Improve hardware facilities and work algorithms of overhead contact line remote monitoring systems

Aleksandr Smerdin[1], *Elena* Butenko[1], *Mikhail* Mikhailov[1], *Victor* Philippov[1*]

[1] Omsk State Transport University, 35, Marx av., Omsk, 644046, Russia

Abstract. An autonomous diagnostic measuring device, that allows to reduce expenses for the maintenance and the need for highly qualified personnel, is proposed in the article. The described algorithm of the work of the measuring system allows setting pre-failure conditions of an overhead contact line during exploitations of the software complex. The Installation scheme of the measuring complex on an overhead contact line equipment and the functional scheme of the software and hardware complex are described. The experimental dependence of the vibration frequency on the contact wire tension is defined for various overhead contact line spans. The limits of the variation of the vibration frequency for various combinations of overhead contact line parameters are defined.

1 Introduction

One of the limiting components of railway infrastructure is an overhead contact line, which is the component of a traction power network and is intended for electric power transmission to electric rolling stock. It has to ensure the trouble-free operation of the power collecting system at various speeds of rolling stock in any weather condition. Overhead contact line parameters can change during its exploitation, which directly affects the performance of the current collection. The performance of the current collection is usually evaluated using the criteria listed in the regulatory documents [1, 2], the most important among them are contact force, tension, linear weight and temperature of the contact wires because they can vary within the length of one overhead contact line section influenced by many factors. With an increase in the speed of electric rolling stock, the potential risks related to overhead contact line failures increase [3, 4], and the interruption of the train traffic results in economic losses. Restoration of operability takes a significant amount of time because the length of a damaged railway section increases with an increase in the moving speed.

Nowadays diagnostic devices of the overhead contact line have been wildly used in the railway network [5-8], which, however, don't provide the required reliability for determining its performance parameters, due to their episodic use of them, and require permanent inspection maintenance. So, it's necessary to improve the technology of

* Corresponding author: fvm-omgups@mail.ru

overhead contact line diagnostics for the reliable and qualitative operation of the current collection system to increase performance parameters and the efficiency of overhead contact line use, as well as determine the operability of the current collection system during its exploitation.

This problem can be solved by using autonomous diagnostic devices, united into the specialized informational system, that allow to increase the quality of the monitoring and decrease the requirement for highly qualified personnel, which has particular relevance to operating conditions of extended and heavy freight traffic railway lines.

The real-time monitoring of overhead contact line parameters allows for timely identification of pre-failure conditions, addressing the causes, that caused them, adjusting the operating mode and thus improving the performance of the current collection system.

2 Materials and Methods

The simultaneous measurement of a number of parameters is required for the full functioning of the system: there are a temperature, tension and frequency of wires vibration. The proposed measuring device is based on the use of sensors of an acceleration dispersed along the overhead contact line section and arranged into the dropper clamp, which allows collecting the information about the vibration process at the points where overhead contact line equipment is installed.

Two-dimensional accelerometers, in which one of the axes is pointed vertical and the other axis is pointed horizontally, are offered to be installed at the contact wire to reduce power consumption, and increase autonomy and power efficiency. The vertical axis signal of the accelerometer is a tracking signal. It detects electric rolling stock passing along a railway line because vertical vibrations of the overhead contact line propagate a considerable distance. The horizontal axis signal is being recorded at high frequency during and for ten seconds after the passage of a pantograph, this allows to get the vibration spectra with high accuracy and a minimum amount of data. The horizontal vibrations of wires are more informative, unlike the vertical vibrations, because they are less affected by interfering mechanical connections (droppers, clamps, longitudinal and transverse electric connectors, and other elements) [3,9].

The assessment methodology of an overhead contact line operability by the frequency of wires vibrations has been offered. This methodology allows to determine the contact wire mass, which makes it possible to detect ice formation, contact wire wear, the mismatch between contact wire tension and its nominal value in real-time, as well as compute limit modes and recommended levels of the traction load without prejudice to the train traffic. With an increase in the contact wire temperature, it is possible to predict possible contact wire overheating based on sensor reading in real-time [10, 11].

