EXPERIMENTAL EVALUATION OF PARAMETERS OF ELECTROMAGNETIC FIELDS

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ABSTRACT

The author investigates the situation with valuation of electromagnetic fields, especially sources, the impact of which threatens a human body, especially in a wide range of frequencies where maximum permissible limits of the EU and Russia differ substantially. Results of experimental measurements of the levels of electromagnetic fields in the workplace of electricians are evaluated. Significant risks and bases to enhance safety in the areas of electric traction power supply are revealed. According to the results of experimental data analysis a conclusion was made on degree of harmful effects of magnetic fields in the frequency range of 50 Hz on the staff.

ENGLISH SUMMARY

Background. *The harmful effects of electromagnetic fields (hereinafter-EMF) of a wide range of frequencies in certain circumstances may cause changes in the functional state of nervous, cardiovascular and endocrine systems of the body, lead to chronic diseases and disorders of labor activity. And from this point of view, to investigate the influence of these fields on people who are at risk is a direct function of engineering and environmental services.*

Objective. *The objective of the author is to evaluate parameters of electromagnetic fields, which influence personnel working with electric installations of a rail transport.*

Methods. *The author uses mathematical methods, analysis and comparison.*

Results.

Controllable levels

Electric installations (hereinafter-EI) of traction power supply of rail transport are a powerful man-made source of EMF. They convert not only one voltage level in another, but also one kind of current in the other.

Traction substations of direct current are equipped with traction power switchgear 3, 3 kV, which is composed of: traction transformers, converters (rectifier or rectifier-inverter) and feeders of a contact network. The availability of powerful rectifiers and inverters in substations leads to emergence of harmonics of currents and voltages in circuits, which

Table 1

MPL of EMF in accordance with the EU Directive

Frequency range	MPL E, V / m	MPL B, mcTl
0–1 Hz	-	2·105
1–8 Hz	20000	$2{\cdot}10^5/f^2$
8–25 Hz		$2{\cdot}10^4/f$
25–820 Hz	$500/f^2$	$25/f$
820–2500 Hz	610	30,7
2500–65000 Hz		

Table 2

Indicative controlled levels of EMF in frequency ranges, which do not have hygienic regulations in the Russian Federation

Frequency range	MPL E, V/m	MPL B, mcTl
1–50 Hz	250 / *f* (kV/m)	5000 / *f* (mcTl)
50 Hz – 10 kHz	500 V/m	50 A/m

Table 3

Permissible levels of physical factors created by medical equipment

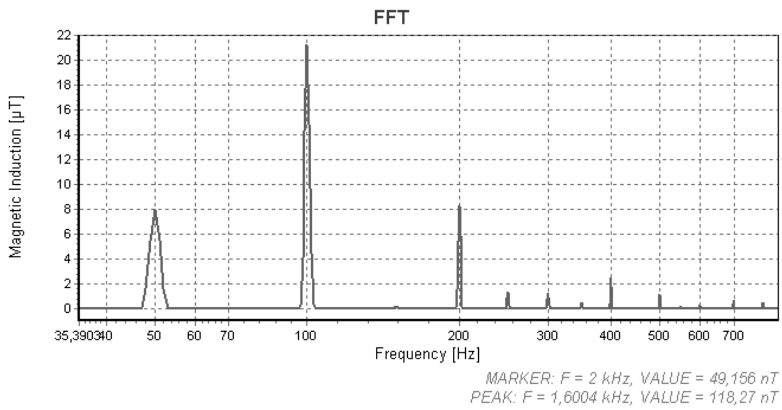
Frequency range	***E*, V/m**	***B*, mcTl**
0 Hz (in the numerator-general, in the denominator – local impact)	–	1000/1500 (mcTl)
1–50 Hz	25 / *f* (kV/m)	250 / *f* (mcTl)
50 Hz	0,5 (kV/m)	5 (mcTl)
50 Hz – 10 kHz	50 (V/m)	5 (mcTl)

