Conference materials
UDC 620.1.08, 681.786.5, 681.7.014.3
DOI: https://doi.org/10.18721/JPM.163.209

Features of the operation of a laser profilometer in an automated rolling stock control system

K.G. Arinushkina[1]✉, A.S. Adadurov[2,3], I.Yu. Savelev[3], V.V. Davydov[1]

[1] The Bonch-Bruevich St. Petersburg State University of Telecommunications, St. Petersburg, Russia;

[2] Emperor Alexander I St. Petersburg State Transport University, St. Petersburg, Russia;

[3] LLC VNIIZHT-Engineering, St. Petersburg, Russia

✉ k-arinushkina@mail.ru

Abstract. Faulty wheelset treads were identified as one of the major problems in the early stages of car repairs. Defects of wheel sets that occur during the operation of the rolling stock of the Moscow Railway are analyzed. When scanning the tread surface of wheel pairs with an automatic complex of technical measurements, the principle of operation and control parameters are taken into account. To reduce the stopping time of passing trains, it is proposed to introduce laser profilers on the railway tracks. The control of the geometric parameters of wheel sets using a laser profilometer is an important element of railway transport maintenance. Incorrect wheel sets can lead to high wheel wear, track damage, and poor passenger comfort and safety. In the course of the work, data obtained from measurements of various profiles of the surfaces of freight cars, including wheelsets, were analyzed in comparison with reference profiles. An increase in measurement accuracy has been established by minimizing the human factor, global digitalization of technological processes and automation of rolling stock control along the route.

Keywords: laser profilometer, geometrical parameters, railway transport, wheelset

Citation: Arinushkina K.G., Adadurov A.S., Savelev I.Yu., Davydov V.V., Features of the operation of a laser profilometer in an automated rolling stock control system, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 16 (3.2) (2023) 56–62. DOI: https://doi.org/10.18721/JPM.163.209

Материалы конференции
УДК 620.1.08, 681.786.5, 681.7.014.3
DOI: https://doi.org/10.18721/JPM.163.209

Особенности работы лазерного профилометра в автоматизированной системе управления подвижным составом

К.Г. Аринушкина[1]✉, А.С. Ададуров[2,3], И.Ю. Савельев[3], В.В. Давыдов[1]

[1] Санкт-Петербургский государственный университет телекоммуникаций им. проф. М.А. Бонч-Бруевича, Санкт-Петербург, Россия;

[2] Петербургский государственный университет путей сообщения Императора Александра I, Санкт-Петербург, Россия;

[3] ООО"ВНИИЖТ-Инжиниринг"', Санкт-Петербург, Россия

✉ k-arinushkina@mail.ru

Аннотация. Неисправные поверхности катания колесных пар были определены как одна из основных проблем на ранних этапах ремонта вагонов. Проанализированы дефекты колесных пар, возникающие в процессе эксплуатации подвижного состава Московской железной дороги. При сканировании поверхности катания колесных пар автоматическим комплексом технических измерений учитываются принцип работы и параметры контроля. Для сокращения времени остановки проходящих поездов предлагается внедрить на железнодорожных путях лазерные профилометры. Контроль геометрических параметров колесных пар с помощью лазерного профилометра является важным элементом технического обслуживания железнодорожного транспорта. Неправильно подобранные колесные пары могут привести к повышенному износу колес, повреждению гусеницы и ухудшению комфорта и безопасности пассажиров. В ходе работы были проанализированы данные, полученные при измерениях различных профилей поверхностей грузовых вагонов, в том числе колесных пар, в сравнении с эталонными профилями. Установлено повышение точности измерений за счет минимизации человеческого фактора, глобальной цифровизации технологических процессов и автоматизации управления подвижным составом в пути следования.

Ключевые слова: лазерный профилометр, геометрические параметры, железнодорожный транспорт, колесная пара

Ссылка при цитировании: Аринушкина К.Г, Ададуров А.С., Савельев И.Ю., Давыдов В.В. Особенности работы лазерного профилометра в автоматизированной системе управления подвижным составом // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2023. Т. 16. № 3.2. С. 56–62. DOI: https://doi.org/10.18721/JPM.163.209

Introduction

Currently, much attention is paid to the problems of monitoring the state of various transport [1–5]. One of the most difficult areas to control is the railway. The traffic safety of railway transport largely depends on the quality of wheelset materials, design, manufacturing technology, its inspection and repair [6, 7]. Due to large static and dynamic loads, as well as violations of the rules for the technical operation of rolling stock, various defects occur in the wheelset. Optical methods are often used to control the state of various moving parts of an object and detect defects [8–13]. The requirements for the parameters of wheel sets in the automated control system for the operation of rolling stock are met by laser profilometers.

