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**** S. R. Baigereyev***
D. Serikbayev East Kazakhstan Technical University,
Republic of Kazakhstan Ust-Kamenogorsk

MATHEMATICAL MODEL OF INDEPENDENT DEPARTURE OF A VEHICLE FROM A ROLLER BRAKE STAND AFTER TESTS

Due to the fact that with the great competition of technical inspection points, there is a need to increase the efficiency of the lines of technical control of road transport. Technical control lines are a whole range of diagnostic equipment designed to assess the technical condition of motor vehicles. The efficiency of vehicle technical control lines is understood as the number of vehicles per unit of time.

Roller stands for diagnosing brake systems of motor vehicles are widely used in the automotive industry. To date, the issue of increasing the efficiency of diagnosing the braking systems of road transport by increasing the reliability and accuracy of the diagnosis is relevant in this area.

The purpose of this article is to provide a mathematical description of the process of a motor vehicle leaving a roller brake tester. The developed mathematical apparatus makes it possible to determine the condition for the independent departure of motor vehicles from the stand, taking into account the values of the traction force and the force of resistance to the departure of the rollers of the stand. During the research, methods of analysis and mathematical modeling were applied. The obtained research results can be used to develop software for the operational calculation of the brake tester parameters.

Keywords: car, brake stand, diagnostics, technical control, traction force, resistance forces

Introduction

The intensive growth in the number of vehicle inspection centers (VIC) and car service enterprises operating in a highly competitive environment necessitates the choice of the structure of technological equipment and methods of organizing work, improving and simplifying the technological process to achieve the best results of economic efficiency.

The complexity of vehicles and their diversity in terms of designs requires the modernization of test equipment for technical control lines to reduce the total service time in conditions of intensive in-line organization of vehicle diagnostics.

Under these conditions, the issue of developing a method for improving the performance of the line of diagnostic control of cars, expressed in the number of serviced cars per unit of time, is relevant.

Car technical control lines are designed to check the technical condition of cars and trucks, as well as buses. Technical control lines are completed with all necessary equipment, quality certificates and all necessary documentation for work [1–6].

Materials and methods

Technical control lines are divided into 4 main types: stationary, mobile, mobile and mobile-block. The most common LTK: stationary and mobile. Stationary LTKs are diagnostic equipment installed in a floor or recessed version. Mobile LTK is a universal container station for working with cars [8].

The stationary line of technical control allows you to identify any deviations in the operation of vehicle components from the normative ones with the possibility of displaying the results on a monitor.

The main advantage of these lines is that you can choose any acceptable option for both indoors and outdoors, which significantly reduces its cost.

The technical control line necessarily includes the LTK program, pre-installed on a computer, which collects and processes data that enters it through wireless communication adapters or is entered manually by the operator.

At the exit of the car from such a line, its complete diagnostic card is received in the form of an analytical summary, which can be printed out or left in the computer's memory. The line installed in the CTO will be in demand not only for technical control of cars, but also for the use of auxiliary diagnostic operations when servicing cars (Figure 1).

The basic element of a standard set of equipment for a stationary vehicle technical control line is a brake stand and a set of additional diagnostic devices: a four-component gas analyzer, a smoke meter, a headlight intensity tester, tire pressure gauges, a backlash detector, a steering backlash meter, a glass light transmission meter and other devices.