Table 4

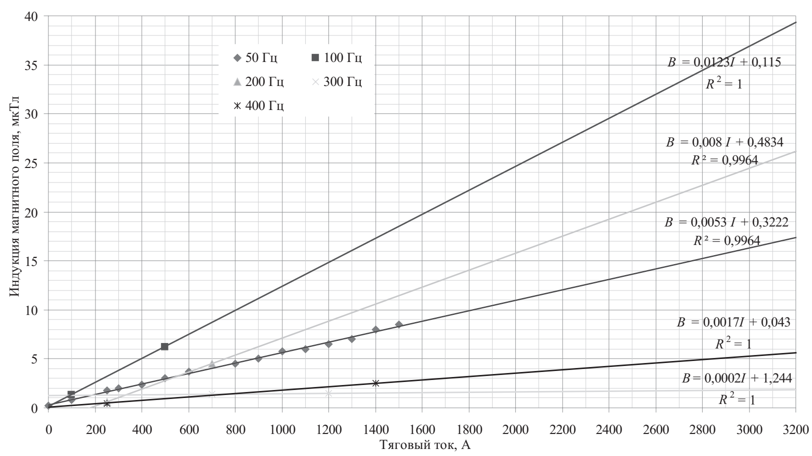
MPL for EMF in the frequency range from 100 Hz to 3 kHz

Frequency range, Hz	MPL E, kV/m			MPL H, A/m		
	at an impact					
	> 2 h	up to 2 h	up to 0,2 h	> 2 h	up to 2 h	up to 0,2 h
100	2,5	5	12,50	40	80	800
200	1,25	2,5	6,25	20	40	400
300–3000	0,8	1,6	4	15	30	270

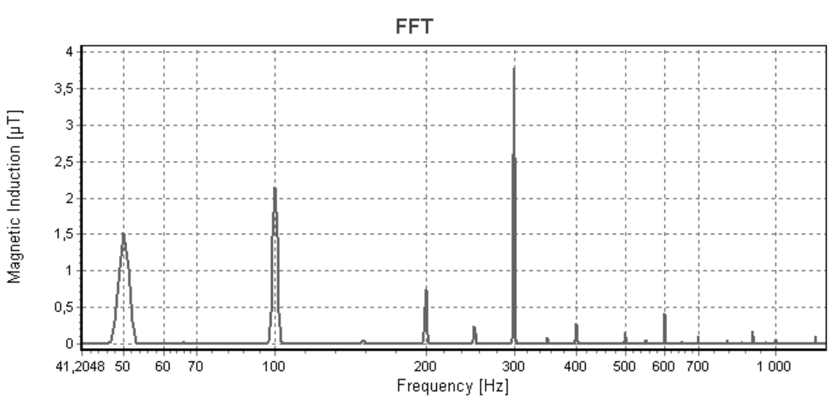
Pic. 1. Measurements of EMF at a traction substation.



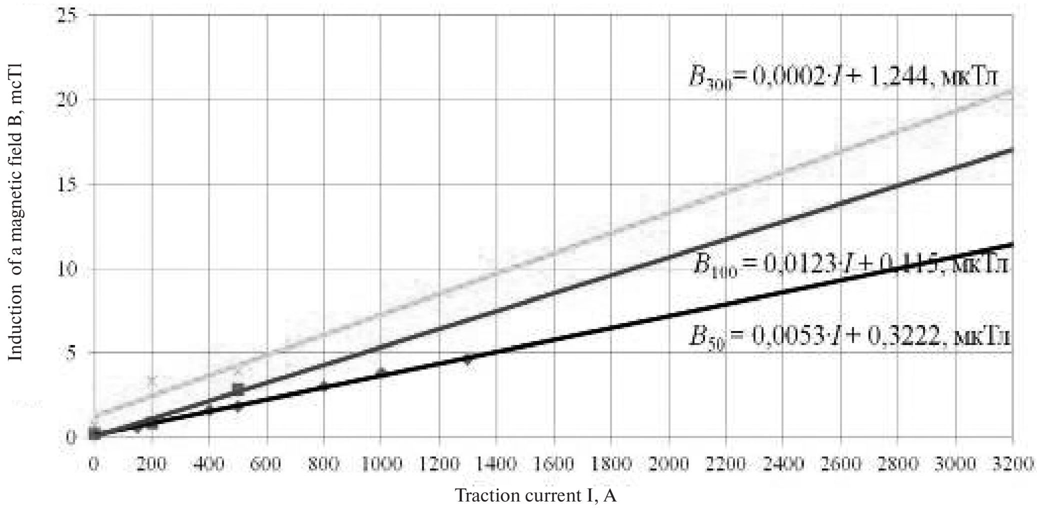
Pic. 2. Spectrum of MF induction in the range of up to 1 kHz at a current of 1400 A.



