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АВТОМАТИЗОВАНІ СИСТЕМИ УПРАВЛІННЯ НА ТРАНСПОРТІ

UDC 656.259.2: 621.315

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STUDY OF TRANSMISSION LINES EFFECT ON THE SYSTEM OPERATIONON OF CONTINUOUS AUTOMATIC CAB SIGNALLING

Purpose. To conduct an effect research of the electromagnetic field of high-voltage transmission lines (HVTL) (750 kV, 50 Hz) on the track circuits and continuous automatic cab signalling (CACS) with a signal current of 50 Hz in the areas of convergence and intersection with the transmission lines and to propose possible methods to improve noise immunity of CACS. **Methodology.** The measurements were performed both by means of car-laboratory and directly on rail lines. During the study the electric field strength in the range of industrial frequency directly under the transmission lines and at the distance from it to the railway lines was measured, as well as the time dependence of CACS codes with signal current frequency of 50 Hz directly under the transmission lines and at a distance from it in the absence of the train and its passing. **Findings.** The root causes analysis of CACS faults and failures was carried out. The effect of the electromagnetic field of high-voltage transmission lines (750 kV, 50 Hz) on the track circuit and CACS with signal current of 50 Hz in the areas of convergence and intersection with the transmission line was investigated. Possible methods to improve noise immunity of CACS were considered. **Originality.** The effect research of transmission lines (750 kV) on the operation of the automatic cab signalling on spans Prishib-Burchatsk and Privolnoye-Yelizarovo, Pridneprovsk railway in places of oblique railroads crossing and transmission lines (750 kV, 50 Hz) was conducted. Electric field strength in the range of industrial frequency directly under the transmission lines and at a distance from it to the railway line, as well as the time dependences of ALSN codes with signal current frequency of 50 Hz directly under the transmission lines and at a distance from it in the absence of the train and as its passing were measured. It was found that CACS codes in track circuits under transmission lines are strongly distorted, as strength measurements of electric field are shown, it can be explained by the electromagnetic field effect of transmission lines on track circuits. **Practical value.** Possible methods of CACS safety enhancement by improving the reliability of signaling from a track on the locomotive were considered.

Keywords: automatic cab signalling system; fault; failure; high-voltage transmission line

Introduction

Recently, in Ukraine there is an increase of train speeds, implementation of accelerated motion, and in the future implementation of high-speed train one, while ensuring the necessary safety level of trains.

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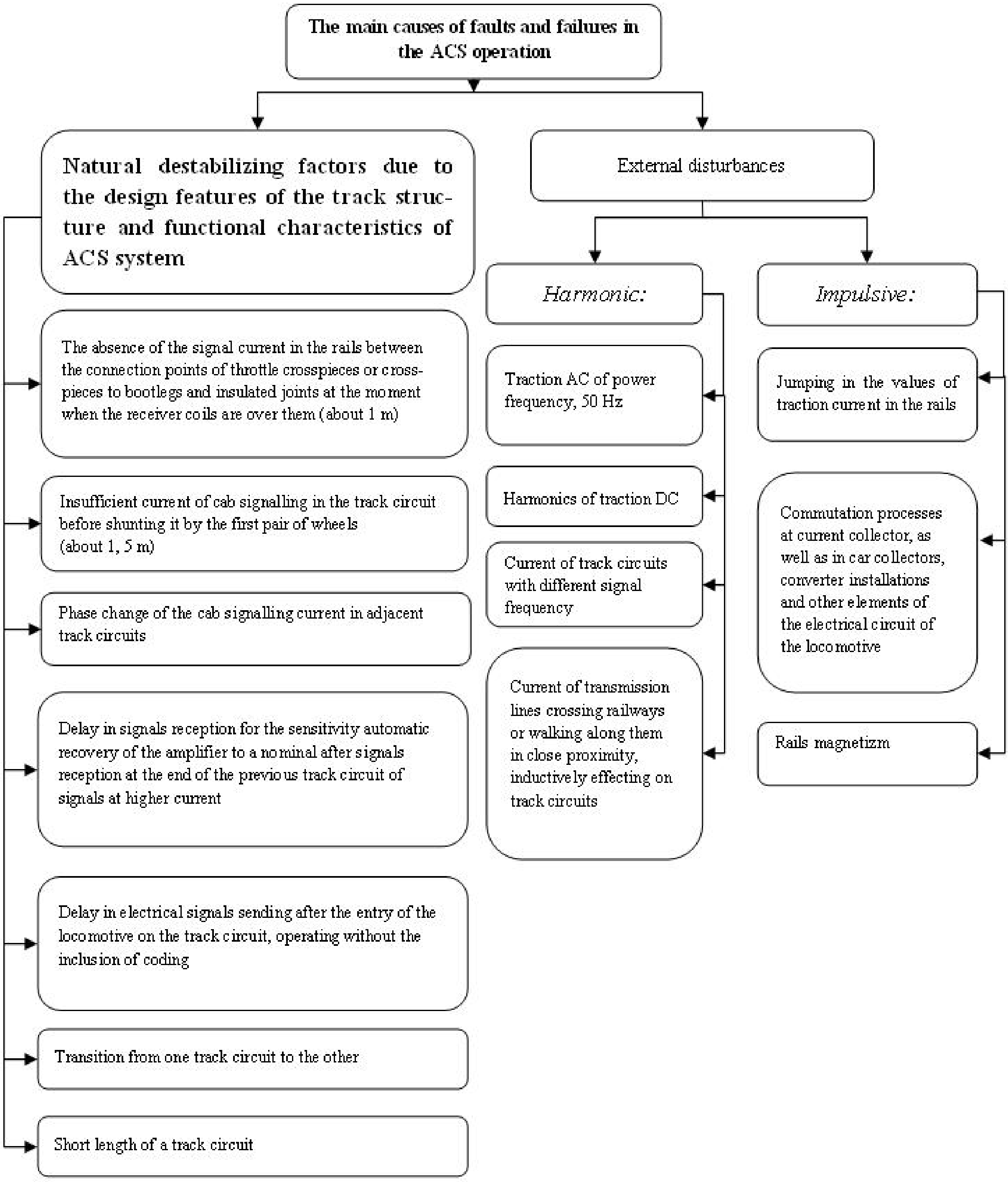

