THE SHORT-CIRCUIT STRAIN OF THE POWER TRANSFORMERS WINDINGS

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SUMMARY

Power transformers are key equipment for transfer and distribution of the electric power. Considering the significance of the power transformers in the electric system, their price and possible damages occurred by accidents, it is necessary to pay attention to their higher prevention.

Power transformers must be designed so, that the effect of short-circuits currents, which can emerge in the place, will not start up on them the destruction or the deformation of the electric, mechanical or thermal character. Except for permanently deformation results of the effects of short-circuit current come to also by correct dimensioning of electric equipment to progressive ageing, which can make worse his mechanical properties.

Norms define dimensioning of transformers for the intensity of short-circuit currents, but do not define theorems for the number of short-circuits, which are able to withstand in failure-free operation.

The paper deal with the decrease of mechanical strength of windings because of the thermal effects of short-circuit currents and table the consideration for further workmanship of dimensioning for determination of the limited number of short-circuits of power transformers.

Various authors experimentally have defined the decrease of material in dependence from the temperature and the time. Big deviations are among the feature curves and the measurement method data are often missing, especially about that, whether for the time of conductor thermal strain was taken in account the elapsed short-circuit duration time, or the real time of thermal strain with some temperature.

With the view of the conservation of the most authentic shape of decrease of mechanical strength after short-circuit, we must keep the basic thermal principles of conductor's material, which are established for exponential decay of refrigeration curves.

Keywords: *short-circuit strain, power transformer, winding, effect of short-circuits currents, thermal shock, temperature*

1. INDRODUCTION

The norms define dimensioning of the power transformers for intensity of short-circuit current and his the limited duration, but do not define theorems for the number of short-circuits, which are able to withstand in the failure-free operation. The higher number of short-circuits introduces generally so big loading condition for the power transformers, that the decrease of mechanical strength of the windings because of the thermal effects of short-circuit currents.

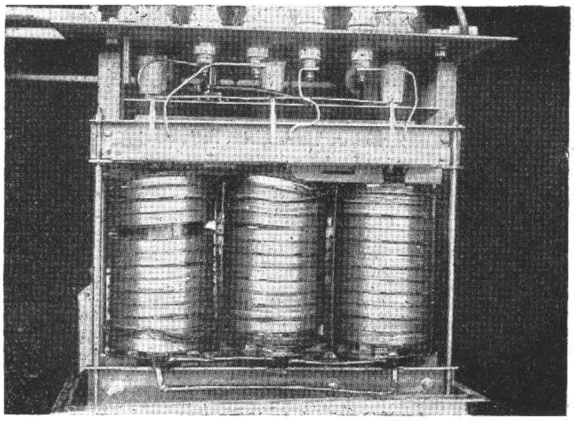

Fig. 1 A view for damaged aluminium winding of transformer as a result effects of short-circuit currents

Cases exist in practice, that power transformer winding will be destroyed also after correct opening of guards. Technical commission in this case need not detect the main failure cause of transformer (e.g. interturn short-circuit by action of excessive axial strengths - fig. 2), if the number of short-circuit is not counted, which forewent this fatal one. Neither previous competent revisions of this equipment, which were not subjected to strict tests, don't have to anticipate the future accident also in the case of the correct short-circuit opening.

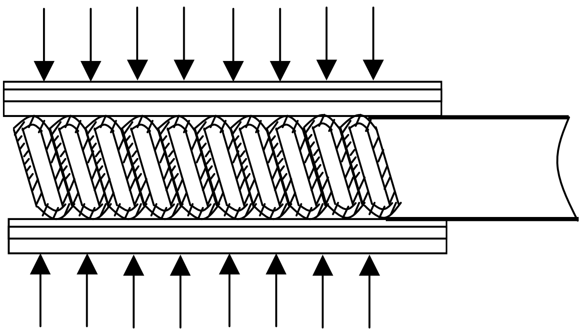

Fig. 2 Pitching of coil conductors by action of the excessive axial strengths (effect to insulation compression)

The paper deal with the decrease of mechanical strength of power transformers windings because of the thermal effects of short-circuit currents and suggest the consideration for further workmanship of dimensioning for definition of the limited number of the short-circuits of this equipment.

Intense increase of the temperature during the duration of short-circuit and its decrease after break of current we will be to call the **thermal shock**.

