INDUCTION HEATING OF THE ALUMINUM WIRE BEFORE ISOLATION.

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ABSTRACT. Production of self-bearing isolated cable includes heating operation up to temperature of 80 – 120°C of continuously moving aluminum wire before making polyethylene isolation. Application of more perspective non-contact induction heating is restrained by low efficiency factor of the traditional induction systems. The different induction systems allowing to raise efficiency of heating of the multiple-strand aluminum wire with bearing steel thread, its numerical models used for optimization of parameters is analyzed. The results of experimental investigations and industrial equipment created on the basis of these researches are described

INTRODUCTION

Manufacturing of self-bearing insulated cable includes the operation of heating of continuously moving aluminum conductors to temperature 80 – 120°C prior to application of polyethylene isolation. The twisted aluminum cable usually consists of aluminum conductors and a central hardened steel wire sustaining tensile load when the cable is used in power lines.

Heating of the cable can be produces using different techniques, including heating in pusher-type resistance furnaces, heating by the contact process with electric current feed through rotating disc contacts and that by high-frequency induction.

The induction heating is the most promising technique due to the inherent combination of contact-free power feed to the moving wire and the ability to produce high-productivity heating in heating equipment having relatively small size.

The main weak point of induction heating systems with the spiral inductor usually used in the equipment for induction heating of cables is their low efficiency, which is normally below 18-25%. This low efficiency is due to not only high electric conductivity of heated aluminum, but also due to substantial exceeding of the distance which the current passes along the surface of the heated cable by the distance which the current passes in the inducing wire.

Impossibility to adjust the gap when the diameter of the heated wire is changed results in practical industrial heating of wires with a wide range of diameters in the same inductor. Thus, the efficiency is additionally decreased due to increasing of the gap when small diameter wires are heated.

Moreover, the efficiency is decreased also due to necessity to increase the gap for obtaining of the reliable isolation of the multiple-turn spiral inductor.

The basic ways of increasing the efficiency of the induction system used for heating of aluminum wires are as follows: decreasing of the difference in the currents path lengths in the inductor and the heated detail, concentration of the current within a small area in the detail cross-section along with decreasing of the current density in the inductor, adjusting of the gap when the heated wire diameter is changed. The said can be realized by using not the spiral inductor but the linear inductor with the optimized shape and dimensions of the inducing conductor and with the adjustable gap between the inductor and the cable. Such an inductor for heating of flat details is described in patent [1].

In the described work, the dependence of the efficiency upon the parameters of the linear induction system with the inducing conductor having circular cross-section was investigated theoretically using computational modeling and practically using the experimental assembly.

MODELING OF LINEAR INDUCTORS

Modeling was used for determination of the optimal shape and dimensions of the inductor by estimation and comparison of the induction systems efficiency. The method of finite elements and the software package MAXWELL 2D [2] were used in modeling. The inducing wires with two shapes (flat and cylindrical) were investigated.

The following assumptions are made for modeling:

• The twisted aluminum cable consisting of several aluminum conductors and a central hardened central steel wire is represented in the model as the uniform cylinder having the equivalent diameter;

• No heating is assumed and the temperature is said to be the same in all the points of the conductors and equal to the steady state average temperature;

• The model is the two-dimensional one and it does not take into consideration edge effects;

• Modeling is made at the specified current in the inductor.

The results of modeling for the flat conductor inductor are shown in Fig. 1.