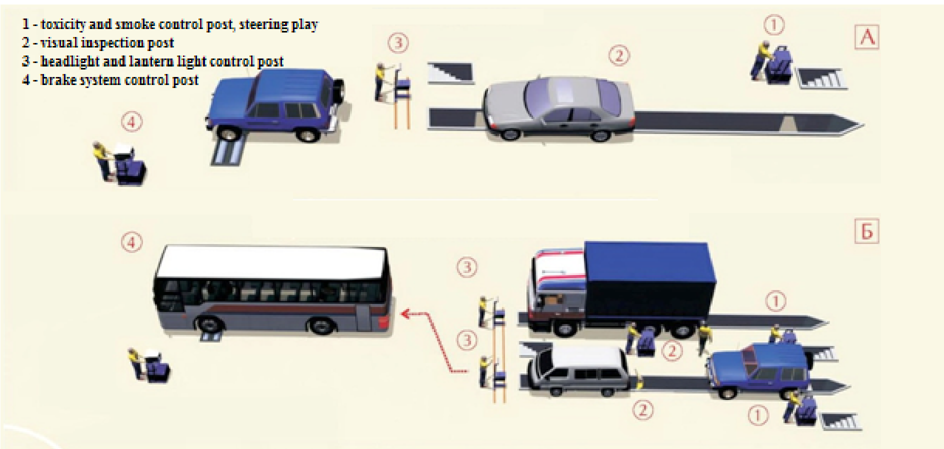

Figure 1 – Schemes of organizing the process of diagnosing cars on the technical control line

With the help of all this equipment, the brake system and steering complex are diagnosed, exhaust gases are analyzed (for a correct assessment of the fuel combustion system), glass light transmission is measured, the condition of the wheels (suspension play) and other indicators are checked.

It should be noted that a lot of publications are devoted to the study of the issue of increasing the efficiency of the technical control line (LTC). For example, the authors of the article [9] developed a mathematical model of the LTK operation to optimize the structure and characteristics of the testing equipment.

The average values of the number of cars in a certain interval obtained in the course of the statistical analysis were chosen as input parameters of the model. As part of the research, the authors considered 5 options for organizing diagnostic lines:

1) one-station single-beam line;
2) two-post single-beam line;
3) three-post single-beam line;
4) six-post two-beam line;
5) a five-post two-beam line.

Based on the numerical values of the mathematical expectation [9-11]:

$$M(n_k) = \sum_{i=1}^{n} n_k \cdot p \quad (1)$$

failure probabilities [9–11] :

$$P_{OTK} = p_n = \frac{\rho^n}{n!} p_0 = \frac{\rho^n}{n!} \cdot \frac{1}{e^n} \quad (2)$$

a mathematical dependence was obtained to determine the absolute capacity of the production line [9-11]:

$$A = \lambda Q = \lambda \left(1 - \frac{\rho^n}{n!} \cdot p_0 \right) \quad (3)$$

As a result, the authors of the article [9] came to the conclusion that the most rational option for the location of diagnostic equipment corresponds to a five-post two-beam line.

Another work is devoted to optimizing the parameters of a roller brake tester for diagnosing vehicle brake systems [12].

The purpose of this work is to determine the rational characteristics of the roller brake stand, ensuring a stable position of the car on the stand. Using the method of mathematical modeling, the authors obtained a mathematical inequality characterizing the condition of non-ejection of a vehicle:

$$\frac{G_{a_1}}{2}\cdot\left[\gamma_T\cdot-f-\sin\left(\frac{1}{1+\sqrt{\dfrac{l_2}{O_1M-h}}}\right)\right]-G_{a_2}\cdot\varphi_2\leq 0 \quad (4)$$

The research results make it possible to minimize the loss of time for the installation of wheel chocks and, thereby, increase the throughput of the diagnostic control line.

Based on the high relevance of research topics, as well as the results of the literature review, the author has identified a new direction for improving the efficiency of the diagnostic line.

As practice shows, after the completion of tests on a roller brake stand, a problem arises associated with the independent departure of the car from the stand. This creates certain time losses in the conditions of the in-line organization of the process of diagnosing cars. To date, this problem is mainly solved through the use of lifts, which has many disadvantages.

As an option, the authors have developed a stand design (Figure 2) with the possibility of varying the position of the rollers, the relative displacement of which helps the wheels of the driving axle of the vehicle overcome the «obstacle force» of the rollers. The main components of the stand include a frame, two pairs of rollers, electric motors and measuring devices, an eccentric, a wheel support, an eccentric shaft, an AC motor, a flange coupling, an electromagnet, a brake disc, a pressure disc, a spring that provide the ability to vary the position of the rear rollers, in depending on the geometric and weight characteristics of the car in order to stabilize the latter on the rollers of the stand. When an electric voltage is applied, the rotor shaft of the AC motor rotates the eccentric shaft 6. In this case, the electromagnets 16 attract the pressure disks 13 under the action of electric current, overcoming the resistance of the springs 24. This ensures unhindered rotation of the brake disk 14, which is rigidly mounted on the shaft with a keyed connection. The eccentric shaft, acting with its eccentricity on the wheel support 1, contributes to changing the position of the rollers. Structurally, this is ensured by the movable base 7 (steel sheet located on the support frame), on which the bearings 3 of the support rollers are permanently fixed.