Fig. 1. Main reasons classification of faults and failures in ACS operation

Short-term faults and failures of continuous automatic cab signalling (CACS) are connected with a large number of reasons (Fig. 1) [7].

Natural destabilizing factors due to the design features of the track structure and functional characteristics of the system itself, can lead to the interval in signalling and brief glimpses of locomotive traffic lights. But the work of the ACS is constructed that the devices recognize the new electric signal is not earlier than 5-6 seconds (time delay for releasing the Compliance relay (CR)), which in most cases let protect the system against faults.

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Furthermore, there are some protective measures:

– accelerated and preliminary signalling to the track circuits, decoding by a decoder the yellow light signal with red one after the second arrival, matching the washer starting in the transmitter;

– fixation by a decoder the green light signals with an extra impulse during a time delay of control relay in code combinations entry (CCE), the use of code transmitters with a shorter duration of code combinations - 1.6 sec. on the stations, the location of insulated joints in the transition curves of switches, and not on the main track [5].

External interferences in turn differ in the nature of impact. Impulsive noise consist of short current pulses, induced in the receiver coils of a locomotive. They have an arbitrary shape and their occurrence moment, amplitude and duration are absolutely sporadic. It is impossible to determine how often the pulses will follow in turn, there is no regularity in their intensity, shape and duration. Impulse noise effect on the electrical signals of cab signalling can lead to quantitative errors (including the received impulses) and quality impulse distortions. Nature of these noise depends on their sources (switch processes in the current collector, in the collectors of cars, converter istallations and other elements of the electrical circuit of the locomotive may be as impulse noise), so the choice of the most effective fighting method is based on the analysis of their characteristics, which are determined during research in those specific conditions in which signal transmission takes place.

In the harmonic noise occurence a certain regularity is defined, so protection against them is often constructed on the frequency selection using electric filters. They prevent effect of oscillations with a frequency different from the frequency of the signal current of cab signalling on the receiving devices.

The percentage of faults caused by the transmission line effect, in relation to the total number of repeated faults due to the blame of signal telephone and telegraph service (Sh) on the Prydneprovsk railway for the last 4 years is shown in Figure 2.

Purpose

Research conducting of the electromagnetic field effect of high-voltage transmission lines (750 kV, 50 Hz) on the track circuit and CACS with signal current of 50 Hz on the sections of approach and crossing with the transmission line and to propose possible methods to improve CACS noise immunity.

Analysis of faults in the CACS operation

An important task of traffic safety is to ensure trouble-free operation of automatic cab signalling.

A special place is the problem of protection against the effects of transmission lines (TL) on the sections with DC electric traction and diesel traction when the cab signalling devices operate at a frequency of 50 Hz, and so the methods of frequency-division signalling and harmonic noise are not applicable [1].

