PRZEGLĄD ELEKTROTECHNICZNY

Ukazuje się od 1919 roku 12b'11

Organ Stowarzyszenia Elektryków Polskich • Wydawnictwo SIGMA-NOT Sp. z o.o.

Karol BEDNAREK

Poznan University of Technology, Institute of Electrical Engineering and Electronics

Research of electromagnetic interaction of heavy-current equipment

Abstract. *The paper presents measurement results of the magnetic field distribution in various heavy-current devices, with special consideration of heavy-current electric power busducts. The research has been carried out in order to depict the differences in the magnetic field distribution with respect to the design solutions of the busducts and the locations of the measurements. The analyses are performed with a view to consider possible excessive temperature growths of the ferromagnetic parts placed in these regions.*

Streszczenie. *W pracy zamieszczono wyniki pomiarów rozkładów pola magnetycznego w różnych układach urządzeń silnoprądowych, ze szczególnym uwzględnieniem torów wielkoprądowych (szynoprzewodów). Badania przeprowadzono w celu uwzględnienia różnic w rozkładach pola magnetycznego w zależności od rozwiązań konstrukcyjnych urządzeń (szynoprzewodów) oraz miejsc (obszarów) wykonywania pomiarów. Analizy dokonywane są pod kątem rozważenia możliwości wystąpienia nadmiernych przyrostów temperatury w elementach ferromagnetycznych, jakie mogą występować w rozpatrywanych obszarach.* ***(Badania elektromagnetycznych oddziaływań urządzeń silnoprądowych)****.*

Keywords: distribution of magnetic flux density, heavy-current equipment, electromagnetic effects, local temperature growth.
Słowa kluczowe: rozkład indukcji magnetycznej, urządzenia silnoprądowe, oddziaływania elektromagnetyczne, lokalne przyrosty temperatury.

Introduction

The electromagnetic field (EMF) accompanies operation of any electric devices, due to gathering or motion of electric charge, i.e. occurrence of voltage and current flow. In some cases EMF is purposely generated in order to obtain some definite usage effects like information transfer, radiolocation, medical diagnostic or therapeutic operations, etc. On the other hand, in many situations it is an inadvertent side effect of operation of the electric equipment. Particular and relatively common case arises when EMF is generated by heavy-current equipment, which is related to generation, transmission and processing of electric power. The EMF is then a slowly-varying field and, therefore, is considered as short-distance interaction (near field). The magnetic and electric components of the electromagnetic field are then separately analyzed. Some problems may arise when people, some devices sensitive to such a field or some ferromagnetic parts are located in the area where strong electric or magnetic field occurs [1-9].

Taking the above into account, the problems of proper identification of interaction of the field becomes extremely important. In such cases particular attention should be paid to specific areas where the interaction is untypical, the fields superpose and magnify each other, or in case of compensated systems to the locations where the compensation does not occur. One of the most important items of information that enables detecting and eliminating the negative effect of the electromagnetic field on the objects existing in its surroundings is the knowledge of the field distribution in the vicinity of its source [1]. Therefore, an important research undertaking consists in measuring the field around various heavy-current devices, in order to check the electromagnetic interaction in their vicinity and to analyze possible large temperature growths arising in the parts of the structure that contains the ferromagnetic parts. The neglect of possible local overheating of the structural parts may lead to worsening of mechanical properties of the object and, in consequence, to break-down condition.

Description of the analyzed systems

Among the devices generating strong and slowly-varying magnetic field there are power electric heavy-current devices like generators, transformers, switching and transmission stations, electric metallurgical equipment, etc. Magnetic field distribution in the neighbourhood of these devices depends on the value of the conducted current, on location of the interaction point (the distance from the field source) and on the design of the system.

