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# METHOD OF RUNNING DIAGNOSTICS OF THE MOTOR VEHICLE BRAKE SYSTEM

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**ABSTRACT**

This work considers the method of the running diagnostics of the motor vehicle brake system. The objective of the work is to develop the theoretical and methodical procedure of the running diagnostics of the brake system of motor vehicles (MV). The main idea of the offered diagnostics method is the estimation of the technical condition of the motor vehicle brake system by recording of the changes of parameters that are the characteristics of the operation (brake) properties of the vehicle. The design brake diagram of a vehicle was formed on the base of the accepted restrictions and allowances. The offered mathematical model was composed on the base of the analysis of the plane system of forces influencing the vehicle during the deceleration process. It is offered to use a complete or partial absence of the deceleration of one wheel (or several wheels simultaneously) as a criterion of a failure of the brake system of a vehicle. The detection of the causes of absence of deceleration of one wheel (or several wheels simultaneously) is performed during the profound diagnostics on the fixed diagnostic equipment at the motor transport enterprise.

**Keywords:** running diagnostics, braking properties, mean fully developed deceleration, mathematical modeling.

## 1. INTRODUCTION

The efficient control process of the vehicle operation system is based upon the continuous, complete and accurate information of the internal changes of the systems and mechanisms of a motor vehicle. The sufficient quality of this information allows making the grounded decisions regarding the technical maintenance and repair of the vehicles.

Now, two types of information are widely used when making decisions of the technical operation of vehicles: probability (statistic) information and individual (diagnostic) information. The first one characterizes the state of the set of objects (vehicles, units, parts) and gives an idea of the average values, and the second one characterizes the state and indicators of work of a particular object - a whole vehicle, unit, part [1].

The diagnostic information is of the biggest interest from the point of view of obtaining of the operation and continuous information of the condition of such system of the vehicle as a brake system.

The review of the scientific and technical literature and also the field of the practical use of the motor vehicles shows that the development of the methods and means of diagnostics of the brake system is performed in two main directions: stationary and running, that is also called vehicle-borne [2-4]. The stationary diagnostics is understood as a diagnostics that is performed by the means structurally made separately from the object. The running diagnostics is a diagnostics performed, firstly, during the motion of the MV along the road and, secondly, by means being an integral part of an object, that is the means built-in into the object.

Until now the first direction was mostly applied because the main attention was paid to the development of the methods and means of estimation of the technical condition of the MVs that were sent directly to the maintenance and repair [5]. Despite the advantages of the running diagnostics in comparison with the stationary one, it is still not widely used. The main reason of this is the absence of the sufficiently developed theoretical and methodic procedures of the running diagnostics allowing performing the diagnostics of the brake system of MV with high accuracy and at minimal costs.

This work offers the method of running diagnostics allowing providing the continuous control of the condition of the vehicle brake system instead of the discrete control that is used during stationary diagnostics.

The basis of the development of the theoretical procedure of the offered method of the running diagnostics of the vehicle brake system is a mathematical model of the motion of three-axis MV, because the mean fully developed deceleration $j_{dd}$is used as a diagnostic parameter [6].

A similar diagnostic parameter in the Appendix 4 “Tests and characteristics of the brake systems” to the Regulations 13 UNECE E/ECE/324 - E/ECE/TRANS/505 is called mean deceleration [7].

The use of the mean fully developed deceleration $j_{dd}$ as a diagnostic parameter is based upon the following ideas.

The occurrence of failures in the brake system during the operation of a motor vehicle leads finally to the decrease of the braking forces and that causes, in its turn, the decrease of the mean fully developed deceleration $j_{dd}$. Comparing the current value $j_{dd}$ with the standardized values of the mean fully developed deceleration for the particular conditions of deceleration, one can determine not only a general condition of the brake system on the whole and consequently to estimate the braking properties of the motor vehicle but to localize the point of failure with a sufficient accuracy. In this case, the performing of the running diagnostics of the braking properties of a motor vehicle is divided into two stages. The first stage provides the determination of the general efficiency of the braking properties of motor vehicles according to a rate

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parameter, i.e. mean fully developed deceleration $j_{dd}^{N}$. If during the first stage the non-conformity $j_{dd}$ to the specified parameters will be revealed, during the second stage the identification of the failure of the brake system is performed according to the degree of decrease $j_{dd}$.

