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Informatics

Fiber-Optic Cable Fragments in Rail Circuits as Distributed Sensors

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For the safety of train traffic the most important step is the introduction of a new type of rail circuits – fiber-optic rail circuits. The high sensitivity of the fiber optic cable to external influences (deformation, vibration) is an important property both for fixing mechanical damage to rails and for monitoring railway rolling stock. The branches (fragments) of the optical fiber through mechanical amplifiers perform both the functions of the information perception element – the sensor and the conducting channel of the transmitted information. Using reflectometer OTDR (Optical Time Domain Reflectometer), based on the analysis of the backscattered light signal, the form of the effect that caused the bending is determined. Knowing the exact distance between the OTDR and the sensors, when analyzing the received signals, it is possible to determine different parameters of the passing rolling stock. The paper shows the schematic diagram and the algorithm of the proposed system developed by the authors. *© 2020 Bull. Georg. Natl. Acad. Sci.*

Fiber optic cable, light signal, rail circuits, reflectometer, sensor

The implementation of large investment programs in the intensification of international transport significantly expands the role of vehicles. The increase in traffic intensity and the number of trains of railway vehicles requires to solve the problems of improving safety, reliability and speed. Modern requirements for traffic safety have sharply revealed the problems of rolling stock monitoring and hazard prediction [1]. One of the main problems of the safe traffic of trains is the monitoring of the interaction of the rail and the wheelset and timely detection of its undesirable results [2,3].

In spite of the use of the modern digital and communication the practice shows that in many cases the modern electric rail circuits do not meet completely the conditions corresponding to the working regimes [4].

On the way of improvement of the train traffic safety and information management systems, the most important step is the introduction of a new type of rail circuits – fiber-optical rail circuits [5,6]. The main idea is to bring the fiber optic cable in tight mechanical contact with a rail. The branches of the optical fiber by means of mechanical amplifiers perform both of the functions:

information perception element and conducting channel of the transmitted information.

Schematic Diagram and the Algorithm of the Proposed System

The high sensitivity of the fiber optical cable to external influence is an important property, since high sensitivity is required to detect thermal expansion of rails, micro cracks and other mechanical damages. The sensitivity of the optical cable is manifested in a violation of the linearity of the light it conducts. With physical impact, the fiber optic cable undergoes deformation and vibration. This process is classified into two groups – micro bends and macro bends. Conducted light is scattered at the bend. Part of the scattered light returns to the light emitter. On this principle the OTDR (Optical Time Domain Reflectometer) device is built. In fact, the fiber optic cable at the bend turns into a sensor [7,8]. On the basis of analysis of the back-scattered signal, the type of impact cause ding the bending is established. The time required from sending the signal to receiving the backscattered signal with high accuracy sets the distance to the bend [9].

The authors proposed the creation of a centralized monitoring system using fiber-optical cable. Such a system has no analogues in the world.

On both rails the identical structure of the system is presented. On the first and second rails, the branches as sensors are located opposite each other, with equal distance. For simple’s description of the presented system in the paper is just one, conditionally first rail is considered.

In Fig. 1 presents a block scheme of the proposed system of the first rail: a single-mode fiber-optical cable (1) is tightly fixed along the rail, the branches of which called “the loops” represent a fragment of a fiber-optical cable with mechanical amplifiers that are fiber-optical sensors (2-1 ÷ 2-n). The task of the “loop” is to increase the sensitivity of the optical cable to external influences.

The sensors are located along the rails at such a distance from each other that excludes the possibility of simultaneous operation of two or more sensors. Also, their distance from the OTDR’s are precisely defined.