The measuring device for measuring the contact wire tension and temperature (fig. 1) has been designed by OSTU specialists, it consists of the flexible element attached to the contact wire by the clamps. Flexible element tension is set by the spring mechanism.

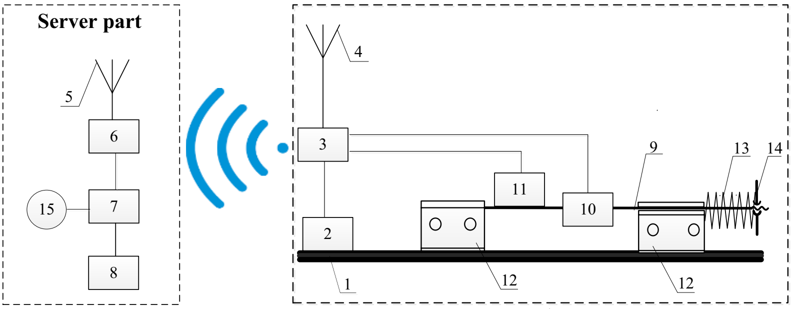

Fig. 1. The scheme of contact wire tension and temperature measuring device: 1 – contact wire; 2 – contact wire temperature sensor; 3 – radio transmitter; 4 – transmitting antenna; 5 – receiving antenna; 6 – radio receiver; 7 – comparison and control unit; 8 – feeder circuit breaker of an overhead contact line; 9 – flexible element; 10 – force sensor; 12 – clamp; 13 – spring; 14 – tension mechanism; 15 – signalling device

When the temperature of the contact wire changes, its tension changes, and it leads to a change in the flexible element tension. The force sensor melded into a flexible element to record its tension, and therefore contact wire tension. The temperature sensor gauges the flexible element warming, which allows for compensating for the thermal deformation of the contact wire.

The force sensor, contact wire and flexible element temperature sensors transmit data to the radio transmitter. Further, data are transmitted to the radio receiver and forwarded into the comparison and control unit, where obtained data are compared with predefined values. On the results of the comparison, the control signal is generated and transmitted to the overhead contact line circuit breaker to disconnect the contact wire from the power source to avoid thermal fault in case of overheating. The comparison and control unit constantly transmits a warning signal to the signalling device, which informs electric substation personnel or an energy dispatcher about changes in contact wire tension or temperature.

Accelerometers and a tension sensor (fig. 2) are mounted near the first unstitched dropper. Electric power is fed by a power supply unit equipped with a solar panel mounted on an overhead contact line bracket.

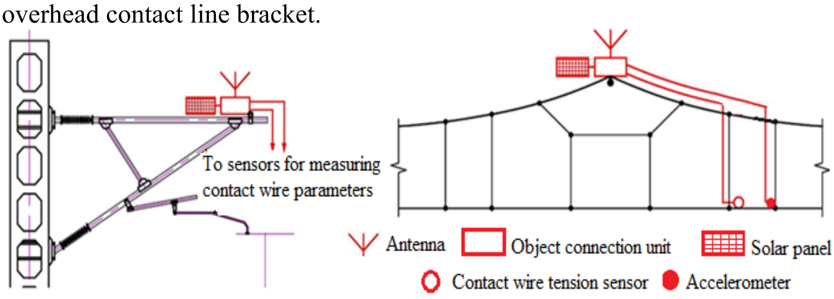

Fig. 2. The installation scheme of contact wire tension and horizontal vibrations measurement device

Fiber-optic sensors based on the Bragg grid are used to measure the contact wire temperature. They are installed on overhead contact line feeder clamps, and the registration unit, laser diode power supply unit, object connection unit and focusing devices unit are mounted on grounded parts of a bracket. When the wire temperature changes the reflected light wavelength changes, and measuring devices allow us to visualize it.

Sensors are connected to a signal converter by a cable with a detachable connector. The power supply unit is connected to the communication unit equipped with a GSM module.

Data are sent to the information server, where the contact wire tension is calculated, a “digital fingerprint” is generated, and matching procedures of the received data with the records obtained earlier are carried out.

