5. Кривошеев В.Н. Анализ неровностей на поверхностях катания колес, выявленных методом силового контроля // Исследование неровностей колес пассажирских вагонов: Сб. науч. трудов ВНИИЖТ. – Вып. № 608. – М.: Транспорт, 1979. – С. 60–74.

6. Кудрявцев Н. Н., Белоусов В. Н., Сасковец В.М. Влияние коротких неровностей колес и рельсов на динамические силы и ускорения ходовых частей вагонов // Влияние неровностей поверхностей катания колес на работу ходовых частей пассажирских вагонов: Сб. науч. трудов ВНИИЖТ. – Вып. № 610. – М.: Транспорт, 1981. – С. 4–22.

7. Замуховский А.В., Квашнин Н.М., Жангабылова А.М. Контроль динамического воздействия на путь // Мир транспорта. – 2014. – № 5. – С. 72–81.

8. Скуріхін Д.І. Удосконалення технології технічного обслуговування та діагностики колісних пар пасажирських вагонів на основі методу акустичного контролю/ Дис... канд. техн. наук. – Харків, 2014. – 143 с.

9. Система дистанційного акустичного контролю рейкового рухомого складу під час руху. Пат. 96483 Україна МПК B61K 9/08 (2006.01), G01S 5/14 (2006.01) / Бондаренко В.В., Візняк Р.І., Скуріхін Д.І.; заявник та патентовласник Українська державна академія залізничного транспорту. – № а200911191; заяв. 04.11.2009; опублік. 10.11.2011. Бюл. № 21/2011–7 с.

10. Спосіб дистанційного акустичного контролю рейкового рухомого складу під час руху. Пат. 95863 Україна МПК B61K 9/08 (2006.01), G01S 5/14 (2006.01) / Бондаренко В. В., Візняк Р. І., Скуріхін Д.І.; заявник та патентовласник Українська державна академія залізничного транспорту. – № а201005510; заяв. 05.05.2010; опублік. 12.09.2011. Бюл № 17/2011–5 с. ●

Координаты авторов: Бондаренко В. В. – bonvya@ukr.net, Скурихин Д. И. – skurikhin@i.ua.
Статья поступила в редакцию 26.09.2014, актуализирована 02.02.2015, принята к публикации 08.02.2015.

Статья подготовлена на основе материалов, представленных авторами на Международной научно-практической конференции «Конструкция, динамика и прочность подвижного состава», посвященной 75-летию со дня рождения В. Д. Хусидова (МИИТ, 20–21 марта 2014 года).

MOBILE ACOUSTIC CONTROL SYSTEM OF WHEEL SETS

Bondarenko, Vyacheslav V., *Ukrainian State Academy of Railway Transport (UkrGAZhT), Kharkov, Ukraine.*
Skurihin, Dmitry I., *Ukrainian State Academy of Railway Transport (UkrGAZhT), Kharkov, Ukraine.*

ABSTRACT

Defective wheels and axle boxes of cars still remain among main reasons that lead to disasters, accidents and significant material costs for rail transport. In this regard, an extremely important problem is reliable and accurate detection of defaults at the early stage of emergence.

It is difficult to completely eliminate the occurrence of failures in the form of local irregularities on the wheel tread taking structural, technological and operational measures, because their causes can be within a range of unpredictable random factors: short-term dynamic unloading of wheel sets when passing over irregularities of rail tracks, the volatility of the coefficient of friction of the wheels and rails, etc. In this case, the actual task is a rapid identification of a wheel defect arose in transit and timely notification of the train crew and rail services to prevent threats to safety, minimize the likelihood of damage and reduce maintenance time trains.

A new wireless onboard diagnostic system of passenger cars is proposed, which is designed to detect defects of wheel sets. This system is based on the method of acoustic control. Under the body of the passenger car microphones are mounted through which in the automatic mode recording and the analysis of frequency range of an acoustic signal from wheels and axle bearings, allowing detecting timely deviations from the set standards.

This onboard diagnostic acoustic system has obvious advantages over its ground acoustic analogs, since the latter, as known, have problems with the reliability of the diagnosis because of the negative impact on the accuracy of the Doppler effect, especially when trains run past the stationary located microphones at high speeds.