Thus, the mean fully developed deceleration$j_{dd}$ as the main complex diagnostic parameter will allow to determine not only a general technical condition of the brake system and its performance but also to localize the point of failure.

## 2. METHOD

Considering the methodology as a set of methods applied when performing the present research, the following can be noticed. Two main methods are used in this work: a method of running diagnostics of the brake system and a method of mathematical modeling of the motion of the object under analysis (three-axis motor vehicle).

### 2.1. Notion of the running diagnostics of brake system

As it has already been mentioned that in this work, the running diagnostics is understood as the diagnostic, firstly, during the motion of a MV along the road and, secondly, by means being an integral part of the object, that is the means built-in into the object. The main element of the running diagnostics is that it is performed in a real-time mode [8].

The essence of the running diagnostics is that in the operation conditions of a motor vehicle on route the indirect parameters are measured characterizing the level of functioning of the brake system of a motor vehicle. Comparing these parameters with the tolerance limit or their limit values the technical condition of the brake system of the motor vehicle is estimated.

During the running diagnostics, the loading and rate modes of the motor vehicle are not imitated but they are realized in the real street conditions during the operation of a motor vehicle.

During the running diagnostics, for the estimation of the functionality of the brake system of a motor vehicle the output parameters are used on the basis of which a general diagnosis of the type “yes”, “no” (“valid”, “non-valid” or, in other words, a wheel or group of wheels “decelerate”, “do not decelerate”). On the base of such diagnosis, a more profound diagnosis based upon the localization of a particular failure is required to determine the necessity of the repair and regulating operation. The search of the particular failure of the brake system shall be performed at the motor transport enterprise.

Thus, the early recognition of the failures of the brake system is achieved, the importance of which for the increase of the reliability of a motor vehicle and road traffic safety provision is without any doubt [9].

When performing the running diagnostics of the brake system, it is offered to use the mean fully developed deceleration $j_{dd}$ as a main diagnostic parameter, and the rotational speed [omega]$_z$ of the vehicle turn regarding its own axis of rotation z as an additional diagnostic parameter. The quantitative value of the mean fully developed deceleration $j_{dd}$ allows estimating the technical condition of the brake system of a motor vehicle according to such criterion as one or several wheels “decelerate” - “do not decelerate”. By means of the additional diagnostic parameter [omega]$_z$, it is determined on which side the wheel does not decelerate, for example, a front right or front left wheel.

When performing the running diagnostics it is important to notice that accumulating the information concerning the change of the structural parameters (gaps, dead strokes, etc.) it is possible to forecast to some extent the change of a technical condition of the brake system excluding the unexpected failure of the brake system and, as a result, the unexpected repair of the motor vehicle [10].

### 2.2. Mathematical modeling of motor vehicle deceleration

#### 2.2.1. Restrictions and allowances

The complexity and degree of approximation of the mathematical model of the motor vehicle motion to the real object is determined, first of all, by the objectives of the solving problem. To solve the most of problems connected to the operation properties of the motor vehicle it is enough to have a two-dimensional model of the motion. So to solve the problems of the brake dynamics of a motor vehicle, in particular, to estimate the efficiency of the brake properties, it is sufficient to use the analytical model [11], composed on the base of the analysis of the plane system of forces applied on the motor vehicle during deceleration.

When choosing the two-dimensional design diagram of traffic it is considered that the motor vehicles have three degrees of freedom: linear movements in the longitudinal and transverse direction in the plane of the road and turn of the motor vehicle regarding the vertical axis coming through the centre of mass of a vehicle. The two-dimensional model is rather often used for the theoretical research of the motion of a vehicle during deceleration [12].

To simplify the mathematical model of the motion of a motor vehicle when composing it, some allowances were accepted: the plane system of forces is considered that is applied to the motor vehicle during motion; the centres of mass of the motor vehicles and their spring-mounted parts are located in the vertical symmetry plane; the motor vehicles are accepted as rigid, every of two wheels of the axis are loaded with the same forces (normal, periphery and side).