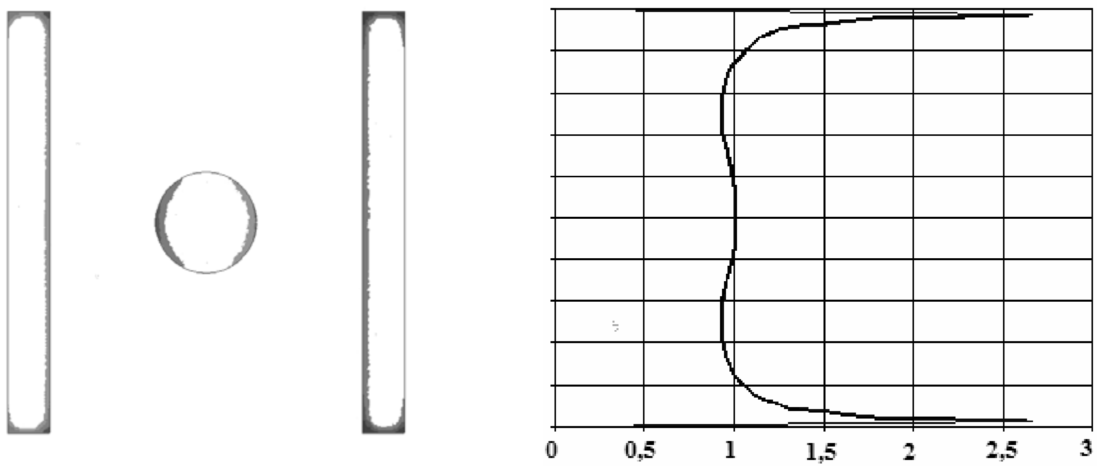

Figure 1. The distribution of the current density in the linear inductor with flat direct and return inducing conductors.

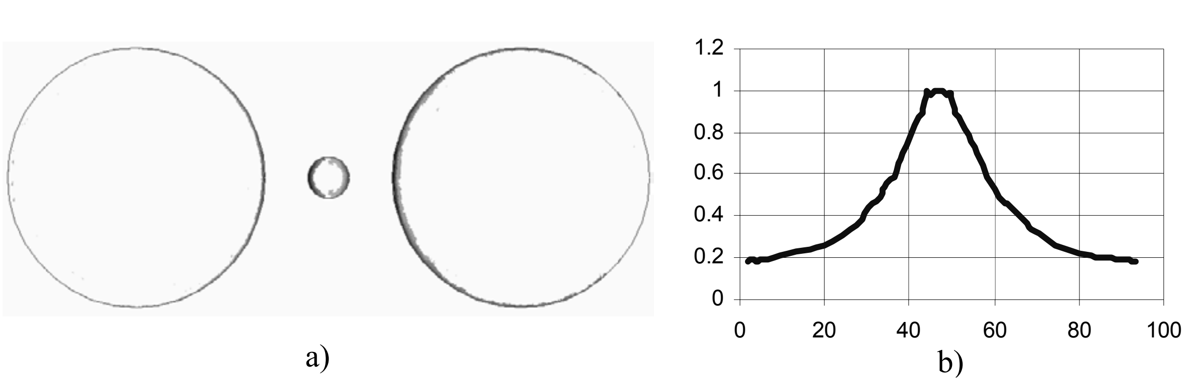

Figure 2. The distribution of the current density.

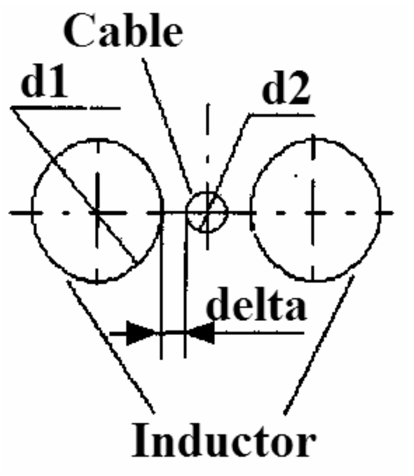

Figure 3. The linear inductor with cylindrical direct and return inducing conductors.

The response for the current density normalized to that at the point of the inductor nearest to the cable shows that the current density of the conductor increases 2.7 times at the edges, causing substantial decreasing of the efficiency equal to 27%.

Using of flat inducing conductor is unreasonable due to unfavorable distribution of the current in conductors with such a shape. Thus, a special attention was paid to investigation of the system with the circular cross-section inducing conductor having the current density distribution near optimal. The calculated pattern for the current distribution over the cross-sections of the inducing conductors and the cable is shown in Fig. 2a. The current density (normalized to the value in the point of the inductor nearest to the cable) distribution along the perimeter of the circular inducing conductor cross-section is shown in Fig. 2b.

