Thermal Properties of Inverter-Driven Induction Cage Machines Under Condition of Energy Saving Work

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Abstract – **One of possibilities to decrease power loss in an induction machine is energy saving work – supplying with lowered voltage when load torque is much less than nominal. Thanks to reduced power loss, temperature of windings is also decreased, and consequently, it is possible to use a machine of less rating power to the same load torque. Ability of energy saving work to lower temperature of windings depends on thermal properties of an induction cage machine, which are different in the case of a machine with own ventilation and foreign one. This paper is devoted to influence of way of ventilation on thermal effect of energy saving work. Results of experimental investigation are presented for a frequency-controlled 3-kW induction cage machine with two ways of ventilation: provided with a fan placed on a shaft and provided with a fan driven by an auxiliary motor.**

1. Introduction

One of possibilities to increase the efficiency of an induction cage machine working with variable load is *energy saving work* [1-10] – lowering supply voltage when load torque is much less then nominal. Reduced voltage leads to decrease in magnetic flux, and as a result to less magnetising current and less power loss in iron. Consequently energy saving work causes reduction in temperature of windings. Less temperature of windings results in longer operating life of a machine and enables to increase value of overload torque if a machine works with periodically variable load (Fig. 1) - for example standard S6 load conditions. What is more, it is also possible to use a machine of less rating power than in the case of nominal supply, without risking overheating of the isolation system.

Value of supply voltage could be determinate using three criteria: minimum current, minimum power loss and minimum temperature-rise of windings. In order to control value of voltage, PWM inverters can be used. It should be stressed that at the present time appropriate inverters with built-in energy saving mode are available on the market. However, taking into account comparatively high prices of inverters, this way of control supply voltage of an induction machine may be recommended for adjustable speed drives only.

To sum it up, application of energy saving work is especially interesting in the case of inverter-fed drives. Consequently, in order to take its full advantages, it is necessary to know thermal properties of a frequency-controlled induction cage machine under condition of energy saving work.

M [Nm]

