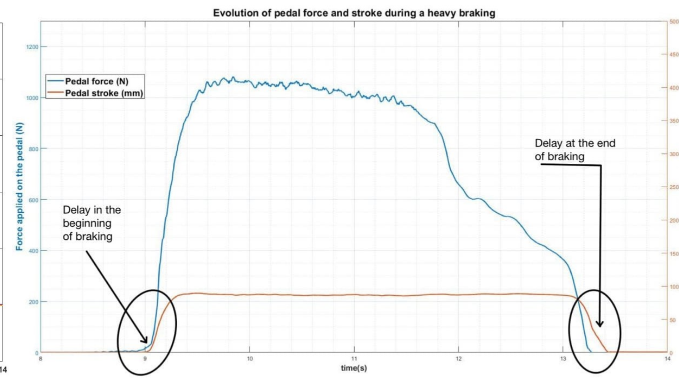

Fig. 5: Applied Force(N) and pedal stroke (mm) during a heavy braking

One of the most crucial parameters influencing the braking process is the temperature of the friction material. At too high temperatures there may arise a phenomenon called brake fading [8]. As a result of the temperature increase, the friction coefficient of the friction material drops dramatically. When speaking about the braking procedure, we realize that the pressure generated in the hydraulic circuit can reach decades of bars and for this reason we have to consider the pad deformation as well. The more the deformation is, the higher is the pedal travel. Also, it is worth mentioning that pad wear and thickness affect the braking operation and, in turn, the brake pedal “feel”. Figure 2 describes the relationship between the actuation force and the pedal displacement with the effects of temperature, pad wear and thickness taken into account.

III Parametric analysis of the deceleration process.

For an objective analysis of the brake pedal "feel", it is necessary to analyze the dynamical behaviour of different parameters under the deceleration phase. For the scope of this paper, the dynamics of brake caliper temperature, pressure in the hydraulic circuit of the braking system and also the vehicle speed during the braking procedure will be presented. Section II indicated the parameters that may influence brake pedal feel, especially those parameters related to the friction material used in the braking system. As can be seen in Figure3, during multiple sequential braking operations the temperature of the brake calipers can reach a value of 700°C . The temperature should be taken care of in order to avoid brake fading phenomenon (the friction coefficient of the friction material in the brake calipers starts to decrease drastically as a result of a temperature increase after a certain limit). The figure also shows that the front calipers have a higher temperature than the rear ones. This is explained by the fact that the front calipers are supplied with a higher hydraulic pressure. The dynamical behaviour of the pressure in the hydraulic circuit during a heavy braking process is shown in Figure 4. From the figure it may become quite evident that during a heavy braking procedure the pressure in the brake and the hydraulic pipelines can reach a value of 200 bar.This fact implies that the design of the braking system components has to be done with great care. it can also be seen that the front calipers are subjected to a higher pressure than the rear ones and this fact justifies the relation between the temperature and pressure in the calipers. The pressure in rear calipers has to be reduced by a proper valve to avoid rear wheel locking and a potential vehicle instability.

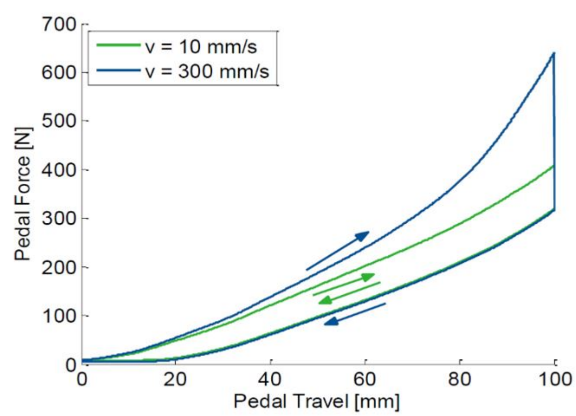

Fig. 6: Pedal Force-stroke characteristic curve [9]

Another important step in understanding the behaviour of the braking system and simultaneously feedback from the pedal, one could investigate the behaviour of the force the driver exerts on the pedal and the pedal stroke (displacement). Figure 5 shows how the pedal force and the pedal stroke change during a heavy braking process. One can see that during a heavy braking process the force exerted by the

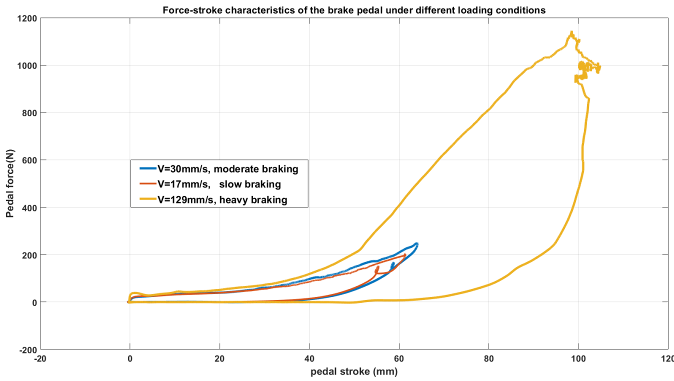

Fig. 7: Characteristic curves of the pedal during different braking regimes

driver can reach a high value of 1000N. It follows that the pedal and other mechanical components have to withstand high loads generated by the driver. When the driver releases the pedal, both the force and stroke fall to zero value. However, it should be mentioned that both in the beginning and the end of the braking operation there is a delay of the profiles which is characterized by the time response of the pedal.In order to improve the perceptions of the driver, the time delay should be reduced as much as possible. The next step could be to plot the curve of relationship between the applied force and the pedal displacement. According to [9],the force-stroke characteristic of a brake pedal represents a hysterical curve which depends not only on the pedal force and stroke, but also on the pedal movement speed during braking (Figure 6). The most optimal solution will be to combine several different braking operations (the pedal speed varies) in one plot. They will represent the general behavior of the pedal force as a function of the pedal stroke. In Figure 7 are represented 3 characteristic curves corresponding to 3 different braking regimes and 3 different average pedal speeds. The dimensions of the hysterical characteristic curves highly depend on how fast the pedal travels during the braking process, especially during heavy braking.

IV Conclusion

The main two reasons for which the development of the braking system has to be done are the passenger safety and comfort. Braking system is one of the most important systems in modern vehicles. The components have to be developed in such a manner to guarantee a safe vehicle deceleration under different road and traffic conditions. Besides, nowadays the overall market requires that the braking system be not only efficient from safety point of view, but also from ergonomic point of view. The braking system has to work efficiently in the sense that lower driver effort could lead to a required output. Moreover, understanding the objective parameters influencing the perception of drivers during the deceleration phase makes it possible to develop brake pedal simulators which can be used for testing in automobile manufacturing companies, gaming industries and driver training schools. Finally, obtained results could be used for the development of brake-by-wire system where there is no direct connection between the brake pedal and the hydraulic circuit. Even without a direct connection the driver has to "feel" how much force he applies by pushing the brake pedal.

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The effect of different regimes for premixed turbulent combustion to the burning speed inside the combustion chamber of a 2 liter 4 in-line cylinder spark ignition ICE.

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Abstract– This article describes different regimes for premixed turbulent combustion in gasoline internal combustion engines and the way they enhance the burning speed of a turbulent flame comparing with a laminar combustion. For this reason, we classify different regimes and summarize them in a single diagram called Borghi plot where it is possible to distinguish them and separately analyze depending on the characteristics of the turbulence. Finally, we can determine the effect of each regime to the turbulent burning speed of a premixed flame.

Key words– turbulent combustion, combustion diagnostics, premixed combustion, flame corrugation, Borghi plot.

I Introduction

In SI engines the time for premixed combustion scales almost linearly with a rotational speed of an engine due to the effect of turbulence, so on a crank angle basis the duration of a combustion is almost constant which is the reason of why SI engines can reach a much higher rotational speed compared to CI engines[1]. It is interesting to notice that while some scales of turbulence are able to enhance the burning speed of a premixed turbulent flame, others can even worsen or destroy the flame front[2]. Analysis starts with a definition of a burning speed S_b and making a comparison with a laminar burning velocity S_l. The question that worth making the focus on is whether the burning speed is locally laminar and the enhancement due to the turbulence occurs due to the flame corrugation effect or there are some modifications in the chemistry of the transformation of reactants to the products inside the corrugated flame front, so altering the local burning speed, which becomes different from laminar one. During this analysis, we will try investigate this phenomenon. Main engine specifications are provided in the following table.

Table 1: Engine specifications

Parameters of the engine	Property
Bore	84 mm
Stroke	90 mm
Compression ratio	10.35
Cylinder number	4
Displacement	1995 cm^3

II Burning speed in ICE

Burning of a premixed air fuel mixture in internal combustion engines occur not under laminar condition due to the corrugation of a flame front by the turbulence[3]. The black wrinkled line indicates the corrugated by turbulence flame front area and is indicated as A_{corr} (Figure 1). In order to define burning speed S_b, we introduce a new hypothetical area, called burning area A_b (Figure 1), such that the volume of burned and unburned gas above and below both areas are equal[2]. By assuming that locally burning speed is laminar, which works only in specific scales of turbulence, we can write

$$[\frac{dm_u}{dt}] = \rho_u S_l A_{corr} = \rho_u S_b A_b \quad (1)$$

Where ρ_u-density of unburbed gas, S_l-laminar burning speed, S_b-turbulent burning speed.

From this relation the turbulent burning speed is

$$S_b = S_l \frac{A_{corr}}{A_b} \quad (2)$$

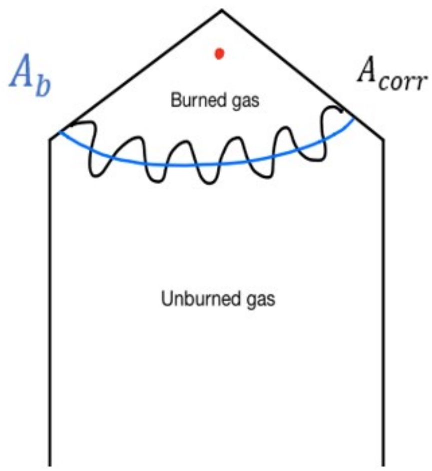

Fig. 1: Premixed combustion

The burning speed is enhanced by the turbulence by a factor which is proportional to the ratio of corrugated and burning areas by assuming that locally flame propagates with laminar burning velocity [3].

III Premixed turbulent regimes diagram

We will consider regimes of premixed turbulent combustion in terms of velocity and length scale ratios proposed by Borghi (1985) [4].

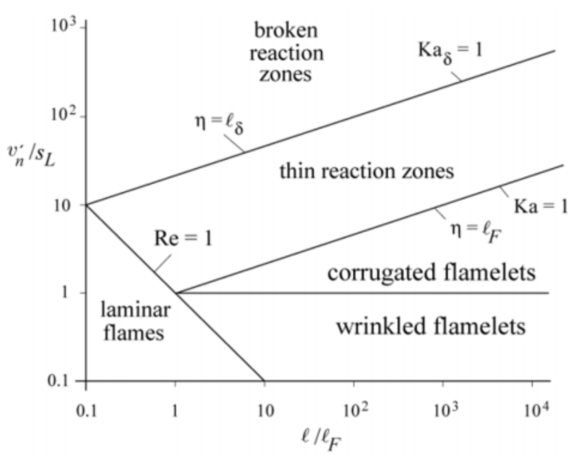

Fig. 2: Borghi plot

This diagram (Figure 2), where x axis indicates the ratio of integral length scale of turbulence and length scale of flame front $v_n^{'}/S_l$ and y axis indicating the ratio of velocity at integral scale and laminar burning speed l/l_F , distinguishes 4 different regimes for premixed turbulent combustion: wrinkled flamelets, corrugated flamelets, thin reaction zones and broken reaction zones. The laminar flames regime is out of consideration for combustion in ICE. In order to study the effect of turbulence, it is important to analyze each regime separately.

1 *Wrinkled flamelets regime*

In the wrinkled flamelets regime, the velocity at integral scale $v_n^{'}$ is lower than the laminar burning speed S_l (Figure 3).

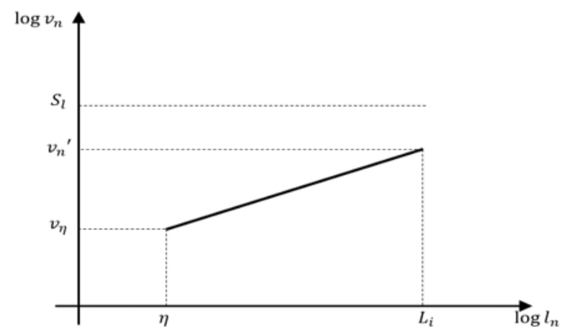

Fig. 3: Inertial subrange for wrinkled flamelets

Where η–Kolmogorov length scale, L_i – integral length scale, v_η – Kolmogorov's velocity scale.

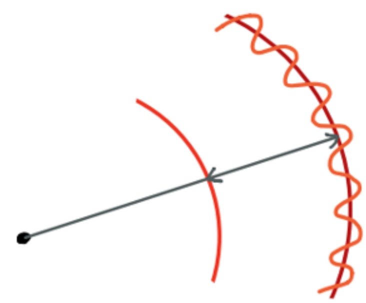

Fig. 4: Wrinkled flame front

Provided higher turbulence content, the fast revolutions of the eddies tends to corrugate the flame front (Figure 4), but the intensity is not enough that he only effect is a wrinkling of a flame front. Still, the combustion is locally laminar and the enhancement of the burning speed is almost negligible [5]. Thus, in the wrinkled flamelets regime, the turnover velocity of the largest eddies is not enough to compete with the advancement of the flame front. Laminar flame propagation dominates over flame front corrugation by turbulence.