Among the parts of the electric power system that usually electromagnetically interact with the environment there are heavy-current busducts (electric power busducts). Their design solutions may be as follows:

- three-phase heavy-current shielded busducts. In this solution all the phase conductors are symmetrically located inside a common cylindrical shield. As an insulation agent the air is usually used [8,13],
- three-phase unipolar shielded busducts. Each phase conductor is located in an individual shield, the air, SF_6 or an N_2/SF_6 mixture is used as insulation agent [10,13],
- three-phase heavy-current busducts (shielded or unshielded) in planar arrangement, with air playing a role of an insulation agent [14],
- the busducts in solid insulation (of epoxy resin or plastics, e.g. polyester) in planar arrangement [11,13],
- heavy-current busducts in bifilar arrangement. They are composed of six conductors located side by side, in which the currents flow in opposite senses (the field is considerably compensated) [4].

While measuring the magnetic field in the neighbourhood of these devices special attention should be paid to singular points of the examined objects where the magnetic flux density reaches the highest level due to specific structure of the design or to the distance of the field source.

Magnetic field distribution in physical systems

In the industry the EMF is measured around the heavy-current devices and the results are often presented for the most representative locations of the considered objects, as, for example, main part of the body, the parts that are available at the easiest, the device centre, etc. While analyzing the EMF interaction with the ferromagnetic parts occurring in the surroundings usually such points of the devices should be considered where the EMF interaction is diametrically opposed to the locations conventionally checked. Special attention should be paid to the points of bends, branchings, electrical connections, the points of weak or missing field compensation, the unshielded parts of the devices, etc. In such locations of the systems usually some additional structural supporting parts (angle bars, mounts) or joining parts (screws, nuts) are inserted. The reinforcing parts are often made of steel (and, in consequence, are ferromagnetic parts). These parts located in such points are conducive to large local EMF concentration and excessive temperature growths of the structural parts.

Among the devices in the surrounding of which the strong magnetic field arises there are power ducts, i.e. three-phase heavy-current busducts.

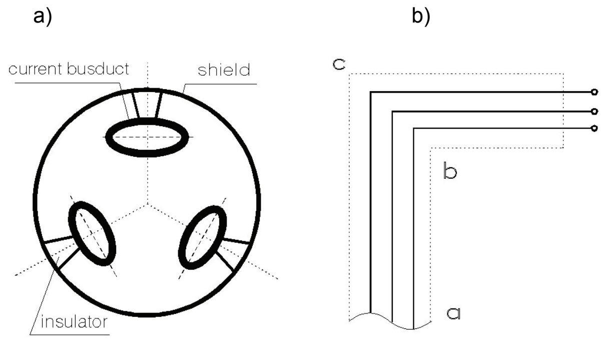


Fig. 1. A three-phase shielded heavy-current busduct: a) the cross-section of the busduct system located in common shield; b) a system with busduct bend – marking of the measurement points

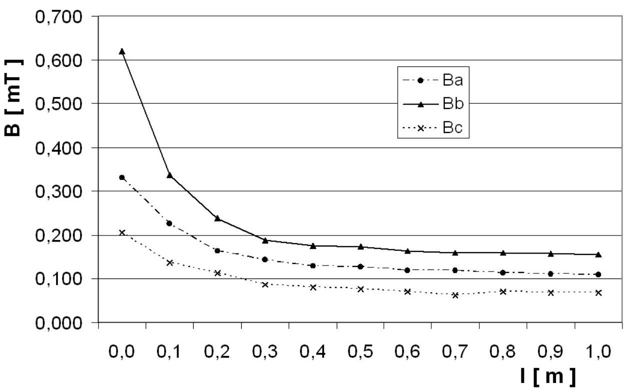


Fig. 2. Measurement results of the magnetic flux density distribution in the vicinity of the three-phase shielded busducts: a) Ba – the measurements in middle part of the busduct; b) Bb – the measurements in the busduct bend area at the inner part; c) Bc – the measurements in the busduct bend area at the outer part

In the tripolar busducts located in the common shield (Fig. 1) the field distribution differences as compared to the straight-line segments of the busducts may appear at the busduct ends (in the electric connection region) and in the busduct bends. During the measurement the current intensity of the considered ELPO busduct amounted to 5 kA (the rms value). Comparison of the magnetic flux density distribution B between the inner and outer sides of the busduct bend and in its middle part is shown in Fig. 2. Maximum values of the magnetic flux density arise at the inner part of the busduct bend (point c in the Fig. 1).