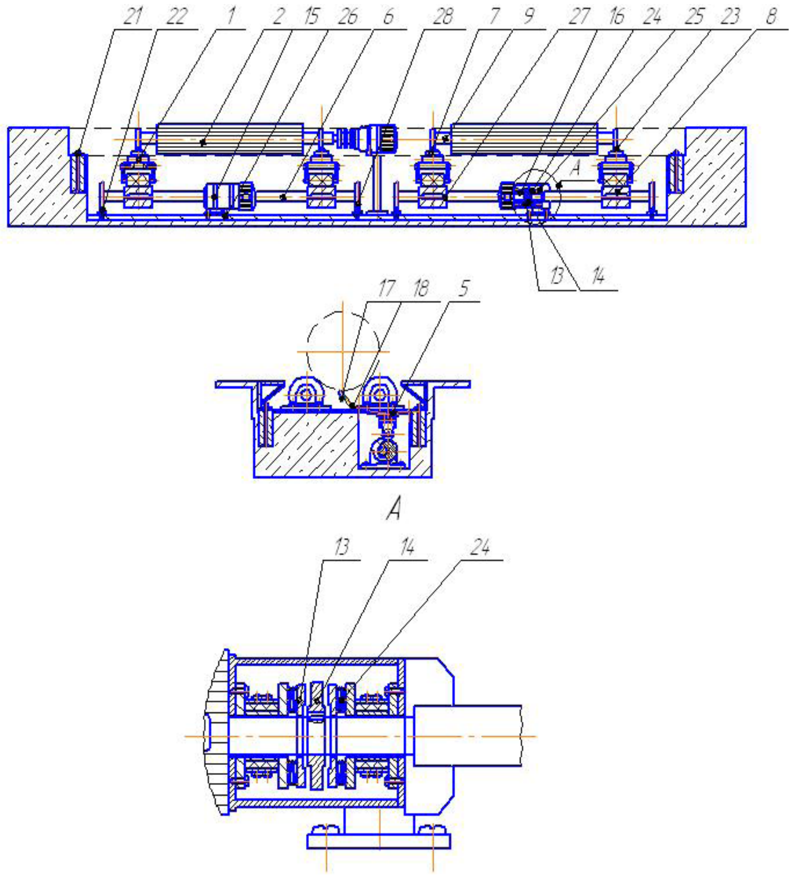

Figure 2 – Design of the developed brake stand

The front side of the base is pivotally fixed on a fixed axle, and the opposite side, through the wheel support, is subjected to the action of an eccentric. After establishing the required displacement of the rear roller, the current supply to the electric motor stops, and the mechanism for fixing the required level of the roller Δh is activated. This is realized by the two-sided action of the pressure discs on the brake disc by means of the elastic force of the springs.

However, there are no theoretical and experimental studies to determine the value of the change in the height of the roller, sufficient for the departure of the car. The results of the research can be of practical importance for the development of an automated stand that can adapt to the parameters of the car and automatically set the necessary geometric characteristics of the roller stand, corresponding to the condition of the independent departure of the vehicle after testing. In this article, the authors propose a mathematical model that allows you to determine the condition for the car to leave the stand on its own after completion of the tests.

Results and discussion

In this article, the authors propose a mathematical model that allows you to determine the condition for the car to leave the stand on its own after completion of the tests.