2 *Corrugated flamelets regime*

The borderline separating wrinkled and corrugated flamelets is characterized by $v_n^{'}/S_l = 1$. Therefore only integral scale turbulence is able to substantially corrugate the flame front. Above this line the ratio is $v_n'/S_l > 1$ and the Karlovitz number $Ka < 1$. From the difinition of Karlovitz number, we have

$$Ka = \frac{t_f}{t_\eta} = \frac{l_F^2}{\eta^2} = \frac{v_\eta^2}{S_l^2} \tag{3}$$

By summarizing all the equations, we have

$$\begin{cases} \frac{v_n'}{S_l} > 1 \\ Ka < 1 \end{cases} \Longleftrightarrow \begin{cases} \frac{v_n'}{S_l} > 1 \\ \frac{v_\eta}{S_l} < 1 \\ \frac{l_F}{\eta} < 1 \end{cases} \Longleftrightarrow \begin{cases} v_n' > S_l > v_\eta \\ \eta > l_F \end{cases} \tag{4}$$

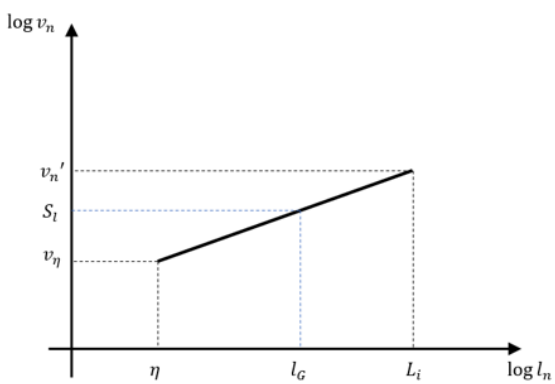

Fig. 5: Inertial subrange for corrugated flamelets

Where l_G is the Gibson length scale, above which there are vortices that are faster than flame front and below which there are vortices that are slower than flame front. However, Kolmogorov length scale is larger than the thickness of the flame front (Figure 5).

Since $\eta > l_F$, the entire reactive-diffusive flame structure is embedded within eddies of the Kolmogorov scale, where the flow is quasi-laminar. Although the eddies larger than the Gibson length scale cause a substantial corrugation of the flame front, the flame structure is not perturbed by turbulent fluctuations and does not change it's structure.(Figure 6) Therefore, the flame front locally propagates with laminar burning velocity, and the enhancement occurs only due to flame front corrugation [5].

3 Thin reaction zones regime

Thin reaction zone regime is characterized by $Ka > 1$ and $Ka_\delta < 1$. Therefore

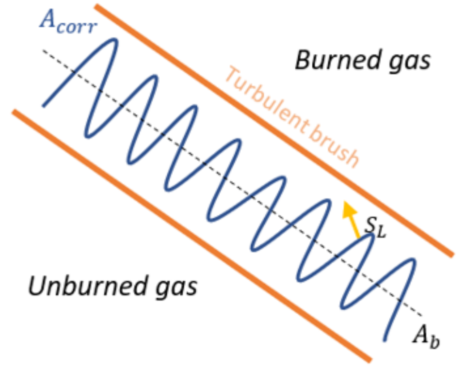

Fig. 6: Corrugated flame front

$$\begin{cases} Ka > 1 \\ Ka_\delta < 1 \end{cases} \Longleftrightarrow \begin{cases} \frac{v_\eta}{S_l} > 1 \\ \frac{l_F}{\eta} > 1 \\ \frac{l_\delta}{\eta} < 1 \end{cases} \Longleftrightarrow \begin{cases} v_\eta > S_l \\ \eta < l_F \\ \eta > l_\delta \end{cases} \tag{5}$$

Where Ka_δ is the second Karlovitz number, l_δ – thickness of inner layer of reaction zone.

Velocity at Kolmogorv Scale is larger than laminar burning velocity, therefore any scale of turbulence can substantially corrugate the flame front (Figure 7). Moreover, Kolmogorov scale is less than flame thickness and higher than the thickness of inner layer of reaction zone. As a result, eddies can enter into the preheat zone and increase mixing of radicals. These eddies during their turnover time might interact with the advancing reaction front and transport preheated fluid from a region in front of the reaction zone over a distance corresponding to eddy size. In addition, the heat transfer is enhanced from inner layer to preheated zone of flame

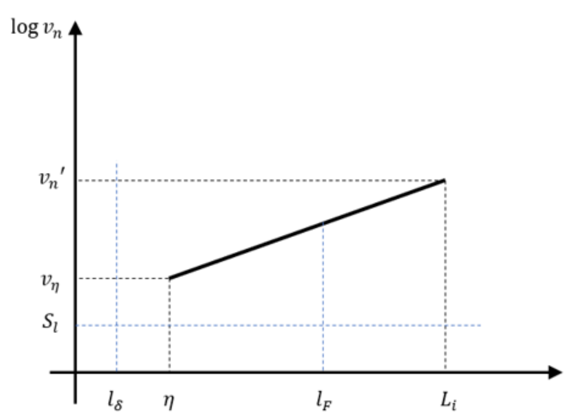

Fig. 7: Inertial subrange for thin reaction zones

front [5]. However, such eddies cannot penetrate into the inner layer because $Ka_\delta < 1$. Therefore, the enhancement of burning speed occurs not only due to corrugation effect but also due to better kinetics of chemical reactions happening in the flame front[6]. The local burning speed is no more laminar. The burning speed is now

$$S_b = S_l' \frac{A_{corr}}{A_b} \tag{6}$$

Where S_l' - enhanced local burning speed, which is different from laminar one.

4 Broken reaction zones regime

Second Karlovitz number is less than one for broken reaction zones [7].

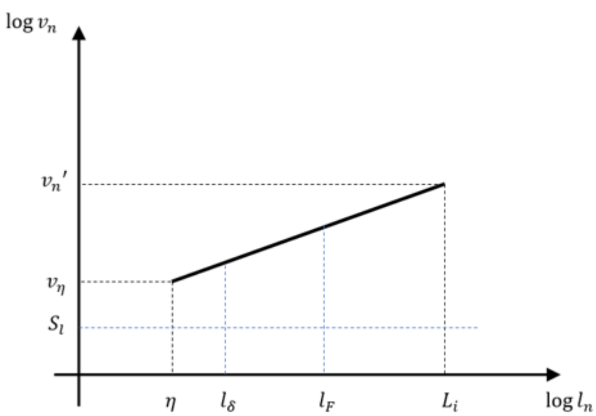

Fig. 8: Inertial subrange for broken reaction zones

$$Ka_\delta < 1 \iff \eta < L_\delta \tag{7}$$

Kolmogorov scale eddies are smaller than inner layer of flame front, so there is direct interaction between the eddies and the inner layer (Figure 8), but unfortunately this is not beneficial since the turbulent motion tends to remove the radicals within the inner layer which are essential for the chain branching reactions. In the broken reaction zones regime, mixing is faster than the chemistry, which leads to local extinction. This can cause noise, instabilities and possibly global extinction. Eddies may enter into the inner layer and perturb it with the consequence that chemistry breaks down locally owing to enhanced heat loss to the preheat zone followed by temperature decrease and the loss of radicals. Finally, flame extinguishes, fuel and oxidizer will inter diffuse and mix at lower temperatures, where combustion reactions have ceased.

IV Conclusion

In conclusion, turbulent flow field could be intensified through several approaches, like bowl-in piston, directed or deflected intake wall ports, helical inlet port and etc. However, although turbulence seems to enhance burning speed at any scale, it is evident that substantial amplification occurs only at corrugated flamelets and thin reaction zones regime and at a specific zone where $v_n'/S_l > 1$ and $Ka_\delta < 1$. Furthermore, local speed of propagation of the flame front remains laminar in case of corrugated flamelets regime and improvement occurs at the expense of increased flame front area. Nevertheless, local burning speed becomes different from laminar in case of thin reaction zone regime due to improved chemical reaction kinetics inside the flame front. Enhancement in this case occurs both from increased flame front area and local burning speed. Finally, concerning the application field, it can be claimed that by properly tuning the turbulence level and matching the burning speed enhancement zones inside the gasoline combustion chamber across all the range of engine rotational speeds, it is possible to further increase the limit of engine revolution speed of a particular engine.

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CONFIGURATIONS OF LARGE TRANSPORT AIRCRAFT: PROSPECT AND PROBLEMS

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Abstract– This paper discusses about problems of possible development of dedicated, high capacity, large civilian freighter aircraft. The main disadvantages of currently operating air transport are discussed. The flight performance of proposed dedicated cargo aircraft with 120 tonnes payload capacity is compared with existing converted freighter aircrafts Boeing 747-200F and Antonov 124 (Ruslan). A wide range of values of payload and flight range are studied to get the better results from parametric research. An assessment of flight performance and economical features are evaluated by three criteria: weight efficiency, fuel efficiency and transportation cost.

Key words– aircraft, freighter, cargo transportation, fuel efficiency.

I INTRODUCTION

The share of cargo transport using aircraft is growing steadily over the last decade of years throughout the world. Currently, the total amount of air transportation exceeds 250 billion tonnes per year (fig. 1). The rate of growth of cargo transportation over the past ten years increased on average by 4.3% annually [1].

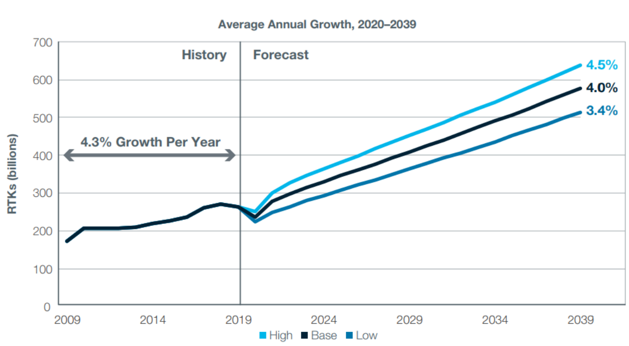

Fig. 1: World Air Cargo Traffic 2009-2039 [1]

In addition to the long-term trend of dedicated freighters carrying more than 50% of global air cargo traffic despite growing wide-body passenger fleets, the COVID-19 pandemic has highlighted the importance of main-deck freighters in our global air transportation system [1]. While increasingly capable passenger widebody airplanes have helped the air cargo industry grow during the past decade, dedicated freighters are anticipated to continue to comprise at least 50% of the world air cargo traffic carried.

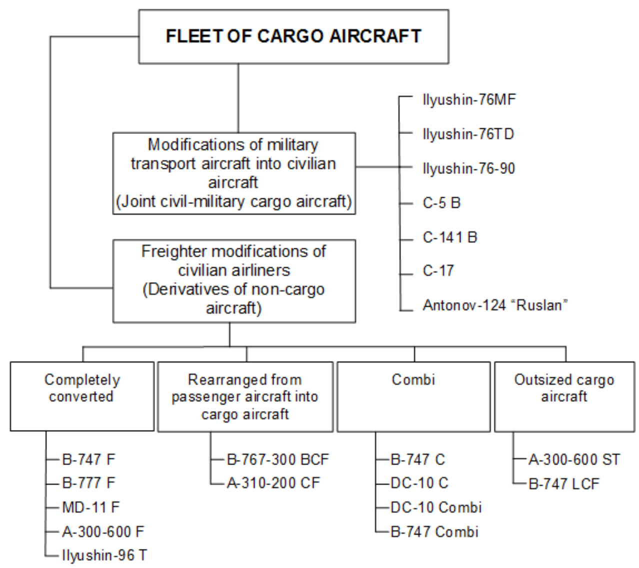

Fig. 2: Fleet of cargo aircraft

There are several key reasons for freighter preference in air cargo flows: 1) most passenger belly capacity does not serve key cargo trade routes; 2) twin-aisle passenger schedules often do not meet shipper timing needs; 3) freight forwarders prefer palletized capacity, which is not available on single aisle aircraft; 4) passenger bellies cannot serve hazardous materials and project cargo, a key sector in air cargo flows; and 5) payload-range considerations on passenger airplanes may limit cargo carriage, which decreases the likelihood that cargo will arrive at its destination on time.

According to the forecasts from the leading airplane manufacturers Boeing and Airbus Industry the annual growth rate of cargo air transport will be not less than 4.1% in the next 20 years. Picture 1 shows that world air cargo traffic may increase more than two times during the next 20 years [1].

Currently more than half of the air transportation work is carried out with almost 2000 freighter modifications of long-haul passenger aircrafts. The second half performs in the cargo compartments of conventional passenger jets. Most aircrafts are not initially designed as a freighter and converted from passenger airliner jets into freighter aircraft by rearrangement and uninstallation of equipment in the passenger compartment (fig. 2, 3). More than 1000 aircrafts are completely converted for cargo transportation such wide-body airplanes as: B-747F, A-300F, MD-11F, A-330F, Ilyushin-96T.

Basically, cargo modifications of airplanes have the same take-off weight and geometrical shape to keep same flight performance equally to conventional passenger airplane. However, in this case the cargo compartment of cargo airplanes become extremely oversized comparing to its payload capacity. For instance, the maximum payload of a B-747-400F equals 122 t, the volume of the cargo compartment is 1002 m^3. In other words, available volume to carry 1 t of freight is 9 m^3. However, analysis of statistical data shows that the maximum capacity for transportation of 1 t of freight needed less than 6 m^3. This means that the relation of ‘cargo compartment capacity and necessary volume for carrying given payload is 30% larger than needed. In addition, if we consider the volume of the external contour of the fuselage (which is equal to 1996 m^3) it is twice as big as the cargo compartment. Therefore the actual necessary capacity for carrying 112 t of freight on the B-747F is only 672 m^3. It is less than 34% volume of the external contour of the fuselage [4, 5]. Inside the cargo compartment of the airliner Ilyushin-96T more than 34 cargo pallets R6 and R2 can be arranged which can total more than 230 t of weight. However the maximum payload carrying ability of this airplane is only 92 t. These examples show us the existence of significant reserves to improve the air cargo transportation efficiency by developing Dedicated Freighter Aircraft (DFA) [6].

In contrast, passenger networks are much broader and often include destinations where cargo demand is minimal. This difference in passenger and cargo traffic distribution explains the considerable load factor difference in belly space and freighters, which average approximately 30% and 75%, respectively over the last decade. In addition, range restrictions on fully loaded passenger aircraft and limited passenger service to major cargo airports make freighter operations essential. For these structural reasons, freighters are forecast to carry more than half of the world’s air cargo for the next 20 years [1].

The main purpose of design of any transport including the airplane is increasing the fraction of the payload in the total weight balance. It is obvious that any kind of machine must do as much useful work as possible while it is as small as possible. The main principle of transport vehicle design is a minimization of its structural mass.