A specific place related to the magnetic field distribution in the busducts operating in planar arrangement (Fig. 3) is the region of the electric connections at the busduct end, where the phase conductors of the busduct are usually separated to larger distance than in the busduct middle. This leads to the growth of the magnetic flux density in these locations. Results of the magnetic flux density values in such an arrangement are presented in Fig. 4. The busduct is supplied with the current of 3×1250 A from the heavy-current TW25 transformers [11].

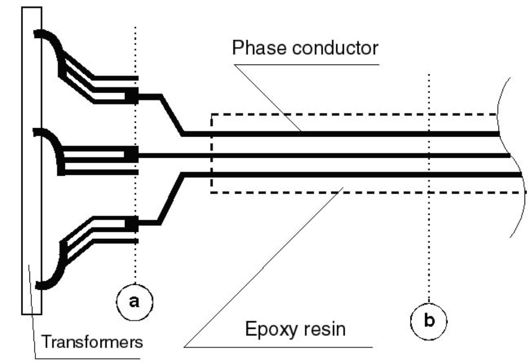


Fig. 3. The points of magnetic flux density measurement in the neighbourhood of the busducts operating in planar arrangement

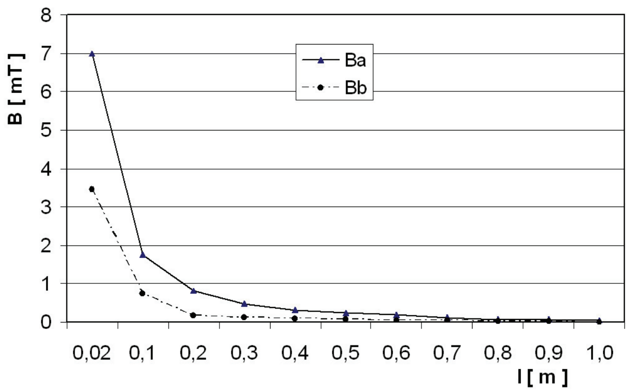


Fig 4. Measurement results of the magnetic flux density distribution in the vicinity of the three-phase busducts operating in planar arrangement (with solid insulation): Ba – magnetic flux density obtained while measuring in the area of the phase conductors drawn aside (in the electrical connection point), Bb – magnetic flux density obtained while measuring in middle part of the busduct [11]

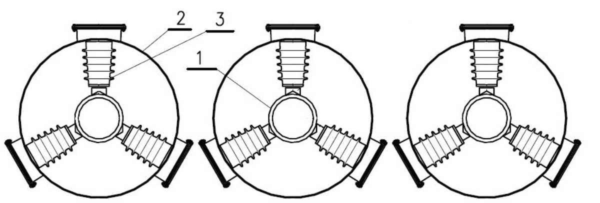


Fig. 5. A three-phase heavy-current busduct designed as a system of individually shielded conductors: 1 – current busduct, 2 – busduct shield; 3 – supporting insulator [13]

The strongest magnetic field interaction arises in three-phase heavy-current busducts of uni-polar systems (Fig. 5). Each phase conductor is located in a separate shield. In order to ensure remarkable reduction of magnetic interaction of the uni-polar busducts the shields of particular phases should be electrically connected by means of the short-circuit plugs (in the form of welded flat bars) located in the busduct ends. Results of the magnetic flux density measurement in various locations of the busduct (I = 17 kA) are shown in Fig. 6.

