ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)

Наука та прогрес транспорту. Вісник Дніпропетровського
національного університету залізничного транспорту, 2015, № 6 (60)

АВТОМАТИЗОВАНІ СИСТЕМИ УПРАВЛІННЯ НА ТРАНСПОРТІ

UDC 629.4.066:656.259.13

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THE USE OF THE EXPERIMENT PLANNING METHOD TO EVALUATE THE ACCURACY OF FLEXIBLE UNITS IDENTIFICATION

Purpose. The identification of rolling stock on the railroads is an integral part of many automation systems as trains in general and cars separately. Various information management systems at sorting yards require the operational information about the object while performing the manufacturing operations. The improvement of the determination accuracy of different parameters characterizing the rolling stock, leads to the immediate quality progress in the traffic volumes management. The aim of the paper is to develop a method to estimate the errors of determination the interaxle distance of the flexible units in the control section using the point path-control transducer for future identification of cars and locomotives. **Methodology**. To achieve this goal the simulation method and experiment planning were used. The simulation model allowing determining the time intervals between the collisions of wheelset of movable units in point path-control transducer on the control section with variable characteristics of identification devices was developed. The values of the time intervals obtained with using the simulation mode were applied in the method of experiment planning to the final target. **Findings**. The calculated analytical values of the errors of the interaxle distances do not have the significant differences from values obtained using the simulation model. It makes possible to use the received functional dependence to estimate the possible errors in the identification of rolling stock. The results of this work can be used to identify separate flexible units, and trains in general. **Originality**. The functional dependence of the error of the interaxle distance error from the fixing point of the wheel path-control transducer, the distance between the sensors and the measured distance was derived using a previously conducted research of the factors influencing the error in determining the interaxle distance of the movable units, and developed simulation model to calculate the interaxle distance. **Practical value.** This functional dependence allows solving the following tasks: to calculate the maximum possible error of determining the interaxle distance of the movable units at known parameters of control section and calculation of parameters of the control section, when the possible acceptable error of determining the interaxle distance of the flexible units is known.

Keywords: experiment planning method; rolling stock identification; control section; axle spacing; point track transducer

Introduction

Identification of rolling stock on the railroads, as trains in general and cars separately, is an integral part of many automation systems. Various information and management systems at sorting yards, performing the manufacturing operations, require the operational information about the object [8-11, 16, 17]. Improving the determination accuracy of different parameters characterizing the rolling stock, leads to the immediate improvement

doi: 10.15802/stp2015/56998

quality progress of car traffic volumes management. The increase in the accuracy of the information, automatic acquisition and processing of signals increase the capacity of the station due to the time advantage when certain manufacturing operations is amenable to automation. And this in turn the decrease in cost of transportation, increase of cars use rationality, the liberation of human resources, improving the traffic safety on the railways, etc.

To the range of such systems tasks the following definition of the static characteristics of the rolling stock that passed the control section relates: the number of axes, number and number of axes of movable units, movable units type (platform, covered car, etc.), etc. In this case, each of the systems is presented in the form of implemented method to identify the flexible units consisting of reset algorithm, processing and analysis of data, and also the constructive possibilities of the control section and their means of railway automatics [1-3, 7, 14].

This paper considers a method of determining axle base of the movable units; more precisely the analysis of possible faults in determination of this parameter identification is carried out. Determination of interaxle distance of the flexible unit is the most often used to determine its type, which in some systems will allow determining a few figures of its item numbers. One of such systems is described in the paper [7].

Purpose

The aim of this work is to develop a method to estimate the determination errors of the interaxle distances of movable units in the control section using the point path-control transducer for future identification of cars and locomotives.

Methodology

The simulation method and experiment planning were used to achieve this goal.

Simulation model for determination the interaxle distance of the flexible units.

Definition of interaxle distance of the movable units used in various automated control systems at sorting yards and the adjacent railroad tracks. It is the most relevant to the tasks of determination the type of movable units, car base or cut, the axle counting systems, etc. Various methods of identification are applied, using special control sections, which includes the point path-control transducer, track circuits, photocells and other trackside assets used at the railway transport. In this paper, a method for determining the type of the movable units according to the calculated interaxle distances is considered. This method uses a control section which consists of three control points (point path-control transducer). The error of determining the interaxle distance arising from the use of such methods are associated with the mismatch moment of actuation of the track point detector with the passage of car wheels over the geometric center of the detector. This mismatch in the operation of the detector is taken as a random variable, distributed according to the normal law (Fig. 1).