When composing the design diagrams of the brake processes of motor vehicles, the forces of road resistance $P_f$and the forces of air resistance $P_w$are not taken into account due to their low value. The force of road resistance is taken into account usually when studying the braking dynamics during the motion of a motor vehicle in the heavy road conditions on the unsurfaced roads during the muddy season, on the dry sand, on the loamy and clay-loam soil in the current condition, because in these conditions the coefficient of rolling resistance $f$ accepts the

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highest values. In other conditions, that is when it is more reasonable to perform the running diagnostics of the brake properties (for example, the asphalt road), $P_f$cannot be taken into account due to the low value of *f*.

The air resistance force $P_w$ is also a low value that is not taken into account when performing the calculations of deceleration of motor vehicles from the low initial rates and also the motor vehicles with the centre of effort located low and rather good air shape.

Thus, when composing the design deceleration diagram of a motor vehicle, the following additional allowances are accepted: the air resistance forces and road resistance forces and also the moments of road resistance and inertia moments of wheels are not taken into account due to their low priority (max 3% of the brake forces); emergency deceleration is considered that is performed by the brake system only that means the friction force in the engine applied to the driving wheels $P_d = 0$; the road-tire contact is point, adhesion coefficient [fi]$_x$ is accepted as the same for all wheels; the deceleration is performed with the complete use of the adhesion force. We would like to pay attention to the latter because the maximal value of the degree of use of the adhesion weight on the limit of the blocking of wheels is also a criterion of the optimal functioning of the brake system not only in this work but in the other similar researches as well [12].

### 2.2.2. Design diagram of deceleration of a three-axis motor vehicle

To compose the design diagram of the motion of a motor vehicle it is accepted that the origin of coordinates is in the centre of mass of the motor vehicle to which the moving coordinate system is connected *Oxyz* (Figure-1) [13]. Positive direction along the axis *x* is considered in the direction of the motion of the motor vehicle, and along the axis *y* in the direction of the instantaneous center of turn. The clockwise rotation is accepted as a positive direction of the link rotation, if we look from the positive direction of the axis *z* to the origin of the coordinates.

Index *i* corresponds to the number of the axis (*i* = 1, 2, 3), and index *k* corresponds to the right (*k* = 1) and left (*k* = 2) wheels of the same axis.

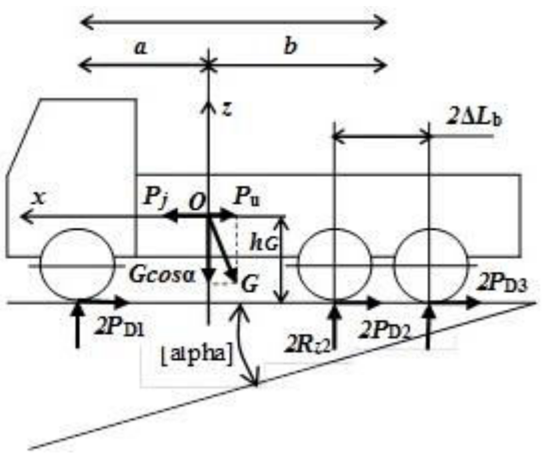


**Figure-1.** Design diagram of deceleration of three-axis motor vehicle.

### 2.2.3. Forces acting on motor vehicle during deceleration

On the base of the accepted allowances, the tangential component $P_{xik}$ of the road reaction is presented by the brake force only $P_{Dik}$ (see Figure-1), that is expressed by the following in the function of the maximal adhesion coefficient [fi]$_x$

$$P_{\mathrm{D}ik} = \varphi_x R_{zik} , \tag{1}$$

where $P_{Dik}$ is the brake force on the *ik* wheel; [fi]$_x$ is the adhesion coefficient of the wheel with the road reduced to the conditions of deceleration; $R_{zik}$is a normal reaction of the road acting on the wheel *ik* of the motor vehicle.

The gravity force *G* is applied to the centre of mass of the motor vehicle and also the inertia force $P_j$ of the reciprocating masses directed in the opposite way to the acceleration (deceleration).