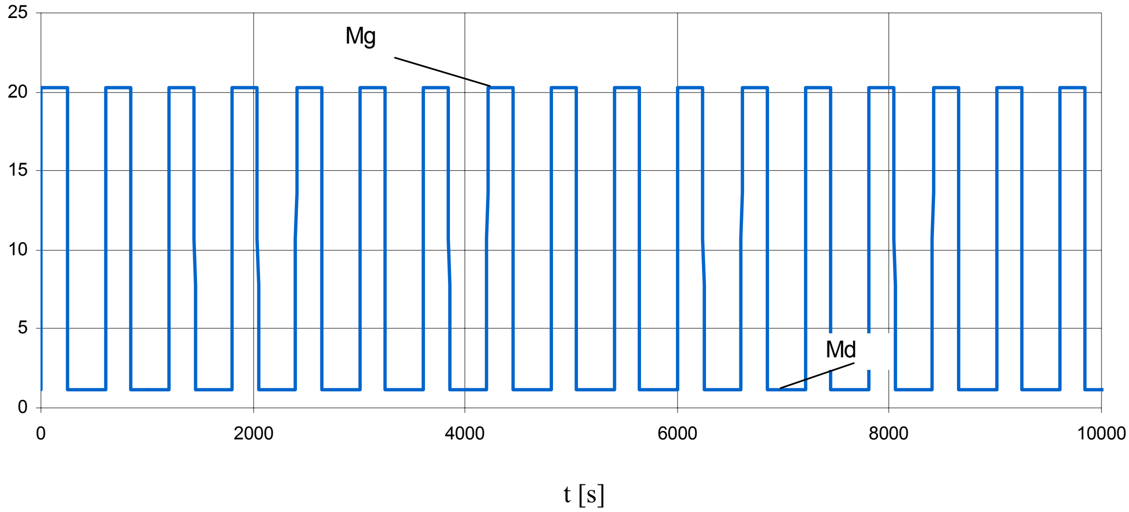

Fig. 1. Periodically variable load torque under consideration

2. Thermal properties of an adjustable speed induction machine

Control of supply voltage frequency influences cooling conditions of an induction cage machine as well as power loss distribution. For example, decrease in voltage frequency leads to significant reduction in power loss in iron. Change of heat transfer has still more important impact on thermal properties of a machine. In the case of a machine with foreign ventilation, speed control influences on heat flow inside the machine only. For instance, lowering of rotational speed leads to increase in thermal resistance between endwindings and endcap air, between rotor and stator iron. The impact of speed control on cooling conditions is especially significant in the case of a machine with own ventilation. For reduced rotational speed thermal resistance between a casing and ambient may be few times as large as for nominal speed, what leads to decrease in continuous load torque. As a result foreign ventilation is recommended for motors with speed control. However, in the case of drives of small power, the cheaper solution is to purchase a larger machine with own ventilation, than a machine with foreign ventilation. For example, 2,2 kW four-pole induction cage machine with foreign ventilation costs 700 zł. (c. 175 Euro), whereas 3 kW machine with own ventilation – only 412 zł. (c. 100 Euro).

Decrease in continuos load is the most important effect of worse cooling conditions. Another one is increase in thermal time-constant of a machine with own ventilation. Namely, the thermal time-constant is proportional to product of equivalent thermal capacity of a machine (proportional do its weigh) and its equivalent thermal resistance. It should be noticed that lengthening of time-constant has significant influence on thermal effect of energy saving work - for periodically variable load reduction in maximal temperature-rise of windings (at the end of overload period) is greater for a machine of longer thermal time-constant [6].

It is also worth mentioning that worse cooling condition of a machine with own ventilation boosts thermal effect of power loss reduction. Namely, decrease in temperature-rise due to energy saving work, is proportional to product of equivalent thermal resistance of a machine and reduction in power loss. Consequently, the capacity of energy saving work to low temperature-rise of windings depends on turning speed. For instance, 1000-W reduction in power loss may cause 10-K decrease in temperature-rise for nominal rotational speed, whereas for lowered speed – 20-K reduction.

The mentioned above factors: change of power loss distribution, boost in thermal effect of power loss reduction as well as increase in thermal time-constant of a frequency-controlled induction machine have impact on the ability of energy saving work to low temperature-rise of windings. Consequently, thermal effect of energy saving work is different in the case of a machine with own and foreign ventilation. In order to compare the differences the author has carried out thermal tests for an induction cage machine with two ways of ventilation: provided with a fan placed on a shaft and provided with a fan driven by an auxiliary motor.

3. Test stand

In the test stand there are installed two induction cage machines with a rated power of 5,5 kW and 3 kW, supply and load systems. In different parts of stators of both the induction machines there are built-in thermocouples: in windings (11 in the 3-kW machine and 9 in the 5,5-kW machine), in teeth, in stator cores, under bearings, on the casings. In rotors there are thermocouples and thermistors. Temperature probes in the stators are monitored by a computer system. All the presented results of measurements were obtained for 3-kW machine with two ways of ventilation: own (motor TSG 100L-4B) and foreign (motor FSG 100L-4B). Change of the way of ventilation needs change of a rotor and endcaps.

The machines can be supplied with an autotransformer, a synchronous generator, and an inverter with independent voltage and frequency control. The motors are loaded with DC generators.