The running drums of the Power brake stand (PBS) support-roller device with a radius $r_б$ have a circular cross-section with centers at the points K_1 and K_2 (Figure 3), and perceive at the points C_1 and C_2 the load G_{a_1} of the driving wheels of the vehicle with a radius r_K with a center O_1. The wheels of the rear axle of a car with a weight G_{a_2} centered O_2 on a flat surface (Figure 3).

The center distance L of the rollers and the vertical offset h of the rear roller are the optimized geometric characteristics of the stand.

According to the accepted assumption, the rollers have a protrusion S from the floor level corresponding to $S = \frac{1}{3} r_б$.

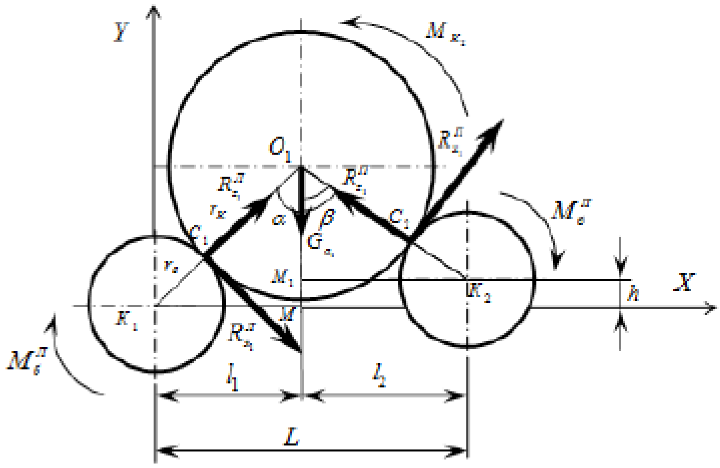

Figure 3 – Design scheme PBS

The algorithm for solving this optimization problem includes determining the initial angular variables by considering the corresponding right triangles ΔK_1MO_1 and $\Delta K_2M_1O_1$ (Figure 3).

$$\alpha_1 = arctg\left(\frac{K_1M}{O_1M}\right) \tag{5}$$

$$\beta_1 = arctg\left(\frac{K_2M}{O_1M - O_1M_1}\right) \tag{6}$$

The geometric parameters $K_1M = l_1$, $K_2M = l_2$ and O_1M , given in formulas (1) and (2) and defined as $l_1 = l_2 = \frac{L}{2}$, $O_1M = \sqrt{(r_{\acute{a}} + r_K)^2 - l_1^2}$ take $h = 0$ into account the displacement of the wheel center O_1 from the initial position under the condition $h > 0$. In this case, the relation $l_1 < l_2$ is true.

The position of the center O_1 of the car wheel is determined by the coordinate method, taking the center of the front roller $K_1(0;0)$ as the origin. $K_2(x_2; y_2)$ - coordinates of the rear roller center. $O_1(x_3; y_3)$- coordinates of the wheel center, determined from the system of equations of circles:

$$\begin{cases} |K_1O_1| = r_б + r_K \\ |K_2O_1| = r_б + r_K \end{cases} \Rightarrow \begin{cases} \sqrt{(x_3-0)^2+(y_3-0)^2} = r_б + r_K \\ \sqrt{(x_3-x_2)^2+(y_3-y_2)^2} = r_б + r_K \end{cases} \quad (7)$$

The solution of system (3) determines the coordinates of the point :

$$(x-x_3)^2 - (y-y_3)^2 = r_K^2 \quad (8)$$

Having determined the coordinates x_3 and y_3, the current values of the legs of right-angled triangles $\Delta K_1 MO_1$ and $\Delta K_2 M_1O_1$ are calculated:

$$l_1^/ = l_1 - (x_3 - x_3^/) \quad (9)$$

$$l_2^/ = l_2 + (x_3 - x_3^/) \quad (10)$$

$$O_1M^/ = O_1M + (y_3 + y_3^/) \quad (11)$$

Guided by the laws of theoretical mechanics, it should be stated that at the points of contact between the wheels of the diagnosed axle and the rollers C_1 and C_2 as a result of the distribution of the vertical load of the front axle G_{a_1}, support reactions $R_{Z_1}^П$ and $R_{Z_1}^П$ directed along the radius of the wheel occur [12].