The dependence of the efficiency upon the ratio of the cable and the inducing conductors diameters and upon the gap between the inducing conductors and the heated cable was investigated for the cylindrical inducing wires.

To generalize the results of the investigations, the relative parameters are used, and the diameter d2 of the heated cable (Fig. 3) is used as the normalizing factor:

- The relative gap between the inducing conductors and the heated cable, delta rel = delta/d_2;
- The ratio of the inducing conductors and the heated cable diameters, d1 rel = d_1/d_2;

The results expressed in relative (normalized) units are true for high frequency because in this case the depth of penetration of current into the inducing conductors and the heated cable is substantially less than the linear dimensions of these elements. This condition is met for heating of real cables product mix at frequency equal to 66 kHz.

The results of modeling are shown in a graphical form in Figs. 4 and 5.

The efficiency vs. relative diameter of the inducing wire response (Fig. 4) has the maximum near d1 rel = 4. The efficiency decreases rapidly at d1 rel < 2 and slightly at d1 rel > 4; in the latter case it still has rather high value. Such a behavior of the response gives

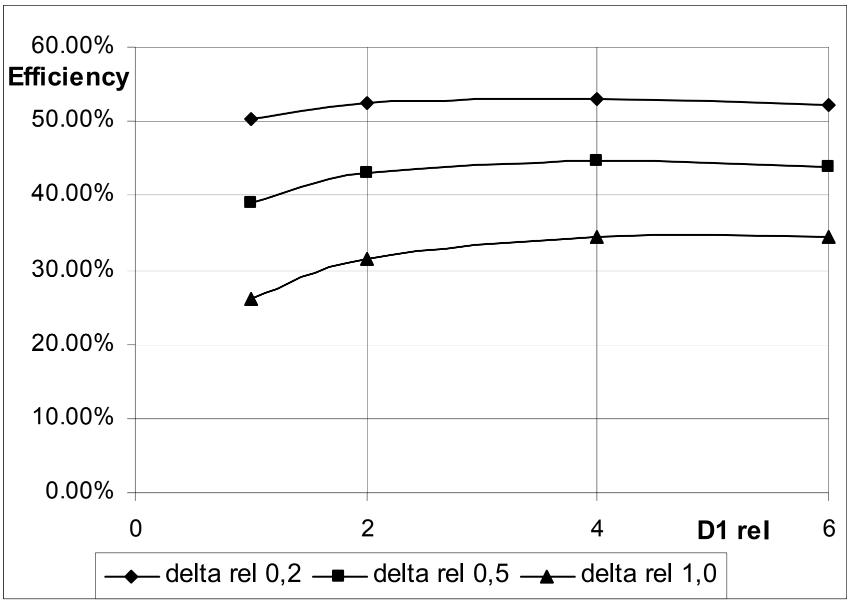

Fig.4. The efficiency vs. relative diameter (D1 rel = D1/D2) of the inducing conductors response for the induction system with the linear inductor (for different gaps).