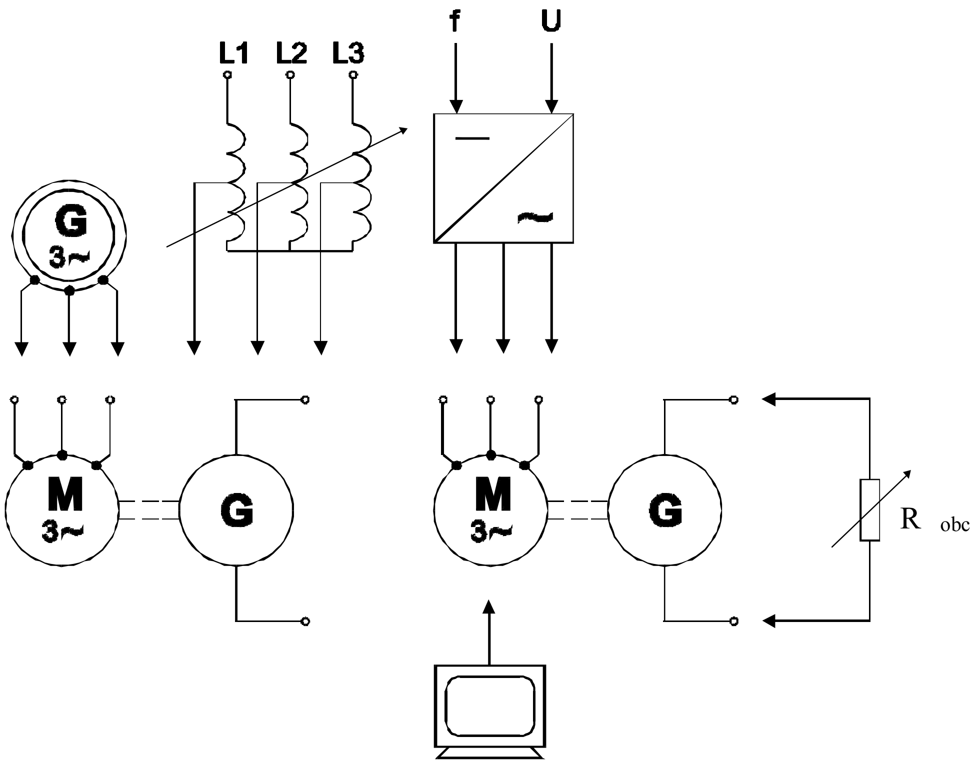

Fig. 2 Scheme of the test stand

4. Thermal effect of energy saving work on a frequency-controlled induction machine

In order to compare thermal effect of energy saving work for both the examined cases of ventilation, thermal investigations have been carried out for the described above 3-kW induction cage machine. During thermal tests the machine was loaded with torque given in Fig. 1, of following parameters: cyclic duration factor equal to 40%, $M_g=M_n$, $M_d=6\%$. Recorded temperature-rise of endwindings and slot windings in state of thermal eqiulibrioum are presented in Fig. 3-8.

In Fig. 3 and 4 there are shown transient temperature-rise of windings for supply voltage frequency equal to 45 Hz and the case of foreign ventilation. Thanks to energy saving work (minimum current) maximal temperature rise at the end of overload period (Fig. 3) is c. 10K less than in the case of nominal flux (Fig. 4). It should be noted that results for the case of own ventilation are very similar. However, for very low supply frequency thermal effect of energy saving work is quite different for both the cases of ventilation, what shows results of investigation presented in Fig. 5 - 8. Fig. 5 and 6 correspond to foreign ventilation and Fig. 7 and 8 – to own one. In all the cases frequency of supply voltage was equal to 10 Hz. For the machine with own ventilation applying of energy saving work leads to 4-K decrease in temperature-rise of windings at the end of overload period only, whereas for own ventilation it results in c. 13-K decrease. It is also worth mentioning that for both the ways of ventilation, the transient characteristics of temperature-rise look rather different. Firstly, the temperature-rise reaches much higher level for the machine with own ventilation. Secondly, the machine needs much more time to reach state of thermal equilibrium. Factors causing those differences – increase in equivalent thermal resistance and thermal time-constant, also boost thermal effect of energy saving work. As a result, for a machine with own ventilation lowering of temperature of windings due to energy saving work is especially significant for very low supply voltage frequency.

To sum it up, for a machine with own ventilation energy saving work causes maximal reduction in temperature of windings for supply voltage frequency much less than nominal, whereas for a machine with foreign ventilation – for supply voltage frequency near nominal value.