At the points of contact of the second axle, located on a flat surface, normal reactions occur, numerically equivalent to the weight of the car falling on the second axle $R_{z_2} = G_{a_2}$.

The condition for the independent departure of the car will depend on a number of factors, in particular, on the traction and geometric characteristics of the car and the geometric parameters of the stand.

One of the main traction properties of a car is its power [15]:

$$N = P_T \cdot V \quad (12)$$

where P_T – is the traction force of the car, H

V – the speed of the car leaving after the test, m/s.

The mathematical condition for the car's independent departure will be written as an inequality, which compares the numerical value of the traction force of the car (taking into account the «obstructing (departure) force» created by the rollers) and the weight of the car falling on the free (in the case of a front- or rear-wheel drive car) axle or axle located on rollers (in case of diagnosing an all-wheel drive vehicle). Depending on the traction characteristics of the vehicle, the following special cases are possible. Case 1 is a front-wheel drive car. In this case, the exit condition will look like this :

Depending on the traction characteristics of the vehicle, the following special cases are possible.

Case 1 – a front-wheel drive car. In this case, the exit condition will look like this:

$$\frac{N \cdot \cos\alpha_{H_2} \cdot f_1}{V} > G_{a_2} \cdot \varphi_2 \cdot f_2 \quad (13)$$

Case 2 – rear wheel drive vehicle:

$$G_{a_1} \cdot f_1 < \frac{N \cdot \varphi_2 \cdot \cos\alpha_{H_2} \cdot f_2}{V} \quad (14)$$

Case 3 – four-wheel drive vehicle:

$$\frac{N \cdot \cos\alpha_{H_2} \cdot f_1}{V} > \frac{N \cdot \varphi_2 \cdot f_2}{V} \quad (15)$$

To test the obtained analytical dependencies, we will conduct a computational experiment (Table 1). The following vehicles will be selected for testing:

Table 1 – Data computing experiment

№	Vehicle brand	Vehicle power	Wheel diameter	Vehicle weight	Drive
1	Lada Largus	79 kW	626 mm	1849 kg (906 kg - front, 943 kg - rear)	front-wheel drive
2	Shevrolet SS	312 kW	669 mm	1803 kg (910 kg - front, 893 kg)	rear wheel drive
3	VAZ 2121	59 kW	406 mm	1285 kg (650 kg - front, 635kg - rear)	four-wheel drive

For the computational experiment, the technical characteristics of the STM-3500 brake tester located in the laboratory «Maintenance and repair of vehicles» of the Competence Center in the field of motor transport operation will be used. The technical characteristics of the stand are given in the table 2.

Table 2 – Technical characteristics of the stand STM-3500N

Parameter	Unit	Value
Brake force measurement range on the diagnosed axle	kN	0–10
Axle mass (weight) measurement range	kg	0–3500
Power consumption	kN kg kW mm kg mm kg hail	7
Overall dimensions of the roller	mm	2340x680x290
Roller weight	kg	500
Power cabinet overall dimensions	mm	400x155x1100
Power cabinet weight	kg	20
Operating temperature range	degree	-30 to +50

Conclusions

The calculation results are shown in the table 3.

Table 3 – The calculation results

№	Vehicle brand	Drive	Left side of the inequality	Right side of the inequality	Departure condition
1	Lada Largus	front-wheel drive	135,8 N	17,1 N	Yes
2	Shevrolet SS	rear wheel drive	324,54 N	54,03 N	no
3	VAZ-2121	four-wheel drive	264,32 N	43,12 N	no

Thus, the condition of independent departure is fulfilled only in the first case. Therefore, to ensure the car's departure from the roller stand, it is necessary to change the geometric characteristics of the stand, reducing the value of the relative vertical displacement of the rollers. The mathematical model developed by the authors will make it possible to determine the condition for the independent departure of the car and can be used as the basis for a computer program for automatic control of the roller stand.