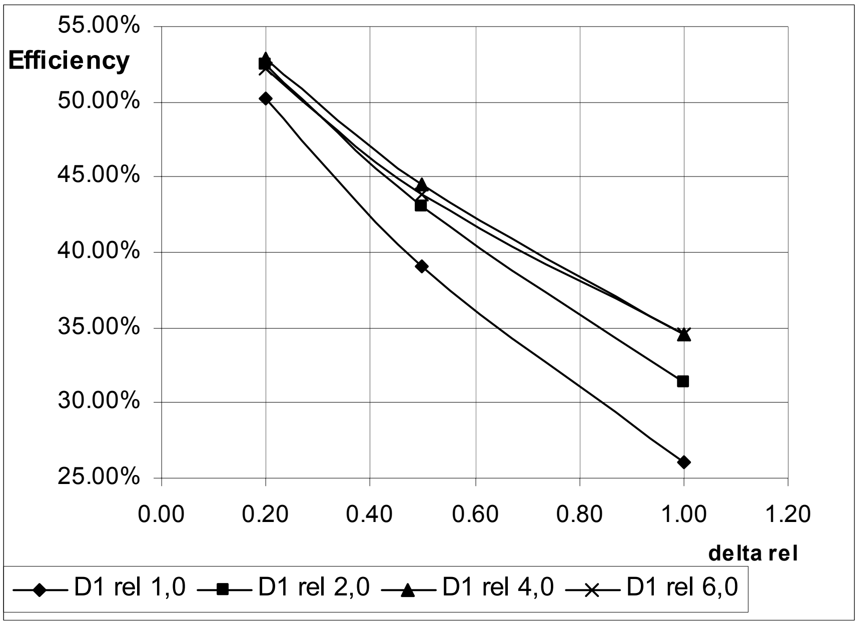

Fig.5. The efficiency vs. relative gap (delta rel = delta D2) response for the induction system with the linear inductor (for different diameters of the inducing conductors).

a possibility to determine the diameter of the inducing conductor common for all the heated cables product mix and corresponding to high efficiency for this mix heating. This optimal diameter of the inducing conductor is $2 * d2_{Max}$, where $d2_{Max}$ is the maximal diameter of the heated cable. In case the maximal diameter of the cable is 14 mm, the reasonable diameter of the inducing conductor is 28 mm.

Increasing of the gap (Fig. 5) decreases the efficiency; if this gap is below 20% of the diameter of the heated cable, the efficiency is over 50%, and if the this gap equal to the diameter of the heated cable, the efficiency is decreased to 30%. In case the diameter of the heated cable is equal to 5mm, the said decreasing of the efficiency corresponds to increasing of the gap from 1 to 5 mm.

The gap providing operation with no short circuits between the centered cable and the inducing conductors having no isolation can be made equal to 2–3 mm in industrial installations with the linear inductor. This minimal gap should be adjusted for different cables by variation of the distance between the inducing conductors.

EXPERIMENTAL INVESTIGATIONS.

The induction system used in the investigations is shown in Fig.6.

The inductor consists of two copper tubes with the outer diameter d1=28 mm and the length 1 m. The heated cable was replaced during experiments for the aluminum tube with the outer diameter d2=10 mm, just as it was made during modeling.

The gap δ between the inducing conductors and the aluminum tube was fixed by several spacers, and the thickness of these spacers was varied during experiments. The measurements were made for three gap values, namely δ = 2, 4 и 6 mm, at the symmetrical orientation of the aluminum tube with respect to inducing conductors and at the displacement of the tube from the central position to obtain the gaps $\delta 1$ = 2mm from one side and $\delta 2$ = 6 from the other side.

The inductor and the heated aluminum tube have independent water-cooling branches. To determine the power dissipated in the inducing conductors and the heated tube and to estimate the efficiency of the induction system, the water flow in the cooling branches and the temperature difference for inlet and outlet water were measured.

Power was supplied to the assembly from the high-frequency transistor generator TGI 40/100-3 with a matching unit. The power level was 3 kW.

The measured and calculated efficiency values of the induction system for different gaps between the inducing conductors and the heated tube are shown in Table 1 and are compared in Fig.7.

The calculated and the measured efficiency of the inductor vs. the gap value responses differ on average for 4%. It seems to be due to the difference in the properties of materials assumed for modeling and that inherent for the materials used in the experimental assembly. Higher calculated efficiency values are also due to no account of loss in connecting elements and leads of the inducing conductors.

Displacement of the heated cable from the axis of the inductor leads to insignificant increasing of the efficiency.