2. THE DECREASE OF MECHANICAL STRENGTH OF WINDINGS FROM THE THERMAL SHOCK

With the view of the conservation of the most authentic shape of decrease of mechanical strength after short-circuit, we must keep the basic thermal principles of conductor's material, which are established for exponential decay of refrigeration curves.

The material mechanical strength is the function of the temperature and the time. According to [1] the curves of decrease of mechanical strength, which are depending on the time and the temperature, are exponential functions for the aluminium and for copper are exponential functions with the definite distortion retardation at the start (at lower temperatures). This distortion retardation is dependent of the temperature. At the higher temperatures it already does not appear. Time constants of exponential function of the decrease of mechanical strength with the time are dependent on the temperature.

For the definition of the mechanical strength of material K in dependence on the temperature and the time we can expect function dependency according to the equation:

$$K = K_0 \cdot e^{-B\,t} \qquad (1)$$

where K_0 is mechanical tensile strength in $MN.m^{-2}$;
B is temperature function $B = B(\vartheta)$ and is defined experimentally;
t is the time in s.

According to [1] for the definition of decrease of mechanical strength of windings from the thermal shock the time behaviour of thermal shock will be divided according to fig. 3 for such temperature intervals ϑ, for which are known the curves in dependence on the mechanical strength from the time (fig. 4) and according to which we can expect time constant $\tau = \dfrac{1}{B}$ for mechanical strength as constant.

We will define single times t_1 till t_n temperature duration ϑ_1 až ϑ_n, as indicated on fig. 3 and by means of we will define the decrease of mechanical strength of winding.

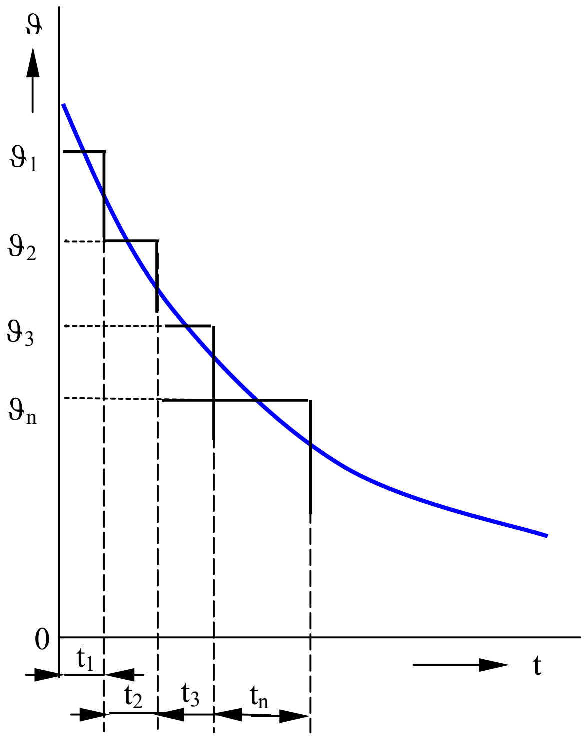

Fig. 3 The temperature behaviour of winding after short-circuit

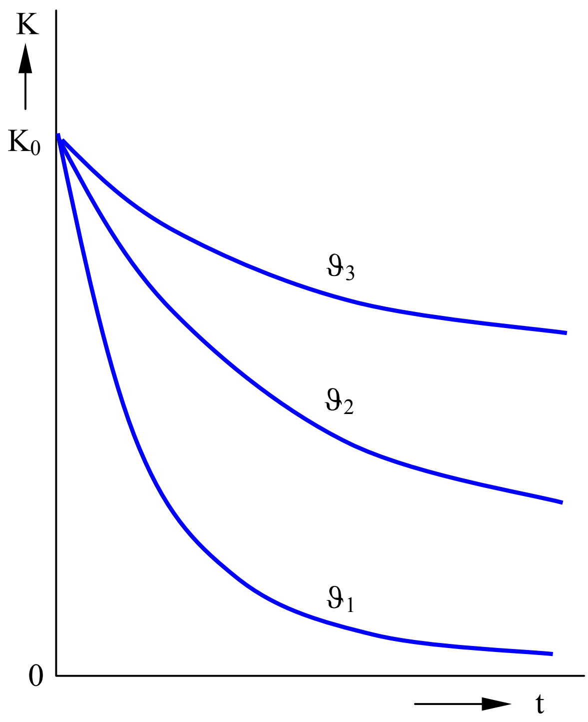

Fig. 4 The time decrease of mechanical strength dependency at the specific temperature intervals