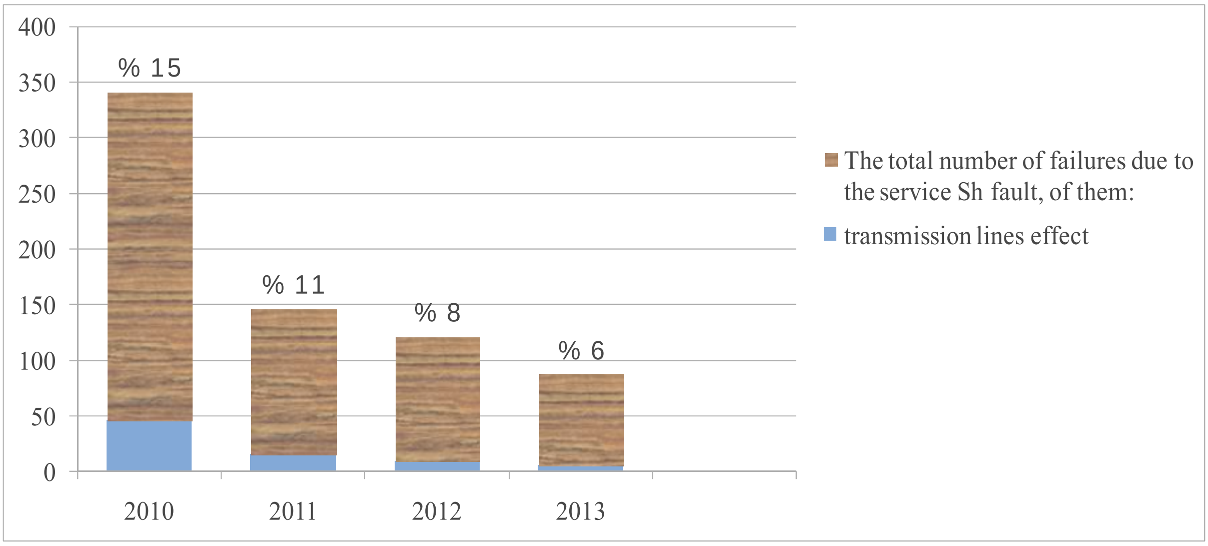

Fig. 2. The percentage of faults caused by the transmission lines effect, in relation to the total number of repeated faults due to the blame of signal telephone and telegraph service (Sh) on the Prydneprovsk railway

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There are two ways of solving this problem. The first method is external in relation to the system and represents the maximum exclusion of the transmission line effect by shielding the current-carrying elements, or electric circuits use with antiphase protection currents which flows in the various circuits in order to reduce effects of electromagnetic noise of the transmission lines on the receiver coils.

The second method of protection is intersystem method. It is a necessity to develop such a mechanism or algorithm of the system operation that transmits traffic lights readings on the locomotive, so that even small changes in the shape, amplitude, duration of pauses and intervals are excluded and do not result in the faults of codes.

One should determine what the most effective method is. To do this we will carry out the analysis of the work and functioning of the automatic cab signalling system under the transmission lines effect. In accordance with the analysis of noise immunity under the effect of high electromagnetic fields one can judge about advantages and disadvantages of a particular protection method.

Fig. 3. Transmission lines crossing the railway track

Ttransmission lines noise have sinusoidal nature and occur in places of transmission lines approach with the railway as crossings or in the form of mutual parallel arrangement [14]. Zone of interference factor is small (approximately 30-40 m on each side from an axis of the transmission lines). However, on a number of roads faults in the vicinity of the intersection with the transmission lines are significant. Lines that are parallel to the railways, are usually low-power, that is why they do not require a special protection methods. But the lines crossing the track at different angle, have a fundamental importance on the ACS receiving system.

The transmission lines effect on ACS receiving devices depends on many factors. The most important is: angle of crossing of transmission lines of the railway line, suspension type of wires on the support, the phase currents and their asymmetry, asymmetry of locomotive receiver coils relatively to the wires of the influencing line and others [10].

Effective protection measures are necessary to reduce the level of noise from transmission lines. To some extent, this protection is ensured with efficiency of automatic gain control (AGC). AGC is required to avoid distortion of the receiving code signals [4]. Current level in the rails under the receiver coils while the locomotive moves may increase more than 20 times, depending on the length of the rail line. The signal amplitude at the output of the filter increases during the impulse and exponential decrease during the pause. If the sensitivity of the locomotive receiver remained unchanged, then with an increase of the input signal would occur pulse stretching and shortening of pause, as at invariable time constant of the transition process in this case the wavefront would decrease and the recession would increase the amplitude of the signal from the steady-state value to the threshold of sensitivity.