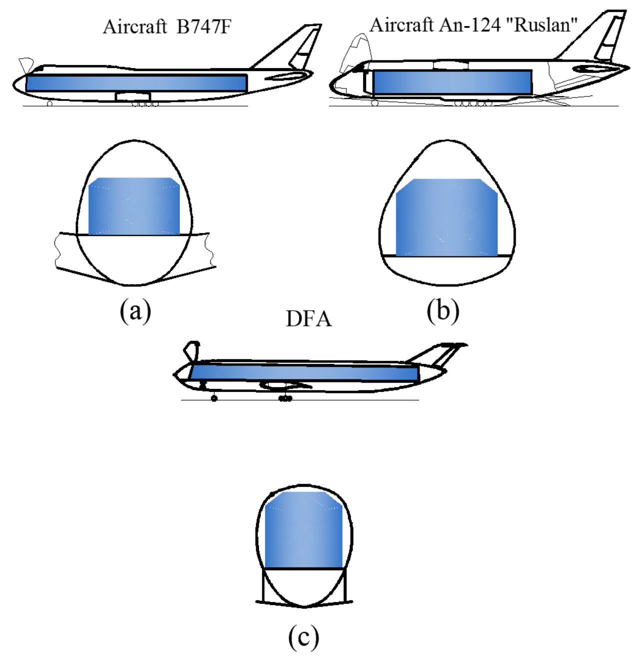

Fig. 3: The cargo compartments of various transport aircrafts: (a) converted, (b) modification of military into civilian (c) DFA

Much research has been done relatively to the flying-wing (FW) configuration [2, 3] but most have disadvantages in stability and implementation into real life comparing to conventional configurations. This paper presents an assessment of the flight performance and the economical features estimation for proposed dedicated freighter aircraft. A wide range of values of payload and flight range are studied to get the better results from parametrical research.

The remaining sections in this paper are organized as follows. In section 2 a comparison of flight and economic performances of existing cargo aircrafts with dedicated freighters are studied. Section 3 introduces about the parametric research of cargo aircrafts. Section 4 shows novel design concepts of aircraft structure. Finally, a conclusion with discussion is given in section 5.

II DEDICATED FREIGHTER AIRCRAFTS

The proposed configurations of the dedicated (universal and specialized) freighter is an aircraft which has been designed from the beginning as a freighter, with no restrictions caused by either passenger or military requirements and belongs to the absolutely new class of air vehicle with new design (fig. 3-c).

Let's look at the example of DFA. The airplane designed for a maximum payload of 120 *t*, an estimated flight range is 6000 *km*. In this design an original decision is applied to the airplane's fuselage. An originality of the fuselage is the location of the flight deck. It is in the lower part of the nose.

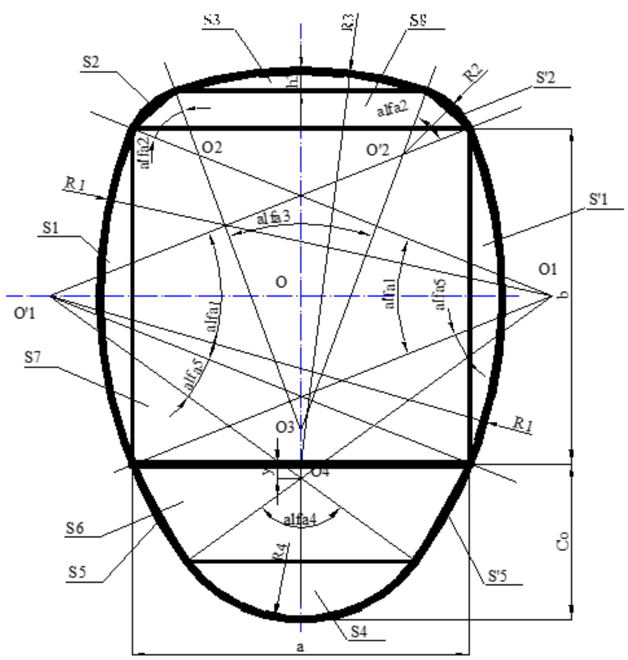

Fig. 4: DFA fuselage cross section

The volume of the cargo compartment (720 m^3) defined as with consideration of relation coefficient of freight density $\mu_{freight}$ equally to 6 m^3/t [7, 8]. The fuselage cross section (fig. 4) is generated with the multiple arc curves and designed as much possible to reduce the empty volume around the containers.

The location of main door for cargo compartment is in the nose part and it opens to upper side (fig 5). Cargo compartment is structurally designed as a regular construction without cutouts on lateral direction of the fuselage. The floor of cargo compartment has a double function. It receives loads from the payload and at the same time carries longitudinal stress from the bending moment which is distributed along the fuselage. The landing gear consist from multiple axle bogies (fig. 6).

(a)

(b)

Fig. 5: DFA with two wing scheme: (a) flight mode (b) cargo compartment door is open

Fig. 6: Multiple axle bogies in landing gear

The upper panel of the wing center section connects to the structural scheme of the cargo compartment's floor in the joint area of wing and fuselage. Thus the upper panel of the center wing section works under longitudinal as well as lateral stress due to the bending moments of wing and fuselage [7, 8].

TABLE 1: COMPARATIVE PERFORMANCE CHARACTERISTICS OF CARGO AIRPLANES

Parameter description	Symbol	Units	B-747-400F	An-124-100	DFA
Maximum Take of Weight	W_{TOW}	t	396.9	405	375
Maximum Payload	$W_{payload}$	t	112	120	120
Volume of Fuselage by external shape (theoretical contour)	V_{fus}^{ext}	m^3	1996	2597	1072
Cargo compartment Capacity (volume)	V_{cargoc}	m^3	1002	1027	720
Usefulness coefficient of fuselage's volume	k_u^V	%	50	39	67
Weight of fuselage (design estimation)	W_{fus}	t	36.1	50.8	24.2
Fuselage Drag in Cruising mode	D_{fus}	t	10	12	6.2
Fuel consumption for Range R=6000 km	W_{fuel}	t	81	108	68
Fuel efficiency (fuel consumption of 1 $t \times km$)	q_{fuel}	$g/(t \times km)$	120	150	95
Weight efficiency (useful takeoff load ratio)	$W_{payload}/W_{TOW}$	%	28	26	32

On the basis of these technical characteristics we have performed some design calculations to define the airplane performance characteristics. Table 1 presents a comparison of some performance characteristics of the proposed airplane with Boeing-747-400F and Antonov-124-100 'Ruslan'. First of all, we may notice the high percentage of the cargo compartment's capacity compared to the external shape of the fuselage (67%). Therefore estimated mass of the DFA fuselage is twice lighter than the Antonov-124-100 Ruslan's fuselage and 1.5 times lighter than the fuselage of the B-747-400F because of the smaller fuselage size.

An estimation of the fuselage aerodynamic drag in cruising regime is equal for DFA =6.2 t, for B-747-400F is equal 10 t and for Antonov-124-100 'Ruslan' is 12 t. Thus, DFA's fuselage drag is 1.5 2 times less than other prototypes. The notably high weight efficiency at 32% (useful takeoff load ratio) and the high aerodynamic quality makes the DFA considerably advantageous in terms of fuel efficiency.

Generally the definition of the necessary volume of the fuselage's cargo compartment results from volumetric density of the cargo.

For example, the design of a dedicated 'container carrier aircraft' may assume $\mu_{freight} = 4.2\ m^3/t$, an aircraft designed for carrying granular cargo $\mu_{freight}$ =2.0 m^3/t, and the tanker for liquid cargo may assume $\mu_{freight}$ =1.2 m^3/t. Thus the fuselage of the most dedicated freighters will have a smaller geometric size, which permits the enhancement of weight and fuel efficiency.

There are two parameters are widely used in assessment of the transport aircraft performance characteristics:

- Freight tonne-kilometer (FTK): One tonne of cargo carried one kilometer.
- Revenue tonne-kilometer (RTK): One tonne of revenue freight carried one kilometer. Usually used interchangeably with freight tonne-kilometer but can include passenger weight for total revenue

To estimate technical and economic factors of DFA we have performed parametric studies. The scope of the parametrical research covered a payload from 100 t to 250 t and estimated flight ranges (R) from 6000 km to 12000 km.

Two main technical criteria have been considered:

- weight efficiency ($W_{payload}/W_{TOW}$) and
- fuel efficiency $q_{fuel} = (W_{fuel}/FTK)$, $[gram/(tonne \times km)]$ which means fuel consumption of carrying 1 t cargo to 1 km range.

One economic criterion is considered: transportation cost (a), which includes 'cost of flight hour', payload and speed:

$$a = \frac{cost\ of\ flight\ hour}{\varepsilon \times W_{payload} \times V_{average\ speed}} \quad \left[\frac{\$USD}{tonne \times km}\right]$$

where ε is the payload factor, taking into account the average annual partial load of the aircraft average loading factor $\varepsilon \approx 0.6 \div 0.8$.

III PARAMETRIC RESEARCH

In the parametric research we have considered three types of DFA:

1. **Universal Cargo Aircraft (UCA).** The cargo compartment of this aircraft has payload capacity per unit of $\mu_{freight} = 6\ m^3/t$.
2. **Aircraft for Granular Cargo (AGC).** The cargo compartment of this aircraft has storage with payload capacity per unit of $\mu_{freight} = 2\ m^3/t$.

3. **Tanker for Liquid Cargo (TLC).** The cargo compartment of this airplane has tanks for transportation of liquids with payload capacity per unit of $\mu_{freight} = 1.2$ m^3/t.

The result of the parameter study of UCA is given below.

Fig.7 presents dependency of weight efficiency ($W_{payload}/W_{TOW}$) on payload of the UCA designed for maximum payload ranges of 6000 *km*, 9000 *km* and 12000 *km*. It is noticeable that these relations have maximum in their weight efficiency. For instance, for the aircraft designed for a range of 6000 *km* the maximum weight efficiency is 0.42 when it carries 180 *t* of payload. In other words, by criteria of weight efficiency an optimum performance of UCA estimated with payload 180 *t*. In this case the maximum take-off weight of the aircraft is estimated at 427.8 *t*. For an UCA designed especially for a range of 9000 *km* the maximum weight efficiency of 0.37 corresponds to the aircraft with a maximum payload of 170 *t*, take-off weight of 465 *t*. An UCA designed especially for a range of 12000 *km* obtains its optimum performance with a payload of 160 *t*, weight efficiency of 0.32 and take-off weight of 507.7 *t*. The results for UCA show that for increasing estimated range the optimum shifts to the left side, and payloads of optimum aircraft decrease. The weight efficiency for an increase of range from 6000 *km* to 12000 *km* payload decreases by about 10%.

In general, we may conclude that the optimum UCA for maximum weight efficiency should be specially be designed for a payload between 160 and 180 *tonnes*. Fig. 8 shows dependence of the fuel efficiency (q_{fuel}) on payload $W_{payload}$ for UCAs designed for ranges of 6000 *km*, 9000 *km* and 12000 *km*.

For the airplane designed for a range of 12000 *km* the optimum payload is 200 *t*, for range of 9000 *km* optimum payload is 220 *t* and for range of 6000 *km* optimum payload corresponds to 250 *t*.

Thus, maximum payload value exerts negative influence on fuel efficiency. How estimated distance is larger, the airplane have to be designed for less payload for good performance. Analysis of dependencies reveals following features. Primarily, it seems that to shorter estimated range corresponds higher fuel efficiency of the airplane. However, in reality, the fuel efficiency of UCA designed for flight range of 9000 *km* shows better results than UCA's designed for flight range of 6000 *km*.

Fig. 9 shows the dependency of economic criteria: the transportation cost (a) on payload ($W_{payload}$) for UCA designed for various flight ranges.

According to this result main characteristics of optimal aircraft are:

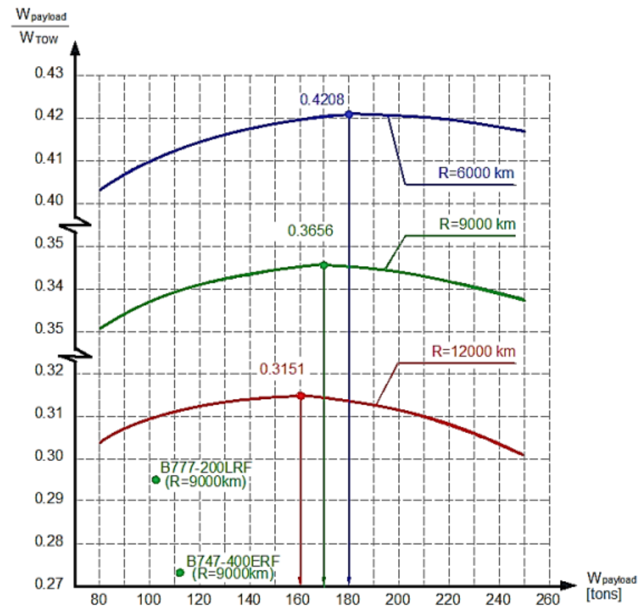

Fig. 7: Dependency of weight efficiency W_E = f ($W_{payload}$, R) on payload for UCA

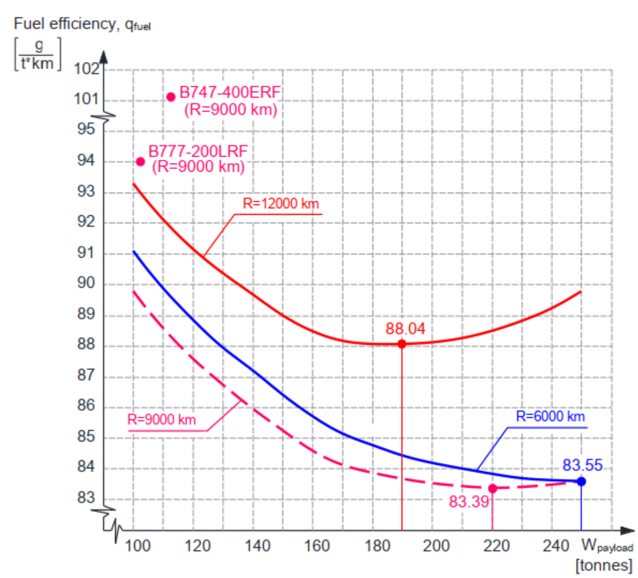

Fig. 8: Dependency of fuel efficiency on payload q_{fuel} = f ($W_{payload}, R$) for UCA