$\Delta\vartheta$ [K]

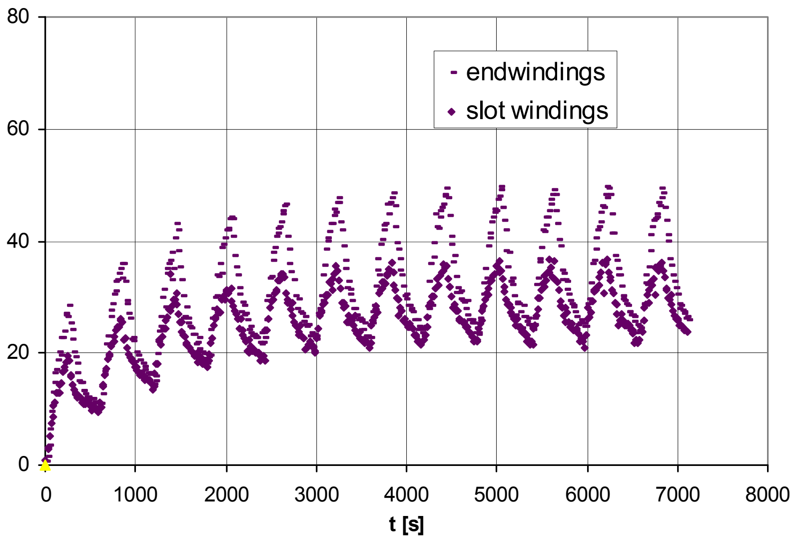

Fig. 3. Measured temperature-rise of windings of the machine with foreign ventilation, f=45 Hz, energy saving work (minimum current)

$\Delta\vartheta$ [K]

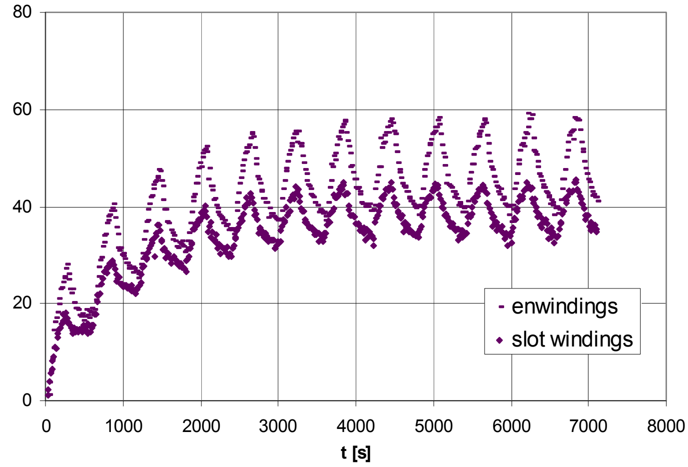

Fig. 4. Measured temperature-rise of windings of the machine with foreign ventilation, f=45 Hz, work with nominal flux

Δϑ [K]

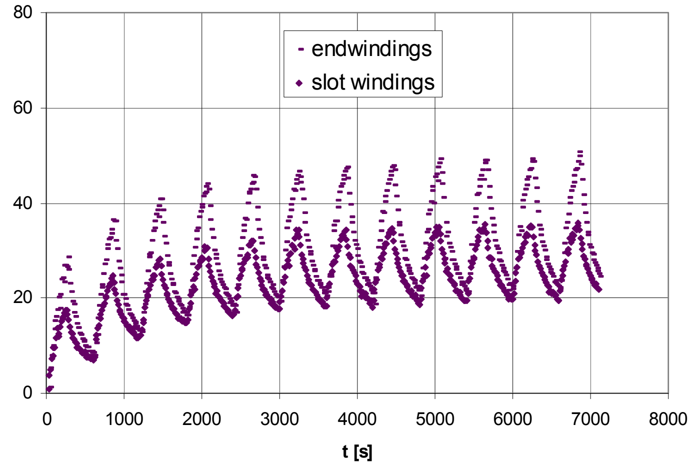

Fig. 5. Measured temperature-rise of windings of the machine with foreign ventilation, f=10 Hz, energy saving work (minimum current)

Δϑ [K]