At the beginning of the rail, there is a OTDR with certain wavelengths $\lambda 1 = 1310$ nm (3) or $\lambda 2 = 1550$ nm, which are included in the circuit of a

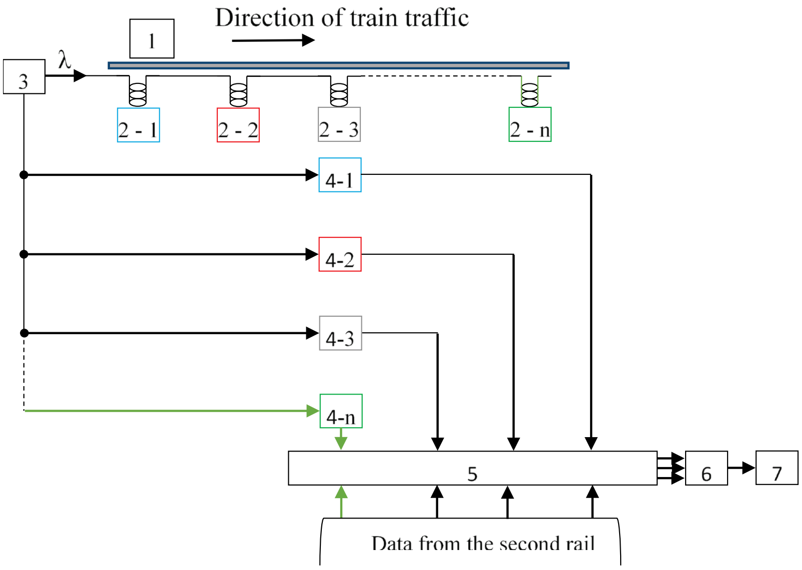

Fig.1. Block-scheme of the system.

single-mode fiber optic cable tightly fixed along the rail. Using the OTDR, an optical pulse is generated, and therefore their shape S is determined. Also, the exact calculation of the coordinates of the impulse signal power drop is carried out (distance from the OTDR to the point of the impulse power drop).

When the wheelset of the rolling stock acts on the corresponding sensor (2-1 ÷ 2-n), OTDR (3) begin to generate signals in the form of pulses Sn. The exit of the OTDR is connected with registers (4-1 ÷ 4-n), each of which corresponds to a determinate sensor (2-1 ÷ 2-n).

Accordingly, to the distance between the pulses (tn interval) of reflectometer (3), signals in the form of pulses (St1÷Stn) the corresponding registers of transmitter (4-1 ÷ 4-n). Also, each register of (4-1 ÷ 4-n) will work when there are sent S signals on the input of the registers.

At the same time, these impulses in the form of ISn signals are passed to the computing block (5). The impulses in the form of IISn signals from the structure located on the second rail are sent to the same computing block where the calculation process occurs according to the following logic:

1. As the result of the passage of the wheel pairs in the computing block 5, in the direction of movement, the number of pulses from the first five registers of the both rails are counted by the counters I4a1 ÷ I4a5 and II4a1 ÷ II4a5, then there is comparison of the quantity of counted impulses, for instance, I4a1 ≠ I4a2 = I4a3 = I4a4 = I4a5 = II4a1 = = II4a2 = II4a3 = II4a4 ≠ II4a1, then the error as presented I4a1 and II4a1 is eliminated and final result is formatted. By the previously developed algorithm there is carried out: determining the number of rolling stocks; determining the speed of the rolling stock, determining the type and number of carriage in the rolling stock, determining the length of the rolling stock;

2. The comparison of the analogue signals, signal S with the etalon ΔS received from the relevant register of the transmitter: from the OTDRs (3) of first and second rails, and allocation of distorted pulses and their subsequent supply to the analysis block (6);

3. In the analysis block 6, the analysis of the received signals forms [10] by the following logic is processed:

a) In the short *cd* section, the IS, IIS signals from the first and second rail sensors, are getting small together comparing to their etalon – on this section the rail is damaged;

b) On the given section, the IS, IIS signals from the first and second rail sensors, are getting small together comparing to their etalon – on this section was moved the heavy weight rolling stock;

c) On the given section, the first and second rail sensors (2-1÷2-n) are detecting the similar changes of signals comparing to the etalon – the rolling stock has the carriages of different weight.

d) On the given section, the first and second rail sensors (2-1÷2-n) are detecting the different changes of the I Sn and II Sn during the movement of the specific rolling stock, namely, if I Sn≈ΔS and II Sn ≠ΔS then there is damaged the rolling stock of that side where was found the inequality.

4. By the previously formatted algorithm, with high precise there are defined: the load on the rail, the worn rail, the worn rolling stock and wear quality.

