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Impact of static and alternating magnetic field on warming up of components fixing the electric wires

Abstract. *Electrical devices and their components designed for operation in potentially explosive atmosphere should be tested before commercialization as regards maximum temperature of their surface. Operational conditions (including power supply) of the tested device should be set in a way ensuring operation at the rated parameters. Results of tests aiming at determination of impact of alternating magnetic field around conductor on the temperature of fixing components made of ferromagnetic materials, diamagnetic materials or paramagnetic materials are presented.*

Streszczenie. *Urządzenia elektryczne lub ich części składowe przeznaczone do pracy w atmosferze potencjalnie wybuchowej, przed wyprowadzeniem na rynek powinny zostać zbadane pod kątem określenia maksymalnej temperatury powierzchni. Warunki pracy (w tym zasilania) urządzenia poddawanego badaniom nagrzewania powinny zostać dobrane tak, aby zapewnić pracę przy parametrach znamionowych. W niniejszej publikacji przedstawiono wyniki badań, których celem jest określenie wpływu zmiennego pola magnetycznego wokół przewodnika z prądem na temperaturę elementów mocujących wykonanych zarówno z materiałów ferromagnetycznych jak i diamagnetyków lub paramagnetyków. (**Ocena wpływu stałego oraz zmiennego pola magnetycznego na nagrzewanie elementów mocujących przewody elektryczne**).*

Keywords: ATEX Directive, warming up, temperature, ferromagnetic material, diamagnetic material.
Słowa kluczowe: dyrektywa ATEX, nagrzewanie, temperatura, materiał ferromagnetyczny, materiał diamagnetyczny.

Introduction

During the tests of warming up the electrical devices, designed for operation in potentially explosive atmosphere, many parameters that can have impact on temperature of their surface should be taken into account. At first, ambient temperature in a vicinity of the tested device as well as stability of parameters supplying the tested device (voltage, current, power) should be mentioned. Experience gained by the author during the above-mentioned tests shows that it is necessary to pay a special attention to a type of current supplying the tested device (AC or DC). According to the Standard provisions [4] it is required that warming up test is carried out in the rated operational conditions. According to generally accepted laboratory practice the devices and their sub-systems supplied with DC should be tested with use of AC current transformers. In this case, attention should be paid to magnetic properties of materials, which are used to make the components fixing the electric wires (e.g. cable glands, rings fixing the dielectrics). In the case, when these components are made of ferromagnetic materials, alternating magnetic field induced by the flow of alternating current can cause warming them up. Selection of improper current supplying the tested device can lead to wrong results, what in a consequence can impact the assessment during certification process.

The problem of losses of energy converted into heat is widely discussed in the literature [6, 7], especially as regards transformers. Total losses in a transformer core (P_{Fe}), which consist of hysteresis losses (P_h) and eddy current losses (P_w), are one of the basic parameters [7]. They are caused by the flow of alternating current through the windings, which causes periodical reverse polarity of the core (hysteresis losses) and induces time-varying magnetic flux (eddy current losses). This happened during the tests described below.

Experience gained during the tests enables to systematize the approach to the selection of type of current that is used during the tests of warming up and draws attention to proper selection of materials that are used to manufacture of the components (e.g. diamagnetic materials or paramagnetic materials).

Method for testing the warming up process

The tests of warming up were carried out for two cable glands (Fig. 1 and Fig. 2). The first cable gland (marked as W1) was made of ferromagnetic material (cast steel L I 450 and carbon steel E295), while the second cable gland (marked as W2) was made of diamagnetic material (brass MO58 and MO59) [1].

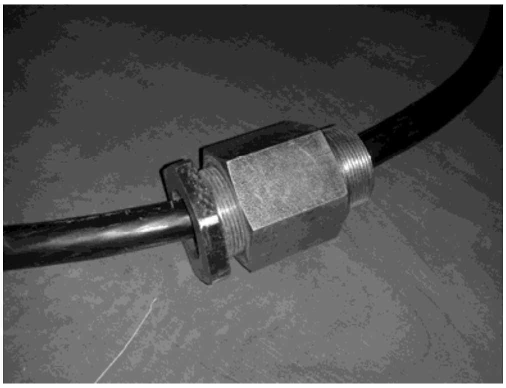

Fig.1. Cable gland W1 – ferromagnetic material [2]

Both cable glands were fixed to copper single-core wire of cross-section 95 mm^2 at a distance of 1 m from each other (Fig. 3). Such a distance resulted from the need of elimination of thermal interaction of cable glands.