A laser profilometer is a device that is used to control the geometric parameters of wheel sets. It operates on the principle of laser interferometry and measures wheel profile height, wheel spacing, wheel diameter, and other parameters that can affect the safety and efficiency of rail transport.

The control of the geometric parameters of wheel sets is an important element of the maintenance and safety of railway transport. For example, incorrect wheel spacing or worn wheels can lead to track damage and even an accident. Therefore, regular monitoring of wheel pair parameters using a laser profilometer allows you to identify and eliminate these problems in a timely manner. This improves the safety and reliability of railway transport, as well as reduces wear and tear and operating costs.

The aim of the work is to develop a new algorithm for describing and evaluating the wheel profile, taking into account such additional requirements as the smoothness and continuity of the resulting profile, including on data with partial gaps. This will allow more accurate determination of geometric parameters, and, consequently, also reduce the number of erroneous rejection decisions.

The point cloud is a set of pairs $\{(x_i,y_ш)\}^n_{i=1}$ that defines the profile boundary, more precisely, the trajectory of the laser beam reflected from the profile boundary. Since the position of the profile boundary is measured with an error, and in some place's detection omissions are possible (for example, the beam turned out to be blocked by something), the regression problem becomes a natural continuation of the problem of finding the profile boundary. The solution of this problem is carried out by means of classical regression analysis.

Materials and Methods

The laser profilometer for determining the geometrical parameters of the surface profile contains a laser radiation source with a laser beam-to-line converter, an optical matrix receiver of reflected radiation, and an information processing device. The source of laser radiation is made in the form of a semiconductor laser operating in a pulsed mode. At least one narrow-band interference light filter is introduced along the reflected beam in front of the optical matrix receiver. In addition, a semiconductor laser operating in the visible red wavelength range was used, the temperature stabilization system was made on the basis of Peltier elements with a control controller and a temperature sensor. These systems are very often used in various optical instruments for accurate measurements [1, 6, 8, 9, 12, 14–16]. The information processing device is made in the form of a programmable logic controller with real-time signal processing and calculation of the surface profile. The block diagram of the laser profilometer is shown in Fig. 1.

The laser profilometer is designed to measure: flange height, rolling, flange thickness, flange steepness, tire thickness, it also provides for the removal and analysis of a complete wheel rolling profile, maintaining an electronic database of wheel pair wear, monitoring tolerances and sorting during technical inspection, certification, repair and formation of railway wheel sets of rolling stock.

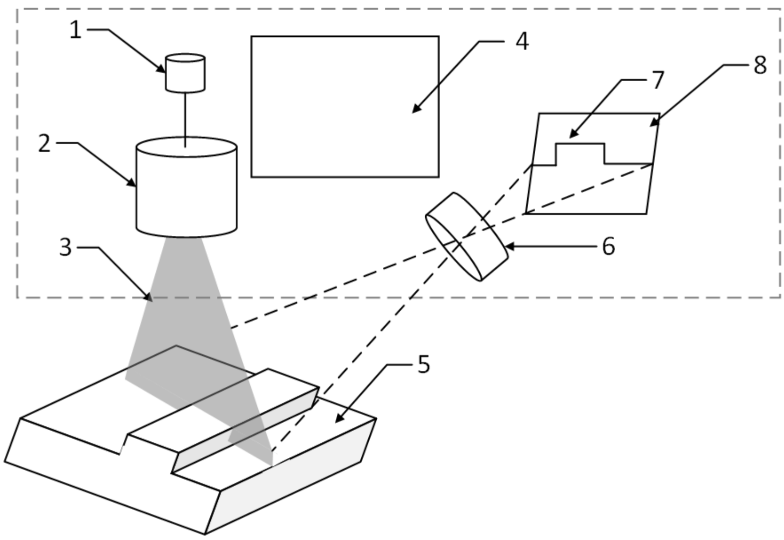

Fig. 1. Laser profilometer. laser module *1*; line generator *2*; plane of laser radiation *3*; controller based on digital signal processor *4*; controlled object *5*; optical system *6* of the photodetector; image *7* of the probing laser radiation line on the photodetector; matrix photodetector *8*

In contrast to the previously used templates for controlling the parameters of the wheel tread, which were applied by employees of the railway transport structure, the laser profilometer in the automated rolling stock control system fully automates this process.