The power supply unit is connected with the analogue-to-digital converter and radio communication module, that unites sensors with the common database into an informational system (fig. 3).

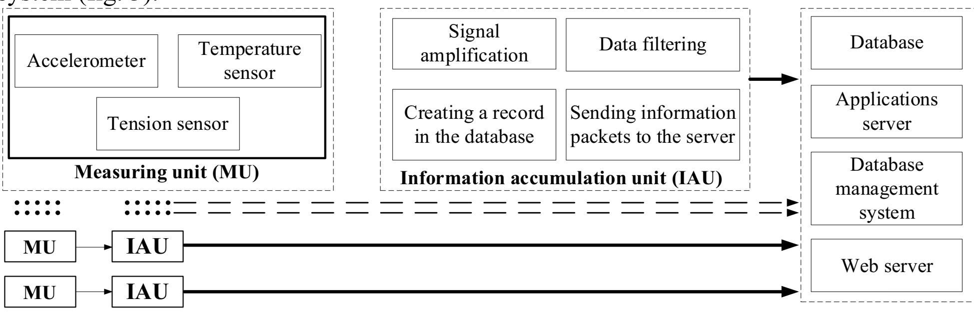

Fig. 3. The functional scheme of the overhead contact line monitoring and diagnostic software and hardware complex

The remote monitoring system’s main task is autonomy and measurement representativeness. The sensor, located on the diagnosis object, receives the diagnosis information (temperature, tension, vibration) and carries out its initial processing. The tasks of the pre-processor designed for the primary processing of the input data array include data filtering, its normalization and subsequent processing based on the fast Fourier transform.

Diagnosis data collected in the database can be stored on different scales. This feature negatively affects the machine learning process, because preliminary normalization is required for data analysis on the server. Thus, data with a larger range of values have more weight and influence on the result.

For the data processing algorithms’ effective operation, the initial array of “digital fingerprints” is converted to the required form. The conversion is necessary for the rational use of the built-in memory and to ensure a high transmission rate of the network packet. To minimize the amount of memory to one byte, the diagnosis data from each unit are scaled to the range from 0 to 255 according to the formula:

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}} \cdot 255 \quad (1)$$

where X_{min}, X_{max} – minimal and maximal values in the resulting dataset.

At the first stage of data processing, they are offset to a new centre, because the data may have a large scatter of values and non-normal distribution law the median value is used for centring.

The interquartile method is used to remove outliers in the data set (fig. 4). The interquartile range is (IQR, «central» 50 % dataset) a difference between the 75th (Q3) and 25th (Q1) percentile of the dataset [12]. Outliers are values that are outside the range [Q1 – 1.5 IQR, Q3 + 1.5 IQR].

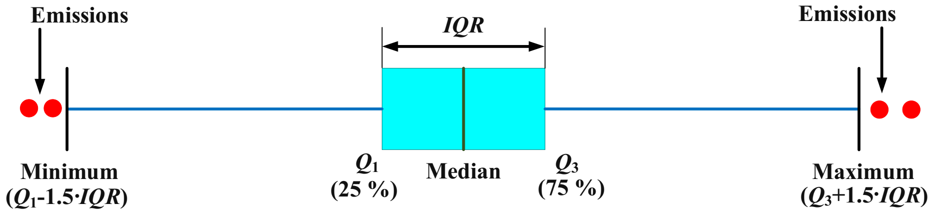

Fig. 4. Interquartile method of treating outliers in a data set

Depending on the placement features of the diagnostic component, various functional schemes for transmitting data from sensors can be realized. In the case of cellular network availability, diagnosis information in the encoded form is transmitted from sensors to the server for further analysis. Another variant is transiting network packets from sensors to a data collection station via a radio channel, which subsequently transmits information via wired or wireless channels to the server.

The diagnosis system sensor complex can be self-diagnosed using a statistical learning theory based on empirical risk minimization offered by V. Vapnik [13] and standard methods of distributed and hybrid control. The self-elimination of malfunctions, such as zero drift and hanging, is carried out using the watchdog hardware control scheme [14].