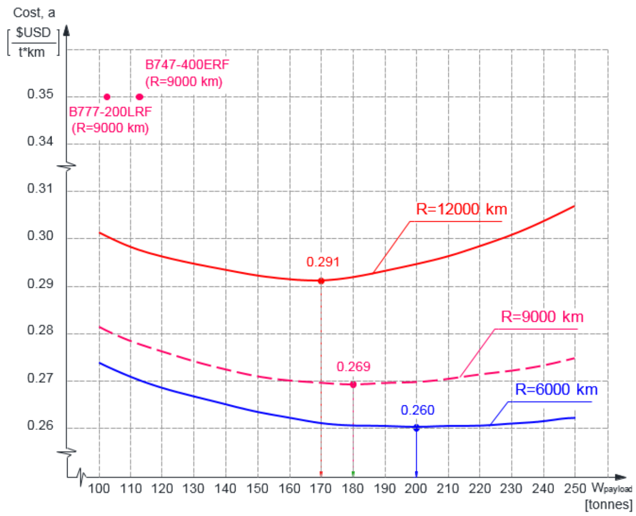

Fig. 9: Dependency of transportation cost on payload a = f (Wpayload, R) for UCA

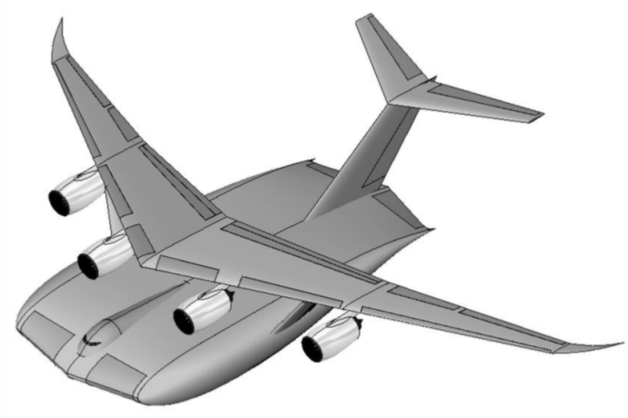

Fig. 10: The hybrid configuration of large cargo aircraft

- with a maximum payload of 200 *t*, takeoff weight 475.8 *t* in estimated flight range of 6000 *km*;
- with a maximum payload of 180 *t*, takeoff weight 492.84 *t*, in estimated flight range of 9000 *km*;
- with a maximum payload of 170 *t*, takeoff weight 540.14 *t*, in estimated flight range of 12000 *km*.

Analysis of these results shows that with the increase of the estimated flight range, the optimal values of the payloads decrease. Additionally, if increase of estimated range from 6000 *km* to 12000 *km* cost of transportation rises from $USD 0.26 to $USD 0.291, i.e. it increases about 12 %.

Similar results were obtained from parametric studies of AGC and TLC projects.

IV FUTURE AIRCRAFT SCHEMES

The future aircraft are predicted to set new standards in civil aviation for the next couple of decades. Aviation community is trying to make future aircraft more environmentally friendly, making fewer harmful emissions, being quieter and cheaper. Here are some latest prototypes of future aircraft are shown in fig. 10-12. The hybrid configuration ('Lifting-body configuration') of large cargo aircraft is shown in fig. 10-11. Based on preliminary estimations it is assumed that the aircraft's main specifications defined as Maximum payload of 300 *t*, takeoff weight of 800 *t* in estimated flight range of 12 000 *km*. An originality of this scheme is its fuselage also can generate lift.

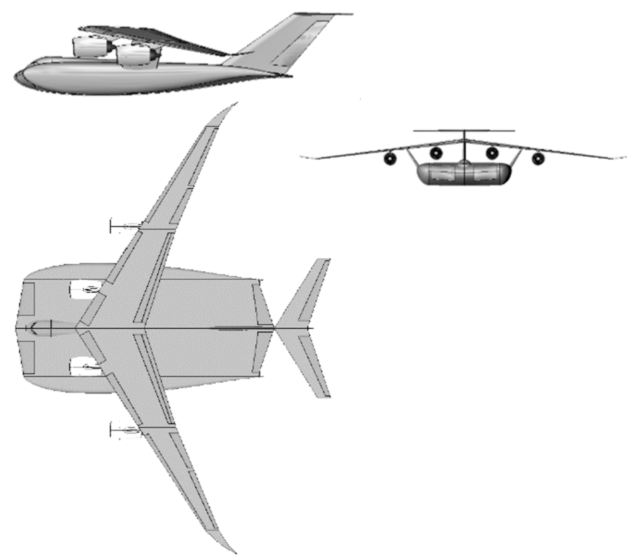

Fig. 11: Three view of the hybrid configuration of large cargo aircraft

The results of studies show [2], that the flying wing can have better results in operating cost than conventional aircraft, especially for large long range transport aircraft. However, the design of a large flying wing transport aircraft can only be successful if one succeeds to find an integrated optimum solution for the key disciplines aerodynamics, flight mechanics and structures. While the problems in the area of aerodynamics and flight mechanics can be solved using existing methods and tools, there still is major work required in the area of structures. Despite the development of several finite element models, mass estimates for this type of aircraft configuration are still hampered by a high degree of uncertainty and more work is required in the future [2].

The Airbus Company engineers are developing a concept which can surely compete with the bravest fantasies of science fiction. The futuristic Airbus concept is following a

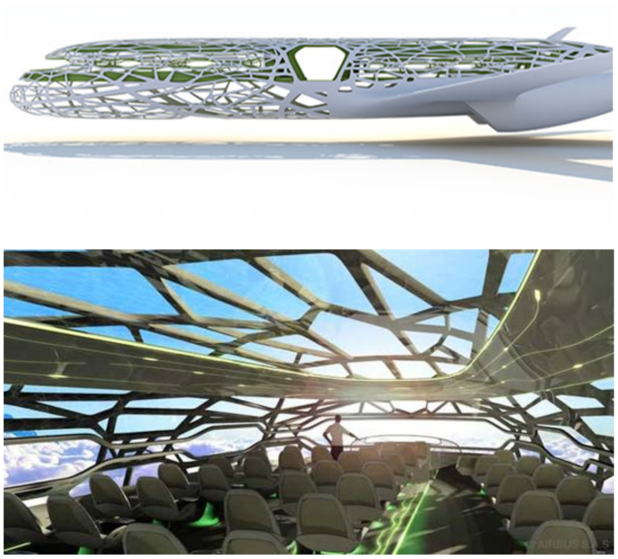

Fig. 12: The fuselage of bionic structure aircraft [9]

"bionic" plane structure (fig. 12). This structure will be based on the properties of a skeleton of the bird [9] and can be 3D printed.

V CONCLUSIONS

Advantages and disadvantages of currently operating air transport are discussed. The need for dedicated cargo aircrafts analyzed and studied. The estimation results of the flight performance and the economical features of proposed configuration of DFA are highlighted. The results of parametric study shows that reasonability of further study and development of DFA. The comparative analysis of DFA by three criteria indicates that DFA can have 7-10% better weight efficiency $W_{payload}/W_{TOW}$, 7-13% better fuel efficiency and 20% lower transportation cost than existing cargo modifications of passenger aircrafts Boeing-747-400ERF and Boeing-777-200LRF.

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ОБОСНОВАНИЕ ЭКСПЛУАТАЦИОННЫХ ПОКАЗАТЕЛЕЙ ДВИГАТЕЛЕЙ АВТОМОБИЛЕЙ С МЕХАТРОННОЙ СИСТЕМОЙ УПРАВЛЕНИЯ

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Аннотация—Производители автомобилей во всем мире уделяют большое внимание использованию мехатронных систем для улучшения эксплуатационных показателей и безопасности автомобилей. На сегодняшний день в мире одной из важных проблем является экономичное использование ресурсов и энергии, а также охрана окружающей среды при эксплуатации двигателей автомобилей. Данное диссертационное исследование является актуальным и направлено на частичное решение данной проблемы с помощью обоснования эксплуатационных показателей двигателей автомобилей с мехатронными системами управления. Эти проблемы изучают такие страны как Германия, США, Япония, Франция, Италия, Южная Корея, Великобритания и другие. В мире за последние годы и недалеком будущем основные инновации в системах автомобиля связаны с мехатроникой. Развитие мехатронных систем автомобилей имеют все большее значение в управлении всеми системами автомобиля и из года в год их производство в автомобилестроении увеличивается. Три основные части автомобиля – двигатель, шасси и интерьер модернизируются путем изменения механических элементов, а также внедрением в них мехатронного управления. К 2017-му ситуация кардинально изменилась и показатели стали следующие: 100 и более 80 процентов соответственно. Увеличение количества электронных систем привело и к росту их доли в себестоимости автомобиля: в 2018-м она составляла 18 процентов, в 2020-м – 40, а прогноз на 2030 год – 50 процентов. Движущей силой такого рода изменений служит улучшение функций и эффективности с производством электроники. Естественно, применение достижений современной электроники существенно изменяет цену компонентов и имеет важность при усовершенствовании.В нашей Республике автомобильная промышленность занимает одно из ведущих мест в экономике. ВВП доли отрасли автомобилестроения страны составила 3,6%, в промышленном секторе – 11,7%, выплаты в бюджет в виде налогов и других платежей – 1,6 трлн суммов. (2018 г.). Ежегодно производится до 250 тысяч автомобилей, в 2019 году выпуск автомобилей достиг 270 тысяч единиц. В последнее время увеличение потока автомобилей в Узбекистане привело к проблеме пробок на городских дорогах. Это вызывает целый спектр негативных явлений, но наиболее ощутимыми из них являются проблемы экологической и экономической безопасности автомобилей. На сегодняшний день требование к топливной экономичности и качеству самого топлива для обеспечения экологических показателей двигателя является одной из важнейших задач, которые пытаются решить различными изменениями и оптимизированием конструктивных параметров двигателя, его систем и применением мехатронного управления двигателя. Процессами в современном двигателе управляют мехатронные системы имеющие связи со всеми силовыми агрегатами автомобиля в том числе с подвеской, рулевым и тормозным управлением. С каждым годом тенденция развития автомобилестроения ведет к ужесточению требований экономической эффективности, а также ужесточающийся нормы по выбросам газов с автомобилей.

Ключевые слова—Автомобили, электронная система управления автомобилем, транспортные средства, двигателей внутреннего сгорания, мехатроника, датчики, актуаторы, система управления, адаптер, математическая модель управления ДВС, мехатроника автомобилей, электрооборудования автомобилей, кислородный датчик, катализатор, экология, автоматическое регулирование ДВС, эксплуатационные показатели автомобилей, эксплуатационные показатели двигателей.

I ОСНОВНОЕ СОДЕРЖАНИЕ ДИССЕРТАЦИИ

Основные компоненты объекта исследования с системой управления двигателем показаны на рис.1. Система получает данные от датчиков, обрабатывает и расшифровывает данные, на основании алгоритмов и калибровочных характеристик, отправляет сигналы на электромеханические актуаторы. Как было отмечено объект исследования имеет сложную конструкцию, включающий в себя элементы для широкого апгрейда, т.е. перевода из одних требований по оснащению мехатронными элементами в другой. Что в свою очередь обеспечивает покрытие более широкого диапазона требований, но затрудняющих интеграцию с другими агрегатами автомобиля. Например, наличие деталей 7 и 8 необязательно для класса в стандарта Евро 2, однако, является обязательным для класса в стандарта Евро 4 и выше.

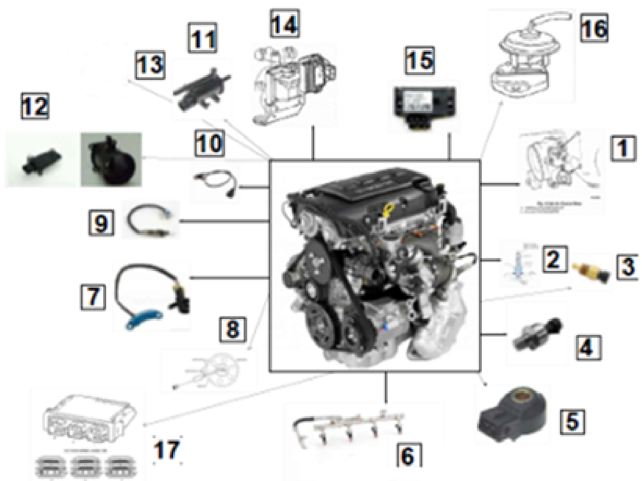

Рис. 1: Система управления двигателем. Основные компоненты объекта исследования: 1 - дроссельная заслонка; 2 - клапан принудительной вентиляции картера; 3 - датчик охлаждения; 4 - датчик давления масла; 5 - датчик детонации; 6 - топливные инжекторы; 7 - датчик положения коленчатого вала; 8 - датчик положения коленчатого вала; 9 - кислородный датчик; 10 - датчик положения распределительного вала; 11 - обратный клапан топливной системы; 12 - датчик массового расхода воздуха; 13 - датчик температуры воздуха; 14 - модуль зажигания и катушки; 15 - датчик абсолютного давления; 16 - клапан рециркуляции выхлопных газов; 17 - электронный блок управления.

Модель улучшения эксплуатационных показателей двигателей внутреннего сгорания и автомобилей.

Научное обоснование улучшения эксплуатационных показателей транспортных средств должно основываться на взаимосвязи и взаимовлиянии его основных элементов. Источником энергии и движущей силой является двигатель внутреннего сгорания (ДВС). Характеристики двигателя оказывают непосредственное влияние на эксплуатационные свойства транспортного средства. В свою очередь они, главным образом, зависят от характера протекания рабочего процесса и показателей двигателя. Поэтому изменение технико-эксплуатационных показателей двигателя повлечет за собой изменение эксплуатационных показателей транспортного средства, на котором он установлен (рис. 2).