Gravity force

$$G = Mg , \tag{2}$$

where *M* is a mass of the motor vehicle; *g* is a free-fall acceleration.

Inertia force

$$P_j = Mj_x , \tag{3}$$

where$j_x$is a longitudinal acceleration (deceleration) of a motor vehicle.

To take into account the impact made upon the brake dynamics of a motor vehicle of the longitudinal slopes of the motor ways, in the design diagram the resistance force to the uphill $P_u$is taken into account.

$$P_u = G\ sin\alpha, \tag{4}$$

where [alpha] is an angle characterizing the uphill gradient (slope gradient) of the road.

### *2.2.4. System of motion equation of motor vehicle*

Motion equations of the motor vehicle can be obtained using the equations of plane motion of a solid body according to D'Alambert's principle.

The system of equations describing the motion of the three-axis motor vehicle along the flat horizontal surface is the following:

$$\begin{aligned} Mj_x &= \sum_{i=1}^{3}\sum_{k=1}^{2} P_{xik} , \\ Mj_y &= \sum_{i=1}^{3}\sum_{k=1}^{2} P_{yik} , \\ J_z\dot{\omega}_z &= \sum M_z , \end{aligned} \tag{5}$$

where *M*is the mass of a motor vehicle; $J_z$ is an inertial moment with respect to the vertical axis of rotation *z*; $j_x$, $j_y$ are the projections of the linear accelerations of the centre

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of mass of a motor vehicle accordingly along the axes *x* and *y*; [omega]$_z$ is an angular acceleration of a motor vehicle regarding the vertical rotation axis *z*; $\sum_{i=1}^{3}\sum_{k=1}^{2}P_{xik}, \sum_{i=1}^{3}\sum_{k=1}^{2}P_{yik}$ is a sum of projections correspondingly to the axis *x* and *y* of all forces applied to the wheel *ik*; $\sum M_z$ is a sum of moments regarding the vertical rotation axis *z*.

## 3. RESULTS

### 3.1. Calculation of analytical dependencies for the estimation of brake properties of motor vehicles

#### 3.1.1. Determinations of normal road reactions during deceleration of a three-axis motor vehicle

Using the design diagram of deceleration of the three-axis motor vehicle (Figure 1) and the system of equations (5), the equation of motion of the three-axis motor vehicle during deceleration at the slope can be shown by the following:

$$\mathrm{Mj_x} = \mathrm{P_{D11}} + \mathrm{P_{D12}} + \mathrm{P_{D21}} + \mathrm{PD_{D22}} + \mathrm{P_{D31}} + \mathrm{P_{D32}} \pm P_u, \quad (6)$$

The sign (+) in the formula (6) means that deceleration is performed during the slope motion, the sign (–) means that deceleration is performed during the uphill motion.

The equation (6), transformed taking into account the equations (1) and (4), will look the following:

$$\mathrm{Mj_x} = (\mathrm{R_{z11}} + \mathrm{R_{z12}})\varphi_x + (\mathrm{R_{z21}} + \mathrm{R_{z22}})\varphi_x + (\mathrm{R_{z31}} + \mathrm{R_{z32}})\varphi_x \pm \mathrm{G}\sin\alpha, \quad (7)$$

Normal road reactions between the right and left wheel of the same axis

$$\mathrm{R_{zi1}} = \mathrm{R_{zi2}} = \mathrm{R_{zi}}, \quad (8)$$

and also between the axes of the bogie of the three-axis motor vehicle

$$2\mathrm{R_{z2}} = 2\mathrm{R_{z3}} \quad (9)$$

are considered the similar in the static condition and during motion as well.