The profilometer consists of several laser sensors that are mounted on the track and aimed at the wheels of passing trains. Lasers measure the distance to the wheel and fix its profile. The received data are transferred to a computer, where they are processed and analyzed.

The laser signal leaves a wide line on the photomatrix covering several points at once. Based on the point cloud obtained on the basis of the image from the photodetector, the wheel profile is analyzed and control values are calculated. Since the wheel geometry changes during operation, it becomes impossible to describe the new profile shape with sufficient accuracy by the classes of initial functions.

To solve this problem, a polynomial model was developed. This model takes into account the features in the distortion of the reflected laser radiation from the changed profiles of the wheel during its movement. Accounting for these features makes it possible to realize the restoration of the shape of the wheel pair profile more clearly in comparison with previously used methods.

The solution of the regression problem was sought in the class of piecewise polynomial functions [17, 18]. In what follows, the boundaries of the domain of definition of each part of the piecewise function will be called points of discord or matching points. So, the solution takes the form given in Eq. (1).

On all sites, a polynomial of degree p is used. The coefficients for each section are their own and the section number is indicated by a subscript. The superscript means the ith component of the vector of coefficients. To obtain the formula for the ith interval, it is sufficient to substitute the corresponding values for x and β.

$$f(x) = \begin{cases} f(x;\beta_0), x < x_1, \\ f(x - x_1;\beta_1), x_1 \le x < x_2, \\ \ldots \\ \ldots \\ f(x - x_{k-1};\beta_{k-1}), x > x_{k-1}, \end{cases} \quad (1)$$

where p is the degree of the polynomial, k is the number of segments, $\beta = (\beta^{(0)}, \ldots, \beta^{(p)})$ are the polynomial coefficients,

$$f(x;\beta) = \beta^{(0)} + \beta^{(1)}x + \ldots + \beta^{(p)}x^p = \sum_{j=0}^{p} \beta^{(j)} x^j$$

is a polynomial function,

$$f(x_i;\beta_i) = \beta_i^{(0)} + \beta_i^{(1)}x_i + \ldots + \beta_i^{(p)}x_i^p = \sum_{j=0}^{p} \beta_i^{(j)} x_i^j$$

is a polynomial function in the ith interval.

The laser signal leaves a wide line on the photo matrix covering several points at once. The laser beam is located vertically relative to the matrix, that is, along its short side. In this case, the image processing objects will be a string. The inverted image on the matrix is shown in Fig. 2,*a*. The processed point cloud in Fig. 2,*b* is a set of $\{(x_i, y_{ш})\}^n_{i=1}$ pairs defining the trajectory of the laser beam reflected from the profile boundary, found by solving the regression problem using the mathematical formulas above.

Based on the point cloud obtained on the basis of the image from the charge-coupled device matrix, the wheel profile is analyzed and control values are calculated.

The analysis of these profiles makes it possible to establish the presence of defects in a pair of wheels during the movement of the car, which was previously more difficult to do.

a) *b*)

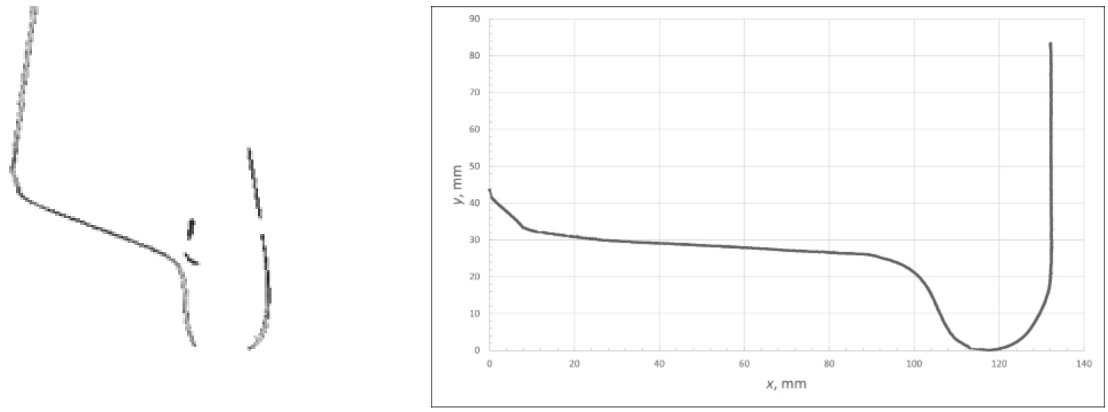

Fig. 2. Wheel profile: inverted image on the matrix (*a*), processed point cloud (*b*)