5. From the analysis block (6) the information is supplied to the indication block (7).

Algorithm of Functioning Systems

In the Fig 2. And Fig. 3 are presented the block-schemes of working algorithm of computing block (5) and analysis block (6). On Fig. 2 is presented working algorithm of computing block (5): 1. From registers (4-1÷4-n) of I and II rails, input of signals ISn and IISn; 2. Calculation of received from each register signals; 3. Comparison of quantity and elimination of errors; 4. Generating of wheelsets quantity; 5. From proper register of sensor: Comparison of the ongoing from the I and II rails reflectometers (3) the analogue signals S with the

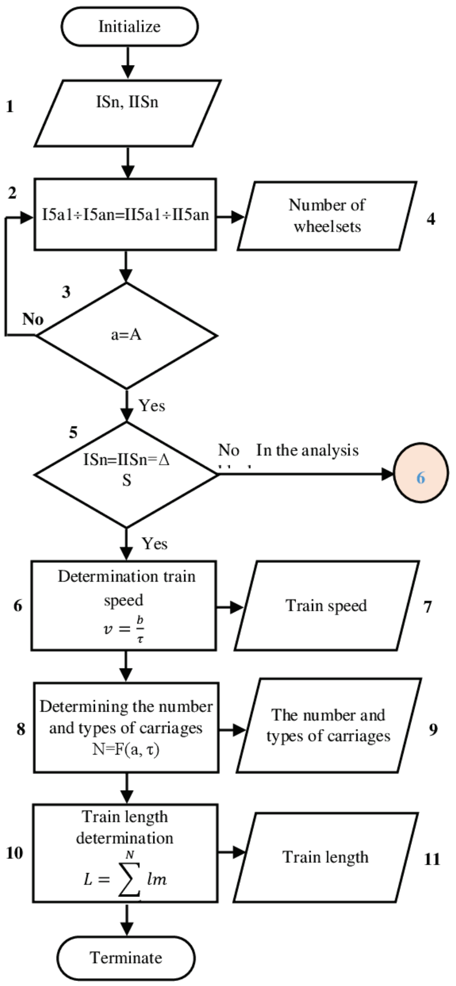

Fig. 2. The block scheme of the algorithm of the computing block (5).

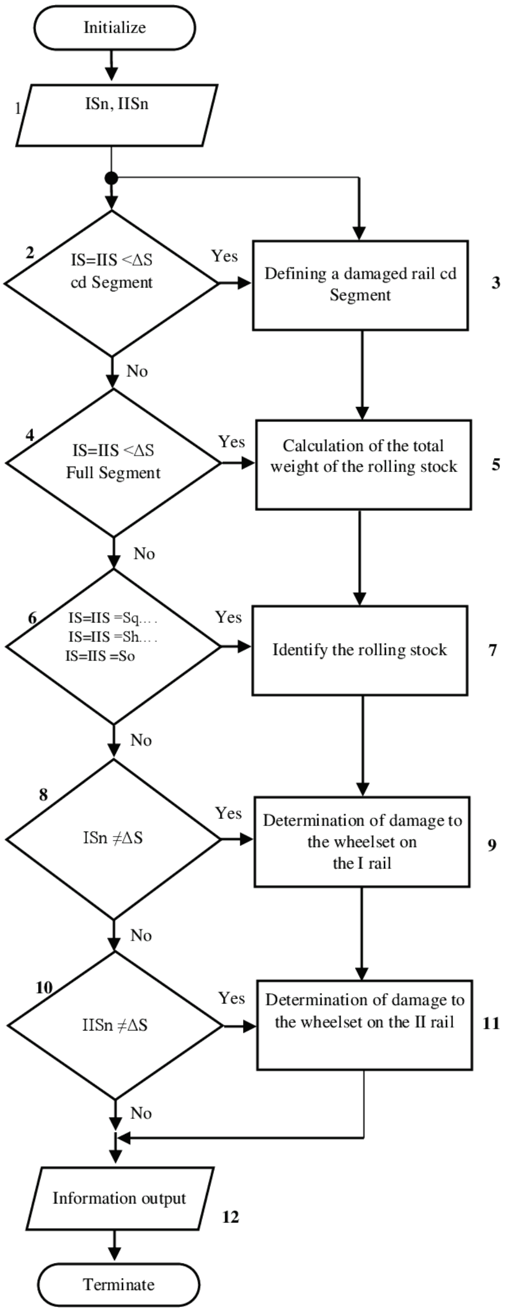

Fig. 3. Presents a block scheme of the working algorithm of the analysis block (6).