Taking into account the accepted allowances the system of balance equation of deceleration of the three-axis motor vehicle is the following:

$$2\mathrm{R_{z2}}(L - \Delta L_D) + 2\mathrm{R_{z3}}(L - \Delta L_D) + Mj_x h_G = aG\cos\alpha \pm h_G G\sin\alpha,$$
$$\sum_{i=1}^{3} \mathrm{R_{zi}} = G\cos\alpha, \quad (10)$$
$$2\mathrm{R_{z2}} = 2\mathrm{R_{z3}},\ \mathrm{R_{zi1}} = \mathrm{R_{zi2}}$$

where *a*, *b* are a distance from the centre of mass of the motor vehicle till the front axle of the motor vehicle and the middle of the rear bogie; *L* is a base of the motor vehicle; $L = a + b$; $h_G$ is the height of the centre of mass of the motor vehicle; $\Delta L_D$ is a distance from the middle of the rear bogie till the front or rear axle of the rear bogie. When the system of equations is solved (10) the equations for determination of the normal road reactions can be obtained during the deceleration of the three-axis motor vehicle taking into account the redistribution of the load along the axes during deceleration

$$R_{z1} = \left[bG\cos\alpha + h_G(Mj_x \pm G\sin\alpha)\right]/2L, \quad (11)$$

$$R_{z2} = \left[aG\cos\alpha - h_G(Mj_x \pm G\sin\alpha)\right]4L, \quad (12)$$

#### 3.1.2. Criterion of the failure of motor vehicle brake system

This work does not consider the systems of activation of brakes (hydraulic, pneumatic or others) [14] and all the chain of reasons causing the occurrence of these or those failures is not analyzed as a result of which the brake properties of a motor vehicle do not correspond to the specified parameters. The main attention is focused upon the following. During operation, some failures occur in the brake system of a motor vehicle, the result of which is that one or several wheels at the same time do not decelerate during the motion of the motor vehicle. Thus, in the offered method of the running diagnostics of the brake system the criterion of failure of the brake system is a complete or partial absence of deceleration on one wheel (or on several wheels simultaneously). As an illustration of the above said in this work, the following several variants of the absence of deceleration of the wheels were considered.

1. One front wheel does not decelerate: $P_{D1}=0$.
2. One rear wheel does not decelerate: $P_{D2}=0$.
3. Only one front wheel decelerates:
$P_{D1}=0$, $2P_{D2}=0$, $2P_{D3}=0$.
4. Only one rear wheel decelerates:
$2P_{D1}=0$, $2P_{D2}=0$, $P_{D3}=0$.
5. Only front wheels decelerate:
$2P_{D2}=0$, $2P_{D3}=0$.
6. Only rear wheels decelerate:
$P_{D1}=0$, $2P_{D2}=0$.
7. Wheels decelerate on one side only:
$P_{D1}=0$, $2P_{D2}=0$, $P_{D3}=0$.

The distribution of the total brake force $P_{T\Sigma}$ along the axes of the motor vehicle till the moment of the blocking of the wheels for the existing brake systems of the motor vehicles is always constant.

$$P_{D\Sigma} = 2P_{D1} + 2P_{D2} + 2P_{D3}. \quad (13)$$

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Consequently, the absence or decrease of the brake force $P_{Di}$on the wheel *ik* leads to the decrease of the total brake force $P_{T\Sigma}$ that in its turn causes the decrease of the mean fully developed deceleration $j_{dd}$ in comparison with the normative values of the brake system in good order.

### 3.1.3. Design analytical dependencies for technical condition estimation of motor vehicle brake system

Solving together the system of equation (10) and equations (7, 11-13), the equations for the determination of the mean fully developed deceleration $j_{dd}$ the three-axis motor vehicle can be obtained that are the basis of the localization of the occurrence of these or those failures of the brake system of the motor vehicle.

**1.** One front wheel does not decelerate

$$P_{D1} = 0; P_{D\Sigma} = P_{D1} + 2P_{D2} + 2P_{D3},$$

Then

$$P_{D\Sigma} = 2P_{D1} + 2P_{D2} + 2P_{D3} = Mj_x \pm G\sin\alpha.$$

From which

$$j_1 = \{\vartheta[\varphi_x(L+a)\cos\alpha \pm (3h_G\varphi_x + 2L)\sin\alpha]\}/(2L + h_G\varphi_x), \quad (14)$$

**2.** One rear wheel does not decelerate

$$P_{D3} = 0; P_{D\Sigma} = P_{D1} + 2P_{D1} + 2P_{D2} + P_{D3}.$$

Then

$$P_{D\Sigma} = P_{D\Sigma} = 2P_{D1} + 2P_{D2} + P_{D\Sigma} = Mj_x \pm G\sin\alpha.$$

From which

$$j_2 = \{\vartheta[\varphi_x(L+2b)\cos\alpha \pm 2(2h_G\varphi_x + L)\sin\alpha]\}/[2(L + h_G\varphi_x)]. \quad (15)$$

Similarly, the equations are solved for the determination of the mean fully developed deceleration $j_{dd}$ in all the other considered cases.