В рассматриваемой модели входные (возмущающие) параметры X характеризуют набор технико-эксплуатационных показателей двигателя (мощность, крутящий момент, расход топлива) и определяются вектор-функцией:

$$X = \{x_1, x_2, x_3, x_4\} \tag{1}$$

Выходные параметры будут характеризовать эксплуатационные показатели транспортного средства Y и определяться вектор-функцией:

$$Y = \{y_1, y_2, y_3, y_4\} \tag{2}$$

Поскольку транспортное средство эксплуатируется в различных природно-климатических и путевых условиях (возмущающие параметры ε_i) и при различных режимах (возмущающие параметры z_i), то результирующее значение параметров Y будет определяться функцией:

$$Y = f(X, Y, Z) \tag{3}$$

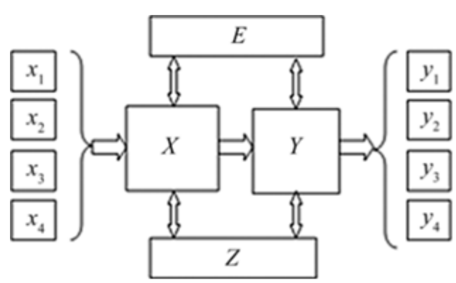

Рис. 2: Информационная модель влияния параметров двигателя на эксплуатационные показатели транспортного средства.

Где

X – технико-эксплуатационные показатели двигателя;

x_1 – эффективная мощность, кВт;

x_2 – индикаторная мощность, кВт;

x_3 – крутящий момент, Н·м;
x_4 – удельный эффективный расход топлива, г/кВт·ч;
Y – эксплуатационные показатели транспортного средства;
y_1 – путевой расход топлива, л/100 км;
y_2 – ускорение транспортного средства, м/с;
y_3 – динамический фактор;
y_4 – экологические показатели (содержание оксидов углерода (CO), углеводородов (CH));
E – природно-климатические и дорожные условия эксплуатации;
Z – режимы эксплуатации транспортного средства.

Тогда корректирующее воздействие на управляемые потоки Y могут быть представлены системой уравнений:

$$\begin{cases} Y(y_1,y_2,y_3,y_4) = X(x_1,x_2,x_3,x_4) \pm E(e_i) \\ Y(y_1,y_2,y_3,y_4) = X(x_1,x_2,x_3,x_4) \pm Z(z_i) \end{cases} \quad (4)$$

В этом случае значение результирующего выходного потока (эксплуатационных показателей транспортного средства) с учетом воздействия природно-климатических, путевых и эксплуатационных режимов эксплуатации может быть представлено следующим образом:

$$Y = \psi(y_i) \cdot E(e_i) \cdot Z(z_j) \quad (5)$$

$$\psi(y_i) = \Sigma((x_i \cdot e_i) + (x_i \cdot z_i)) \quad (6)$$

при ι=1,2,. . . ,n

С учётом принятия допущения, что e_i=const и z_i=const, т.е. условия эксплуатации имеют определенное фиксированное значение для определенного времени работы транспортных средств.

Как видно, для улучшения эксплуатационных показателей транспортного средства необходимо провести изменение технико-эксплуатационных показателей двигателя.

С целью выявления наиболее существенных показателей двигателя, оказывающих наибольшее влияние на эксплуатационные показатели транспортного средства, рассмотрим двигатель как управляемую параметрическую систему. Модель функционирования ДВС может быть представлена в виде определенной многомерной и многоуровневой системы.

Такая система будет формироваться с учетом вход¬ных и выходных процессов. При этом часть входных процессов является управляющей и определяется n-мерным вектором $A(a_1,a_2,...,a_n)$, определяющим параметры рабочего процесса двигателя (индикаторное давление, количество свежего заряда и др.), и да-мерным вектором $B(b_1,b_2,...,b_m)$, определяющим параметры и конструктивные особенности его механизмов (материалы и параметры цилиндропоршневой группы (ЦПГ), кривошипно-шатунного механизма (КШМ), газораспределительного механизма и т.д.). Входной поток воздействий, представленный k-мерным вектором $E(e_1,e_2,...,e_k)$ является неуправляемым и характеризует природно-климатические и путевые условия, в которых эксплуатируется двигатель (рис.3). Выходные характеристики системы определяются i-мерным вектором $A'(c'_1,c'_2,....,c'_i)$ и $B''(c''_1,c''_2,....,c''_j)$ представляющими, соответственно, технико-эксплуатационные и топливно-экономические показатели транспортного средства, на котором установлен двигатель.

Выходной p-мерный вектор $K_{\text{ТЭП}}(\Pi_1,\Pi_2,...,\Pi_p)$ содержит критерии комплексной оценки технико-эксплуатационных показателей рассматриваемой системы. Скалярные выходные характеристики вектора $K_{\text{ТЭП}}$, формирующие оценку двигателя, будут зависеть от скалярно-векторных значений входных потоков, имеющих вероятно-статистические параметры и формирующих граничные значения, в пределах которых будет проходить изменение функционала $K_{\text{ТЭП}}$.

Подобная система не только отражает известные потоки $A(a_1,a_2,...,a_n)$ и $B(b_1,b_2,...,b_m)$ но и позволяет учесть влияние выходных потоков $A'(c'_1,c'_2,....,c'_i)$ и $B''(c''_1,c''_2,....,c''_j)$ причинно-следственную связь их образования и влияния на выходных потоках $K_{\text{ТЭП}}$ в пределах модели выходные потоки $A'(c'_1,c'_2,....,c'_i)$ и $B''(c''_1,c''_2,....,c''_j)$ будут являться управляемыми параметрами, а их скалярно-векторные значения могут рассматриваться как граничные условия, в которых наиболее эффективно могут быть изменены управляющие потоки A, B и $K_{\text{ТЭП}}$ Предлагаемая модель позволяет учесть влияние выходных параметров $A'(c'_1,c'_2,....,c'_i)$ и $B''(c''_1,c''_2,....,c''_j)$ на выходной факториал и управляемые потоки A и B. При этом скалярно-векторные величины управляемых потоков $A(a_1,a_2,...,a_n)$ и $B(b_1,b_2,...,b_m)$ будут формировать пределы границ допустимых интервалов выходных потоков $A'(c'_1,c'_2,....,c'_i)$ и $B''(c''_1,c''_2,....,c''_j)$.

$$K_{\text{ТЭП}} f(A,B,E,A',B') \quad (7)$$

Выходные потоки A' и B' формируют систему с обратной связью в виде потоков X и Y с учетом ограничений, устанавливаемых $K_{\text{ТЭП}}$ при $0 < p \leq 1$:

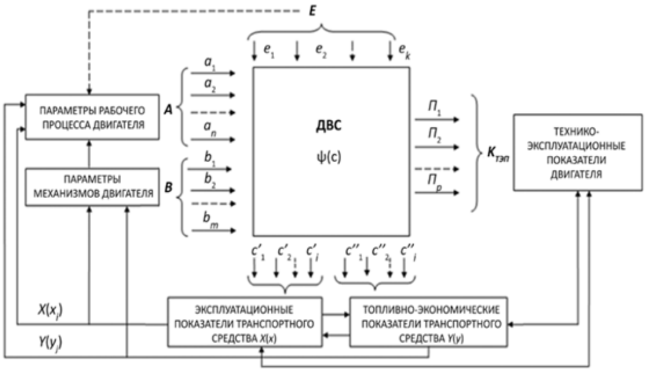

Рис. 3: Многопараметрическая модель формирования технико-эксплуатационных показателей ДВС.

$$\begin{cases} Y(x_i) = A'(c'_1, c'_2, ..., c'_i) \cdot K_{\text{ТЭП}}(\Pi_1, \Pi_2, ..., \Pi_p), \\ Y(y_j) = B'(c'_1, c'_2, ..., c'_j) \cdot K_{\text{ТЭП}}(\Pi_1, \Pi_2, ..., \Pi_p), \end{cases} \tag{8}$$

Тогда корректирующее воздействие на управляемые потоки A и B, могут быть представлены системой уравнений:

$$\begin{cases} A_x(a_1, a_2, ...a_n) = A(a_1, a_2, ...a_n) \pm X(x_i), \\ B_x(b_1, b_2, ...a_m) = B(b_1, b_2, ...a_m) \pm Y(y_j), \\ A_y(a_1, a_2, ...a_n) = A(a_1, a_2, ...a_n) \pm Y(y_j), \\ B_x(b_1, b_2, ...a_m) = B(b_1, b_2, ...a_m) \pm X(x_i). \end{cases} \tag{9}$$

В этом случае значение результирующего функционала может быть представлено следующим образом:

$$K_{\text{ТЭП}}(\Pi_1, \Pi_2, ..., \Pi_p) = \psi(c) \cdot X(x_i) \cdot Y(y_j), \tag{10}$$

где

$$\psi(c) = \Sigma((a_{ij} \cdot e_{iz}) + (b_{ij} \cdot e_{iz})) \Big|_{\substack{i=1,2,...n, \\ j=1,2,...m, \\ z=1,2,...k.}} \tag{11}$$

Представленные положения показывают, что наибольшее влияние на изменение параметров двигателя оказывают рабочий процесс, проходящий в двигателе, и его система управления. Но, поскольку рабочие параметры зависят от системы управления, можно предположить, что оптимальным воздействием, позволяющим изменить технико-эксплуатационные показатели двигателя, будет изменение в системе мехатронного управления. Так как основной рабочий процесс проходит в цилиндре двигателя, то наибольшее влияние на изменение выходных параметров двигателя будут оказывать момент зажигания и подача топливо - воздушной смеси.

Тогда выходной поток параметров рабочего процесса может быть представлен системой уравнений:

$$A = \begin{cases} \eta_v = f(P_a, P_o, T_r, \rho_o) \\ N_i = f(\eta_i, \eta_v, \rho_o) \\ N_e = f(N_i, \eta_M) \\ \eta_i = f(P_i, V_h, Q_m) \\ g_i = f(H_M, \eta_i) \\ g_e = f(H_u, \eta_i, \eta_M) \end{cases} \tag{12}$$

где
η_v - коэффициент наполнения;
P_a - давление в конце такта впуска, Мпа;
P_o - давление окружающей среды, Мпа;
T_r - температура остаточных газов, °C;
ρ_o - плотность свежего заряда на впуске, г/см2;
N_i - индикаторная мощность, кВт;
η_i - индикаторный КПД;
N_e - эффективная мощность двигателя кВт;
η_M - механический КПД;
P_i - среднее индикаторное давление действительного цикла, Мпа;
V_h - рабочий объем одного цилиндра, л;
Q_m - количество теплоты, подведенное с топливом за цикл, кДж;
H_u - теплотворная способность (низшая теплота сгорания) топлива (кДж/кг);
g_i - удельный индикаторный расход топлива, г/кВт*ч;
g_e - удельный эффективный расход топлива, г/кВт*ч.

Известно, что индикаторный КПД, удельный индикаторный расход топлива, эффективный КПД, удельный эффективный расход топлива зависят от коэффициента наполнения. Эффективная мощность и удельный расход топлива будут зависеть от механического КПД, который определятся механическими потерями в двигателе, в частности ЦПГ.

В соответствии с информационной моделью влияния параметров двигателя на эксплуатационные показатели транспортного средства его параметры также могут быть представлены системой функций:

$$A = \begin{cases} g_s = f(g_{\text{еэ}}, N_{\text{еэ}}, v, \rho_T) \\ J_a = f(N_{\text{еэ}}, M_{\text{к}}) \\ D = f(N_{\text{еэ}}, M_{\text{кр}}, v) \\ C = f(Q_m, H_u, N_{\text{еэ}}, v) \end{cases} \tag{13}$$

где
g_s - путевой расход топлива, кг/100 км;

$g_{еэ}$ - эксплуатационный удельный эффективный расход топлива, г/кВт·ч;
$N_{еэ}$ - эксплуатационная мощность двигателя, кВт;
$M_к$ - крутящий момент двигателя, Н·м;
v - скорость транспортного средства, км/ч;
ρ_T - плотность топлива, г/л.

На основании вышеизложенного можно предложить следующую концептуальную модель взаимосвязи и влияния модернизации системы управления на технико-экономические показатели двигателей и эксплуатационные показатели транспортного средства (рис.4).

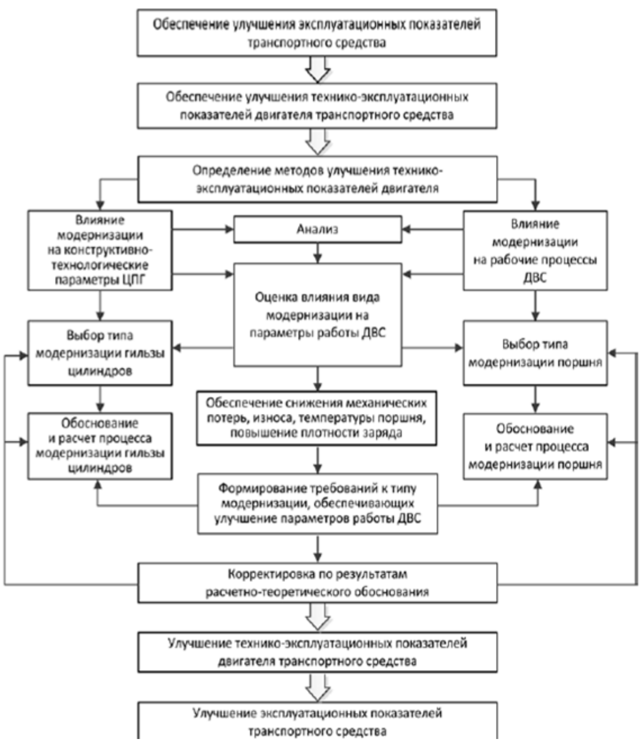

Рис. 4: Концептуальная модель повышения эксплуатационных показателей транспортного средства

Изменение коэффициента наполнения может быть осуществлено без изменения конструктивных параметров системы воздухоподачи за счет увеличения количества свежего заряда. Не прибегая к механическим устройствам (компрессорам), это может быть реализовано только снижением температуры заряда. Поскольку при поступлении в цилиндр свежий заряд подогревается от деталей камеры сгорания, одним из решений этого будет являться снижение температуры деталей.

Повышение мощности и снижение удельного расхода топлива возможно опять же без изменения конструкции за счет снижения механических потерь в сопряжениях двигателя. Практическая реализация предложенной модели заключалась в оптимизации системы управления двигателя внутреннего сгорания.