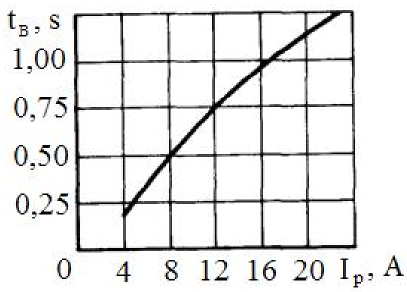

Fig. 4. Time dependence of the amplifier sensitivity recovery

With the help of AGC sensitivity of a locomotive receiver is reduced, it promotes undistorted reception of code signals.

The effectiveness of the AGC is characterized by the generalizing parameter $t_{в}$. It is defined as the time during which the sensitivity of the amplifier after the termination of the current I_p remains below the nominal one. Time $t_{в}$ at switching of the current corresponding to 10-fold overload is 1 sec (see Fig. 4) [10]. The effectiveness and anti-interference features of the AGC are in the Figure 5.

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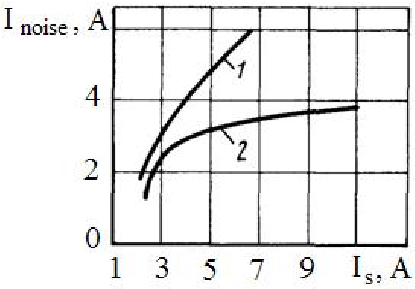

Fig. 5. Efficiency graphics and anti-interference features of the AGC:
1 – maximum value of interference current for provision of normal ACS operation during the noise in phase with the desired signal; *2* – maximum value of interference current for provision of normal ACS operation during the noise influemece in antiphase

Another way to improve the reliability of the ACS operation is the development of protective devices (Fig. 6) [9]. The proposed device allows preventing the effects of the noise influence from transmission lines on the ACS work regardless of the train speed. This greatly improves the operation reliability of the ACS devices.

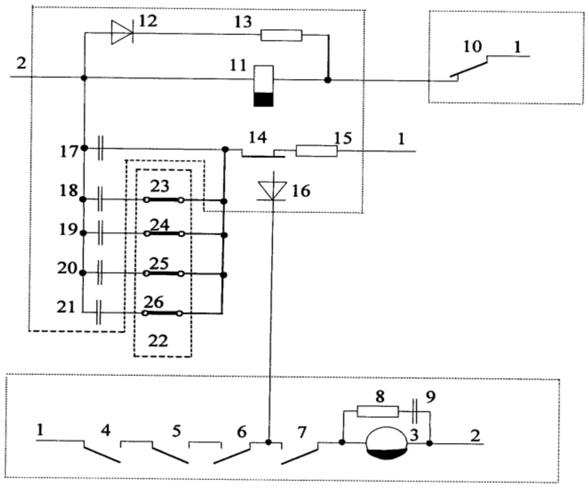

Fig. 6. Protection equipment of operation devices of automatic cab signalling from transmission lines noise:
1 – plus and *2* – minus poles of energy source; *3* – equivalent relay; *4* – frontline contacts of code presence relay; *5* – third counter; *6* – green light relay; *7* – red and yellow light relay; *8* – resistor; *9* – condenser; *10* – contact of impulse relay; *11* – reversal repeater of impulse relay; *12* – spark quenching diode; *13* – spark quenching resistor; *14* – contact of reversal repeater; *15* – additional resistor; *16* – additional diode; *17* – the first additional capacitor; *18* – the second additional capacitor; *19* – the third additional capacitor; *20* – the fourth additional capacitor; *21* – the fifth additional capacitor; *22* – speed gauge; *23* – the first, *24* – the second, *25* – the third and *26* – the fourth contacts of speed gauge

In addition, there are other ways to reduce the transmission lines effect: increasing the height of the suspension and reducing the distance between the wires of transmission lines at the point of intersection, arranging of special, closed and suspended or laid on the ground stubs, which are served with the current, frequency of 50 Hz, the phase-shifted with respect to the current of induced noise, compensation of current interference by specially laid on the locomotive circuit and increase the signal current at the intersection.

Since the effect of transmission lines can be conditionally subdivided into direct and indirect, it is necessary to take into account that most of the protection methods grade the direct influence of the transmission lines magnetic field on ACS coils. But studies show [13] that the noise level is determined mainly by an indirect effect, i.e. it is a consequence of the guidance in the electromagnetic mass (frame, bogies, body and so on.) the locomotive of eddy current, their magnetic field directly affects on the receiver coils. Therefore, the task of protective measures development remains vital.

