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Generation of local overheating of contact connections in heavy-current equipment caused by electromagnetic effects exerted on ferromagnetic connecting parts

Abstract. *The paper analyses electromagnetic effects of heavy-current equipment and local excessive temperature growth of ferromagnetic parts (arising in their vicinity) and contact connections including ferromagnetic parts. The results of magnetic measurements and thermovision tests are presented in the considered cases, the effects have been commented and discussed.*

Streszczenie. *W pracy analizowane są oddziaływania elektromagnetyczne urządzeń silnoprądowych oraz powstawanie lokalnych przyrostów temperatury elementów ferromagnetycznych (występujących w ich otoczeniu) i połączeń stykowych zawierających elementy ferromagnetyczne. Przedstawiono i skomentowano wyniki pomiarów magnetycznych oraz badań termowizyjnych. (**Powstawanie stanów lokalnych przegrzań połączeń stykowych urządzeń silnoprądowych w wyniku oddziaływań elektromagnetycznych na ferromagnetyczne elementy łączące**).*

Keywords: local temperature growth, electromagnetic effects, heavy-current equipment, contact connections.
Słowa kluczowe: lokalne przyrosty temperatury, oddziaływania elektromagnetyczne, urządzenia silnoprądowe, połączenia stykowe.

Introduction

One of the most important aspects of operation of an equipment consists in its reliability. This factor takes particular importance in case of the systems related to electric power supply, i.e. the electro-power equipment. High power transmission is accompanied by slowly-alternating magnetic and electric fields generated by these devices while conducting high current under high voltage. These fields interact with the objects located in their vicinity, but also with subassemblies of the devices generating them. In consequence, they may give rise to a risk [1-10]. Particular case arises when contact connections of heavy-current parts are locally overheated that may be conducive to break-down and temporary interruptions of operation of the electric power equipment. Therefore, identification of such cases becomes a very significant factor taking into account proper operation of the power systems.

The paper deals with identification of magnetic interaction of heavy-current equipment and local overheating of the parts, particularly the contact connections that include ferromagnetic parts. The results of magnetic measurements and thermovision tests related to the considered interactions are presented and commented.

Slowly-alternating magnetic field generated by heavy-current equipment

The use, processing and transmission of the electric power are accompanied by the electromagnetic field. In case of low frequency the interaction in the approximate zone is considered and, in effect, the magnetic and electric components of the electromagnetic field may be considered separately [1,3,4,6].

Many parts of an electromagnetic system conduct very high currents, generating high magnetic field. The field interacts with the objects located nearby. Some problems may appear if people work in the interacting field area, and if some devices sensitive to such interaction or ferromagnetic parts are located there.

Induction of the magnetic field in a definite point of the space depends on the value of the current (being its source), on the environment properties, as well as on the distance between the considered point and the field source.

In many cases of electromagnetic effects of the heavy-current equipment the magnetic fields arising in their vicinity is apparently not very strong, as it is usually considered in the places located in definite (often relatively large) distance from the field sources, i.e. from the parts conducting the current (the phase conductors, windings etc.). As an example, the present paper shows distribution of the magnetic field, that occurs near an electrical connection of the secondary side of a three-phase furnace transformer with the busducts operating in bifilar arrangement, supplying an arc furnace in a steel plant (Fig. 1).

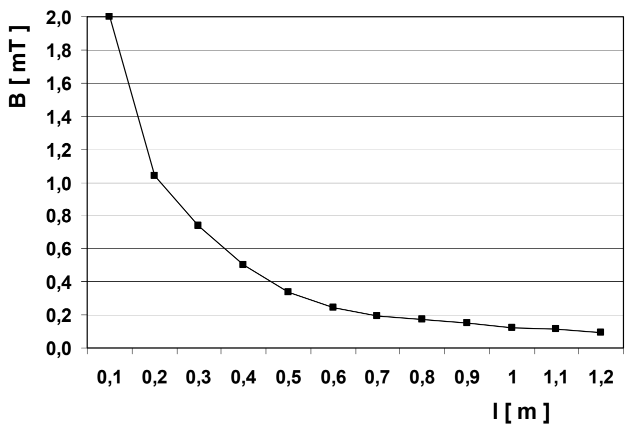

Fig. 1. Distribution of the magnetic field in the vicinity of an electric connection of the terminals of secondary side of a three-phase transformer with the busducts supplying an arc furnace