3 Results

The experimental determination of the contact wire vibration frequency in the horizontal plane for various tension values has been carried out at the OSTU overhead contact line testing site to check the operability of the proposed device. The testing site has a KS-160 catenary system with a length of 224.4 m. It consists of an MF-100 contact wire with a tension of 9375 N and a linear weight of 0.89 kg/m, an M-120 messenger wire with a tension of 14250 N and a linear weight of 1.058 kg/m. The range of the tension is 13124 N – 24376 N. The span lengths vary from 28.5 to 34.5 m.

Carried-out experiments have shown that the change in the contact wire vibration frequency has non-linear features, therefore experiment should be carried out according to the developed program of second-order rotatable designs. The experiment consists of four full-factor tests (tests 1-4), four tests in “star” points (tests 5-8), and five tests in the middle of the plan (tests 9-13).

The rotatable design allows ensuring the same prediction accuracy of the study object response values for all points. According to the second-order rotatable design of the two-factor experiment, two parameters have been changed: the span length has varied from 28.5 to 34.5 m and contact wire tension has varied from 2×6,562 to 2×12,188 N. The conditions matrix of the test sequence of the experiment has been based on the levels and range variation of the factors.

The wire vibration in horizontal plane regression equation depending on the variable parameters has been obtained:

$$f = 19.02 - 1.09 \cdot l + 23.68 \cdot 10^{-5} \cdot K - 10.66 \cdot 10^{-6} \cdot K \cdot l + 16.95 \cdot 10^{-2} \cdot l^2 - 3.23 \cdot 10^{-9} \cdot K^2 \quad (2)$$

where f – contact wire vibration frequency, Hz; K – contact wire tension, N; l – span length, m.

Fig. 5 shows experimental dependencies between the fundamental harmonic frequency of the vibration spectrum and the contact wire tension change for the various span lengths.

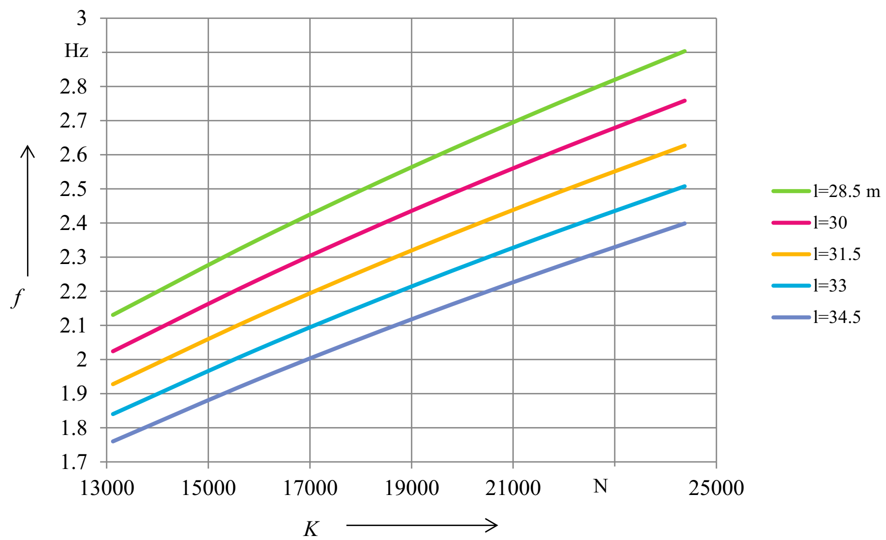

Fig. 5. The experimental dependencies between the wire vibration frequency and its tension

The Fisher criteria value for the regression equation and experimental values doesn't exceed experiment inaccuracy (< 5 %), which evidences the adequacy of the regression model to experimental data. The median validation error value of the calculation method is 5 %. Therefore, the suggested model has a high percentage of reliability and can be used in the software.

4 Conclusions

Theoretical and practice researches reveal that the wire tension and linear weight changes lead to vibration in a horizontal plane in the range of 1 – 4 Hz depending on the KS-160 overhead contact line span, which allows using of this indicator as a diagnostic parameter.

The proposed device allows sending information from railway transport equipment to a distributed database due to technical and schematic technical solutions that are implemented in it. Information in the database is suitable for its use in software specially developed for this measuring system.