We can also define the times t_1 and t_2 for the definition of specific value at mechanical strength of material according two different exponential functions with time constants:

$$\tau_1 = \frac{1}{B_1} \quad \text{and} \quad \tau_2 = \frac{1}{B_2} \tag{2}$$

valid for the strain temperature of the conductor material ϑ_1 a ϑ_2. We get the equations:

$$t_2 = \frac{B_1}{B_2} \cdot t_1 \quad \text{till} \quad t_n = \frac{B_{n-1}}{B_n} \cdot t_{n-1} \tag{3}$$

where B_1 till B_n mean the inverted values of time constants τ_1 till τ_n of exponential functions of dependence material mechanical strength from the time at the temperatures ϑ_1 till ϑ_n.

Concerning exponential functions characteristics, which are formulated by the equations (3), can be the single time behaviours of strain of winding through time intervals t_1 till t_n transformed on one curve. This way we can define consequential mechanical strength of material after short-circuit by one curve e.g. for temperature ϑ_3.

Competent **the duration fictitious time of strain**, during that would decrease mechanical strength at winding strain with the temperature ϑ_3 for the same value K as it would be at strain of different temperatures ϑ_1 till ϑ_3:

$$t = \left(t_1 \frac{B_1}{B_2} + t_2 \right) \cdot \frac{B_2}{B_3} + t_3 = t_1 \frac{B_1}{B_3} + t_2 \frac{B_2}{B_3} + t_3 \tag{4}$$

On principle of the last equation **the consequential mechanical strength of material** will be defined after the short-circuit thermal shock:

$$K = K_0 \cdot e^{-B_3.t} = K_0 \cdot e^{-(B_1.t_1 + B_2.t_2 + B_3.t_3)} \tag{5}$$

where K_0 is conductor mechanical strength before the short-circuit.

If winding is strained n short-circuits with the same thermal shock behaviours, the **consequential conductor mechanical strength after n short-circuits** will be:

$$K_n = K_0 \cdot e^{-n(B_1.t_1 + B_2.t_2 + \ldots + B_n.t_n)} \tag{6}$$

3. CONCLUSION

Transformers can be lowered with aluminium winding with the decrease of mechanical strength of aluminium their dynamic safety, which is greatly lowered by the decrease of the short-circuit voltage uk. Apart from failures on windings (interturn short-circuit, short circuit with tank) can be destroyed the lonely transformer tank because of pressure from arcing too.

Because it is necessary to pay higher attention to the decrease of mechanical strength of aluminium windings of transformers as a result of thermal shocks, according to, that the mechanical tensile strength of aluminium is by the temperature 20 °C 89 MN/m2 against 220 MN/m2 by copper.

In conclusion I would like to point out, that by transformers with aluminium winding it is necessary to stress the whole length of interval time of the short-circuit current (the number of short-circuits), to prevent unpredictable failures during operation. It is necessary to choose the suitable diagnostics, which could anticipate such a state [2].

REFERENCES

[1] Gutten, M.: The short-circuit strain of conductors of the electric equipment , Transcom 2001, 4-th European Conference of Young Research and Science Workers in Transport and Telecommunications, Section 2, Žilina 2001

[2] Gutten, M., Skalický, M.: Sledovanie vplyvu tepelných účinkov skratových prúdov na vinutiach transformátorov, Zborník prednášok - Technická diagnostika elektrotechnických materiálov elektrických zariadení, ATD SR, EDIS 2001

BIOGRAPHY

Miroslav Gutten was born on 03.02.1972. In 1997 he graduated (Ing.) with distinction at the department of Electric Traction and Power Engineering of the Faculty of Electrical Engineering at University of Žilina. In 2002 he defended his PhD. in the field of short-circuits currents in the electric traction; his thesis title was "The dimensioning of electric equipment in the traction feed stations concerning the effects of short-circuit currents". Since 1999 he is working as a assistant lecturer with the Department of Theoretical and Applied Electrical Engineering at University of Žilina.