Simulation of defects on contactor coil

Z Erdei, M Horgos and O Zetea

Technical University of Cluj-Napoca, North University Centre of Baia Mare, Electrical Engineering, Electronics and Computers Department, Baia Mare, Romania

E-mail: erdeiz@cunbm.utcluj.ro

Abstract. By definition, a coil is an electrical passive device, which have two terminals, use in electrical circuits to keep the power in magnetic field or to detect the magnetic fields. In winding process, is possible to appear different defects, or issues which can cause in time problems in functionality of products. In this paper, we will analyze two types of defective what were observed in winding process. In first type of defect, some wires of beginning of winding remain out of normal winding, and the wires are visible from outside, and in second type of defect, same beginning of winding remain inside of coil, under the normal winding, not in correct position. For simulation, we will used an assembly compose by anchor, electromagnet and coil. Those are parts of contactor.

1. Introduction
A coil, which is part of contactor, is compose by: coil body (plastic part), contacts (copper with silver surface), and copper wire. The coil what we will used for studying the defects, have wire by 0.112 mm diameter, covered with isolation lake. Together with it, the wire has 0.125 mm. On coil body were winded 4900 windings, divide in 27 levels. In each level are winded 181 windings. The defects what will be described in these papers, appeared when one coil is finished, and winding machine did not cut the wire correctly. These wires will be out of normal winding as in Figure 1 [1], [2].

![Figure 1. Beginning of defect winding](image-url)
After finished the winding process, these wires can be hide inside of normal winding, and cannot be observe from outside (Figure 2), or can remain outside of normal winding (Figure 3), and can be observe from outside and scrap.

**Figure 2.** Wires will be hide by normal windings  
**Figure 3.** Wires remain outside of normal windings

### 2. Parameters of coil

In circuit, this type of coil is charge with 27 V c.c., and have resistance 764 Ω. This mean, according with Ohm law, the current through coil is 0.035 A [3-8].

The inductance is calculating with equation (1):

$$L = \frac{0.008 \cdot N^2 \cdot d^2}{3 \cdot d + 9 \cdot l + 10 \cdot h} \text{ [μH]}$$

(1)

Where:
N - number of turns
\(d\) - middle diameter of coil
\(l\) – length of coil
\(h\) – high of coil

**Figure 4.** Parameters for inductance calculation

If we replace all values in equation (1), we have:

$$L = \frac{0.008 \cdot 4900^2 \cdot 21.8^2}{3 \cdot 21.8 + 9 \cdot 22.4 + 10 \cdot 3.3} = \frac{192080 \cdot 475.24}{65.4 + 201.6 + 33} = \frac{91284099.2}{300} = 304280.33 \text{ [μH]} = 0.3 \text{ [H]}$$

(2)
The density of current can be calculated with equation (3):

\[ I = \frac{I}{A} \text{ [A/mm}^2\text{]} \]  

(3)

Where:

I – the current through wire
A – section of wire

For wire with diameter 0.125 mm2:

\[ A = \pi R^2 = 3.14 \cdot \left(\frac{0.125}{2}\right)^2 = 3.14 \cdot 0.0625^2 = 3.14 \cdot 0.004 = 0.01 \text{ mm}^2 \]  

(4)

If we use equation (3), we obtain:

\[ I = \frac{0.035}{0.01} = 3.5 \text{ A/mm}^2 \]  

(5)

3. Simulation of coil

For simulation of coil we used FEMM software. We simulate from magnetic point of view, and also from electric point of view. In Figure 5, is a section of coil, design in FEMM, before charging, when the anchor is up [9-12].