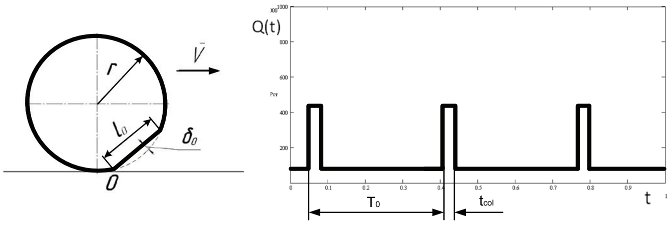
Keywords: *car, wheel set, damaged wheels, defect diagnostics, acoustic method, onboard control system.*

Background. *In recent years, among failures of joints and equipment of passenger cars en route most of them fall on the wheel sets (54%), the most of the defects are chips (44%), wheel flats (14%) and built up metals (5%) on the wheel tread [1, 2]. Many studies have shown similar pattern of facts and it is associated with the negative influence of the roughness of the wheels on the strength and durability of the wheel set axles, roller bearings, gears of undercar generators, switches, rails, welded and insulating joints, bolted connections [3–7].*

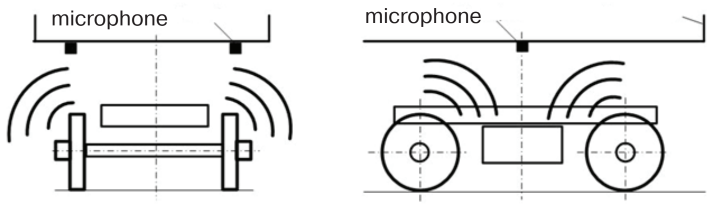
It is difficult to completely eliminate the occurrence of failures in the form of local irregularities on the wheel tread taking structural, technological and operational measures because their causes can be unpredictable random factors: short-term dynamic unloading of wheel sets when passing over irregularities of rail tracks, the volatility of the coefficient of friction of the wheels and rails, etc. In this case, the actual task is a rapid identification of a wheel defect arose in transit and timely notification of the train crew and rail services to prevent threats to safety, minimize the likelihood of damage and reduce maintenance time trains.

We believe it necessary first of all, to proceed with detection of wheel flats and built up metals to the wheel sets of passenger cars, which, when rolling up form uneven rolling, particularly dangerous at high speeds (120–160 km/h) and are difficult to identify in operation. In places of rolled up wheel flats and built up metal, among other things chipping of steel of the rim occurs, which further leads to the destruction of the wheel.

Objective. *The objective of the authors is to present a new wireless onboard diagnostic system of passenger coaches designed to detect defects of wheel sets, which is based on the method of acoustic control.*



Pic. 1. The curve of change of force in the form of a sequence of rectangular pulses.



Pic. 2. Onboard system of acoustic control of car wheel sets.

Methods. *The authors use analysis, scientific description, mathematical methods, engineering methods.*

Results. *The technical state of wheel sets is most fully manifested in the movement in the process of interaction with the rails. Short irregularities on the wheel tread cause shock loads, triggering sound vibrations of unsprung parts of the car, and therefore can be detected by means of an acoustic (noise-diagnosing) control.*

Acoustic signal from the interacting wheel and rail is formed as the sum of disturbances which do not differ much in size and represent a complex quasi-stochastic sequence. During the passage of the rail joints and points on the background of quasistochastic sequence of weak pulses several of them appear with a larger amplitude. In the presence on the wheel tread of a short irregularity the pulse period is proportional to the speed of the car V, and the amplitude – to the collision intensity that depends on the depth of irregularities δ_0 (Pic. 1).

The analytic curve of change of force in contact of wheel and rail in the form of a Fourier series [8]:

$$Q(\mathrm{t}) = \frac{Q_{st}(\mathrm{T}_0 - \mathrm{t}_{col}) + Q_{imp}\,\mathrm{t}_{col}}{T_0} + \sum_{n=1}^{\infty}\left[\begin{array}{l} 2\left(\dfrac{Q_{imp}-Q_{st}}{\pi n}\right)\left(\cos\dfrac{\pi n(2t_з + t_{col})}{T_0}\sin\dfrac{\pi n t_{col}}{T_0}\right) + \\ 2\left(\dfrac{Q_{imp}-Q_{st}}{\pi n}\right)\left(\sin\dfrac{\pi n(2t_з + t_{col})}{T_0}\sin\dfrac{\pi n t_{col}}{T_0}\right)\end{array}\right], \quad (1)$$

where $t_з$ is time shift with respect to t=0;

n is a number of pulses in the sequence;

t_{col}, T_0 is duration and pulse repetition period;

Q_{imp} is an impact force of the wheel on the rail;

Q_{st} is static load from the wheel on the rail.