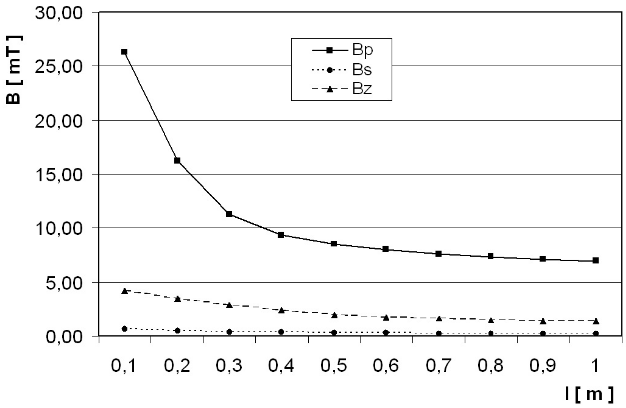
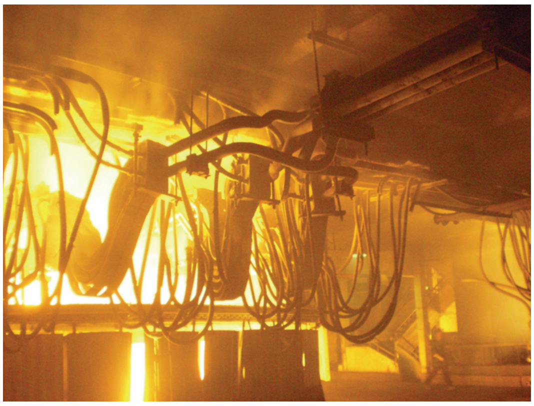


Fig. 6. Magnetic induction distribution in the neighbourhood of three-phase uni-polar busduct with short-circuited shields: Bp – in the neighbourhood of the electric connection (at the busduct end), Bz – in the shielded region between the short-circuit plug and the busduct end (beyond the region of short-circuit plug influence), Bs – in the busduct middle (between the shield short-circuit plugs)

a)



b)

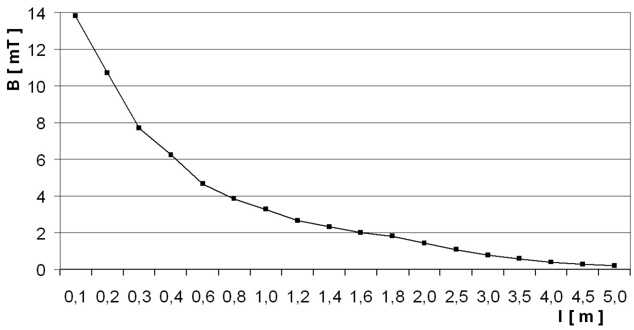


Fig. 7. Connection of the bifilar busduct with an arc furnace by means of copper bands: a) view of the system; b) distribution of magnetic flux density in the system

The magnetic flux density in the area of the electrical connection (next to the phase conductors) is many times as large as the one measured with regard to the shield (in the middle part of the busduct). In the distance of 0.1 m from the busduct electrical connection the magnetic flux density is 40 times higher than the one at the same distance from the shield in the middle part of the busduct. The tests show that in the points located at the same distance from the shield the magnetic flux density in the shielded part of the busduct beyond the shield short-circuit plugs is more than 5 times larger than in the area between the plugs (where the field is strongly compensated). In all the considered locations some ferromagnetic connecting or supporting structural parts may be placed and the electromagnetic effects may appear accordingly to the field intensity.

Maximal differences in the magnetic field distribution are found in case of bifilar busduct design (Fig. 7).

It is a six-wire supply system. The conductors parallelly located and connected to the beginning and end of the definite transformer phase, respectively, transmit the currents of opposite senses. This results in remarkable compensation of the magnetic interaction. Maximal values of the magnetic flux intensity arise in the locations where only a part of the busduct between the transformer and the area of the receiver connection is designed as a bifilar system, while the electrical connection to the receiver (e.g. an arc furnace) is made by means of flexible conductors, usually drawn aside to larger distance. The results of magnetic field measurements at the end of the bifilar system are presented in Fig. 7.

a)

b)