![Figure 5](image)

**Figure 5.** Section of coil: 1 – winding of coil; 2 – coil body; 3 – electromagnet; 4 – anchor

3.1. Magnetic simulation

The magnetic field of correct winding coil can be saw in Figure 6. This simulation is made in function position, when coil is charge with 27 V cc., and has 35 mA thought wire. If we simulate the two defects, in same conditions, the magnetic field has another form in anchor. This could be saw in Figure 7 and Figure 8.
The magnetic field is modified by additional wires, because all parameters of coil are modified in right side of section. The defect is composed by 5 wires, winding together. These wires have 10 mm length [4], [5], [11].

The resistance of these 5 wires can be calculated with equation (6):

$$R = \delta \cdot \frac{l}{A} \ [\Omega]$$  \hspace{1cm} (6)

According to FEMM simulation, the average of magnetic inductance value of anchor increase. This mean the forces applied in anchor increase also, because:

$$B = \frac{F}{l \cdot l} \ [T]$$  \hspace{1cm} (7)

$$F = \frac{B}{l \cdot l} \ [N]$$  \hspace{1cm} (8)

The value of is around of 0.06 N. In Figures 9, 10, 11, could be see the evolution of magnetic inductance on entire surface of assembly. We have areas where values of inductance drop down from 1 T to 0, but also surfaces where values increase from 0.7 to 1.2 T. all those values influence the functionality of coil. In points where wires are out of normal winding, the forces are bigger than in normal cases. These forces produce bigger vibration and in time can destroy the lake of wire [13-15].
The meaning of each color from figures can be seen in Figure 12.

![Figure 12. Meaning of color](image)

3.2. Electrical simulation

The electrical simulation is made also in FEMM, in same conditions as magnetic simulation. If we look in Figure 13, we can see that in upside and in down side of coil, is bigger density of voltage, than in the middle of coil. Also, in Figure 14, because in upside we have the other 5 wires, which are remaining out because of bad winding.

If we analyze each case, and we compare the density of voltage from entire surface of coil, we can say that, where density of voltage is bigger, the temperature is bigger. The defects wires, have other direction of electrical field. This is opposite with the direction of electrical field of normal winding.

![Figure 13. Normal winding coil](image)  ![Figure 14. Wires outside](image)  ![Figure 15. Wires inside](image)

The graphics for voltage density on surface of coil, show us the instability of voltage in defect area. In Figure 16 is presented the voltage density for correct coil, and in Figure 17 is density of voltage for defect coil [16], [17]. The real component of voltage density from Figure 16 is constantly, but in Figure 17, in defect coil we can saw that drop of voltage in defect area. This voltage drop can produce inside of coil some shocks, which can affect the functionality and the life time of coil. Especially because, according with bellow graphic, this drop is on short distance of wire.

![Figure 16. Correct winding](image)  ![Figure 17. Bad winding](image)
In electrical simulation, we can study also the moving of electrons inside of electrical field. In Figure 18, we can see this moving in coil with wires outside of normal windings. This moving should produce a normal electrical field, but because the wire has opposite orientation, we have two electrical fields. One produce by normal windings, and one produce by 5 wires which are out of normal windings. This mean, there we have an intersection of two different electrical fluxes, with different directions.

**Figure 18.** Moving of electrons

4. Conclusions

After all those simulation, we can affirm that each little deviation from normal process can affect more or less the functionality of products. The products must respect some parameters, and, as in our cases, some wires can take out the coil from normal parameters. Because those wires what have different direction, produce a second electrical field, and inside of coil, result a difference of potentials. At firs look those values are not so bigger than normal, but in time can cause damages. The lake of wires can be destroyed, and a short circuit can appear.

Those differences can grow up the forces and the temperature. According with Joule Lentz law, the temperature of conductor is proportionally with current values, time and resistance. So in this case, few Ohm will increase the temperature in coil.

\[ Q = I^2 \cdot R \cdot t \]  

(9)

If we charge three contactors with those three studied types of coils, the correct one will have a longer life. The two defective coils have bigger resistance. This difference, together with voltage drop saw in Figure 17, can reduce the life of coils. This thing cannot be anticipated exactly, because these two types of defect can be different for each coil.

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