Methodology

Among the all varieties the transmission lines with a voltage of 110 kW, 220 kW, 330 kW and 750 kW are most commonly used. Transmision lines with voltage 500 kW and above, with currents exceeding 600 A, and typical unbalances besause of the large distances between the phase wires and the increasing load currents have the greatest interfering effect. Maximum EMF (electromotive force) of noise induced by transmission lines in the receiver coils can reach 800 mW (accordingly to measurements). This is equivalent to a disturbing current approximately of 5.5 A in rails. Transmission line of 220 kW (current up to 500 A) with vertical wires are more symmetrical and less disturb significantly in the receiver coils. The induced EMF in the receiver coils in the first case is 400-500 mW and in the vertical placement is 135-165 mW. Other transmission lines usually do not have perseptible effect. To determine the protective measures it is convenient for EMF, induced by transmission lines in the receiver coils, to represent as an equivalent current in rails (1 A directs in coils 165 mW) at 220 kW (transmission lines) - 1.5-2.5 A at 330 kW – 2-3 A at 500 kW - 3.5-5 A, 750 kW - A 4-6 [9].

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Electric Codes of Ukraine regulate norms of railway tracks crossing (item 2.5.207-2.5.211) [6, 11]:

– crossing angle of HVL with electrified railways or subject to railway electrification, as well as the crossing angle of 750 kW with the railways of general use should be approximately 90°, but not less than 40°;

– for the non-electrified railways distance from the wire to the rail head in the normal mode of the HVL vertically should be at least 7.5 m - 20 m at a voltage of 110 kW to 750 kW properly;

– span of railroad crossing limited with spun poles (Fig. 7).

Let us take for the research two spans on Prydniprovsk railway stations on the crossing sections with the transmission line 750 kW: Prishib-Burchatsk, Zaporizhzhia region (Figure 8) and distilled Privolnoye–Yelizarovo (Figure 9).

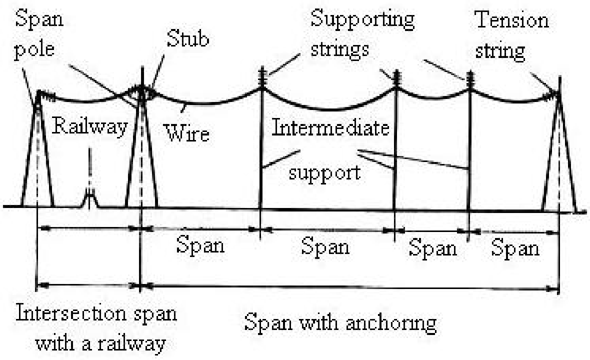

Fig. 7. Scheme of the span crossing with the railway

Span Prishib-Burchatsk is electrified with direct current, measurements were carried out with system "Control" on the basis of a car-laboratory of Prydniprovsk signal telephone and telegraph service.

Fig. 8. Span Prishib-Byrchak

Fig. 9. Span Privolnoye–Eylizarovo

On the span Privolnoye Eylizarovo the continuous welded railway track with self-contained traction. The length of the track circuit between signal points 1 and 18, where there is a crossing section with the transmission lines, 839 m.

The electromagnetic emission meter levels P3-41, ampervoltmetr TS-43-80 («C-4380») with an internal resistance of 0.06 ohms, Rogowski coil were used for the research.

The following methods for measuring the ACL signal current in rails are presented [12]:

1) Continuous current measurement sent to the RC during the check-up instead the impulse. Do this requires to shunt transmitter relay contact with a jumper for temporary sending the continuous current;

2) Measurement of pulse current. During this prosess one shunt a track circuit at the input end by an ampervoltmeters with a special driver provided with an outer head or by ammeters with the internal resistance not more than 0.06-0.08 ohms TS-56 («C-56»), TS-760 («C-760»), TS-4380 («C-4380»), at a scale 6A);

3) Current measurement in the additional winding of an impedance-bond. The ammeter is connected parallel to this winding without disconnecting the load. In this case, the ammeter shunts the track circuit. Current strength in rails one can determine by multiplying the readings on the volt ratio. The disadvantage of this method is due to an important role of the ammeter resistance. It is rec-

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ommended to use an ammeter TS-4380 («C-4380»), with a scale of 0-1.5 A with a resistance of 0.32 ohms;

4) Current measurement with track circuit shunting with a test shunt. This method finds application in the absence of an ammeter with low input impedance. Voltage on a shunt is measured and divided on its resistance (0.06 ohms), the resulting value is current of locomotive signaling.