In the foregoing embodiment, the problem of detecting damage to the wheel is reduced to identification of periodic pulses in the audio signal in noise and determining the correspondence between the amplitude of the sound pressure and depth of short irregularities.

At the department of railway cars of UkrGAZhT were developed a method and system of acoustic control of wheel sets while driving the car [9, 10], as well as model sample analyzer. The system consists of a microphone, a sound signal analyzer and GPS / GSM / GPRS-tracker. The microphones are located under the body of the passenger car (Pic. 2), the analyzer and the tracker – in the main cabinet of the car.

Using the analyzer of the audio signal during the movement of the car periodic pulses are indentified corresponding to impacts of the faulty wheel on the rail with reference to the wheel speed. Data on identifying the damaged wheel are transmitted via tracker to both onboard and ground control stations of cars.

This active acoustic control method also allows the identification of defects, not only on the wheel tread, but also in the bearings of axle equipment on the basis of an analysis of the frequency range of the acoustic signal from the axle box bearings with known frequencies of their defects based on the design, dimensions and speed of the train:

frequency with the defect on the outer ring

$$F_n = \frac{N}{2}\cdot\left(1 - \frac{B_d}{P_d}\cos\alpha\right)\cdot\frac{RPM}{60}, \quad (2)$$

frequency with the defect on the inner ring

$$F_v = \frac{N}{2}\cdot\left(1 + \frac{B_d}{P_d}\cos\alpha\right)\cdot\frac{RPM}{60}, \quad (3)$$

frequency with the defect on the roller

$$F_r = \frac{P_d}{2B_d}\cdot\left(1 - \left(\frac{B_d}{P_d}\right)^2(\cos\alpha)^2\right)\cdot\frac{RPM}{60}, \quad (4)$$

where N is a number of rollers in the bearing;

RPM is a rotation speed of the bearing, rpm/min;

B_d is a diameter of a roller;

P_d is a diameter of the separator (outer diameter of the bearing plus the inner diameter of the bearing, divided by 2);

α is an angle of contact of the rolling elements and raceways.

The acoustic control system has the following advantages:

– The possibility of continuous monitoring of wheel sets on the route of the car, as well as early warning of repair crews increases the readiness of passenger cars for operation;

– Registration of short irregularities immediately after the occurrence enables to quickly take action to

change the speed limit of the train, as well as to prevent the development of non-uniform rolling (which occurs when rolling up short irregularities), mileage calculation of wheel set with short irregularities;

– This onboard acoustic diagnostic system is more accurate and efficient, in contrast to existing ground acoustic diagnostic means, since the latter are known to have problems with the reliability of the diagnosis because of the negative impact on the accuracy of the Doppler effect, especially when trains run past the motionless located microphones at high speeds;

– High system reliability due to less loaded operating conditions, since sensors (microphones) are placed under the unsprung body of the passenger car and do not require wiring to a control object, unlike known systems with the acceleration sensors;

– The ability to conduct parallel acoustic control of the technical condition of damaged sections of the track automatically, attaching it to the coordinates by GPS;

– Additional convenience and economy are provided by the possibility of mounting on the design of any year of construction, because the system is autonomous and independent of the electrical circuit of the car.

Conclusions.

1. On the railways of CIS and Europe there are no effective systems of continuous monitoring of the technical condition of wheel sets, which has a negative effect on traffic safety and reduces the operational availability of passenger cars.

2. Sound vibrations are a reliable source of information about the technical condition of the wheel sets and axle bearings while driving a passenger car.

3. The use of acoustic control system on the basis of the developed method can effectively detect the most dangerous damage to the wheel sets and axle bearings, which has a pVositive effect on the provision of high operational availability of passenger cars in operation.

REFERENCES

1. Martinov, I.E., Bondarenko, V.V., Skurihin, D. I. Increase of operational reliability of passenger coaches on the basis of acoustic control of wheel sets [*Pidvischennya ekspluatatsiynoї nadiynosti pasazhirs'kih vagoniv na osnovi akustichnogo kontrolyu kolіsnih par*]. *Vagonniy park*, 2011, Iss.6, pp. 36–39.

2. Bondarenko, V.V., Skurihin, D.I Onboard acoustic control system of wheel sets [*Bortova sistema akustichnogo kontrolyu kolіsnih par*]. *Zalіznichniy transport Ukraїni,* 2012, Iss.1, pp. 32–35.