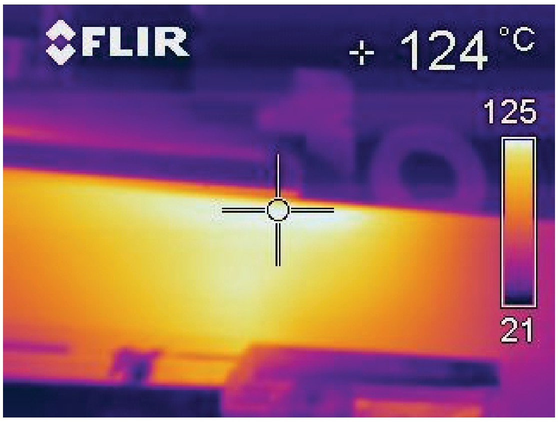


Fig. 8. Electromagnetic interaction of a planar busduct: a) steel structure of the electrochemical equipment housing provided with planar busducts; b) thermovision picture of the (a) system

Local excessive temperature growth in ferromagnetic parts induced by the electromagnetic interaction

A part made of ferromagnetic material located in the area of interaction of alternating magnetic field causes a strong concentration of the field. In case of interaction of the magnetic EMF component with the objects composed of ferromagnetic materials the eddy currents induced by the concentrated alternating magnetic field may be conducive to the hazard of local overheating of the structural parts. The excessive temperature growth of the parts or subassemblies may worsen the strength of material, durability and reliability of the considered objects or even lead to breakdown of the structure.

The example of excessive temperature growths in ferromagnetic parts caused by magnetic field of a planar busduct are presented in Fig. 8.

Ferromagnetic structural parts of the fixtures of electrochemical heavy-current equipment supplied by means of an unshielded busduct operating in planar arrangement are subject to the eddy currents induced by the alternating magnetic field, leading to local strong overheating of the ferromagnetic parts. Temperature of the parts of steel frame located the nearest to the busduct amounted to 124ºC, while the environment temperature was only 21ºC.

A similar case from the point of view of the electromagnetic interaction is the wall culvert of the three-phase heavy-current busduct provided with individual shields, that was located in the building wall at the power plant area. In this system the steel rods located in the hole area between the phase conductors shields have been used for reinforcing the culvert structure (Fig. 9).

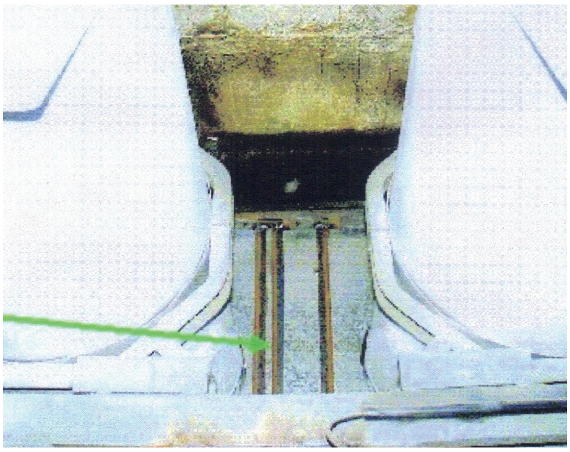


Fig. 9. View of the wall culvert of the busducts in individual shields provided with structural reinforcement in the form of steel rods [12]

In result of electromagnetic interaction the active power loss was induced and transformed into heat in the ferromagnetic supports. The thermovision measurements show [12] that temperature of the supporting parts exceeded 147 ºC (Fig. 10).

Moreover, the busduct shields have been provided with steel clamps playing a role of fixing parts. They were overheated too. The clamp temperature exceeded 100 ºC, with busduct shield temperature amounting to about 50 ºC.

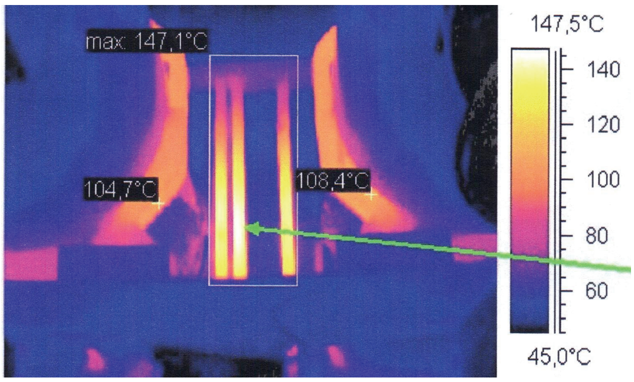


Fig. 10. The thermovision image of the busduct culvert in individual shields provided with structure reinforcement in the form of steel rods [12]