The values taken in figure 1: δ – error of the detector, ΔL – the operating range of the detector, S – the interaxle distance of the movable unit, L – the distance between the control points CP1, CP2, CP3 which include one or two coupled track point detectors.

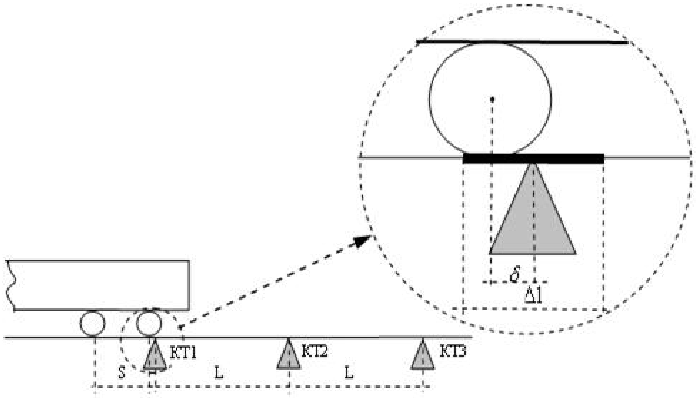

Fig. 1. The section structure of the identification phase of the rolling stock that is implemented in the simulation model

doi: 10.15802/stp2015/56998

To study the effect of various factors affecting the identification process the simulation was chosen. The description of the simulation model is represented in the work [6]. It was suggested that the following factors affected the error of identification the most significantly:

- the initial speed of the wheel pair run over on the control section
- the acceleration of motion at the control section;
- the distance between the detectors;
- the value of the interaxle distance;
- accuracy of the point path-control transducer work (root mean square of the distance of the fixing wheel of movable unit by the normal law of distribution from the detector center, distributed by the normal law of distribution [15]).

The researches have shown that the speed and acceleration of flexible unit movement not have effect on the error of the interaxle distance determination in compared with other factors significantly.

The application of the experiment planning method. The obtained results with using the simulation model provide an opportunity to analyze quantitatively and qualitatively the possible errors of movable units identification, as well as their dependence on a number of factors affecting the identification process. However, this research does not allow calculating an expected error of identification definitely. To complete the task the method of experiment planning was chosen. Using this method, it is necessary to define the formula using of which is possible to determine the expected error for selected control section, means of railway automatics and identifiable rolling stock unambiguously.

All subsequent calculations in this chapter were carried out according to the method of experiment planning which was presented in the works [5, 13].

The control section on which was the determination of interaxle distance of the movable units was chosen as the object of research. The factors influencing on this process and described above were selected as the effects on the process, namely:

- the initial speed of the wheel pair run over on the control section, namely the first control point CP1 (V_i);
- the acceleration of motion at the control section (a);
- distance between the detectors (L);
- the value of the measured interaxle distance (S);
- precision of point path-control transducer work (σ_t).

In this case the response is taken as the value of the average quadratic deviation the error of determining the interaxle distance $\sigma_{\Delta S}$.

In result the chosen research object is described with five influences and one response, the study of which is our task. The resulting model of the experiment corresponds to a multifactorial experiment with one response.

In the initial experiment was consisted of five factors. The plan FFE 25 (five-factor two-level full factorial experiment) was used. The following values of the factors were taken as levels:

- initial speed V_i – 3 and 15 m/s;
- acceleration a – 0.1 and 0.5 m/s^2;
- distance between the detectors L – 3 and 6 m;
- the value of the measured interaxle distance S – 2 and 14 m;
- the accuracy of point path-control transducers σ_t – 0.002 and 0.01 m.

The following results were obtained at processing the conducted experiments:

- the above mentioned factor levels of the simulation model did not meet the requirements of uniformity and adequacy;
- to achieve uniformity and adequacy of the model is possible only if reduce the intervals of variation of factor levels, which in turn is unacceptable for the description of the identification process;
- the values of speed and acceleration were not significant in compared with other factors as it was in the analysis of simulation results, and at processing the results of applying the method of experiment planning.