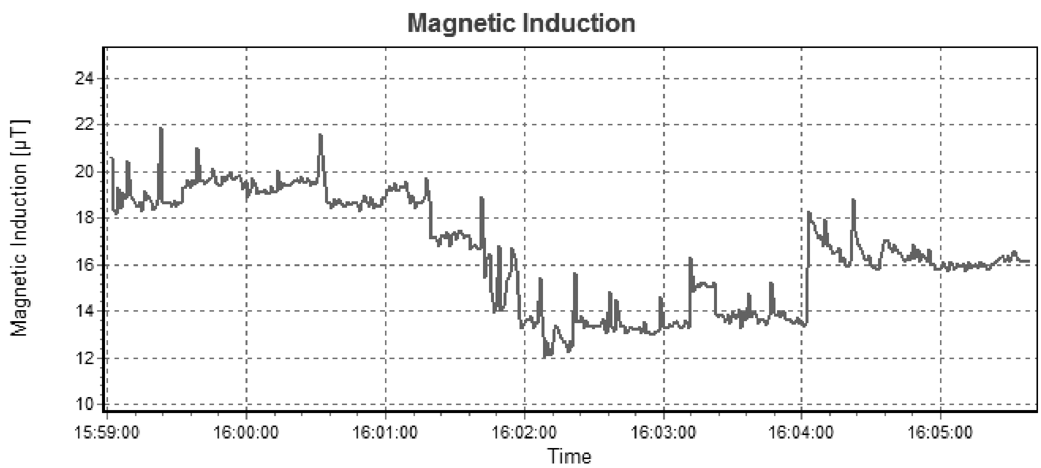
Pic. 3. The dependence of MF induction from the traction current under a busbar bridge.



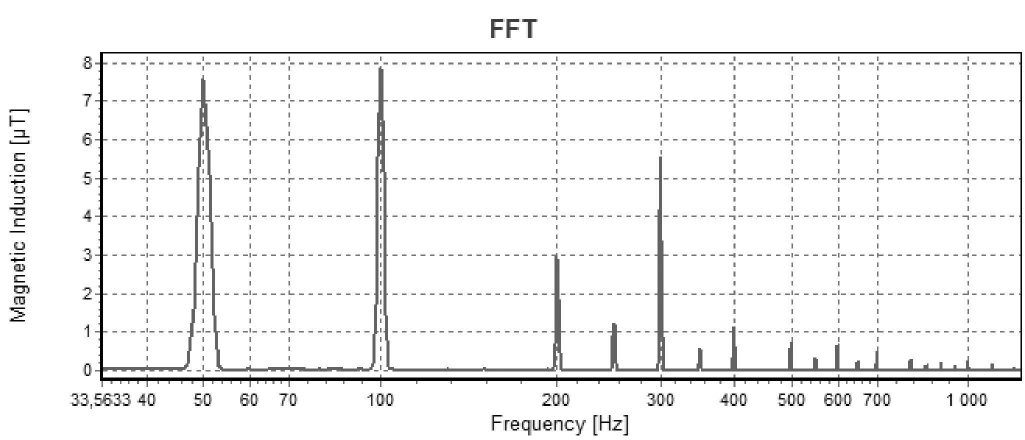
Pic. 4. Spectral characteristics of MF induction under bus bars of 3,3 kV at a traction current of 500 A.