3. Kudryavtsev, N.N., Baklanov, B. V. Evaluation of the operational loading of wheel sets of passenger coaches by inertial forces and their normalization [*Otsenka ekspluatatsionnoy nagruzhennosti kolesnyh par passazhirskih vagonov inertsionnymi silami i ih normirovanie*]. In: Study of irregularities of wheels of passenger cars: collection of scientific works of VNIIZhT [*Issledovanie nerovnostey koles passazhirskih vagonov: Sb. nauch. trudov VNIIZhT*]. Iss. № 608. Moscow, Transport publ., 1979, pp. 88–101.

4. Obraztsov, V.L., Malyshev, V. P. Automation of technical diagnostics of wheels while moving the train [*Avtomatizatsiya tehnicheskoy diagnostiki koles pri dvizhenii poezda*]. Moscow, Transport publ., 1978, 48 p.

5. Krivosheev, V. N. Analysis of irregularities on the wheel tread identified by a power control method [*Analiz nerovnostey na poverhnostyah kataniya koles, vyyavlennyh metodom silovogo kontrolya*]. In: Study of irregularities of wheels of passenger cars: collection of scientific works of VNIIZhT [*Issledovanie nerovnostey koles passazhirskih vagonov: Sb. nauch. trudov VNIIZhT*]. Iss. № 608. Moscow, Transport publ., 1979, pp. 60–74.

6. Kudryavtsev, N.N., Belousov, V.N., Saskovets, V. M. Influence of short irregularities of wheels and rails on the dynamic force and acceleration of running parts of cars [*Vliyanie korotkih nerovnostey koles i rel'sov na dinamicheskie sily i uskoreniya hodovyh chastey vagonov*]. In: Influence of irregularities of the wheel tread on the work of running parts of passenger cars: collection of scientific works of VNIIZhT [*Vliyanie nerovnostey poverhnostey kataniya koles na rabotu hodovyh chastey passazhirskih vagonov: Sb. nauch. trudov VNIIZhT*]. Iss. № 610. Moscow, Transport publ., 1981– pp. 4–22.

7. Zamukhovskiy, A.V., Kvashnin, N.M., Zhangabylova, A. M. Control of Vehicle's Dynamic Impact on a Track. World of Transport and Transportation, 2014, Vol.12, Iss. 5, Vol .54, pp .72–81 .

8. Skurihin, D. I. Improving technology, technical servicing and diagnostics of wheel sets of passenger cars on the basis of acoustic control. Ph. D. (Eng) thesis [*Udoskonalennya tehnologiї tehnichnogo obslugovu-vannya ta diagnostiki kolіsnih par pasazhirs'kih vagoniv na osnovi metodu akustichnogo kontrolyu. Dis... kand. tehn. nauk*]. Kharkov, 2014, 143 p.

9. System of remote acoustic control of rail rolling stock while driving [*Sistema distantsiynogo akustichnogo kontrolyu reykovogo ruhomogo skladu pid chas ruhu*]. Pat. 96483 Ukraine IPC B61K 9/08 (2006.01), G01S 5/14 (2006.01). Bondarenko, V.V., Viznyak, R.I., Skurihin, D.I.; applicant and patentee: Ukrainian State Academy of Railway Transport. – № a200911191; applied 04.11.2009; published 10.11.2011. Bull. № 21/2011–7 p.

10. The method of remote acoustic control of rail rolling stock while driving [*Sposib distantsiynogo akustichnogo kontrolyu reykovogo ruhomogo skladu pid chas ruhu*]. Pat. 95863 Ukraine IPC B61K 9/08 (2006.01), G01S 5/14 (2006.01). Bondarenko, V.V., Viznyak, R.I., Skurihin, D.I.; applicant and patentee: Ukrainian State Academy of Railway Transport. – № a201005510; applied 05.05.2010; published 12.09.2011. Bull № 17/2011–5 p.

Information about the authors:

Bondarenko, Vyacheslav V. – Ph.D. (Eng.), associate professor at the department of railway cars of the Ukrainian State Academy of Railway Transport (UkrGAZhT), Kharkov, Ukraine, bonvya@ukr.net.

Skurihin, Dmitry I. – assistant at the department of railway cars of the Ukrainian State Academy of Railway Transport (UkrGAZhT), Kharkov, Ukraine, skurikhin@i.ua.

Article received 26.09.2014, revised 02.02.2015, accepted 08.02.2015.

The article is based on the papers, presented by the authors at the International scientific and practical conference «Rolling stock's Design, Dynamics and Strength», dedicated to the 75th anniversary of V. D. Husidov, held in MIIT University (March, 20–21, 2014).