**3.** Only one front wheel decelerates

$$j_2 = \{\vartheta[b\varphi_x\cos\alpha \pm (h_G\varphi_x + 2L)\sin\alpha]\}/[2(L - h_G\varphi_x)]. \quad (16)$$

**4.** Only one rear wheel decelerates

$$j_4 = \{\vartheta[a\varphi_x\cos\alpha \pm (h_G\varphi_x + 4L)\sin\alpha]\}/[4(L - h_G\varphi_x)]. \quad (17)$$

**5.** Only front wheels decelerate

$$j_5 = \{\vartheta[b\varphi_x\cos\alpha \pm (h_G\varphi_x + L)\sin\alpha]\}/[(L - h_G\varphi_x)]. \quad (18)$$

**6.** Only rear wheels decelerate

$$j_6 = \{\vartheta[a\varphi_x\cos\alpha \pm (h_G\varphi_x + L)\sin\alpha]\}/[(L + h_G\varphi_x)]. \quad (19)$$

**7.** Wheels decelerate on one side only

$$j_6 = \{\vartheta[\varphi_x\cos\alpha \pm (h_G\varphi_x + 2L)\sin\alpha]\}/2L. \quad (20)$$

Thus, because of undershoot, due to the failures, the total brake force and consequently, due to the decrease of mean fully developed deceleration of a motor vehicle in comparison with the normative one during the emergency deceleration, we can determine not only the efficiency of the brake properties of a motor vehicle on the whole, but to reveal the failures in the brake system of the motor vehicle, that is when one or several wheels do not decelerate.

The reveal of such failures of the brake system is especially true for the motor vehicles having several axles - three and more. It is due to the fact that a driver during the motion of a motor vehicle cannot always adequately determine organoleptically what wheel does not decelerate.

Excluding the human factor [15] from the diagnostics process of failures of the brake system, we can obtain the objective estimation of the condition of the brake system that is especially important in the complicated road situations (for example, in the emergency situations and unfavourable weather conditions).

### 3.2. Analysis of technical condition estimation of brake system

The analysis of the running diagnostics of the brake system of the particular types of three-axis motor vehicles was performed on the base of use of the mathematical deceleration model of a motor vehicle. Several models of the single motor vehicles were chosen for research. As an illustration of the conducted analysis of the running diagnostics of the brake system, the vehicle KAMAZ-5350 will be considered. The results of the conducted researches are shown in the form of graph in the Figure-2.

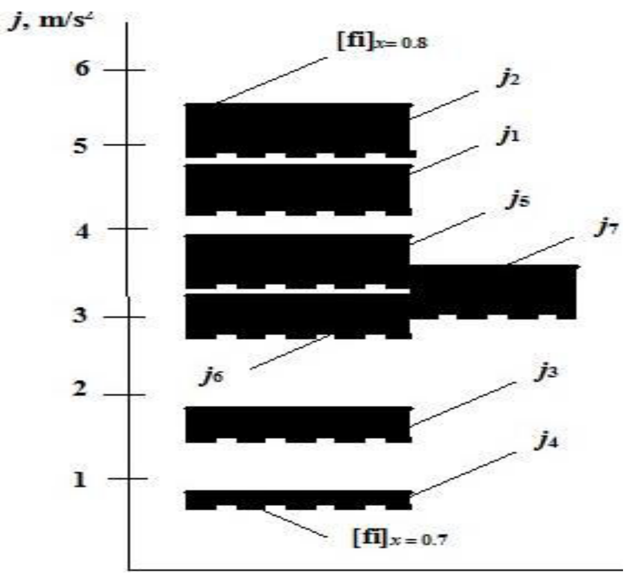


**Figure-2.** The zones of distribution of the mean fully developed deceleration $j_{dd}$ during the deceleration of the three-axis motor vehicle: $j_1$ - one front wheel does not decelerate; $j_2$ - one rear wheel does not decelerate; $j_3$ - one front wheel decelerates only; $j_4$ - one rear wheel decelerates only; $j_5$ - front wheels decelerate only; $j_6$ – rear wheels decelerate only; $j_7$ wheels on one side decelerate only.