It was decided to conduct a multi-level three-factor experiment after analyzing the results of the previous experiment. The following independent variables were selected as factors:

- distance between the detectors L;
- the value of the measured interaxle distance S;
- precision of point path-control transducer work σ_t.

doi: 10.15802/stp2015/56998

The variation of the factors was made as follows: the distance between the detectors was varied at two levels (range 3-6 m), the levels values – 3 and 6; the accuracy of the detector work on three levels (range 0,001–0,008 m), the levels values 0,002, 0,004 and 0.006; interaxle distance at four levels (range 1.5–15 m), the levels values 2, 5, 8 and 11. The levels values of interaxle distance factor were adopted according to the conducted analysis of cars and locomotives of 1 520 mm gauge [4, 12].

As it was noted above, the aim of the study is the analytical dependences obtaining the average quadratic deviation of the determination errors of the interaxle distance $\sigma_{\Delta S}$ as a function of three variables – L, S and σ_i. Preliminary analysis showed that this dependence cannot be described neither linear nor quadratic dependence. To determine the required dependence the device of orthogonal polynomials and planning of multi-level experiments was adopted.

Control points used to construct the system of orthogonal polynomials, will be varied with a constant step, therefore, the polynomials can be obtained using the recurrence formula [5]:

$$P_{r+1}(X)=P_1(X)\cdot P_r(X)-$$

$$-\left(r^2\cdot(N^2-1)/4\cdot(4\cdot r^2-1)\right)\cdot P_{r-1}(X),\quad (1)$$

where $\overline{X}$ – some of the physical independent variable or factor; N – number of experimental points; r – degree of the corresponding polynomial, $r=-1,0,1,...,N-1$.

In our case, the maximum degree of used polynomials is equal to 3. Therefore, the polynomials will be calculated by the following formulas:

$$P_0(X)=1,\quad (2)$$

$$P_1(X)=\lambda_1\cdot X-\overline{X}/d,\quad (3)$$

$$P_2(X)=\lambda_2\cdot\left[\left(\frac{X-\overline{X}}{d}\right)^2-\frac{N^2-1}{12}\right],\quad (4)$$

$$P_3(X)=\lambda_3\times$$

$$\times\left[\left(\frac{X-\overline{X}}{d}\right)^3-\left(\frac{X-\overline{X}}{d}\right)\cdot\left(\frac{3\cdot N^2-7}{20}\right)\right],\quad (5)$$

where λ_r – the multipliers, which depend on the number of variation levels N and the degree of polynomial r; $\overline{X}$ – average value of factor; d – the step of varying.

It is necessary to make the transition from the physical to the coded variables by the formulas for the more compact forms of the orthogonal polynomials:

$$x_u=X_u-\overline{X}/d\quad (6)$$

when N – odd number,

$$x_u=X_u-\overline{X}/d/2\quad (7)$$

when N – even number.

In result the values of the polynomials for each of the variables will be as follows:

– variable L ranges at two levels, it will fit to a single polynomial of the first degree:

$$P_1(X_1)=\lambda_1\cdot\frac{X_1-\overline{X_1}}{d_1}=$$

$$=2\cdot L-4.5/3=x_1=P_1(x_1)\ \{\text{-}1,\ 1\};\quad (8)$$

– variable σ_t, ranges at three levels, it will correspond to the polynomials of the first and second degree:

$$P_1(X_2)=\lambda_2\cdot\frac{X_2-\overline{X_2}}{d_2}=\frac{\sigma_t-0.004}{0.002}=x_2=P_1(x_2),$$

$$P_2(X_2)=3\cdot x_2^2-2=P_2(x_2)\ \{\text{-}1,0,1\};\quad (9)$$

– variable S ranges at four levels, it will correspond to the polynomials of the first, second and third degree:

$$P_1(X_3)=\lambda_3\cdot\frac{X_3-\overline{X_3}}{d_3}=2\cdot\frac{S-6.5}{3}=x_3=P_1(x_3),$$

$$P_2(X_3)=\frac{1}{4}\cdot x_3^2-\frac{5}{4}=P_2(x_3),$$

$$P_3(X_3)=\frac{5}{12}\cdot x_3^3-\frac{41}{12}\cdot x_3=P_3(x_3)\ \{\text{-}3,\text{-}1,1,3\}.\quad (10)$$