Fig.2. Cable gland W2 – diamagnetic material [2]

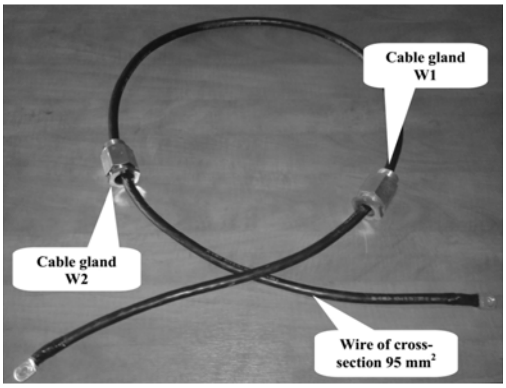

Fig.3. Wire with fixed cable glands [2]

Tests of warming up were carried out with DC and AC supply conditions. In both cases the currents were the same. Currents of 50, 100, 150, 250 and 290 A were selected. Maximum current resulted from the accepted current-carrying capacity of wire that was used [3].

Test stand for warming up tests with DC is presented in Fig. 4. Direct-current generator combined with motor test bench was a source of DC. Wire with cable glands was connected to the generator terminals. Current value was set by changing the excitation current of generator. Current flowing through the wire was controlled by current probe with multimeter.

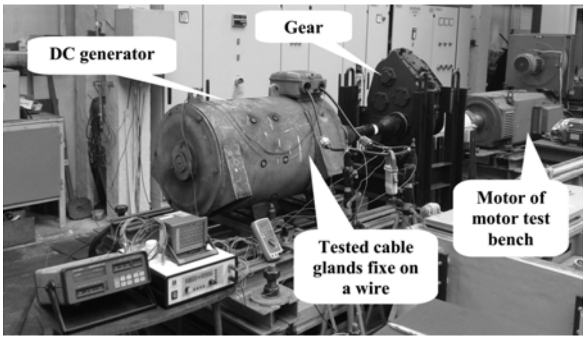

Fig.4. Stand for tests of warming up with DC [2]

Stand for warming up with AC is presented in Fig. 5. Transformer of current referencing unit was a source of AC. Wire with cable glands was connected to the terminals of the secondary windings of transformer. As it was in the case of tests of warming up with DC, the current was controlled by current probe with multimeter.

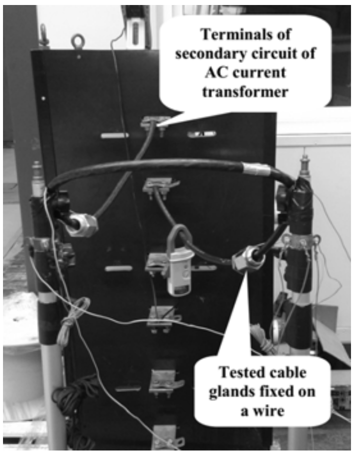

Fig.5. Stand for tests of warming up with AC [2]

The temperature was measured with use of contact method at the following points of the tested objects:

- elastomer of cable gland W1,
- external surface of cable gland W1,
- elastomer of cable gland W2,
- external surface of cable gland W2,
- surface of wire insulation,
- ambient temperature.

Arrangement of temperature transducers on the surface of tested cable gland is presented in Fig. 6.

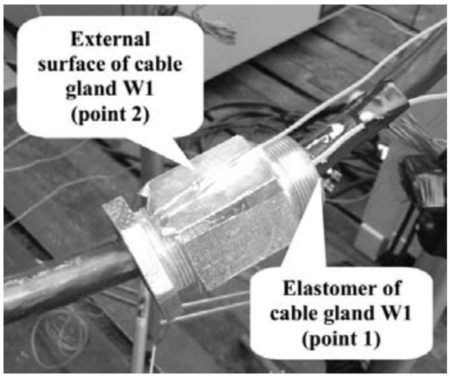

Fig.6. Arrangement of temperature transducers on the surface of cable gland W1 [2]

Condition for temperature stabilization was assumed according to the requirement of Item 26.5 of the PN-EN 60079-0:2013-03 Standard [4]. For the set current each test lasted until the temperature was stabilized (temperature at each point within one hour not changed by more than 2 K).

Test results

Maximum temperature of selected surfaces of cable glands during warming up with DC and AC is given in Table 1 and Table 2.

Table 1. Maximum temperature of the selected surfaces of cable glands obtained during warming up with DC [2]

Temperature measuring point	Temperature [ºC]		
	100 A DC	200 A DC	290 A DC
Elastomer of cable gland W1	26.5	31.0	39.1
External surface of cable gland W1	25.4	26.8	30.2
Elastomer of cable gland W2	26.6	31.4	39.7
External surface of cable gland W2	25.4	26.9	30.3
Surface of wire insulation	25.9	32.3	42.8
Ambient temperature	22.1		

Table 2. Maximum temperature of selected surfaces of cable glands obtained during warming up with AC [2]

Temperature measuring point	Temperature [ºC]		
	100 A AC	200 A AC	290 A AC
Elastomer of cable gland W1	35.5	64.5	92.4
External surface of cable gland W1	44.5	91.4	131.4
Elastomer of cable glad W2	24.1	31.8	45.2
External surface of cable gland W2	22.6	26.9	34.8
Surface of wire insulation	24.9	35.2	51.4
Ambient temperature	20.7		

Maximum temperatures of surfaces of cable glands made of ferromagnetic material and diamagnetic material during warming up with DC and AC are compared in Fig. 7÷10.