The measurement results presented here enable drawing a conclusion that in the approximate zone an intense change in the induction of the magnetic field occurs, according to variations of the field source distance. This is confirmed by theoretical consideration too.

The magnetic field generated by an electric device may remarkably change from one point to another in the approximate surrounding, due to the differences in the distances of the considered points from the field source, due to occurrence of shielded regions, field concentration caused by ferromagnetic parts, etc.

Particular cases of the considered electromagnetic interaction arise in the locations of the mechanical coupling parts (the screws, washers, rivets etc.) used in the contacts of the phase conductors with the heavy-current equipment terminals (transformers, arc furnaces, switchgears, etc.) or in permanent connections between the busducts. They occur just near to the surfaces of the current conducting parts, i.e. the parts generating the field. In consequence, taking into account very small distance from the source, they are subject to very strong magnetic field.

The comparison of the magnetic field distributions in the surroundings of three-phase busducts in individual shields for various regions of the considered device is shown in Fig. 2. In these busduct systems the shield of each of the phases is, at the same time, an electromagnetic shield. However, taking into account that the eddy currents induced in the shields amount to several per cent of the phase current level, the compensation of the magnetic interaction of the phase conductors is weak. In order to ensure more significant reduction of the magnetic interaction, the shields of particular phases are often electrically connected by means of the short-circuit plugs (in the form of welded flat-bars) located at the busduct ends. According to [7] the shields bring then the currents of the values approximating the ones flowing in the phase conductors (but in opposite direction). This leads to intense compensation of the magnetic field interaction.

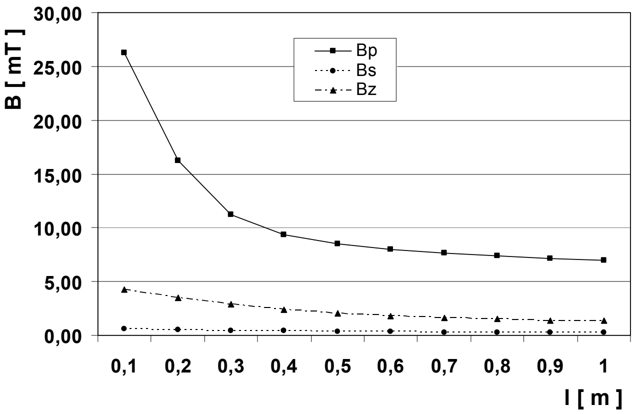

Fig. 2. Distributions of magnetic flux density in the vicinity of the three-phase busducts in individual shields for the system with short-circuited shields [7]
B_p – in the surroundings of unshielded electric terminal (electric connection at the busduct end); B_z – in the shielded region between the short-circuit plug and the busduct end (beyond the plug influence), and B_s – in the middle of the busduct (between the shield short-circuit plugs)

The magnetic flux density in the region of the electric connection (in direct surroundings of the phase conductors) is many times as large as the one measured with regard to the shield in the middle part of the busduct [7]. At 0.1 m from the electrical connection of the busduct the magnetic flux density is more than 40 times larger than in the same distance from the shield in the middle part of the busduct. For equal distances from the shield the magnetic flux density in the shielded part of the line beyond the shield plugs is more than 5 times larger than in the line part located between the plugs (where the field is intensely compensated).