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СЫНАҚТАРДАН КЕЙІН КӨЛІК ҚҰРАЛЫНЫҢ РОЛИКТІ ТЕЖЕГІШ ТІРЕГІНЕН ДЕРБЕС ШЫҒУЫНЫҢ МАТЕМАТИКАЛЫҚ МОДЕЛІ

Техникалық байқау пункттерінің үлкен бәсекелестігіне байланысты автомобиль көлігін техникалық бақылау желілерінің тиімділігін арттыру қажеттілігі туындады. Техникалық бақылау желілері – автокөліктердің техникалық жагдайын бағалауға арналған диагностикалық жабдықтардың тұтас кешені. Автокөлікті техникалық басқару желілерінің тиімділігі уақыт бірлігіндегі көліктердің саны ретінде түсініледі.

Автокөліктердің тежеу жүйелерін диагностикалауға арналған роликті стендтер автомобиль өнеркәсібінде кеңінен қолданылады. Бүгінгі таңда осы салада диагностиканың сенімділігі мен дәлдігін арттыру арқылы автомобиль көлігінің тежеу жүйелерін диагностикалау тиімділігін арттыру мәселесі өзекті болып отыр.

Бұл мақаланың мақсаты – роликті тежегіш сынаушыдан шыққан автокөліктің процесінің математикалық сипаттамасын беру. Әзірленген математикалық аппарат тартым күшінің мәндерін және тіреу роликтерінің кетуіне қарсылық күшін ескере отырып, автокөліктердің стендтен тәуелсіз шығу жағдайын анықтауға мүмкіндік береді. Зерттеу барысында талдау және математикалық модельдеу әдістері қолданылды. Алынған зерттеу нәтижелерін тежегіш сынағыш параметрлерін операциялық есептеу үшін бағдарламалық қамтамасыз етуді әзірлеу үшін пайдалануға болады.

Кілтті сөздер: автомобиль, тежеу стенді, диагностика, техникалық бақылау, тарту күші, қарсылық күштері

С. Р. Байгереев
Восточно-Казахстанский технический университет имени Д. Серикбаева,
Республика Казахстан, г. Усть-Каменогорск

МАТЕМАТИЧЕСКАЯ МОДЕЛЬ САМОСТОЯТЕЛЬНОГО ВЫЕЗДА АВТОТРАНСПОРТНОГО СРЕДСТВА С РОЛИКОВОГО ТОРМОЗНОГО СТЕНДА ПОСЛЕ ИСПЫТАНИЙ

Вследствие того, что с большой конкуренцией пунктов технического осмотра, появляется потребность в увеличении эффективности линий технического контроля автомобильного транспорта. Линии технического контроля представляют собой целый комплекс диагностического оборудования, которые предназначены для оценки технического состояния автомобильного транспорта. Под эффективностью линий технического контроля автотранспортных средств понимается количество автомобилей в единицу времени.

Роликовые стенды для диагностирования тормозных систем автомобиьного транспорта находят очень широкое применение в сфере автомобилестроения. На сегодняшний день актуальным в этой сфере является вопрос повышения эффективности диагностирования тормозных систем автомобильного транспорта с помощью повышения достоверности и точности постановки диагноза.

Цель данной статьи заключается в математическом описании процесса выезда автомобильного транспорта с роликового тормозного стенда. Разработанный математический аппарат позволяет определить условие самостоятельного выезда автомобильного транспорта со стенда, учитывая значения силы тяги и силы сопротивления выезду роликами стенда. Во время проведения исследований были применены методы анализа и математического моделирования. Полученные результаты исследований могут быть применены для разработки программного обеспечения по оперативному расчету параметров тормозного стенда.

Ключевые слова: автомобиль, тормозной стенд, диагностика, технический контроль,сила тяги, силы сопротивления

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«Toraighyrov University» баспасынан басылып шығарылған
Торайғыров университеті
140008, Павлодар қ., Ломов көш., 64, 137 каб.

«Toraighyrov University» баспасы
Торайғыров университеті
140008, Павлодар қ., Ломов к., 64, 137 каб.
67-36-69

e-mail: kereku@tou.edu.kz
nitk.tou.edu.kz