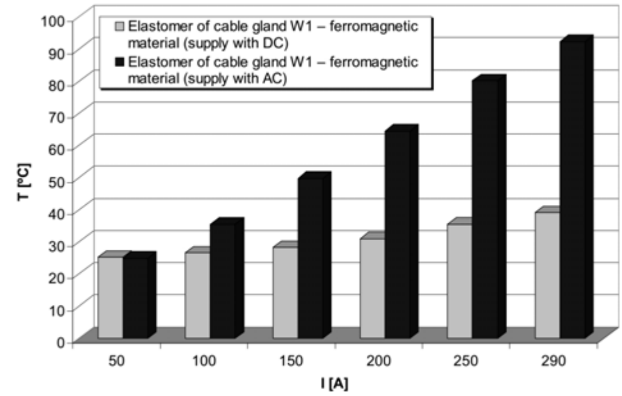

Fig.7. Comparison of maximum temperatures of elastomer of cable gland W1 (ferromagnetic material) during warming up with DC and AC [2]

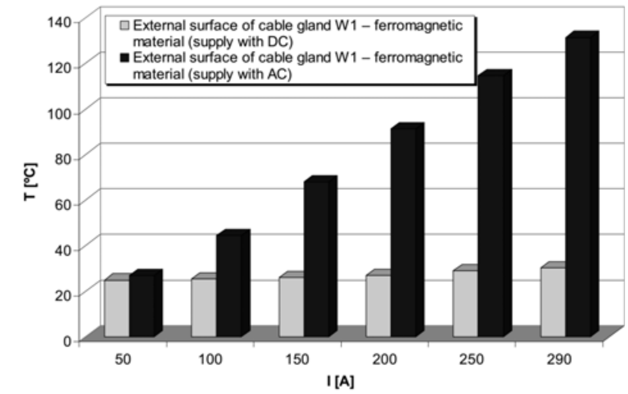

Fig.8. Comparison of maximum temperatures of external surface of cable gland W1 (ferromagnetic material) during warming up with DC and AC [2]

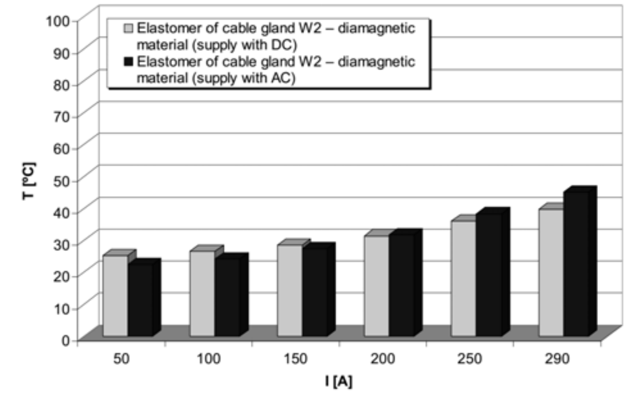

Fig.9. Comparison of maximum temperatures of elastomer of cable gland W2 (diamagnetic material) during warming up with DC and AC [2]

It can be noticed that inducing the alternating magnetic field around AC supplied wire (black) resulted in higher increase of temperature than in the case of inducing the static magnetic field by DC (gray). The temperature of surface of cable gland made of ferromagnetic material increased with increase of current in the wire. Temperature increase for warming up with DC and AC are defined as the absolute values ΔT_{DC}, ΔT_{AC} are calculated according to the following relationships (1, 2):

(1) $$\Delta T_{DC} = T_{DC} - T_{AMB}$$

(2) $$\Delta T_{AC} = T_{AC} - T_{AMB}$$

where: T_{DC} – maximum temperature measured on the selected surface of cable gland exposed to static magnetic field (DC), - T_{AC} – maximum temperature measured on the selected surface of cable gland exposed to alternating magnetic field (AC), - T_{AMB} – average ambient temperature recorded during the tests.