etalon ΔS signal and transmitting different (modulated) impulses to the analysis block (6); 6. Calculation of train movement speed between successive sensors on known distance x, and interval τ at passage of wheelsets between these sensors. 7. Displaying values of speeds. 8. Calculation of quantity of received impulses a including existing berween them time intervals τ by quantity of carriages N=F(a,τ) and determiantion of type; 9. Displaying the quantity and type of the carriages; 10. Summation of lengths of received quantity of carriages and calculation of length of trains; 11. Displaying of trains lengths.

In Fig. 3 is presented the description of operation of block-scheme of algorithm of analysis block (6): 1. Inputting values ISn and IISn from computing block; 2. Detention of damaged rail; 3. Determination of cd segment and calculation of degree of damage; 4. Determination of weight of train; 5. Calculation of total weight of train; 6. Detention of carriages with different weight; 7. Monitoring of train accordingly of carriages weight; 8., 9, Detention of damaged wheelsets; 10, 11. Calculation of degree of whellset damage; 12. Displaying of results of analysis.

Conclusion

A review of existing patents also proves obvious advantage of the proposed method of universal system, characterized by high measurement accuracy, advanced functionality and simplified design compared to existing methods.

The developed schematic diagram of the multifunction systems based on fiber optic cable, which produces new innovative method, with the help of which it will be possible to: detect out or damaged wheel-set in the rolling stock; detect without fail the station-to-station block occupation of rolling stock; ascertain precise location of occupation of the station-to-station block by the rolling stock; determine a place of the worn out or damaged rail (rail); identify the rolling stock; detect overheated boxes in the rolling stock; control the load on the rolling stock axles.

Equipping the railway sections with these systems will significantly increase the economic efficiency of transportation, which in turn leads to an increase in the region's budget revenues.

The developed design scheme can also be successfully used to monitor the status of strategic facilities.

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ინფორმატიკა

ბოჭკოვან-ოპტიკური კაბელის ფრაგმენტები სარელსო წრედებში განაწილებული გადამწოდების სახით

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წარმოდგენილ ნაშრომში გამოკვლეულია საკონსტრუქციო მასალების ახალი კლასის – დეფორმირებადი მაღალმტკიცე თუჯების სტრუქტურა და თვისებები. შესწავლილია სხმული და დეფორმირებული მაღალმტკიცე თუჯების აუსტენიზაციის პარამეტრების გავლენა შენადნობების ფაზურ შედგენილობებზე. ნაჩვენებია, რომ პლასტიკური დეფორმაციის და თერმული დამუშავების პროცესების თანმიმდევრული შეთავსება უზრუნველყოფს გაცილებით მრავალფაქტორიან გავლენას მაღალმტკიცე თუჯის სტრუქტურასა და სამომხმარებლო თვისებებზე. კვლევის ობიექტად შერჩეულ იქნა მაღალი სიმტკიცის თუჯები 3,45% C, 2,30% Si, 0,25% Mn, 0,003% S, 0,05% P და 0,045% Mg-ით. საცდელი ნიმუშების გლინვა ხორციელდებოდა საფეხურებად 20%-იანი პირველადი მოჭიმვებით. ჯამში, 60% მოჭიმვით მიღებულ იქნა უდეფექტო ფურცლოვანი ნამზადი. ჩატარებული ცდების შედეგად დადგენილია, რომ მაღალმტკიცე თუჯის ცხლად პლასტიკური დეფორმაცია აწვრილმარცლოვანებს ლითონური ფუძის სტრუქტურას, ხელს უწყობს პირველადი აუსტენიტის დაშლას ტემპერატურების შუალედურ ინტერვალში, ზრდის ნახშირბადის დიფუზურ აქტივობას, აჩქარებს აუსტენიტის ჰომოგენიზაციას და ამცირებს აუსტენიტიზაციის ხანგრძლივობას.

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