In the research of the span Privolnoye-Eylizarovo a second method using an ammeter TS-4380 («C-4380»), with an internal resistance of 0.06 ohms was applied. Using probes the track circuit was shunted for a short time. On one of the probes a Rogowski coil was put on, which was connected to the analog-to-digital converter. Wiring diagram is presented in Figure 10. In addition, since the interfering effect area of transmission lines is approximately 30-40 m, measurements of a level of electromagnetic field emission were conducted by means of unit RR-41 («PP-41») at a given distance, a height of about 20 cm above the railhead elevation (taking into account the height of the receiver coilws) and at a height of about 2.5 m.

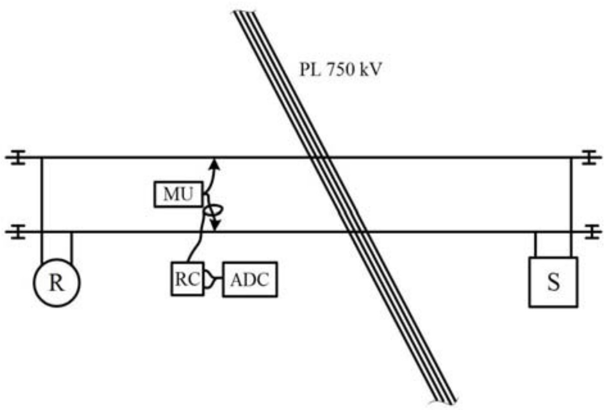

Fig. 10. Wiring diagram for the organization of measurements:
MU – measurement unit TS-4380 («C-4380»);
RC – Rogowski coil; ADC – analog-to-digital converter;
R – relay end of track cicuit; S – supply end of track circuit

Findings

Measurements results of signal current of the green light code (Z) with a car-laboratory of signal telephone and telegraph department on Prydniprovsk railway are presented in Figure 11.

As in the Figure, noise in the coils, induced by transmission lines of 750 kV, are so strong that code availability [3] is hardly discerned. Noise fill short pause, long interval between codes and superimposed on impulses of code. The magnitude of the greatest noise reaches more than 1 W, which is about equivalent to a disturbing current in the rails, value 6 A.

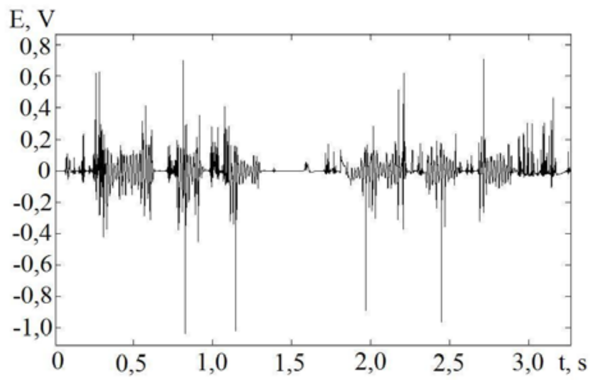

Fig. 11. Signal current code Z

The measurements results of the signal current of yellow light code (W) with a car-laboratory are presented in Figure 12.

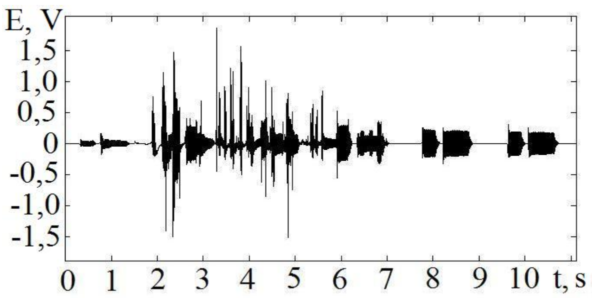

Fig. 12. Signal current code W

As in Figure noise in locomotive coils distort three consecutive cycles W. The magnitude of the greatest interference reaches about 1 W that is also approximately equivalent to a disturbing current in rails 6 A as in the previous measurement. In these both cases, the signal through the ADC was taken directly from the locomotive coils, so we observe both direct and indirect effects of transmission lines.

The measurements results of the signal current, code W (a tested section of a track is located in front of preinput signal point) are presented in Fig. 13.