Results and Discussion

The use of a new model made it possible, using a laser profilometer, to create an automated system that can more accurately control the geometric parameters of the surface profile, the contour dimensions of the object, the relative position of parts, and the deviation from flatness.

Based on a mathematical model built on a cloud of points, the key parameters of the wheel were calculated. As part of the work, only one wheel was considered, since its data are indicative and contained gaps.

The decision on the need to send the wheel set for repair (turning) can be made according to the allowable ranges defined in the regulatory documents, which are unique for each type of wheels.

According to the processed data of the wheel set, the output of the parameter T3 was found - the steepness of the ridge from the allowable limits.

The ridge steepness parameter is the horizontal distance measured between two points on the outer surface of the ridge, one of which is 2 mm from the top and the other is 13 mm from the wheel circle.

The steepness parameter or the dangerous shape of the ridge characterizes almost all types of tire wear. It is measured in millimeters and depends on the drawing height of the comb. From this, it should further be concluded that the wheel with a dangerous ridge shape is rejected.

The ridge steepness parameter is complex and characterizes changes in the shape and dimensions of the ridge and the entire profile of the wheel tread surface associated with wear during operation.

The defect is the steepness of the ridge and the unacceptable value of the parameter at which the operation of the wheel set is prohibited is less than 6 mm. The resulting value was 3.8 mm.

This parameter is calculated by software. From which it was assumed that this wheel set is subject to prolonged exposure when passing one-sided curved sections of the track.

From which follows the conclusion about the need to reject this wheel.

A restored profile with wheel parameters was also obtained. From which we can conclude that the data processing system is working correctly and the laser profilometer is working correctly.

Conclusion

Just as a template is applied to a real wheel for measurements during the technical inspection of a rolling stock car, so in the proposed method, measurements are made at points according to the template. The technical result is an increase in measurement accuracy by minimizing the human factor, global digitalization of technological processes and automation of rolling stock control along the route.

The automated profilometer system allows not only taking pictures, analyzing the data obtained based on their comparison with the basic standard, but also transmitting information. This helps to estimate the number of errors in the received measurements and allows them to be converted into digital data. This made it possible to integrate it into the universal digital hardware and software platform of the automatic system for the operation of the rolling stock.

Thus, the use of a laser profilometer in an automated rolling stock control system is an effective way to control the geometric characteristics of freight cars and platforms. However, to achieve the best result, it is necessary to take into account a number of features of the laser profilometer, such as choosing the optimal installation height and scanning angle, as well as proper data processing.

In addition, it should be taken into account that the use of a laser profilometer is not the only way to control the geometric characteristics of the rolling stock, and in order to achieve maximum efficiency, it is recommended to combine its work with other control methods using an automated rolling stock control system.

Thus, it can be concluded that the use of a laser profilometer in an automated rolling stock control system is a promising and effective method for controlling the geometric characteristics of a rolling stock, subject to certain features of operation and taking into account technical and economic restrictions. In general, the use of this technology improves the quality of control and increases the efficiency of the rolling stock control system.

REFERENCES

1. **Davydov V.V., Kruzhalov S.V., Grebenikova N.M., Smirnov K.Y**., Method for Determining Defects on the Inner Walls of Tubing from the Velocity Distribution of the Flowing Fluid, Measurement Techniques. 61(4) (2018) 365–372.

2. **Mihov E.D., Nepomnyashchiy O.V**., Selecting informative variables in the identification problem Journal of Siberian Federal University - Mathematics and Physics. 9(4) (2016) 473–480.

3. **Ryzhenko I.N., Lutsenko A.E., Varygin O.G., Nepomnyashchiy O.V**., Carrier compensation mode implementation in satellite communication channels. In: Proceedings of 2019 International Siberian Conference on Control and Communications, SIBCON 2019, vol. 8729665 (2019) 23–29.