In addition to these polynomials the model will include paired and triple products of different variables polynomials. Thus, for ease of notation the polynomials the symbols of the received as follows will be applied: $P(x_i)=Pr_i$. The experiment plan

doi: 10.15802/stp2015/56998

includes 24 control points, and therefore the same number of coefficients. Numbers of experimental points u, plan and results of the received response are presented in the table. The 5 parallel experiments were conducted for each selection.

The row mean values and dispersion were computed using the formulas:

$$\overline{y}_u = \sum_{i=1}^{n} y_{ui} \Big/ n, \tag{11}$$

$$S_u^2 = \sum_{i=1}^{n} y_{ui}^2 - n \cdot \overline{y}_u^{\,2} \Big/ n-1, \tag{12}$$

where n – the number of parallel experiments; y_{ui} – the value of i-th response for u-th selection

The Cochran criterion was chosen for the checking of row dispersions uniformity. According to this criterion, the coefficient G_{cf} =0,192 (for n=5 and N=24) was obtained from the Cochran distribution for the significance level of α =0,05. The Cochran criterion for conducted experiments was obtained by the formula

$$G_p = S_{u\max}^2 \Big/ \sum_{u=1}^{N} S_u^2 . \tag{13}$$

The value of the G_p is equal to 0,165 that is less than the value G_{cf}, and then the uniformity of the row dispersions estimates is evident.

The values of b-coefficients were calculated according to the formula

$$b_i = \sum_{u=1}^{N} P_i(x_u) \cdot \overline{y}_u \Big/ \sum_{u=1}^{N} P_i^2(x_u) . \tag{14}$$

The obtained values of b-coefficients were included in the resulting table of calculations. In the resulting table the columns of only those model members were taken into account, b-coefficients of which were statistically significant. The statistical significance of the b-coefficients was tested by the formula

$$|b_i| \le b_{cr} = S_{bi} \cdot t_{table} =$$

$$= \sqrt{\frac{\dfrac{1}{N\cdot(n-1)} \sum_{u-1}^{N} \left(\sum_{j=1}^{n} y_{uj}^2 - n \cdot \overline{y}_u^{\,2} \right)}{N \cdot n}} \cdot t_{table} . \tag{15}$$

The coefficient t_{table} = 2.06 was taken from the tables of the Student distribution on significance level α = 0,05 the number of freedom degrees is equal to 24. The next step is to test the adequacy of the model, which was performed by F-criteria. According to this criterion the critical value F_{cr}=1,94, taken from tables of F distribution for significance level α =0,05 and number of degrees of freedom f_{ad}=8 and f_y=96, must be less than the calculated F_{calc} calculated by formulase

$$F_{calc} = \frac{n \cdot \sum_{u=1}^{N} \left(\overline{y}_u - \overline{\overline{y}}_u \right)^2}{N-l} \Big/ S_y^2 , \tag{16}$$

where $\overline{\overline{y}}_u$ – the value of the response at the point; l – the number of significant b-coefficients.

The value of F_{calc} appeared to be equal to 0.49, which is less than F_{cr}, and it shows the adequacy of the model.

As a result of the experiments and processing the data, it became possible to write the adequate equation models

$$\begin{aligned} \overline{\overline{y}}_u = {} & 0,00966 - 0,00425 \cdot P11 + 0,00496 \cdot P12 + \\ & +0,00227 \cdot P13 + 0,00265 \cdot P23 + 0,00024 \cdot P33 - \\ & -0,00228 \cdot P11 \cdot P12 - 0,00227 \cdot P11 \cdot P13 - \\ & -0,00293 \cdot P11 \cdot P23 - 0,00016 \cdot P11 \cdot P33 + \\ & +0,00123 \cdot P12 \cdot P13 + 0,00152 \cdot P12 \cdot P23 + \\ & +0,00018 \cdot P12 \cdot P33 - 0,00124 \cdot P11 \cdot P12 \cdot P13 - \\ & -0,0016 \cdot P11 \cdot P12 \cdot P23 - \\ & -0,00013 \cdot P11 \cdot P12 \cdot P13. \end{aligned} \tag{17}$$