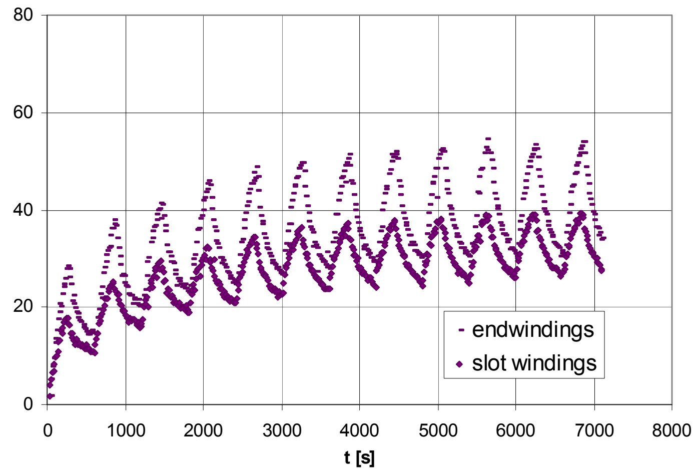

Fig. 6. Measured temperature-rise of windings of the machine with foreign ventilation, f=10 Hz, work with nominal flux

Δϑ [K]

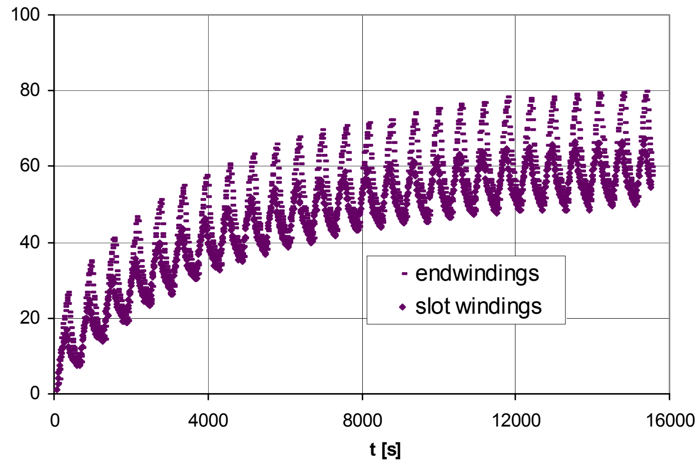

Fig. 7. Measured temperature-rise of windings of the machine with own ventilation, f=10 Hz, energy saving work (minimum current)

Δϑ [K]

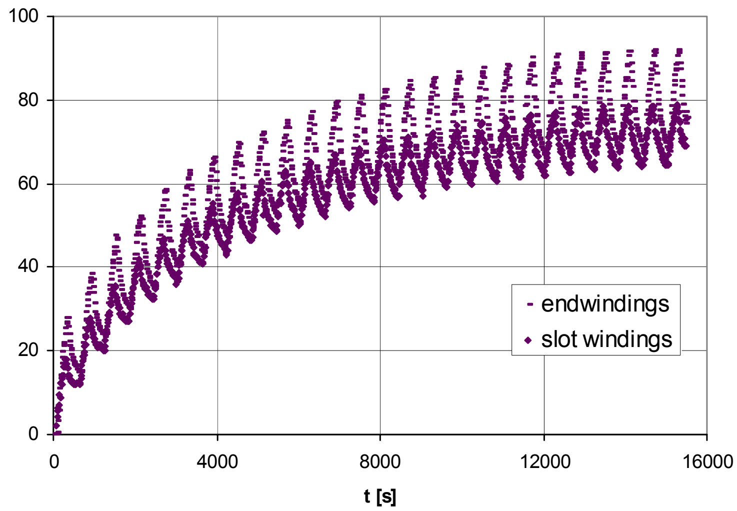

Fig. 8. Measured temperature-rise of windings of the machine with own ventilation, f=10 Hz, work with nominal flux

4. Conclusions

One of most important advantages of energy saving work is lowering temperature of windings. The ability to lower temperature depends on thermal properties of an induction machine, which are different in the case of own ventilation and foreign one. For a machine with foreign ventilation the reduction in temperature is most effective for supply voltage frequency close to nominal one, whereas for a machine with own ventilation – for supply voltage frequency much less than nominal value. The results of investigation may be useful for designing direct electric drives (low speed, high torque).

5. References

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