This is a clear proof that in spite of similar distances from the structural parts of the considered device, the magnetic flux density distributions may significantly vary in various locations within the device. It should be noticed that the regions of the heavy-current electric junctions, being located near the field source, are always critical for the analysis of electromagnetic interaction.

Interaction of the magnetic field with ferromagnetic parts of permanent electric connections

Magnetic component of the electromagnetic field generated by heavy-current equipment interacts with the environment and may give rise to various electrodynamic effects. Once a ferromagnetic part is located in the vicinity of the magnetic field source, the field focuses in the ferromagnetic. Eddy currents will be generated in the magnetic material and total power loss appearing in it is converted into heat. Small ferromagnetic parts are subject to very high temperature growth resulting in extreme local overheating of these parts of the structure. Among the parts that are the most commonly subject to the above mentioned interaction there are mechanical connection elements (bolts, nuts, washers) or supporting assemblies (angle bars, structural reinforcements, etc.).

As it was mentioned above, a particular case of the interaction arises in the region of permanent electric connections in the heavy-current objects. When the contact connection between the heavy-current busducts or the busduct and the transformer include e.g. a ferromagnetic bolt, the eddy currents and magnetic hysteresis of the material give rise to power loss and, in consequence, significant local temperature growth. In result of thermal expansion the connection loosens, the quality of the connection between the contacting surfaces worsens, thus resulting in growing contact resistance. This, in turn, leads to larger heat emission, further temperature growth, and worsening of the contacting surface conditions. In consequence, the contact connection becomes locally overheated, giving rise to the risk of damage of the equipment.

Figure 3 shows the view of a system (a) and the thermovision picture (b) of the contact connection between the busduct and the transformer of the power of 7.75 MVA supplying a metallurgical arc furnace.

a)

b)

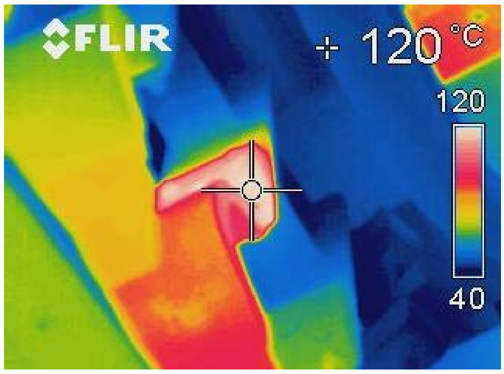

Fig. 3. Electric connections between the busduct and the transformer supplying an arc furnace: a) view of the system; b) thermovision picture of the contact connections

The current flowing through a single branch of the secondary transformer winding is of the order of 7.5 kA. One of the contact connections includes a ferromagnetic bolt. In result of the above mentioned interaction the contact connection is highly overheated – its temperature grew to 120ºC, while temperature of the other connections amounted to about 50÷70ºC.

Figure 4 presents a view of the considered system after exchange of the ferromagnetic screws to non-magnetic ones and after improving the quality of the adjacent surfaces of the electric connection. Temperature of the correct connection amounted to about 47ºC.

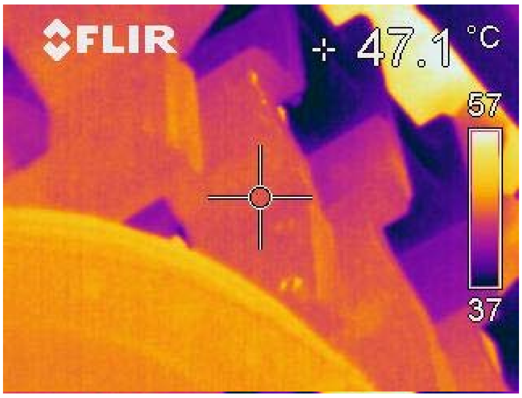

Fig. 4. Thermovision picture of the electric connections between the busducts and the transformer supplying an arc furnace after exchange of the ferromagnetic screws to non-magnetic ones

Similar effects have been observed in the system of connections between the branch of the busducts supplying the furnace transformer in the steel plant (Fig. 5) [10]. In L3 phase in the screwed branch connection a ferromagnetic washer has been used as an additional coupling part. Similarly to the former case, the ferromagnetic part was overheated, the terminal quality worsened, and the temperature of the terminal exceeded 120ºC. Temperatures of the other connections were of the order of 50ºC (Fig. 5). Once the washer was exchanged to a non-magnetic one and the terminal quality was improved, the connection temperature decreased below 60ºC (Fig. 6).