It is necessary to move from coded variables to their physical variables to obtain the required analytical dependences. Finally the required equation will be as follows:

$$\begin{aligned} \sigma_{\Delta S}(S, L, \sigma_t) = {} & -0,0593 \cdot L \cdot S^2 \cdot \sigma_t - 0,0054 - \\ & -0,0000132 \cdot L \cdot S^3 + \\ & +0,000277 \cdot L \cdot S^2 - 0,6181 \cdot L \cdot \sigma_t + \\ & +0,00004 \cdot S^3 + 0,1344 \cdot S^2 \cdot \sigma_t - 1,5811 \cdot \sigma_t \cdot S + \end{aligned}$$

doi: 10.15802/stp2015/56998

$$+0,0111\cdot S^3\cdot\sigma_t+0,4659\cdot\sigma_t\times$$
$$\times L\cdot S-0,0015\cdot L\cdot S+$$
$$+0,00548\cdot S+0,00151\times$$
$$\times L-0,001\cdot S^2+3,4956\cdot\sigma_t. \tag{18}$$

Findings

In the result of research and calculations the analytically valid values computation of the errors of the inteaxle distances of the movable units depending on the parameters of the control section, means of railway automatics and object identification became possible.

Originality and practical value

In the work the estimation mechanism of the possible errors of determination the center distance of the movable units was improved. That can improve the accuracy of identifying methods work, using the control section with defined point path-control transducer. Using the previously conducted studies of factors influencing on the errors of determining the interaxle distances of the movable units and developed simulation model to calculate the interaxle distance, the functional dependence of the error of the inteaxle distances from the error of the fixing point with the wheel point path-control transducer, the distances between the detectors and the measured distance was derived.

This functional dependence allows solving the following tasks: to calculate the maximum possible errors of determining the interaxle distance of the movable units at known parameters of control section and the parameters computations of the control section, at the possible acceptable errors of determining the inteaxle distance of movable units.

Conclusions

Results processing of the simulation process of determining the interaxle distance of the movable units on the control section allow drawing the following conclusions:

- values of speed and acceleration motion of the movable units are not essential for the identification process in comparison with other factors;
- the errors increase of the detector work leads to the error increasing in determining the interaxle distance;
- the increase of the measured interaxle distance increases the value of the identification error;
- increasing of the control section length leads to a reduction of the identification error.

Applying the method of experiment planning the analytical dependence of the interaxle distance error determination was obtained as a function of the following quantities:

- distance between the detectors L;
- the value of the measured interaxle distances S;
- precision of the point path-control transducer σ_t.

These recommendations are relevant for building the various information systems which are used as the input data of the movable units characteristics, received using the measuring on the control sections with applying the point path-control transduce.

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ВИКОРИСТАННЯ МЕТОДУ ПЛАНУВАННЯ ЕКСПЕРИМЕНТУ ДЛЯ ОЦІНКИ ТОЧНОСТІ ІДЕНТИФІКАЦІЇ РУХОМИХ ОДИНИЦЬ

Мета. Ідентифікація рухомого складу на залізницях, як поїздів у цілому, так і вагонів окремо, займає невід'ємну частину багатьох систем автоматизації. Різні інформаційно-керуючі системи на сортувальних станціях, виконуючи технологічні операції, потребують оперативної інформації про об'єкти управління. Підвищення точності визначення різних параметрів, що характеризують рухомий склад, призводить до безпосереднього поліпшення якості управління вагонопотоками. Мета роботи полягає в розробці способу оцінки помилки визначення міжосьових відстаней рухомих одиниць на контрольній ділянці з використанням точкових колійних датчиків для проведення подальшої ідентифікації вагонів та локомотивів. **Методика**. Для досягнення поставленої мети були використані імітаційне моделювання та метод планування експерименту. Була розроблена імітаційна модель, що дозволяє визначати тимчасові інтервали між наїздом колісних пар рухомих одиниць на точкові колійні датчики, розташовані на контрольній ділянці з варійованими характеристиками пристроїв ідентифікації. Отримані з використанням імітаційної моделі значення часових інтервалів були застосовані в методі планування експерименту для досягнення кінцевої мети. **Результати**. Обчислені аналітично значення похибок визначення міжосьових відстаней не мають значущих відмінностей від значень, отриманих із використанням імітаційної моделі. Це в повній мірі дозволяє використовувати отриману функціональну залежність для оцінки можливих похибок ідентифікації рухомого складу. Результати даної роботи можуть бути використані як для ідентифікації окремих рухомих одиниць, так і для всього поїзда в цілому. **Наукова новизна**. Використовуючи попередньо проведені дослідження факторів, що впливають на похибку визначення міжосьових відстаней рухомих одиниць та розроблену імітаційну модель для обчислення міжосьових відстаней, була виведена функціональна залежність похибки визначення міжосьо-