При этом математическая модель расчета эксплуатационных показателей транспортных средств от параметров формируемых покрытий реализовывалась численно при использовании комбинации методов конечных разностей и конечных элементов. С использованием методов планирования эксперимента проводилась редукция исходной модели к эмпирико-статистической.

Применение математического моделирования позволяет разработать концепцию улучшения эксплуатационных показателей транспортного средства, оптимизировать процесс выбора путей модернизации двигателя и автомобиля. Использование предлагаемой модели взаимозависимости эксплуатационных показателей от системы управления двигателя позволит сократить временные и трудовые затраты при проектировании новых и модернизации существующих типов двигателей и моделей автомобилей, исключить ошибочные проектировочные решения, сократить время от начала проектирования до массового производства автомобилей и двигателей. Вывод модели управления двигателем. Определим математическую зависимости, описывающих ДВС, относительно управляемой величины – впрыска и подачи зажигания в зависимости от сигналов датчика кислорода ДВС. Решение этого уравнения позволит получить зависимость частоты вращения вала от времени впрыска и подачи зажигания.

ДВС без наддува, как управляемый объект по частоте вращения коленчатого вала $\omega(t)$ описывается линейным дифференциальным уравнением:

$$T_D \frac{d\omega(t)}{dt} + K_D \omega(t) = h(t) - T_c M_c(t). \qquad (14)$$

Здесь $\omega(t)$ - частота вращения коленчатого вала; h(t) – время подачи впрыска топлива и зажигания; $M_c(t)$ – значение нагрузки; t – время; T_D, K_D, T_C – постоянные величины, зависящие от конструктивных особенностей двигателя.

Идентификация динамических объектов в общем случае состоит в определении их структуры и параметров по измеряемым данным - входным воздействиям и выходным процессам - и осуществляется при помощи настраиваемой модели той или иной структуры, параметры которой могут изменяться.

В качестве примера рассмотрим упрощённую одномерную схему непрерывной настраиваемой модели объекта экспертизы (ОЭ).

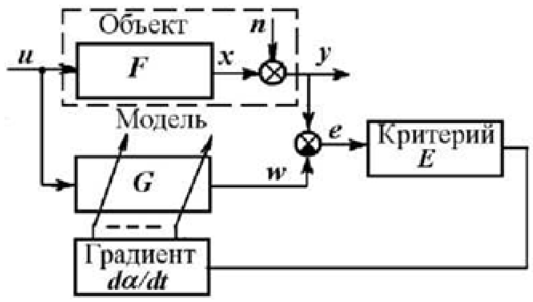

Рис. 5: Схема непрерывной настраиваемой модели: u – входное управляющее воздействие; x и w – выходные процессы ОЭ и модели; n – возмущающие воздействия; F и G – операторы связи

$$E = L[q(e)] \to min \tag{15}$$

где L – функционал от чётной функции q(e), $e = y - \omega$ - погрешность идентификации, $\omega = G[u;\alpha]$. Настройка модели G осуществляется изменением параметров $\alpha^T = (\alpha_1, ...\alpha_m)$ в соответствии со значением градиента E:

$$\frac{d\alpha}{dt} = -\gamma \nabla E \tag{16}$$

где $\gamma = \alpha(0)$ – начальные условия. Компоненты вектора градиента определяются дифференцированием:

$$\frac{\partial E}{\partial \alpha_j} = L\left[\frac{\partial q(e)}{\partial e}\frac{\partial e}{\partial \alpha_j}\right]; \frac{\partial e}{\partial \alpha_j} = -\frac{\partial w}{\partial \alpha_j} = -\frac{\partial G[u;\alpha]}{\partial \alpha_j}$$

причём $\frac{\partial w}{\partial \alpha_j}$ представляет собой функцию чувствительности (ФЧ) параметра α_j .

Градиент E

$$\nabla E = -L\left[\frac{\partial q(e)}{\partial e}K[u;\alpha]\right] \tag{17}$$

где $K_j[u;\alpha] = \frac{\partial G[u;\alpha]}{\partial \alpha_j}$. Множество $K_{\text{АКД}}[u;\alpha]$ позволяют получить все функции чувствительности параметров α.

$K_{\text{АКД}} = \alpha \pm u$, здесь α имеет диапазон $\alpha = (0 \div 0,9)$.

Итак, ставится задача вычисления функции чувствительности изменяемых параметров модели и далее – использования модели динамики ДВС для вычисления времени впрыска от углового ускорения коленчатого вала и его составляющих с целью идентификации состояния двигателя.

Для двигателя с адаптером кислородного датчика, объекта исследования введем корректирующий коэффициент $K_{\text{АКД}}$ в уравнение (15)

$$T_D\frac{d\omega(t)}{dt} + K_D\omega(t) = h(t)\cdot(\alpha \pm u) - T_C M_C(t). \tag{18}$$

Время подачи впрыска топлива и зажигания h(t) получим из соотношения (15):

$$h(t) = \frac{T_D}{(\alpha \pm u)}\cdot\frac{d\omega(t)}{dt} + \frac{K_D}{(\alpha \pm u)}\cdot\omega(t) + \frac{T_C M_C(t)}{(\alpha \pm u)}. \tag{19}$$

При испытаниях необходимо переводить ДВС из одного состояния в другое, тогда за t_i и ω_i примем конкретное состояние режима испытания, которое осуществляется при переходе из одного состояния двигателя в другое, а i – номер точки перехода.

Участки изменения частот в заданных интервалах можно выразить из уравнения прямой, где ω_i – требуемое начальное значение частоты вращения вала двигателя в момент времени t_i, ω_{i+1} – конечное требуемое значение частоты вращения вала двигателя в момент времени t_{i+1}.

Зависимость ω_t будет выглядеть как

$$\omega_t = \frac{\omega_{i+1} - \omega_i}{t_{i+1} - t_i}\cdot t - \frac{t_i(\omega_{i+1} - \omega_i)}{t_{i+1} - t_i} + \omega_i, \tag{20}$$

где $i = 1...n$; n – число точек перехода ДВС из одного состояния в другое.

При известной математической модели (19) и заданных значениях изменения частот, необходимо определить управляющее значение $h(t)$, приводящее к требуемым значениям.

Результатом вычислений является зависимость:

$$h(t) = \frac{T_D}{(\alpha \pm u)}\cdot\frac{\omega_{i+1} - \omega_i}{t_{i+1} - t_i} + \frac{K_D}{(\alpha \pm u)}\cdot\frac{\omega_{i+1} - \omega_i}{t_{i+1} - t_i}\cdot t -$$

$$-\frac{K_D}{(\alpha \pm u)}\cdot\frac{t(\omega_{i+1} - \omega_i)}{t_{i+1} - t_i} + \frac{\omega_i K_D}{(\alpha \pm u)} + \frac{T_C M_C(t)}{(\alpha \pm u)} \tag{21}$$

где $i = 1...n$;

В результате вычислений получены соотношения, позволяющие управлять объектом испытаний по двум входным параметрам: времени подачи впрыска, а также изменению частоты вращения на валу двигателя.

В модель вносим замену в место $\alpha \pm u$ величину характеризующую свойства мехатронного адаптера

$K_{\text{АКД}}$, регулирующего время впрыска топлива в зависимости от частоты вращения на коленчатом валу.

Уравнение для объекта исследования примет окончательный вид:

$$h(t) = \frac{T_D}{K_{\text{АКД}}} \cdot \frac{\omega_{i+1} - \omega_i}{t_{i+1} - t_i} + \frac{K_D}{K_{\text{АКД}}} \cdot \frac{\omega_{i+1} - \omega_i}{t_{i+1} - t_i} \cdot t -$$

$$- \frac{K_D}{K_{\text{АКД}}} \cdot \frac{t(\omega_{i+1} - \omega_i)}{t_{i+1} - t_i} + \frac{\omega_i K_D}{K_{\text{АКД}}} + \frac{T_C M_C(t)}{K_{\text{АКД}}} \qquad (22)$$

С помощью её определяется время впрыска топлива в коллектор и время подачи искры зажигания.

Уравнение вносится в систему управления двигателем (ЭБУ) и на основе калибровочных данных, характерных для каждого из типов двигателей, управляется подача сигналов времени впрыска топлива и зажигания.

Алгоритм мехатронной системы управления двигателем с мехатронным адаптером кислородного датчика. Оптимизация имеет смысл только при наличии обобщенного показателя качества - критерия оптимальности (или целевой функции), достаточно ощутимо отражающего эффективность управления. Важна также доступность критерия оптимальности, возможность его определения и использования в системе управления. В общем случае качество двигателя определяется совокупностью технических, экономических и экологических показателей. Среди этих показателей есть как непосредственно управляемые, так и предопределяемые возможностями мехатронной системы управления (МПСУ).

Мехатронные системы управления, куда входит ЭБУ, в совокупности влияют на мощностную характеристику ДВС, величину крутящего момента, экономичность двигателя, а также на токсичность выхлопных газов.

Каждая отдельная мехатронная система автомобиля имеет свой собственный блок управления. Все блоки объединяются в единую связанную схему благодаря специальной CAN-шине (Controller Area Network). Связанные шиной блоки иногда называются компьютером автомобиля, а количество контроллеров может доходить до 80 (рис. 6).

В число непосредственно управляемых мехатронных систем управления технических показателей двигателя внутреннего сгорания входят: частота вращения, крутящий момент, давление и температура в системах топливоподачи, давление и температура наддувочного воздуха, давление смазочного масла, температура охлаждающей жидкости, содержание кислорода в отработавших газах и др.

Важными непосредственно управляемыми из экономических и эксплуатационных показателей являются текущий расход топлива и расход воздуха.

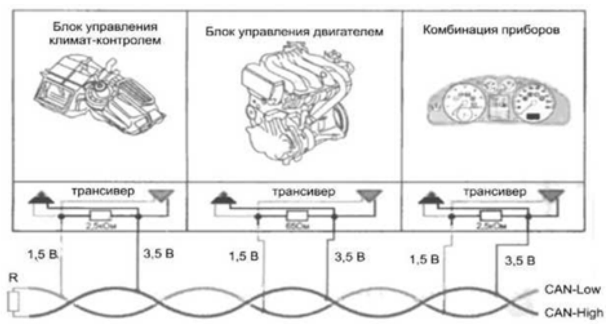

Рис. 6: Бортовая сеть и CAN-шина ЭБУ

Непосредственно управляемыми мехатронной системой управления являются экологические показатели: состав и количество вредных выбросов, уровень и спектр шума и вибрация.

Повышение показателей качества двигателя достигается оптимизацией его конструкции и технологии изготовления, методов и средств доводки его систем и агрегатов, включая систему управления и обеспечиваемое ею качество управления двигателем.

Двигатель внутреннего сгорания представляет собой многомерный объект управления, так как число входных параметров у него больше единицы и каждый входной параметр воздействует на несколько выходных управляющих воздействий. В таком случае система управления ДВС является многомерной.

На рис.7 представлен один из вариантов алгоритма управления моделью бензинового ДВС с адаптером мехатронной системой управления, зажиганием, топливоподачей и с нейтрализацией отработавших газов трехкомпонентным нейтрализатором.

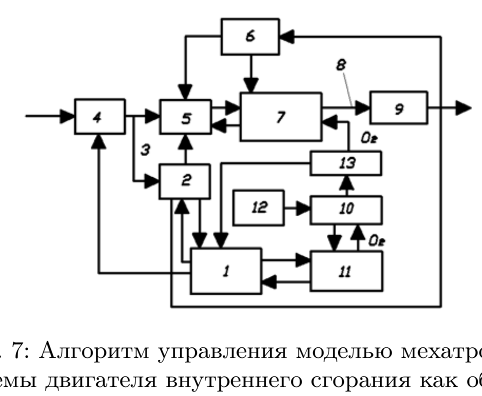

Рис. 7: Алгоритм управления моделью мехатронной системы двигателя внутреннего сгорания как объекта регулирования по минимуму расхода топлива и по ограничениям токсичности отработавших газов с учетом мехатронного адаптера кислородного датчика

Где:
1 - контроллер управления ДВС;
2 - блок впрыскивания топлива;
3 - сигнал датчика давления на всасывании Рк (нагрузка ДВС);
4 - дроссельная заслонка во всасывающем патрубке ДВС;
5 - цикловая подача топлива (расход топлива) и воздуха (расход воздуха);
6 - система зажигания;
7 - параметры индикаторного и рабочего процесса ДВС;
8 - параметры математической модели ДВС;
O_2 - концентрация кислорода;
9 - параметры нагрузки ДВС;
10 - выпускной тракт двигателя;
11 - датчик кислорода в отработавших газах;
12 - нейтрализатор отработавших газов;
13 - мехатронный адаптер кислородного датчика.

Алгоритм адаптации управления такой мехатронной системы по математической модели двигателя имеет следующие шаги.

1. Выбор исходной комплектации двигателя (в данном случае это система зажигания, система впрыскивания топлива, датчики, адаптеры и исполнительные механизмы).

2. Определение модели двигателя с проверкой ее адекватности путем экспериментального определения ее параметров.

3. Расчет режимов работы ДВС при выполнении ездового цикла с определением опорных точек матрицы управления, которые должны быть заложены в ППЗУ контроллера блока управления. Основными параметрами являются углы опережения зажигания, цикловая подача топлива в зависимости от циклового расхода всасываемого воздуха или положения дроссельной заслонки, температуры охлаждающей жидкости, параметры мехатронного адаптера кислородного датчика.

4. Формирование структуры управления.

5. Расчетная оценка достигнутого уровня показателей. В случае эффективности управления проводится оптимизация управления, а в случае отсутствия эффективности расчет возобновляется с предыдущих этапов.

6. Расчетное определение оптимального управления без ограничений по токсичности отработавших газов вне зоны ездового цикла с целью получения регулировок с минимальным расходом топлива и оптимальной динамикой двигателя.

7. Формирование базовой матрицы управления зажиганием и впрыскиванием топлива.

Полученные значения опорных точек управления закладывают в постоянную программируемую память (ППЗУ) микроконтроллера мехатронная система управления с учетом технологических допусков на детонационную стойкость топлива и интенсивность городской езды.