Figure-2 shows the zones of distribution of the mean fully developed deceleration $j_{dd}$ during the deceleration of a KAMAZ-5350 depending upon the availability of the failures in the brake system of a motor vehicle. In this case, the variant of deceleration on the dry asphalt surface with the adhesion coefficient $[fi]_x$ = 0.7…0.8 was considered. This variant was chosen because on the dry asphalt-concrete roads the decrease of the adhesion forces is rather low, but on the slippery roads the decrease $[fi]_x$ can reach up to 50% in comparison with the realized wheels skidding at optimal mode [19].

As we can see from the Figure-2, the whole range $j_{dd}$ of the mean fully developed deceleration $j_2$ (one rear wheel does not decelerate) is bigger than of the mean fully developed deceleration $j_1$ (one front wheel does not decelerate). The upper boundary of the zone for all $j_{dd}$ corresponds to [fi] = 0.8, and the low border [fi] = 0.7. Thus, the whole range [fi] $j_2$ corresponding to the dry asphalt can be easily determined according to the value $j_{dd}$ that according to the value $j_1$ or $j_2$ one front or one rear wheel does not decelerate. However, $j_{dd}$ does not provide the information what wheel - right or left - does not decelerate. Therefore, to perform the more complete diagnostics of the technical condition of the brake system it is necessary to introduce the second, additional parameter, i.e. rotational speed $[omega]_z$of the turn of a motor vehicle regarding its own rotation axis $z$ [16-17]. The possibility to use is when $P_{Dik}$ is absent there is an additional rotation moment $M_{Dz}$ on the right or left wheel acting regarding the axis in the direction of the wheel where the $P_{Dik}$ is absent. The occurrence of $M_{Dz}$ causes the appearance of the rotational speed $[omega]_z$ regarding the axis $z$. According to the direction $[omega]_z$, i.e. according to its sign, it is determined which wheel does not decelerate, right or left. The rotational speed can be determined directly by measuring using the existing technical devices (for example, angular rate sensor).

Analyzing the possibility of the estimation of technical condition of the brake system by means of the offered running diagnostics method, the following should be mentioned. If the brake system of a motor vehicle is in such condition that only one front wheel ($j_3$) or only one rear wheel ($j_4$) decelerates of the distribution zone $j_{dd}$ , also [fi] does not cross along the whole range for the dry asphalt (see Figure 2). It can be easily determined what wheel decelerates (front or rear wheel and on what side - right or left) (similarly to $j_1$ and $j_2$) according to their value (i.e. according to $j_3$ or $j_4$) and direction $[omega]_z$.

As we can see from the Figure-2, in case when only the front wheel decelerates ($j_5$), only rear wheels decelerate ($j_6$), and the wheels on one side decelerate only ($j_7$), the zones $j_5 - j_7$ overlap. In this case, there is uncertainty that prevents the detection of the failure in the brake system, to reveal which the boundary condition shall be determined [18]. For this purpose, to perform the diagnostics and identification of the failures of the brake system it is necessary to use the additional diagnostic parameter $[omega]_z$, by means of which at the first stage of the diagnostics the zone $j_7$ is separated (when $M_{Dz}$and $[omega]_z$ occur) from the zones $j_5$ and $j_6$, where $M_{Dz}$and $[omega]_z$ are absent. At the second stage of the diagnostics, the failure is detected by means of determination of the corresponding mean fully developed decelerations $j_7$ or $j_5$ - $j_6$ that differ from each other by their value along the whole range $[fi]_x$ and their estimation is not complicated.