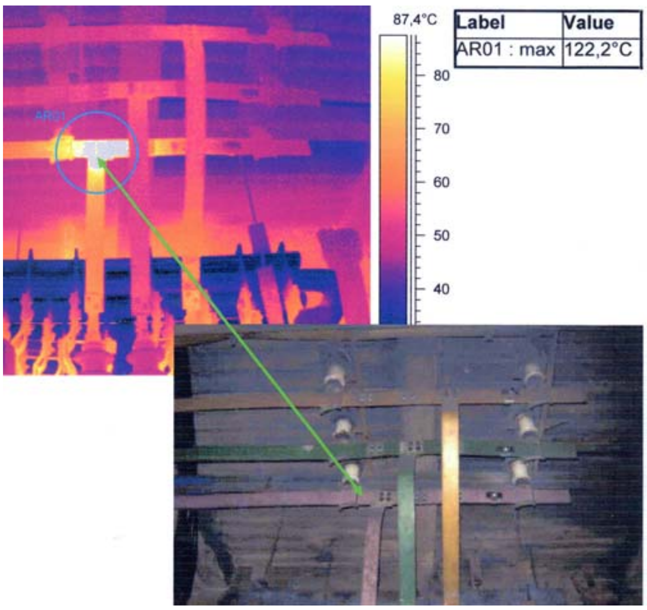

Fig. 5. View and thermovision picture of the branch of the busducts supplying the furnace transformer in a steel plant [10]

Fig. 6. Thermovision picture of the system of Fig. 5 after exchange of the washer in the L1 phase to a non-magnetic one and after improving the quality of the electric connection

Still more dangerous thermal conditions arose in the system of the busduct junction with the electric output at the primary side of the transformer of the power 7.75 MVA, supplying another arc furnace (Fig. 7). The L1 phase junction included ferromagnetic screws. In result of concentration of magnetic field undergoing in the ferromagnetic the strong eddy currents were induced leading to the loss of power that exchanged into heat. In result of the thermal and mechanical interaction in the region of the considered connection the temperature of the faulty contact connection exceeded 250ºC (Fig. 8) [10]. Temperatures of two other phase connections were below 70ºC. Similarly like in the previous cases, the exchange of the screws to non-magnetic ones and the improvement of the quality of the electric connection surfaces reduced the junction temperature to 63ºC (Fig. 9).

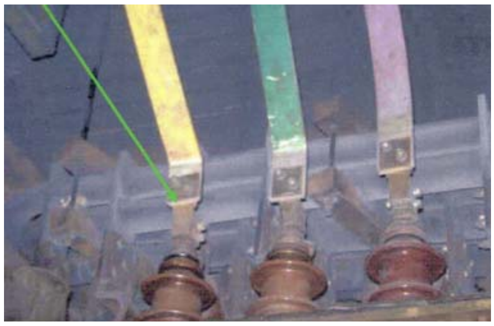

Fig. 7. Configuration of the primary side connections in the arc furnace transformer including ferromagnetic screws in L1 phase [10]