Pic. 5. Dependence of MF induction from the traction current under bus bars of 3,3 kV.



Pic. 6. Change of MF induction in the frequency range of 5 Hz – 2 kHz near a feeder compartment at a current of 200 to 600 A.



Pic. 7. Spectrum of MF induction in close proximity to the rectifier compartment.

are sources of electromagnetic interference to the staff in the frequency range from 0 to 10 kHz.

Conversion at substations or electric rolling stock of AC energy to rectified current and back with the help of static semiconductor converters is associated with a significant consumption of reactive energy. Semiconductor converters consume non-sinusoidal current from the network, distorting the voltage curve of supply power systems. Ongoing USURT researches [1–3] show that the levels of EMF on the traction power supply facilities may be close to the maximum permissible (hereinafter- MPL) or exceed them in some cases in the working areas of the personnel.

Norming of EMF parameters for the staff of electric installations is carried out in Russia in accordance with sanitary rules and regulations (SanPin) [4]. But normable parameters do not cover the low frequency range from 50 Hz to 10 kHz. From this perspective, it is important to highlight the EU directive [5], which contains MPL of frequencies for which there are no standards in Russia (Table 1).

In recent years proposals have appeared in the country for norming of EMF in the frequency range up to 10 kHz. Thus, for the hygienic assessment of electromagnetic fields generated by physiotherapy equipment in the frequency ranges and modes of generation, for which there are no regulations in the Russian Federation, a partial extrapolation of appropriate hygienic standards is offered. These options are included as standard in SanPin [6] and are presented in Tables 2 and 3.

In 2011 appeared a project of a normative document SanPin «Hygienic requirements for physical environment factors», developed by the Research Institute «Occupational Medicine» RAMS [7]. This document provides for the first time MPL for the frequency range from 0 to 30 kHz. At the moment it is not accepted, so its values are used as a guide only. Table 4 shows the parameters of MPL of EMF for individual frequencies.

The analysis of existing and planned regulations makes it possible to draw a conclusion that parameters of EMF with frequencies in the range from 0 to 10 kHz should be considered as occupational hazards in the workplace of EI personnel and require adequate remedies.

Analytics of experiments

To investigate the levels of EMF in the range up to 10 kHz a series of experiments has been conducted on a number of DC traction substations. The researcher have obtained parameters of the fields at the working places of personnel of electric installations of railways. Measurements were conducted using an analyzer of electromagnetic fields EFA-300.

Pic. 1. shows individual points of experimental studies.

Moreover, measurement of EMF was conducted in the frequency range from 5 Hz up to 32 kHz in different working areas of the personnel at a height of 1,8 m over prolonged periods of time. At the studied traction substations (hereinafter-TS) 6 -pulse and 12- pulse converters are in operation. With the analyzer intensity of an electric field and induction of a magnetic field (hereinafter-MF) at frequencies of 100, 150, 250, 300, 350, 450, 600 Hz, etc. were measured in the form of spectral characteristics, as well as a change graph of the intensity amplitude of the field of a given frequency over time. One of the main objectives was to assess the dynamics of the parameters of EMF when the current of a traction substation changed.

It should be emphasized, that the obtained values of intensity of the electric field with frequency of more than 50 Hz showed that their levels are significantly lower than the standardized and are not considered further in this publication.

As a result of long-term observations spectral characteristics of MF induction were recorded at different traction current. Thus, Pic. 2 shows the characteristics of the magnetic field induction under a busbar bridge of a traction substation at a traction current of 1400 A. It can be seen that the amplitude of 100 Hz frequency (2–3 times depending on the current) is predominant, and the amplitude of the induction of 200 Hz and 300 frequencies are similar in the amplitude values with a frequency of 50 Hz and amounts to a range from 1 to 9 mcTl depending on the current. However, at large currents amplitude at a frequency of 300 Hz is much lower in amplitude than amplitudes 50 and 200 Hz. The analysis of the spectral characteristics at different currents found that when the traction current changes MF parameters vary considerably.