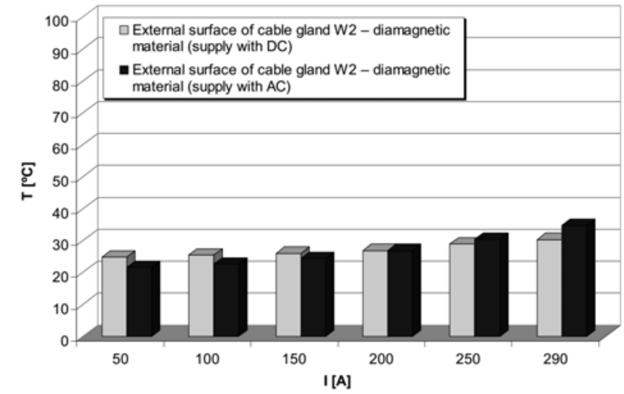

Fig.10. Comparison of maximum temperatures of external surface of cable gland W2 (diamagnetic material) during warming up with DC and AC [2]

According to the equation (2), for AC equal to 50 A the temperature measured on elastomer of cable gland W1 made of ferromagnetic material increased by 4.2°C, while for AC equal to 290 A it increased by 71.7°C. Maximum temperature increase recorded on external surface of cable gland W1 made of ferromagnetic material was equal to 110.7°C. Higher temperature of external surface of cable gland W1 shows that ferromagnetic material, due to hysteresis losses and eddy current losses caused by alternating magnetic field, is a source of heat [5, 6]. In the case of cable gland W2 made of brass, which is qualified as diamagnetic material, alternating magnetic field did not cause significant increase of temperature [1, 5, 6]. Maximum increase of temperature for elastomer was equal to 24.5°C, while for the surface of cable gland it was of 14.1°C. In that case wire with current RMS value of 290 A was the source of heat.

In the case, when static magnetic field was induced (DC) both cable glands had similar maximum temperature acceptable from the point of view of explosion safety requirements [4]. Maximum increase of temperature (in relation to ambient temperature – defined by equation 1) was equal to 17.0°C in the elastomer of cable gland made of ferromagnetic material and 17.6°C in the elastomer of cable gland made of diamagnetic material. Current-carrying wire, not the cable gland material, was the source of heat in this case. It shows that ferromagnetic materials and diamagnetic materials do not react thermally to the static magnetic field [5, 6].

Summary

Testing the impact of static and alternating magnetic field on warming up of cable glands made of ferromagnetic materials and diamagnetic materials was presented. The tests showed that cable glands made of ferromagnetic materials warm up significantly when exposed to alternating magnetic field (induced by AC). According to the tests, hysteresis losses and eddy current losses of ferromagnetic materials are the source of heat. Cable gland made of diamagnetic material warmed up differently. In that case the temperature increase was small and it was caused by the current-carrying wire.

The tests revealed a significant problem associated with design and testing the cable glands, bushings and other components protecting the electric wires, designed as uniform, closed rings. Technical solution of fixing the wires with use of glands installed on bases (made of diamagnetic material), reducing the final temperature on insulation of each wire, is presented in Fig. 11.

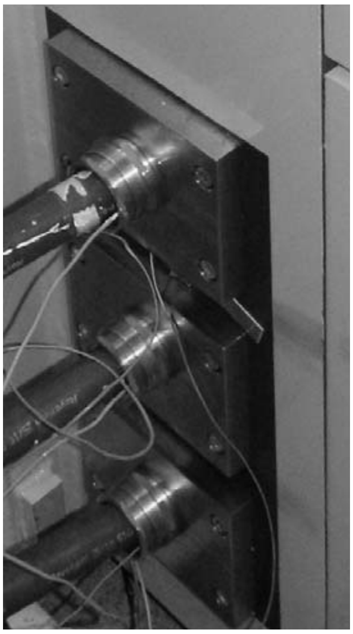

Fig.11. Technical solution of fixing the wires used in electrical power device manufactured by Elgór+Hansen S.A. (photographic documentation made available by Elgór-Hansen S.A.)

The test results enable to make the following recommendations for the manufacturers of electrical equipment:

- diamagnetic materials should be selected in the case, when it is required to separate the wires with AC (e.g. brass),
- in the case, when it is impossible to use the diamagnetic material for single wires the ferromagnetic materials of cut rings (air gap or gap filled with diamagnetic material) should be used,
- the composition of metal alloys used for manufacture of cable glands (or other sub-assemblies) should be properly assessed to identify the possible admixtures of ferromagnetic materials of wide hysteresis loop.

In the case, when cable gland holds a cable including three wires (L1, L2, L3) it is possible to use ferromagnetic materials, because resulting magnetic flux is equal to 0.

The discussed thermal effect should be the subject of investigations in the research centres. The centres carrying out the tests of warming up of cable glands, according to the ATEX Directive, should pay attention to a type of material of tested component and to its destination, i.e. if it is for single-phase wire or for three-phase wire. Also during the tests of insulators equipped with fixing ring, which can be made of ferromagnetic material or diamagnetic material, the attention should be paid to the proper selection of current type (DC or AC) for warming up. Due to this, it will be possible to avoid the mistakes that can impact assessment of the device during certification.

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