Особое значение при разработке программного обеспечения контроллера мехатронной системы управления имеют статическая и динамическая погрешности датчиков, а также исполнительных устройств. Особое значение приобрел обмен информацией по линиям связи CAN с появлением на транспортных средствах комбинированных силовых установок, которые позволили сократить расход топлива и снизить токсичность отработавших газов в условиях интенсивного городского движения.

Двигатель внутреннего сгорания как объект автоматического управления по входным параметрам вырабатывает управляемые характеристики (мощностные, экологические и динамические). Остальные агрегаты автомобиля выполняют функции обеспечения безопасности движения и комфортных условий для водителя и пассажиров.

Входные параметры, измеряемые датчиками электронных систем управления (частота вращения коленчатого вала двигателя, угол открытия дроссельной заслонки, угол опережения зажигания, цикловой расход топлива, расход воздуха и др.), влияют на протекание рабочего процесса двигателя. Значения входных параметров определяются внешними воздействиями на двигатель со стороны водителя или системы автоматического управления, поэтому они называются управляющими.

Кроме входных управляющих параметров на двигатель во время его работы воздействуют случайные возмущения, которые мешают управлению. К случайным возмущениям можно отнести изменение параметров состояния внешней среды (температура окружающей среды, атмосферное давление, влажность окружающего воздуха), свойства топлива и масла, состояние дорожного покрытия и т.д.

Частота вращения коленчатого вала двигателя может быть определена путем измерения интервала между соседними импульсами на выходе датчика положения коленчатого вала. Интервал между импульсами измеряется в секундах, одному обороту двигателя соответствуют два импульса от датчика положения коленчатого вала (для 4 цилиндрового двигателя), поэтому:

$$n = \frac{60}{2T} = \frac{30}{T}\text{мин}^{-1}, \tag{23}$$

где Т - интервал между соседними импульсами на выходе датчика положения коленчатого вала.

Для определения количества воздуха могут использоваться методы непосредственного или косвенного определения массы воздуха. При измерении массы воздуха непосредственным методом измеряется количество воздуха, поступающего в двигатель. Используются два различных метода, определяемые конструкцией применяемых датчиков:
- измеряется масса воздуха;
- измеряется объем, плотность и температура воздуха, а затем вычисляется его масса.

При использовании косвенного метода количество поступающего в двигатель воздуха не измеряется, рассчитывается по измерению значения параметра, от которого зависит. Масса воздуха, поступающего в цилиндры двигателя, определяется выражением:

$$A = \frac{nV\mu P}{RT} \tag{24}$$

где A - масса воздуха; n - частота вращения двигателя; V - объем цилиндра двигателя; μ - коэффициент использования объема двигателя; P - давление (разрежение) во впускном коллекторе; R - газовая постоянная; T - температура во впускном коллекторе.

Из приведенного выражения следует, что количество воздуха, поступающее в цилиндр за один цикл, зависит от двух переменных величин: разрежения во впускном коллекторе и температуры воздуха. На этом и основан метод косвенного измерения количества воздуха.

Существует большое число разновидностей датчиков расхода воздуха, однако в основном используются датчики, измеряющие объём воздуха (на основе вихрей Кармана) или массу воздуха (на основе терморезисторов). Датчики на основе вихрей Кармана на выходе имеют импульсный сигнал, частота которого пропорциональна объему проходящего воздуха в единицу времени (измеряется в л/с).

Количество воздуха при этом определяется по зависимости:

$$g \sim \frac{A}{n_e} \tag{25}$$

где g - количество впрыскиваемого топлива; A - количество воздуха; n_e - частота вращения коленчатого вала двигателя.

Масса воздуха в этом случае рассчитывается электронным блоком управления двигателем с использованием данных расходомера, температуры воздуха и барометрического давления. Датчики на основе терморезисторов на выходе имеют аналоговый сигнал, изменяющийся пропорционально массе проходящего воздуха (измеряется в г/с).

Системы косвенного измерения в качестве параметра для определения расхода воздуха используют величину абсолютного давления во впускном коллекторе за дроссельной заслонкой. При этом количество впрыскиваемого топлива определяется выражением:

$$g \sim \frac{P}{n_e} \tag{26}$$

где g - количество впрыскиваемого топлива; P - давление (разрежение) за дроссельной заслонкой; n_e - частота вращения вала двигателя.

При использовании этого метода необходимо учитывать запаздывание изменения разрежения по отношению к изменению массы. Такой метод измерения получается более дешёвым, но менее точным. Требования к двигателю меняются в зависимости от режима работы двигателя, соответственно должны изменяться и программы управления.

Работу мехатронной системы управления нельзя обеспечить, если не определить режим, на котором в данный момент времени работает двигатель. На основании этого выбирается алгоритм, по которому в данный момент должно осуществляться управление.Режим работы двигателя определяется с помощью программы - диспетчера режимов на основании информации, поступающей в микроконтроллер, в первую очередь от датчиков.

Алгоритм работы этой программы, распознающей режим работы двигателя, в упрощенном виде показан на рис. 5 (применительно к бензиновому двигателю).

После включения зажигания переход на программу управления пуском осуществляется или в случае включения стартера, или в случае трогании автомобиля с места при движении под уклон, если коленчатый вал двигателя начинает вращаться. После включения стартера дальнейший выбор программы горячего или холодного пуска зависит от показаний датчика температуры жидкости в системе охлаждения. При $t_{\text{охл}} < t_1$ (рис. 8) включается алгоритм холодного пуска, при $t_{\text{охл}} < t_1$ – алгоритм горячего пуска.

Переход от пуска двигателя к рабочим режимам происходит в том случае, если частота вращения двигателя превышает заданную ($n_{de} > n_e$). Сразу после выхода из режима пуска производится проверка того, работает ли двигатель на режиме холостого хода или принудительного холостого хода. В обоих случаях дроссельная заслонка полностью закрыта; если $n_{de} > n_1$, то включается алгоритм принудительного холостого хода, а если $n_{de} < n_1$ - алгоритм режима холостого хода.

Промежуточное положение дроссельной заслонки между полным открытием и полным закрытием характеризует работу двигателя на режимах частичных нагрузок, а полное открытие дроссельной заслонки на режиме максимальной нагрузки.

Программа диспетчер режимов может быть общей для всех управляющих воздействий или встраиваться непосредственно в контуры управления отдельными управляющими воздействиями. Она также может быть дополнена специальными критериями для идентификации определенных режимов. В программу диспетчер могут быть включены функции определения области режимов, где должна работать система рециркуляции отработавших газов, области режимов, в которой осуществляется замкнутое регулирование подачи топлива по сигналам датчика содержания кислорода в отработавших газах, и др. Однако эти задачи могут быть решены и введением необходимых требований непосредственно в программы управления определенными воздействиями.

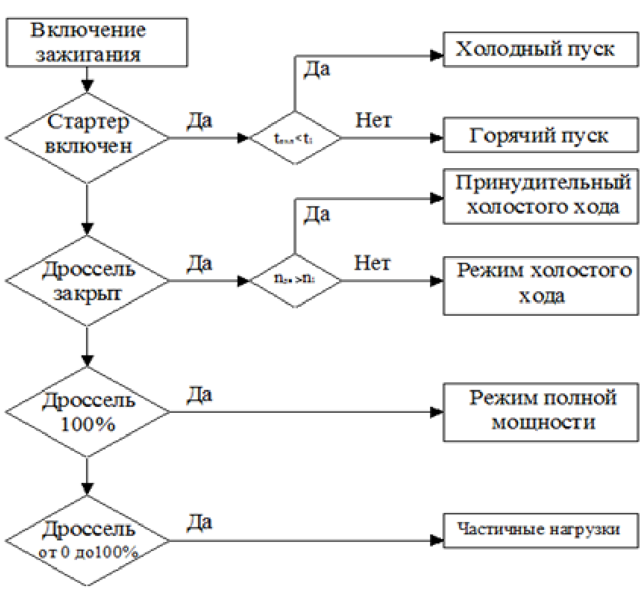

Рис. 8: Алгоритм идентификации режима работы бензинового двигателя

Где:
$t_{\text{охл}}$ - температура жидкости в системе охлаждения;
n_{de} - частота вращения двигателя;
t_1 - значение температуры жидкости в системе охлаждения, разграничивающее условия холодного и горячего пуска;
n_1 - предельная частота вращения холостого хода.

За исключением режима запуска двигателя время (длительность) впрыскивания топлива (T) определяется с учетом следующих факторов:

- базовой длительности впрыскивания (T_1), которая изменяется с изменением количества воздуха;
- значения корректирующего коэффициента (K_c) базовой длительности впрыскивания;
- задержки срабатывания форсунки (T_2).

$$T = T_1 \cdot K_c + T_2, \tag{27}$$

В режиме запуска длительность впрыскивания топлива (T) определяется с учетом следующих факторов:

- базовой длительности впрыскивания (T_1), которая рассчитывается с учётом температуры охлаждающей жидкости;
- значения корректирующего коэффициента (K_t), зависящего от температуры всасываемого воздуха;
- продолжительности срабатывания форсунки (T_2)

$$T = T_1 \cdot K_t + T_2, \tag{28}$$

Количество воздуха, поступающего в цилиндр двигателя за один цикл, рассчитывается электронным блоком управления двигателем на основании сигналов, поступающих от датчика расхода воздуха и датчика положения коленчатого вала двигателя.

Блок управления двигателем закрывает силовые транзисторы, обеспечивая воспламенение смеси в цилиндрах в соответствии с рассчитанным им порядком работы цилиндров, на основании сигналов от датчиков положения коленчатого и распределительного валов. При расчете момента закрытия транзистора нужно учитывать, что с изменением частоты вращения коленчатого вала двигателя время, за которое он поворачивается на 1°пкв, также изменяется (если обороты увеличиваются, то время уменьшается, и наоборот). Поэтому вначале рассчитывается время (t), необходимое для поворота коленчатого вала на 1°. Оно легко определяется из времени цикла (T), которое уже известно:

$$t = \frac{T}{180} \tag{29}$$

После определения времени t имеются все необходимые данные для расчета момента закрытия силового транзистора (момент подачи искры). За начало отсчета берется угол 75°пкв до ВМТ.

$$T_1 = t(75 - \vartheta) \quad (30)$$

где ϑ – угол опережения зажигания, рассчитанный электронным блоком управления двигателем. Двигатель, оснащенный мехатронной системой управления, обеспечивает существенное улучшение экономических и экологических характеристик, увеличение мощности двигателя и эксплуатационной надежности. Мехатронное управление обеспечивает устойчивость переходных процессов в двигателе и меньшую жесткость его рабочего процесса, а следовательно, уменьшение шума и вибрации.

Наличие мехатронной системы управления повысило качество эксплуатации двигателей, создав возможность введения централизованного контроля и управления эксплуатацией, при одновременном ее упрощении. Это явилось следствием исключения ручных регулировок и настроек агрегатов двигателя, оперативного контроля и наличия автоматической коррекции настроек, систематического совершенствования алгоритмов управления на основе анализа информации о результатах эксплуатации как конкретного двигателя, так и всех однотипных двигателей. Кроме того, мехатронная система управления привела к уменьшению затрат на ремонтное обслуживание и его упрощению (например, за счет исключения механических и гидромеханических регуляторов частоты вращения, необходимости ручных регулировок топливной аппаратуры на специальных стендах).

Мехатронным управлением оснащаются системы: топливоподачи, газообмена, наддува, зажигания, изменения степени сжатия, рециркуляции отработавших газов, охлаждения, смазки и другие. Чем больше число электронных систем, примененных в двигателе, тем больше возможности оптимизации управления двигателем. Для каждой конкретной модификации двигателя и условий его эксплуатации может быть выбран перечень электронных систем, являющийся оптимальным по соотношению достигаемого экологического и экономического эффекта и стоимости. Таким образом, для эффективного управления как рабочим процессом, так и двигателем в целом необходимо получать и обрабатывать информацию о различных физически разнородных процессах, протекающих в системах и агрегатах двигателя. Вся необходимая информация поступает от измерительных устройств, которые включают датчики, адаптеры и схемы обработки первичных сигналов.

В диссертационной работе приведен расчет цепи управления двигателем внутреннего сгорания автомобиля с учетом мехатронного адаптера кислородного датчика. Изменение элементов мехатронной системы может приводить к нестабильной работе системы впрыскивания топлива двигателя внутреннего сгорания. Рассмотрим один из элементов, датчик кислорода двигателя на выпуске. В зависимости от их сигнала также производится дозированной подачи топлива, его распыления в камере сгорания (впускном коллекторе) и образования топливно-воздушной смеси. При износе каталитических нейтрализаторов, неисправности самих датчиков кислорода или при замене катализаторов на другой тип Евро стандарта, могут возникать проблемы с адаптированием сигналов, получаемых от датчиков определения кислорода в составе отработавших газов.

Система впрыскивания топлива вместе с системой зажигания определяют состав и качество поджига рабочей смеси, влияют на динамику автомобиля, полноту сгорания топлива, топливную экономичность и, следовательно, на экологию окружающей среды. Для корректировки сигнала кислородного датчика можно использовать адаптер калибровки подаваемого сигнала на электронный блок управления при применении альтернативных типов катализаторов в место штатных различными типами Евро стандартов.

Работа мехатронного управления осуществляется следующим образом. В соответствии с заложенным алгоритмом электронный блок управления обеспечивает в нужный момент подачу импульса напряжения на инжектор и корректирует момент зажигания.

Казалось бы, задача адаптации кислородного датчика решается элементарно: доста¬точно к проводке датчика последовательно подключить дополнительное активное сопротивление. Однако такое решение - ошибочное: при возрастании R время t_{cp} подачи сигнала действительно снижается, но при отсутствии адаптации, это может привести к увеличению расхода топлива.

II ЗАКЛЮЧЕНИЕ

На основе результатов проведенного исследования по диссертации доктора философии (PhD) на тему "Обоснование эксплуатационных показателей двигателей автомоблей с мехатронной системой управления" предтавляется следующее заключение:

1. Разработана математическая модель мехатрон-

ного управления двигателем автомобиля учитывающая зависимость состава смеси при смене катализатора.