For clarity, Pic. 3. shows a dependence of MF induction of different frequencies from the traction under a busbar bridge.

In the study spectrum of MF induction was obtained at different currents under bus bars of 3,3 kV s, on which rectified traction current flows. Pic. 4 shows spectral characteristics of MF induction at a current of 500 A, and Pic. 5 dependence of MF induction of different frequencies from the traction current.

A comparison of Pic. 3 and 5 clearly shows a difference between the spectrum under a bus bar bridge and bus bars of 3,3 kV. Under a bus bar bridge maximum amplitude is at a frequency of 100 Hz, and under bus bars – 300 Hz.

It is still far to the standards

Studies of MF near a compartment of 3,3kV at different currents showed that during certain time intervals the amplitude of MF induction may vary within wide limits, from a few mcTl (at small traction currents) to relatively high levels of 30 mcTl at currents of about 1000 A. In Pic. 6 a graph of MF induction change obtained for a period of 5 minutes illustrates the fact that the change in MF induction is random and depends on changes in the traction current and the staff at the same time is subjected to harmful factors, which constantly change over time.

In addition to the working areas spectral characteristics of MF induction were obtained near the rectifier, in the reactor, compartment 3,3 kV and under a feeder of a contact network. Individual spectra are shown in Pic. 7–10.

According to the analysis of the spectral characteristics we can conclude that the presence of a magnetic field with a frequency of 300 Hz of significant levels is noticable for electric installations of traction substations.

Generalized results of research with account of results in [9,10], namely MF induction in comparison with the different working places of EI personnel are shown in Table 2.

Thus, the highest values of MF at frequencies of 50, 100, 200 Hz and 400 Hz are obtained under a busbar bridge, at a frequency of 300 Hz – in the reactor compartment, under a feeder of a contact network and near a feeder compartment.

Given the current data on the biological effects of EMF and additive effects when exposed to electromagnetic fields of different frequencies [5, 8], we can determine the degree of complex impact on staff with the expression:

Table 5

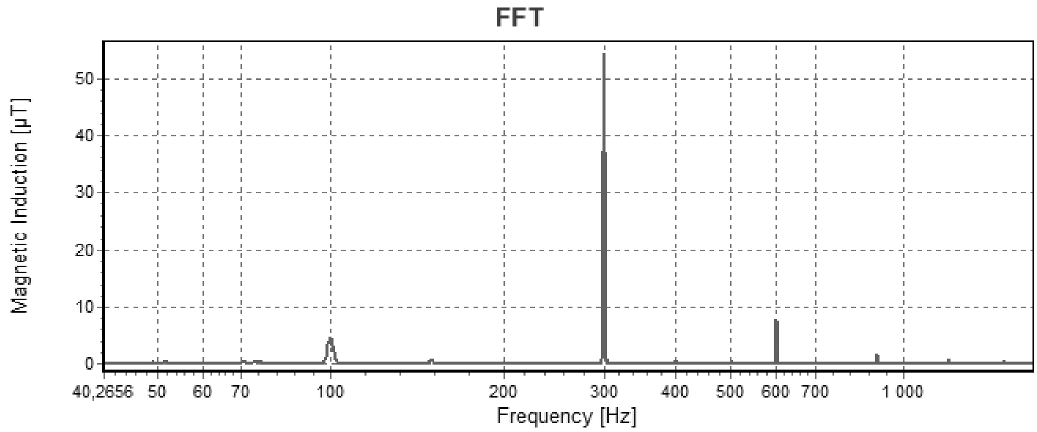
MF parameters of different frequencies in EI of traction substations at a traction current of 3000 A