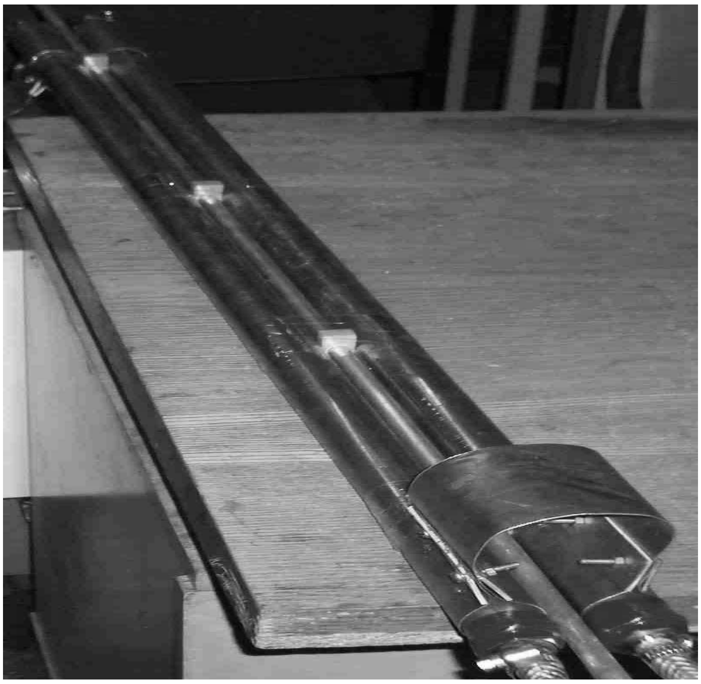

Fig. 6. The induction system of the experimental assembly.

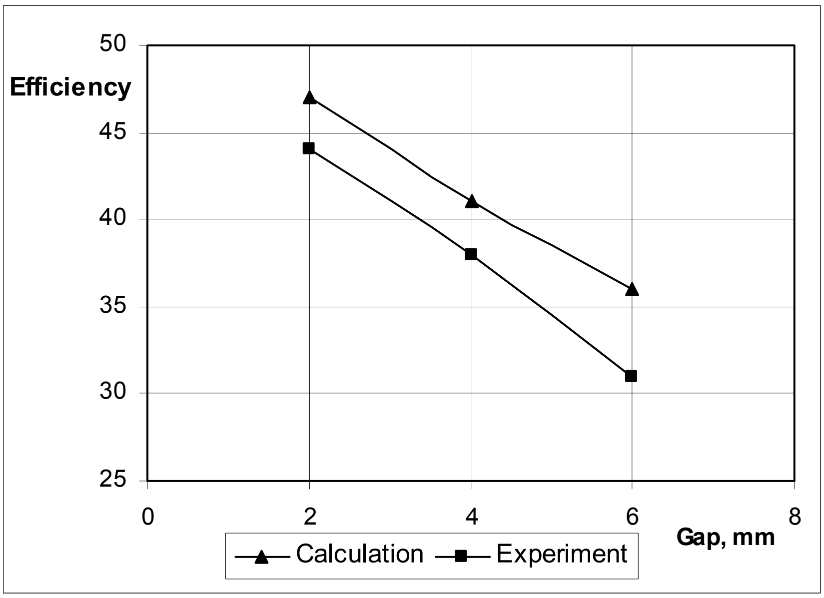

Fig. 7. Comparison of calculated and measured efficiency values of the induction system.

Table 1.

No	δ1/ δ2, mm	Efficiency,%	
		Calculated values	Measured values
1	2/2	47	44
2	4/4	41	38
3	6/6	36	31
4	2/6	43	40

CONCLUSIONS.

The linear inductor with the cylindrical inducing conductor has the following substantial advantages over traditionally used spiral multiple-turn inductor:

- High efficiency (over 40%);
- Ability to maintain high efficiency of heating of wide cables product mix using the same inductor due to a possibility of adjusting the gap;
- The inductor design ensures undamaging misalignment with the moving cable.

The linear inductor with the cylindrical inducing conductor could be recommended for application in the installations for manufacturing of self-bearing insulated cables.