doi: 10.15802/stp2015/56998

вих відстаней від помилки фіксації колеса точковим колійним датчиком, відстані між датчиками та вимірюваної відстані. **Практична значимість**. Дана функціональна залежність дозволяє вирішити наступні завдання: обчислення гранично можливих помилок визначення міжосьових відстаней рухомих одиниць при відомих параметрах контрольної ділянки та обчислення параметрів контрольної ділянки при відомих можливо допустимих помилках визначення міжосьових відстаней рухомих одиниць.

Ключові слова: метод планування експерименту; ідентифікація рухомого складу; контрольна ділянка; міжосьові відстані; точковий колійний датчик

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ИСПОЛЬЗОВАНИЕ МЕТОДА ПЛАНИРОВАНИЯ ЭКСПЕРИМЕНТА ДЛЯ ОЦЕНКИ ТОЧНОСТИ ИДЕНТИФИКАЦИИ ПОДВИЖНЫХ ЕДИНИЦ

Цель. Идентификация подвижного состава на железных дорогах, как поездов в целом, так и вагонов в отдельности, занимает неотъемлемую часть многих систем автоматизации. Различные информационно-управляющие системы на сортировочных станциях, выполняя технологические операции, нуждаются в оперативной информации об объектах управления. Повышение точности определения различных параметров, характеризующих подвижной состав, приводит к непосредственному улучшению качества управления вагонопотоками. Цель работы заключается в разработке способа оценки ошибки определения межосевых расстояний подвижных единиц на контрольном участке с использованием точечных путевых датчиков для проведения последующей идентификации вагонов и локомотивов. **Методика**. Для достижения поставленной цели были использованы имитационное моделирование и метод планирования эксперимента. Была разработана имитационная модель, позволяющая определять временные интервалы между наездом колесных пар подвижных единиц на точечные путевые датчики, расположенные на контрольном участке с варьируемыми характеристиками устройств идентификации. Полученные с использованием имитационной модели значения временных интервалов были применены в методе планирования эксперимента для достижения конечной цели. **Результаты**. Вычисленные аналитически значения погрешностей определения межосевых расстояний не имеют значимых отличий от значений, полученных с использованием имитационной модели. Это в полной мере позволяет использовать полученную функциональную зависимость для оценки возможных погрешностей идентификации подвижного состава. Результаты данной работы могут быть использованы как для идентификации отдельных подвижных единиц, так и для всего поезда в целом. **Научная новизна**. Используя предварительно проведенные исследования факторов, влияющих на погрешность определения межосевых расстояний подвижных единиц, и разработанную имитационную модель для вычисления межосевых расстояний, была выведена функциональная зависимость погрешности определения межосевых расстояний от ошибки фиксации колеса точечным путевым датчиком, расстояния между датчиками и измеряемого расстояния. **Практическая значимость**. Данная функциональная зависимость позволяет решить следующие задачи: вычисление предельно возможных ошибок определения межосевых расстояний подвижных единиц при известных параметрах контрольного участка и вычисление параметров контрольного участка, при известных возможно допустимых ошибках определения межосевых расстояний подвижных единиц.

Ключевые слова: метод планирования эксперимента; идентификация подвижного состава; контрольный участок; межосевые расстояния; точечный путевой датчик

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doi: 10.15802/stp2015/56998

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Accessed: Aug. 14, 2015
Received: Oct. 13, 2015

doi: 10.15802/stp2015/56998