Also as in Figure 11 one can observe that noise from transmission line of 750 kW fill a signal code lengthwise. But unlike the previous figure, the magnitude of the disturbing current in the rails is no more than 1 A. In actual operating conditions on the given sector there is a problem of major faults in the ACS reception code. In the measure-

Doi 10.15802/stp2014/30833

ments, the average position of the instrument indicator TS-4380 («С-4380») at steady-state oscillations under the influence of the measured current has shown the current rate in rails of 8 A. On the given section the current signal level is too high due to the need for protection against noise, induced with HTL (see Fig. 12). In this case, we can talk about research of direct transmission lines impact, as readings were taken directly from the track circuit without the presence of the rolling stock. Consequently significant disruptions in the ACS codes on this section are caused by the indirect effect of the HVL.

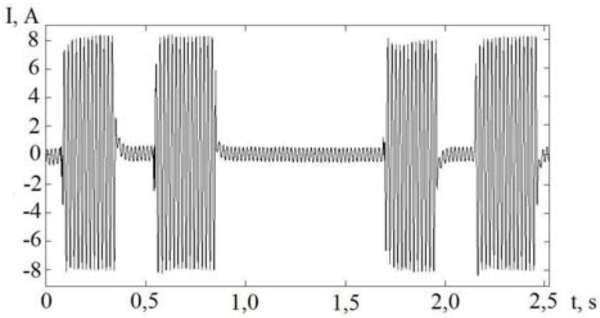

Fig. 13. Signal current code W

The results of measurements with the RR-41 («РР-41») are presented in Table 1.

Table 1

The electromagnetic field strength in the zone of interference effect of transmission line

The distance from the zero point-projection on the railway track m	Height 20 cm above the head level of a rail, V/m	Height 2.5 m above the head level of a rail, V/m
-30	4,4	7,4
-27	5,3	8,0
-24	5,7	8,3
-21	6,1	8,5
-18	6,7	8,8
-15	8,5	9,6
-12	8,8	12,4
-9	9,9	17,9
-6	11,5	24,8
-3	12,3	27,0
0	12,6	35,0
+3	12,0	26,0
+6	11,7	24,9
+9	9,3	18,2
+12	8,3	13,4
+15	7,2	10,0
+18	6,5	9,1
+21	6,2	8,6
+24	5,4	8,0
+27	4,9	7,8
+30	4,2	7,6
The average electromagnetic field strength	7,98	14,35

The results of measurement with an instrument RR-41 («РР-41») are presented in the Table 1. The electromagnetic field strength at a height of 2.5 m is 2-3 times greater than at a height of 20 cm from the railhead elevation - height of receiver coil suspension.

Originality and practical value

The research of transmission line 750 kW effect on the operation of automatic cab signalling on spans Prishib-Burchatsk and Privolnoye-Yelizarovo Prydniprovsk railway in the places of oblique railroad crossing and transmission line of 750 kW, 50 Hz were conducted. Measurements were made both by means of the car-laboratory and directly on rail lines. In the research course the electric field intensity in the range of industrial frequency directly under the transmission line and with distance from it along the railway, as well as the time dependences of CACS codes with signal current frequency of 50 Hz is directly under the transmission lines and with distance from it in the absence of the train and its passing were measured. It was found that CACS codes in rail circuits under the transmission lines are strongly distorted, which as shown by measurements of the electric field intensity can be explained by the influence of the electromagnetic field of the transmission line on the track circuits.

The possible methods of CACS safety increasing by improving reliability of signaling from their way on a locomotive were considered.

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Conclusions

Root causes analysis of the faults and failures in CACS was conducted. The effect of the electromagnetic field of high-voltage transmission lines (750 kV, 50 Hz) on the track circuits and CACS with signal current of 50 Hz in the areas of convergence and intersection with the transmission line was studied.

The possible methods of increasing interference protection of CACS were considered.

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ДОСЛІДЖЕННЯ ВПЛИВУ ЛІНІЙ ЕЛЕКТРОПЕРЕДАЧІ НА РОБОТУ СИСТЕМИ АВТОМАТИЧНОЇ ЛОКОМОТИВНОЇ СИГНАЛІЗАЦІЇ НЕПЕРЕРВНОЇ ДІЇ