### 3.3. Technical facilities of running diagnostics

The offered method of running diagnostics is based upon the measurement and analysis of the information about the current technical condition of the brake system of a motor vehicle by means of the control and diagnostic means and upon the decision made according to the specially developed diagnostic algorithms. The base of the development of the running diagnostics algorithms is a mathematical model of motion of a motor vehicle during deceleration.

The sensors of longitudinal acceleration and rotational speed are used as the means of obtaining information while using the offered method of estimation of the technical condition of the brake system. The current values of these diagnostic parameters accepted by them such as mean fully developed deceleration $j_{dd}$ and rotational speed $[omega]_z$will be transformed into a signal convenient for the processing in the information and computer device, for example, on the base of microprocessor devices or programmable logical controllers (PLC) [20] and the following representation of the results of the diagnostics in the device (counter-pointer instrument, digital indication, monitor screen). Graphical User Interface can significantly facilitate the actions of a driver when making decision about the time of elimination of the revealed failure, the repair at site or at the motor transport enterprise, or even the necessity of the immediate stop of the motor vehicle if, for example, any smart-device is used with the Internet connection [21]. The existing network technologies (for example, Wi-Fi and cellular communication) allow coming to the creation of the intellectual transport systems in perspective [22].

## 4. DISCUSSIONS

The obtained results allow making the particular conclusions. First of all, it concerns the principal possibility to perform the diagnostics of the brake system of a motor vehicle during its motion along the road, carried out by the technical means built-in into the vehicle. The design and analytic dependencies obtained on the base of the mathematical model of deceleration of the motor vehicle allow extending the boundaries of the theoretical field of diagnostics of the technical condition of the vehicle brake system. The main idea of the offered method of diagnostics is the estimation of the technical condition of the vehicle brake system by means of record of the change of parameters that are the characteristics of the vehicle operation (brake) properties.

The practical value of the obtained design and analytic dependencies is that they are a base for the creation of structural and functional diagrams of the estimation of the technical condition of the vehicle brake system.

However, despite the achieved positive results, this method has some restrictions. In comparison with the fixed diagnostic test-bench, the results of the running diagnostics cannot show the high accuracy and stability. First, it can be explained by the fact that the results depend mostly upon the road conditions. On public roads, it is not always possible to find a special measuring area of the required length with a particular adhesion coefficient of tires. Besides, it is also rather difficult to give an accurate determination of the centre of mass during the motion of the vehicle especially for the truck vehicle transporting the cargo of various classes during the shift. The mentioned circumstances to a certain extent can make it difficult to use this method of running diagnostics.

However, despite the existing restrictions in the practical application of the running diagnostics, the obtaining of the current and continuous information of the brake system condition is an extremely important operation of the system of maintenance and repair of the rolling stock of the motor vehicle because they allow to reveal reliably the main failures of the motor vehicle brake system. Besides, the offered method of running diagnostics allows to control in a current time mode the condition of the brake system of a motor vehicle and that is especially actual and reasonable from the point of view of the road traffic safety.

## 5. CONCLUSIONS

In conclusion, we would like to note the following. The practical application of the offered theoretical and methodical approach to the estimation of the technical conditions of a motor vehicle allows to perform not only the running diagnostics of the brake system of the vehicle but also to reveal the failures occurred in the brake system (one or several wheel do not decelerate). What is more important is that running diagnostics can significantly decrease the downtime of the vehicles during repair of the brake system due to the exclusion of such procedure as a general diagnostics of the brake system from the list of the manufacturing operations of the current repair of a motor vehicle. Nevertheless, regardless of the theoretical grounding of the possibility of running diagnostics of the brake system of a vehicle, some problems, which arose during the process of development of the offered method of running diagnostics, are still unsolved. Such problems include the absence of the possibility to perform the determination of the coordinates of the centre of mass or adhesion coefficient of wheels with a road automatically in the current time mode. The answer to these questions is supposed to be obtained as a result of the further research.

Beyond the scope of this work there are still such problems as the estimation of the technical condition of the brake system of the multilink road trains (three, four, five and more axle road trains). The further research in the field of the running diagnostics of the brake properties of motor vehicles will be dedicated to this range of problems.

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