4. **Tarasenko M.R., Lenets V.A., Akulich N.V**., Features of use direct and external modulation in fiber optical simulators of a false target for testing radar station, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 10531 LNCS (2017) 227–232.

5. **Davydov R.V., Dmitrieva D.S., Pilipova V.M., Dudkin V.M.**, The research of radioactive exposure compensation on optical material for optical fibers by powerful laser radiation," Proceedings – International Conference Laser Optics, (ICLO–2020), vol. 9285820 (2020) 376.

6. **Chunsheng Li., Shihui L., Colin C., et al.**, An overview: modern techniques for railway vehicle on-board health monitoring systems, Vehicle System Dynamics. 55(7) (2017) 1045–1053.

7. **Kutner M., Nachtsheim C., Neter J**., Applied Linear Regression Model, Technometrics. 26(4) (2004) 165–171.

8. **Zharikov I.A., Rud V.Yu., Rud Yu.V., Terukov E.I.**, Polarization sensitivity of ZnSe single crystals based structures, Journal of Physics: Conference Series. 1410(1) (2019) 012088.

9. **Smirnov K.J., Glinushkin A.P**., Long–range night vision camera based on SWIR photocathode, Journal of Physics: Conference Series. 1695(1) (2020) 012090.

10. **Kosolapov V.M., Cherniavskih V.I., Zarudny V.A., Mazur K., Konieczna, A., Tseiko, L., Dumacheva E.V., Dumachev D.V.** Observations on the Productivity of Breeding Specimens of Urtica dioica L. from European Russian Ecotopes in Comparison with the Breeding Variety under Field Crop Conditions, Agronomy. 12 (2022) 76–82.

11. **Myazin N. S., Dudkin V. I., Grebenikova N. M., Davydov R. V., Podstrigaev A. S.,** Fiber - optical system for governance and control of work for nuclear power stations of low power, Lecture Notes in Computer Science. 11660 (2019) 744–756.

12. **Smirnov K.J., Tushavin G.V., Glagolev S.F.,** Temperature investigations of inp/ingaas based photocathodes," Proceedings of the 2018 IEEE International Conference on Electrical Engineering and Photonics, (EExPolytech–2018), vol. 8564416 (2018) 209–211.

13. **Wardal W.J., Mazur K.E., Roman K., Roman M., Majchrzak M.,** Assessment of Cumulative Energy Needs for Chosen Technologies of Cattle Feeding in Barns with Conventional (CFS) and Automated Feeding Systems (AFS), Energies. 14 (2021) 8584–8592.

14. **Kuzmin M. S., Rogov S. A.,** On the use of a multi-raster input of one-dimensional signals in two-dimensional optical correlators, Computer Optics. 43(3) (2019) 391–396.

15. **Yakusheva M. A., Davydov R. V., Isakova D. D.,** Features of signal absorption fronts of laser radiation in rapid diagnosis of human health. IEEE Proceedings 8th International Conference on Information Technology and Nanotechnology, (ITNT-2022). 23-27 Mat 2022. Samara, Russia. (2022). 145–149.

16. **Kazanskiy N.L., Butt M.A., Degtyarev S.A., Khonina S.N.,** Achievements in the development of plasmonic waveguide sensors for measuring the refractive index. Computer Optics. 44(3) (2020) 295–318.

17. **Gregory C.,** Tests of Equality Between Sets of Coefficients in Two Linear Regressions. Applied Mathematics. 28 (1960) 591–605.

18. **Huber P. J.,** Robust statistics, New York: John Wiley & Sons, 1981.

THE AUTHORS

ARINUSHKINA KSENIYA G.
k-arinushkina@mail.ru
ORCID: 0000-0002-1156-2071

ADADUROV ALEKSANDR S.
adadurov.aleksandr@vniizht-engineering.ru
ORCID: 0000-0002-9520-4596

SAVELEV IGOR YU.
savelev.igor@vniizht-engineering.ru
ORCID: 0009-0002-7511-7740

DAVYDOV Vadim V.
davydov_vadim66@mail.ru
ORCID: 0000-0001-9530-4805

Received 26.07.2023. Approved after reviewing 16.08.2023. Accepted 16.08.2023.