Мета. Робота має за мету проведення дослідження впливу електромагнітного поля високовольтної лінії електропередачі (ЛЕП) (750 кВ, 50 Гц) на рейкові кола і автоматичну локомотивну сигналізацію неперервної дії (АЛСН) з сигнальним струмом 50 Гц на ділянках зближення і перетину з ЛЕП та запропонувати можливі методи підвищення перешкодозахищеності АЛСН. **Методика.** Виміри проведені як засобами вагон-лабораторії, так і безпосередньо на рейкових лініях. В процесі досліджень вимірювали напруженість електричного поля в діапазоні промислової частоти безпосередньо під ЛЕП і в міру віддалення від неї по залізничній колії, а також тимчасові залежності кодів АЛСН з частотою сигнального струму 50 Гц безпосередньо під ЛЕП і на відстані від неї у відсутності поїзда та при його проходженні. **Результати.** Проведений аналіз основних причин виникнення збоїв і відмов у роботі АЛСН. Досліджено вплив електромагнітного поля високовольтної ЛЕП (750 кВ, 50 Гц) на рейкові кола і АЛСН із сигнальним струмом 50 Гц на ділянках зближення і перетину з ЛЕП. Розглянуто можливі методи підвищення перешкодозахищеності АЛСН. **Наукова новизна.** Проведено дослідження впливу ЛЕП 750 кВ на роботу автоматичної локомотивної сигналізації на перегонах Пришиб-Бурчацьк і Привільне-Єлізарове Придніпровської залізниці в місцях косого перетину залізничних колій і ЛЕП 750 кВ, 50 Гц. Виміряні напруженість електричного поля в діапазоні промислової частоти безпосередньо під ЛЕП і в міру віддалення від неї по залізничній колії, а також тимчасові залежності кодів АЛСН з частотою сигнального струму 50 Гц безпосередньо під ЛЕП і на відстані від неї у відсутності поїзда та при його проходженні. Виявлено, що коди АЛСН в рейкових ланцюгах під ЛЕП сильно спотворені, це, як показують виміри напруженості електричного поля, може бути пояснено впливом електромагнітного поля лінії електропередачі на рейкові кола. **Практична значимість.** Розглянуто можливі методи підвищення безпеки АЛСН шляхом підвищення достовірності передачі сигналів зі шляху на локомотив.

Ключові слова: система автоматичної локомотивної сигналізації; збій; відмова; високовольтна лінія електропередачі

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ИССЛЕДОВАНИЕ ВЛИЯНИЯ ЛИНИЙ ЭЛЕКТРОПЕРЕДАЧИ НА РАБОТУ СИСТЕМЫ АВТОМАТИЧЕСКОЙ ЛОКОМОТИВНОЙ СИГНАЛИЗАЦИИ НЕПРЕРЫВНОГО ДЕЙСТВИЯ

Цель. В работе необходимо провести исследования влияния электромагнитного поля высоковольтной линии электропередачи (ЛЭП) (750 кВ, 50 Гц) на рельсовые цепи и автоматическую локомотивную сигнализацию непрерывного действия (АЛСН) с сигнальным током 50 Гц на участках сближения и пересечения с ЛЭП, а также предложить возможные методы повышения помехозащищенности АЛСН. **Методика.** Измерения проведены как средствами вагон-лаборатории, так и непосредственно на рельсовых линиях. В процессе исследований измеряли напряженность электрического поля в диапазоне промышленной частоты непосредственно под ЛЭП и по мере удаления от нее по железнодорожному пути, а также временные зависимости кодов АЛСН с частотой сигнального тока 50 Гц непосредственно под ЛЭП и на удалении от нее в отсутствии поезда и при его прохождении. **Результаты.** Проведен анализ основных причин возникновения сбоев и отказов в работе АЛСН. Исследовано влияние электромагнитного поля высоковольтной ЛЭП (750 кВ, 50 Гц) на рельсовые цепи и АЛСН с сигнальным током 50 Гц на участках сближения и пересечения с ЛЭП. Рассмотрены возможные методы повышения помехозащищенности АЛСН. **Научная новизна.** Проведены исследования влияния ЛЭП 750 кВ на работу автоматической локомотивной сигнализации на перегонах Пришиб-Бурчацк и Привольное-Елизарово Приднепровской железной дороги в местах косого пересечения железнодорожных путей и ЛЭП 750 кВ, 50 Гц. Измерены напряженность электрического поля в диапазоне промышленной частоты непосредственно под ЛЭП и по мере удаления от нее по железнодорожному пути, а также временные зависимости кодов АЛСН с частотой сигнального тока 50 Гц непосредственно под ЛЭП и на удалении от нее в отсутствии поезда и при его прохождении. Обнаружено, что коды АЛСН в рельсовых цепях под ЛЭП сильно искажены, что, как показывают измерения напряженности электрического поля, может быть объяснено влиянием электромагнитного поля линии электропередачи на рельсовые цепи. **Практическая значимость.** Рассмотрены возможные методы повышения безопасности АЛСН путем повышения достоверности передачи сигналов с пути на локомотив.

Ключеые слова: система автоматической локомотивной сигнализации; сбой; отказ; высоковольтная линия электропередачи

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