Frequency	The maximum induction of a magnetic field with account of instrument error, mcTl at different working places of the personnel						
	Busbar bridge	Under bus bars 3,3 kV	Near rectifier	Near feeder compartment	Inside feeder compartment	In reactor compartment	Under a feeder of a contact network
50 Hz	16 ± 0,8	11 ± 0,55	11 ± 0,55	< 1	1,5 ± 0,07	3 ± 0,15	< 1
100 Hz	37 ± 1,85	16 ± 0,8	15 ± 0,55	6 ± 0,3	< 1	25 ± 1,25	8 ± 0,4
200 Hz	25 ± 1,25	4 ± 0,2	5 ± 0,25	< 1	< 1	< 1	< 1
300 Hz	3 ± 0,15	19 ± 0,95	12 ± 0,6	72 ± 3,6	20 ± 1	180 ± 9	120 ± 6
400 Hz	5 ± 0,25	1,8 ± 0,09	1,6 ± 0,8	< 1	< 1	< 1	< 1
600 Hz	< 1	2,5 ± 0,13	3 ± 0,15	13 ± 0,65	2,5 ± 0,13	30 ± 1,5	16 ± 0,8
> 600 Hz	< 1	< 1	< 1	< 1	1,2 ± 0,06	< 1	< 1

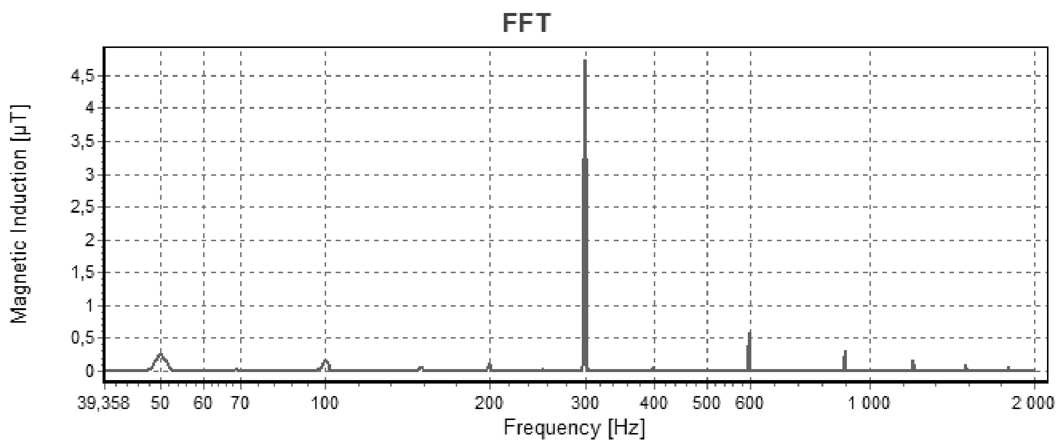
Table 6

The results of calculation of total MF induction ratio for assessing adverse impact on staff