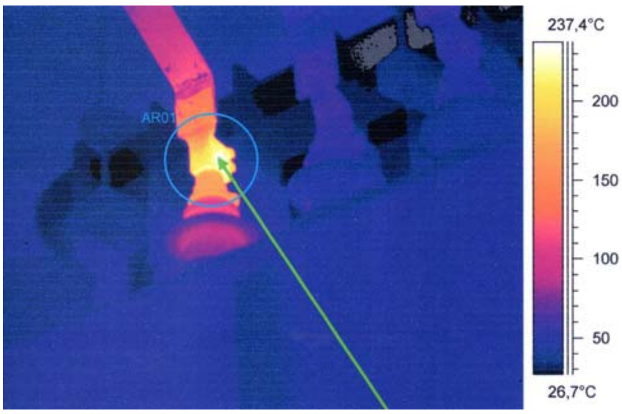

Fig. 8. Thermovision picture of the primary side connections in the arc furnace transformer including ferromagnetic screws in L1 phase [10]

Fig. 9. Thermovision picture of the primary side connections in the arc furnace transformer after exchange of the screws to non-magnetic ones and after improving the quality of the contact

In the connection system of a measuring transformer of the power of 7.75 MVA (supplying an arc furnace) [10] the electric connection of L2 phase included a ferromagnetic screw (Fig. 10). In result of the electromagnetic interaction with the screw material the lost power exchanged into heat. Temperature of the screw reached approximately 130ºC. Temperatures of two other phase connections did not exceed 65ºC. Once the screw was exchanged to a non-magnetic one, the temperature of the connection operating under similar conditions decreased to 67.2ºC (Fig. 11).

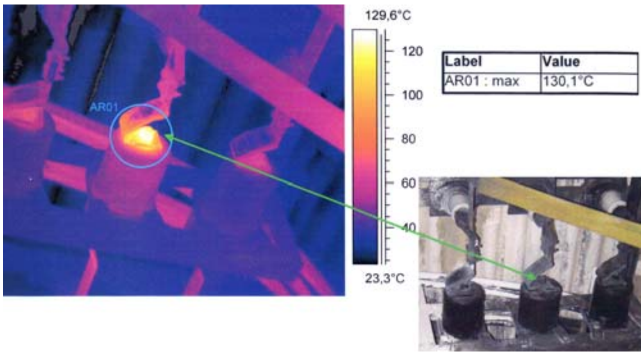

Fig. 10. View and thermovision picture of the measuring transformer connection with the busduct supplying a metallurgical furnace transformer [10]

Fig. 11. Thermovision picture of the measuring transformer connection with the busduct supplying a metallurgical furnace transformer after exchange of the screw to a non-magnetic one

Notes and conclusions

Overheating of the contact connections is a significant problem that frequently occurs in electric equipment operation.

In all the cases mentioned above the ferromagnetic coupling elements that made parts of the heavy-current contact connections gave rise to excessive temperature growth caused by the electromagnetic interaction occurring there. In each of the situations the exchange of the ferromagnetic elements to the ones made of non-magnetic material and the improvement of the contact quality of the parts resulted in reduction of the contact temperature to the level justified by technological conditions of operation of the considered devices.

The excessive temperature growth of the electric equipment connections is conducive to break-down hazard, the need of repairs and, in consequence, to shutdown of operation of the considered device. Sometimes, additionally burdensome procedures must be carried out in order to put the equipment into operation again. This may lead to financial loss resulting from the production downtime or to overloading of the equipment of the devices operating in parallel.

Proper identification of the above described cases makes a key condition for ensuring correct operation of the heavy-current equipment and for improving its durability and reliability. Thermographic tests make an advantageous approach to such cases. They enable efficient touchless (i.e. invasionless) detection of excessive temperature growth of the equipment and subassemblies.

During the designing process, during assembly and maintenance of the heavy-current equipment any ferromagnetic parts should be avoided in the locations of strong and varying magnetic field. This is particularly important in case of small mechanical coupling (the screws, washers, rivets) or supporting (angle bars, suspension elements etc.) parts. In such cases the parts made of non-magnetic materials should be used, that allows avoiding excessive local concentration of electromagnetic interaction and disadvantageous thermal effects.

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