The distributed diagnosis system can be used not only at overhead contact lines but at general industrial purpose overhead power lines. The proposed autonomous system has a self-diagnosis operation mode, in which data coming from the system units is compared to pre-recorded data as well as to each other.

The proposed system is low-manned technology and it will allow significantly reduce the costs of operation and maintenance of the overhead contact line and the number of service personnel in sparsely populated areas.

References

1. IRS 60913 Railway Application – Fixed Installations – Electric traction overhead contact lines. (2013).
2. IRS 70019 Railway Application – Fixed Installations – Overhead Contact Lines interoperability assessment. (2016).

3. A. Smerdin, E.A. Butenko, S.A. Stupakov, G. Ermachkov, *Transverse horizontal vibrations of contact network wires for monitoring their tension during operation*. E3S Web of Conferences **217**, 03002 (2020). doi:10.1051/e3sconf/202021703002.
4. A. Golubkov, G. Ermachkov, A. Smerdin, O. Sidorov, V. Philippov, *Increasing the forecasting fidelity of current collection system operating capability by means of contact pressure simulation modelling.* E3S Web of Conferences **217**, 03003. (2020) doi: 10.1051/e3sconf/202021703003.
5. A. Rønnquist, P. Nåvik, *Wireless monitoring of the dynamic behavior of railway catenary systems*. Conference Proceedings of the Society for Experimental Mechanics Series **7**, pp. 129-139. (2016) doi:10.1007/978-3-319-29956-3_15.
6. P. Nåvik, A. Rønnquist, S. Stichel, *A wireless railway catenary structural monitoring system: Full-scale case study*. Case Studies in Structural Engineering **6**, pp. 22-30. (2016) doi: 10.1016/j.csse.2016.05.003.
7. J. Bechmann, A. Dölling, G. Hahn, H.-J. Schwab, T. Wolpensinger. *Contact line monitoring system*. Eb - Elektrische Bahnen **106**(8-9), pp. 400-407. (2008) doi: 10.1016/j.csse.2016.05.003.
8. X. Huang, Q. Sun, X. Han, *An on-line monitoring method of temperature of conductors and fittings based on GSM SMS and Zigbee*. In: 3rd IEEE conference on industrial electronics and applications, pp. 1522–1527. (2008) doi:10.1109/ICIEA.2008.4582773.
9. F. Duan, Z. Liu, D. Zhai, A. Rønnquist, A siamese network-based non-contact measurement method for railway catenary uplift trained in a free vibration test. Sensors (Switzerland) **20**(14)3984, pp. 1-17. (2020) doi: 10.3390/s20143984.
10. N. Theune, N. Theune, T. Bosselmann, J. Kaiser, M. Willsch, H. Hertsch, R. Puschmann, *Online temperature monitoring of overhead contact line at the new German high-speed rail line Cologne-Rhine/Main*. WIT Transactions on State of the Art in Science and Engineering. Vol. **39**. (2010) doi:10.2495/978-1-84564-498-7/09.
11. A. Galkin, A. Buynosov, A. Paranin, A. Batrashov, *Improving of the Electrothermal Characteristics of the Contact Line*. Advances in Intelligent Systems and Computing, 1115 AISC, pp. 195-205, (2020) doi: 10.1007/978-3-030-37916-2_21
12. H. Guo, Y. Li, J. Shang, M. Gu, Y. Huang, B. Gong, *Learning from class-imbalanced data*. Review of methods and applications," Expert Syst. Appl., **73**, pp. 220–239, (2017) doi: 10.1016/j.eswa.2016.12.035.
13. N.M. Guerrero, J. Aparicio, D. Valero-Carreras, Combining Data Envelopment Analysis and Machine Learning. Mathematics **10**(6), P. 909. (2022) doi: 10.3390/math10060909.
14. B. Xiong, L. Jiang, L. Yang, X. Pan, *Design and performance testing of production performance determination system for boar*. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering **33**(9), pp. 174-179. (2017) doi: 10.1109/ECIE52353.2021.00017.