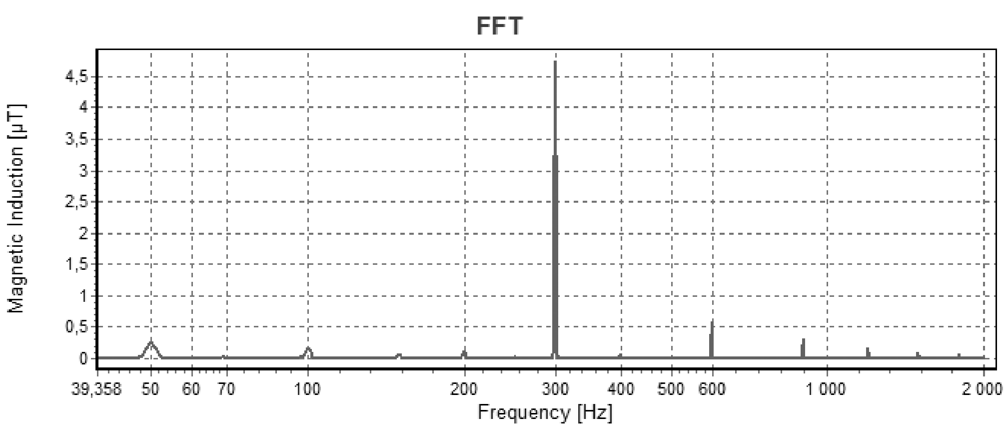
Frequency, Hz	Controlled values of magnetic field induction, mcTl		Maximum induction of a magnetic field with account of instrument error, mcTl at different workplaces of the staff						
	$B_{ПДУi}$ (EU)	$B_{ПДУi}$ (RF)	Busbar bridge	Under bus bars 3,3 kV	Near rectifier	Near feeder compartment	Inside feeder compartment	In reactor compartment	Under a feeder of a contact network on the street
50	500,00	100,00	16,8	11,55	11,55	0	1,57	3,15	0
100	250,00	50,00	38,85	16,8	15,75	6,3	0	26,25	8,4
200	125,00	25,00	26,25	4,2	5,25	0	0	0	0
300	83,33	18,75	3,15	19,95	12,6	75,6	21	189	126
400	62,50	18,75	5,25	1,81	1,68	0	0	0	0
600	41,67	18,75	0	2,63	3,15	13,65	2,63	31,5	16,8
> 600	30,70	18,75	0	0	0	0	1,26	0	0
Total ratio according to standards of Russia			2,44	1,92	1,57	4,89	1,34	12,32	7,78
Total ratio according to standards of the EU			0,52	0,46	0,38	1,26	0,36	3,14	1,95



Pic. 8. Spectrum of MF induction in the range of 5 Hz to 2 kHz near the premises of the reactor compartment.



Pic. 9. Spectrum of MF induction on the street under a feeder of a contact network.



Pic. 10. Spectrum of MF induction in a compartment of 3,3 kV.

$$\sum_{i=50\,Гц}^{10\,кГц} \frac{B_i}{B_{ПДУi}} \leq 1,$$

where B_i – actual value of induction of a magnetic field with frequency i; $B_{ПДУi}$ – MPL of induction of a magnetic field with a frequency i.

To assess the degree of harmful effects of magnetic fields of a wide range of frequencies on the staff, a ratio of the total MF induction was calculated. Results are given in Table 6.

From the table it is clear that when taking into account the simultaneous impact of MF of different frequencies on the staff an indicator of the total exposure at individual work areas does not meet the normalized values (as it is higher than 1), both in comparison with the proposed standards in the Russian Federation and the EU standards. For individual work areas excess of normalized parameters for MF induction of separate frequency is stated.

Conclusions. *The experimental results showed that:*

1. In EI of a rail transport in addition to EMF of direct current, EMF 50 Hz electromagnetic fields are present with a frequency greater than 50 Hz, which should be considered when assessing the impact on the staff, and certainly accounting of the impact of magnetic fields with a frequency of 50 Hz is required.

2. MF frequencies and work areas were revealed that require special consideration in terms of the occupational safety of personnel, in particular – the room of the reactor compartment, near the feeder compartment of 3,3 kV, under a feeder of a contact network.

3. It was established experimentally and graphically shown that the levels of EMF parameters with frequencies of 100, 150, 200, 300, 600 Hz have high amplitudes and here it is necessary to assess the impact of EMF on the staff.

4. It was found with a change in the value of the traction current the amplitude of harmonic components of MF induction varies directly proportional; the change in the intensity amplitude over time is random and depends on the traction load.

5. The staff of EI of a rail transport is subjected to the combined effect of MF of a wide frequency range of significant levels, which requires accounting using the generalized coefficients, hygienic standardization, as well as instruments for individual and collective control of the parameters of the magnetic field.

It seems that in the context of the findings the priority areas should be biomedical research on the impact of broadband EMF on the staff and establishment of criteria and standards of the harmful effects of such fields on humans, as well as the development of the means of protection from EMF impact in the frequency range up to 10 kHz.

Keywords: electromagnetic fields, magnetic fields, electrical personnel, traction substations, traction power supply, regulation, maximum permissible levels.

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