2. Создан алгоритм мехатронной системы управления двигателем с мехатронным адаптером кислородного датчика при различных комплектациях катализаторов Евро стандартов и выбора оптимальных режимов.

3. Обоснованы параметры внедренного мехатронного адаптера кислородного датчика электронной системы управления двигателя.

4. Обоснованы топливно-экономические и экологические показатели двигателей автомобилей с мехатронной системой управления при использовании мехатронного адаптера кислородного датчика.

5. Разработана методика выбора характеристик адаптера кислородного датчика в системе мехатронного управления двигателем автомобиля.

6. По результатам экспериментальных исследований определены величины максимальной мощности, крутящего момента, вредных элементов в составе отработавших газов и расхода топлива которое составило разницу в 8% улучшения в двигателе с мехатронным адаптером кислородного датчика относительно без его использования.

7. Создана технология адаптации системы мехатронного управления двигателем автомобиля с применением различных каталитических нейтрализаторов на автомобилях определённой платформы для производителей легковых автомобилей.

8. Внедрена и обоснована эффективность применение мехатронного адаптера кислородного датчика в системе управления двигателем для гибкого переоснащения каталитических нейтрализаторов.

9. Технико-экономический эффект от внедрения исследовательской работы в производственный процесс при производстве Nexia 3 (T250) в зависимости от использованного катализатора и Евро стандарта с адаптером кислородного датчика двигателя внутреннего сгорания, от одной машины составляет до 227,15$ долларов США. Это подтверждено справкой №07/06-25-870 от 26 мая 2021 года АК “Узавтосаноат”.

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ASSESSMENT OF EFFICIENCY OF MARKETING OF AUTOMOBILE ENTERPRISES

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Abstract– The article explores the theoretical and methodological basis for improving the efficiency of the marketing system of the automotive industry. Scientific proposals and practical recommendations for improving marketing efficiency with a methodological approach to performance evaluation based on criteria and indicators aimed at a comprehensive study of the factors influencing the effectiveness of the marketing system of automotive enterprises.

Key words– brand of automotive enterprises, competitiveness, marketing efficiency, marketing strategy, mass communication, export potential, marketing costs, marketing activities.

I Introduction

Today, the results of large-scale studies of the automotive market reflect the need for marketing activities aimed at studying the activities of the international and domestic markets, as well as the process of developing automotive enterprises, organizing a large part of production. at enterprises based on high technologies. It is especially important to analyze the results of a wide range of activities of competitors, customers, buyers and marketing intermediaries when assessing the marketing effectiveness of automotive enterprises. In this regard, it is necessary to formulate long-term and short-term marketing programs to study consumer behavior, processes associated with the level of nepotism in their consumption, dominating the market. It is also desirable to widely implement the results of international research institutes in order to improve the efficiency of the marketing system of the automotive industry. Extensive marketing research to improve the efficiency of the marketing system of the automotive industry has a positive effect on increasing the investment and innovation potential of enterprises and ensuring their competitiveness.

The effectiveness of the marketing system of automobile enterprises is assessed not by the level of prices, but by the process of ensuring a free competitive environment. President of the Republic of Uzbekistan Sh.M. Mirziyoyev said that the effectiveness of the marketing system depends on the competitive environment and price levels. In his Address to the Oliy Majlis on January 24, 2020, he said: "Now we must focus not on setting prices, but on reducing prices and improving quality by ensuring healthy competition between enterprises. It is necessary to study international experience and open up an opportunity for the private sector to monopolize areas in which competition can be introduced, and thereby create a competitive environment. A number of tasks and activities in this area serve to justify the relevance of marketing research aimed at increasing the investment and innovative potential of automotive enterprises, ensuring competitiveness, and increasing sustainable sales.

II Literature review

Extensive research in the field of increasing the efficiency of the marketing system of automotive enterprises, improving its areas of activity, increasing the work and market activity of industrial enterprises by foreign economists A.Bankin, G.Beckwit, S.N.Berdyshev, S.Bojuk, M.Gorshtein, A.Karasev, R.Fathuddinov, G.Harding, V.Shkardun and others.

Scientific-theoretical bases of relations with market participants and buyers in the study of market activity of industrial enterprises of the country, the role of internal and external marketing environment in the formation of marketing strategy of industrial enterprises from economists Sh.Ergashkhodjaeva, U.Sharifkhodjaev, M.Ikramov, L Researched by T.Abdukhalilova, N.M.Nabieva, S.A.Salimov, T.A.Akramov, G.B.Muminova and others.

The main purpose of the above research is to study the processes related to the targeted use of market factors in the formation of marketing strategy of industrial enterprises, the formation of marketing strategy to increase the efficiency of enterprises, the competitive advantage of the enterprise over consumer demand and competitors. However, the role of innovation factors in expanding the market opportunities of industrial enterprises, in particular, the processes of forming a targeted development strategy of marketing in the international competitive environment and expanding its role in national production through innovative orientation of automotive enterprises has not been studied as an independent research object.

RESEARCH METHODOLOGY

Scientific abstraction, induction and deduction, economic-mathematical modeling, expert evaluation, survey, SWOT-analysis, correlation, regression analysis, factor analysis (FIT index analysis) were used during the research.

III ANALYSIS AND RESULTS

In the organization of innovative marketing activities of the automotive industry, first of all, transport companies need to have innovative transportation technologies, programs to create innovative products or services in the service process, and to move through innovative methods. It is based on the diagnosis of innovative marketing potential in the implementation of marketing activities aimed at improving the safety of enterprises providing modern transport services to the population and the formation of an ecological culture. In general, we should consider innovative marketing activity as a management concept aimed at the effective use of the opportunities and resources of the enterprise, which can be achieved through the creation and implementation of innovations and the satisfaction of consumer needs. Innovative marketing potential is manifested as a process of testing innovative marketing activities. Therefore, in order to increase the effectiveness of innovative marketing, first of all, it is necessary to systematically study the increase and development of its potential. Innovative marketing potential is part of the overall economic potential of the enterprise. Including the economic potential of the enterprise, the marketing potential and the innovation potential, they form the basis for complementarity. Therefore, in the systematic study of innovative marketing potential, it is necessary to better understand the essence of the concepts of "economic potential of the enterprise", "Marketing potential" and "Innovative potential".

The potential of the enterprise is all the opportunities to meet the needs of the population in goods and services at a high level, using the available resources wisely. In a number of economic studies, the economic potential of the enterprise is recognized as a separate object of study. Competitiveness of the enterprise increases the market potential and efficiency of its use, which is one of its private economic potentials. The marketing potential of the automotive industry means, first of all, its internal system, and the ability to implement its strategies is expressed through the decisions made in this regard.

To determine the effectiveness of marketing activities of the enterprise, first of all, it is necessary to develop a system of indicators. The effectiveness of determining the effectiveness of marketing activities of the enterprise must ensure the implementation of its economic and financial, market activities, strategic and tactical plans, the achievement of positive results of domestic and foreign trade.

It is expedient to determine the effectiveness of innovations in the automotive industry by dividing them into a number of blocks on the basis of a general economic analysis, taking into account the findings of the study. The following additive model is recommended to determine whether the marketing strategies implemented by the enterprise increase or decrease the efficiency of economic activity over a period of time:

$$\Delta P_1 = P_{1n} - P_{1n-1} \tag{1}$$

Here:

ΔP_1 - absolute growth (decrease) of enterprise market activity;

P_{1n} - the result of the implementation of marketing strategies of the enterprise sums;

P_{1n-1} - the result of the current marketing activities of the enterprise, sums.

A number of methods for determining the effectiveness of the results of marketing activities at the enterprise, a comprehensive system of evaluation criteria in 3 areas by the nature of performance indicators, i.e. indicators of changing customer relationships; development of market activity of the enterprise as a result of marketing activities; financial and economic indicators of the marketing activities of the enterprise.

Factors enabling the automotive industry to generate innovative marketing potential include:

1. Reflecting the growing share of innovative services for all players in the automotive services market;

2. Application of innovative transport technologies and marketing management in the automotive industry to ensure the creation and promotion of innovations;

3. Maximum satisfaction of the needs of market participants, taking into account the totality of enterprises engaged in innovative marketing activities, in particular, the promotion of innovative activities of an enterprise, consisting of human capital and internal entrepreneurs.

In our opinion, the innovative marketing potential of motor transport enterprises can be considered as a combination

Countries	2019 y.*			2020 y.*			2025 y.		
	Thousands of units	Share of Uzbekistan %	Export of Uzbekistan, thousands of units	Thousands of units	Share of Uzbekistan %	Export of Uzbekistan, thousands of units	Thousands of units	Share of Uzbekistan %	Export of Uzbekistan, thousands of units
Russia	3572,1	3,5	125	4035	3,3	133,2	4193	3	125,9
Kazakhstan	305,7	7,8	23,8	406,9	8	32.5	490,2	8,1	39,7
Turkmenistan	27,6	2,5	0,69	44,2	3	1,33	81,4	4	3,3
Kyrgyzstan	25,9	1	0,26	41,5	1,2	0,49	76,3	1,2	0,9
Ukraine	761	3	22,8	1040	3,1	32,2	1313,7	3,1	40,7
Belarus	29,4	3,5	1,03	35,9	3,5	1,25	46,7	3,7	1,7
Moldova	13,5	1,5	0,2	20,5	2	0,41	28,8	2	0,6
Total	4735,2	x	173,78	5624	x	168,88	6230,1	x	212,8

Fig. 1: Forecast of the volume of the car market of countries importing cars from Uzbekistan

of factors related to material resources, human resources, information and marketing tools.

Research on the study and assessment of the innovative marketing potential of automobile enterprises should have a clear methodology for assessing the factors influencing the marketing system, and the indicators chosen by them.

Based on all of the above ideas and comments on the methodology for assessing the innovative marketing potential of the automotive industry, the methodology for assessing the innovative marketing potential of the automotive industry with its material and resource potential, human resources, information resource potential and marketing. tools are offered. As a result, the innovative marketing potential of the automotive industry is estimated using the following formula:

$$P = f1(P1, P2, P3, P4, P5) \qquad (2)$$

Here:
P1 - the innovative potential of the automotive industry;
P2 - material and resource potential of the automotive industry;
P3 - human resources of the automotive industry;
P4 - information resource potential of the automotive industry;
P5 - the potential of marketing tools for the automotive industry.

This formula, along with an assessment of the innovative marketing potential of the automotive industry, serves to substantiate the possibility of a positive expression of all economic indicators and the achievement of energy efficiency.

The analysis shows that Uzbekistan's exports have declined significantly in recent years. Accordingly, the development of a marketing strategy focused on the external market was based on two types, namely the traditional and evolutionary approaches.

Judging by the dynamics of the market development in the CIS countries, if the competitiveness of domestic cars increases, the total volume of exports in 2020 may reach 300-350 thousand units. It is a targeted strategy based on vehicle production capacity without considering local market demand. This indicates that if such a situation is observed, a further increase in production capacity is necessary.

Taking into account the forecast of domestic demand in the CIS countries, it is necessary to increase double the production capacity of cars. However, the risk level of this scenario is high because the ongoing engineering projects in Russia and the expected results will further increase the risk level given their restrictions on car imports.

In an evolutionary scenario, the marketing strategy was developed based on realistic export forecasts. According to the analysis of the market opportunities of the countries that are the main consumers of Uzbek cars, the market volume in 2020-2025 will reach 5624 and 6230 thousand units (Figure 1).

To achieve the main goals of the evolutionary scenario, Uzbekistan must maintain a 3% share in Russian imports. This will allow Uzbekistan to increase the production of cars by 125 thousand units per year.

There is an opportunity to increase the production of cars in Uzbekistan over the next 5 years by 162% by increasing the production of automated models of cars of categories A, B, C, updating the technical aspects of cars, such as convenience and safety, automatic adjustment.

In the future, improve the marketing activities of the industry, including the organization of production of new models of cars on the basis of a single unified platform, the development of targeted programs to attract investment and attracting preferential credit lines from foreign banks and export credit agencies to finance localization projects It is advisable to implement the measures in a systematic manner.

According to scientific research, the search and production of new sales markets and new products that create consumer demand, differing in novelty, quality, consumer qualities, is of vital importance. JSC Uzavtosanoat needs to have reserves for at least 3-5 years in order to succeed in the global market and predict the return on investment. Delay to market essentially lengthens the product's life cycle in the market or in the growth phase, and the strategies chosen generally fail. Therefore, the proposed marketing strategy should be considered as the main approach to solving these problems.

Marketing strategy structure: competitive challenges in the market; marketing opportunities; tasks in the field of automotive production; areas of activity. Based on the marketing concept of development of JSC "Uzavtosanoat", a marketing strategy was developed in various directions, which consists of the following (Figure 2).

Fig. 2: Marketing concept of development of JSC "Uzavtosanoat"

When developing marketing strategies in the automotive industry, one should take into account the effectiveness of factors affecting the activities of the enterprise. On the basis of this strategy, the tasks at the enterprises of the automotive industry, specific areas of activity are outlined. Before determining the effectiveness of the marketing activities of enterprises in the automotive industry, it is necessary to understand, first of all, that this activity depends on human, logistics, information and organizational resources, which are the main tasks facing the enterprise

IV CONCLUSION AND RECOMMENDATIONS

Modernization of the economy, technical and technological renewal of production requires further development of economic activity in the economy of the country and its enterprises. This can be achieved by organizing marketing activities in industrial enterprises and increasing its efficiency.

The experience of large firms in economically developed countries shows that marketing activities allow businesses and organizations to survive and increase productivity. The implementation of marketing activities depends on the development of the theory and practice of marketing. The development of the theory and practice of marketing directly depends on the directions of marketing research and research. Every industrial enterprise, along with various activities, must pay great attention to marketing activities and constantly improve them.

The effectiveness of reforms related to the radical improvement of the automotive industry in our country requires an increase in the work and market activity of the industry. The work and market activity of the industry are directly related to the investment process, its efficiency and capacity, which is reflected in the massive placement of shares of joint-stock companies on the domestic and international stock markets.

The market activity of the automotive industry requires an increase in the efficiency and quality of products, an increase in the export potential of enterprises, an increase in their competitiveness in international and national markets through the use of market marketing strategies.

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