Notes and conclusions

The most important factor allowing for detecting and avoiding the negative EMF effect on the objects subject to EMF interaction includes the knowledge of the field distribution in the surroundings of the field source. The best method of determining the field distribution consists in measuring characteristic values of the field, i.e. the magnetic flux density, electric field intensity and, for high frequencies, also the density of radiation power.

The obtained measurement results clearly indicate that while analyzing the electromagnetic interaction of heavy-current equipment the specific locations of the considered objects should be taken into account (the regions of non-compensated field, non-shielded regions, the point of the electric connections) where the values of magnetic field induction are many times higher than in the places where the magnetic interaction is usually measured.

In consequence of interaction of the magnetic field generated by heavy-current equipment with ferromagnetic structural parts located in its area a local excessive temperature growth may arise that may be destructive for the respective construction parts or elements. Therefore, effective identification of such cases with a view to preclude breakdown of such parts becomes an important problem.

REFERENCES

[1] Bednarek K., Electromagnetic field generated by heavy-current equipment and its effects on the environment, *Electrical Review*, 86 (2010), No 12, 9-12
[2] Bednarek K., Electromagnetic action of heavy-current equipment operating with power frequency, *International Journal of Occupational Safety and Ergonomics (JOSE)*, (2010), Vol. 16, No 3, 357-368
[3] Griffiths D. J., *Introduction to electrodynamics*. Prentice-Hall Inc., New Jersey 1999
[4] Kurbiel A., *Elektrotermiczne urządzenia łukowe*, WNT, Warszawa 1988
[5] Turowski J., *Elektrodynamika techniczna*, WNT, Warszawa 1993
[6] Rawa H., *Elektryczność i magnetyzm w technice*, PWN, Warszawa 2001
[7] Bednarek K., Oddziaływania elektromagnetyczne torów wielkoprądowych, *Przegląd Elektrotechniczny*, 79 (2003), nr 12, 897-899
[8] Bednarek K., Nawrowski R., Tomczewski A., Electromagnetic compatibility in the neighborhood of high-current lines, *Electromagnetic Fields in Electrical Engineering, Studies in Applied Electromagnetics and Mechanics*, (2002), vol. 22, IOS Press, 363-368
[9] Bednarek K., Normative and legal conditions pertaining to the effects of electromagnetic fields on human organism, *Academic Journals, Electrical engineering*, (2006), No 52, Poznan Uniwersity of Technology, Poznań, 91-101
[10] Bednarek K., Nawrowski R., Tomczewski A., Trójfazowe tory wielkoprądowe złożone z przewodów rurowych w indywidualnych osłonach, *Przegląd Elektrotechniczny*, 84 (2008), nr 1, 62-64
[11] Bednarek K., Nawrowski R., Pomiary indukcji magnetycznej w otoczeniu torów wielkoprądowych oraz ocena oddziaływania torów wielkoprądowych na pracę monitorów komputerowych, *Zeszyty Naukowe, Elektryka*, (1999), nr 93, Politechnika Łódzka, Łódź, 55-64
[12] Opracowania wewnętrzne (na zlecenie), Badania termowizyjne elementów i urządzeń elektroenergetycznych na terenie elektrowni, 2003
[13] Katalog produktów firmy Elektrobudowa S.A. Katowice
[14 Katalog produktów firmy HOLDUCT Sp. z o.o. Mysłowice
[15] Betobar-r Catalogue, Cast-Resin Insulated Busway Systems, Eta-com group, 2003

***Author**: dr inż. Karol Bednarek, Poznan University of Technology, Institute of Electrical Engineering and Electronics, ul. Piotrowo 3a, 60-965 Poznań, e-mail: Karol.Bednarek@put.poznan.pl*