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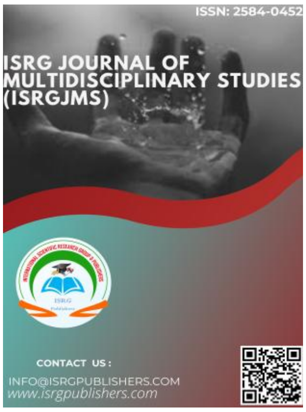

The influence of temperature on the parameters of PMDC and SMDC electric motors

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Abstract

The article analyzes the influence of temperature on the efficiency and mechanical characteristics of selected DC electric motors. The computer simulation method was used in the research. Simulation models of PMDC and SWDC motors were developed in Simcenter Amesim software. Comparative analysis of the obtained results allowed to identify the effects of temperature on the operation of both types of DC motors. Conclusions drawn from the analysis indicate a significant effect of temperature on the efficiency and mechanical characteristics of PMDC motors and the SWDC micromotor. No significant effect of temperature on the operation of the 3 kW SWDC motor was observed.

Keywords: *PMDC motor, SWDC motor, Simcenter Amesim*

Introduction

The operation of electric motors is inevitably accompanied by the phenomenon of heat generation. The associated losses of electrical energy not only reduce the efficiency of the machine, but also cause a number of phenomena that reduce the reliability of operation. These mainly include aging processes of the electrical insulation system of the motor. The static and movement characteristics of the motor also change. An increase in temperature generally causes an increase in the resistance of conductive materials, such as wires used in the motor windings. An increase in resistance causes an increase in the temperature of the windings during the operation of the motor. Excessive heating of the windings can lead to overheating of the electric motor, which in turn can damage the insulation of the wires, reduce the service life of the machine or even cause its damage.

Efficiency is one of the most important parameters taken into account when selecting a motor for a drive system. Its value determines the operating costs of the motor. The motor efficiency

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is influenced not only by the power supply and load conditions, but also by the ambient temperature, which affects the winding temperature and, consequently, the winding resistance and power losses.

The main objective of the article is to understand and assess the influence of thermal phenomena on the properties and operation of PMDC and SWDC motors (Orłów, 2024).

Literature Review

Theoretical considerations regarding the influence of external factors on the operation of electric motors have been carried out in extensive literature. The publication (Korkosz, 2014) describes the influence of temperature on the static characteristics determined in laboratory conditions of the designed high-speed switched reluctance motor SRM 4/2. It was found that in the case of determining the static torque characteristics of the machine at a constant position, the influence of temperature on their shape is insignificant. The winding temperature, due to its pulsed power supply, reaches a value below the permissible value resulting from the insulation class H. The influence of temperature on the determined static torque characteristics using the constant current method is much more significant. Due to the duration of the measurement, the temperature of the supplied winding should be controlled due to the risk of exceeding the permissible value resulting from the insulation class H (180 °C).

The influence of temperature on the ageing of the insulation system strength depends to a large extent on the type of the electrical insulation system. Studies have shown that there is an influence of the air temperature in the room on the amount of partial discharge emission in the insulation of electrical machines. Each electrical machine can react differently to the microclimatic conditions prevailing in its environment (Szymanec, Plutecki, 2013; Szymanec, Plutecki, 2014).

The article (Venkataraman, 2005) focuses on theoretical considerations. The basics of the thermal model of the motor and its mathematical interpretation and physics for different stages of the motor operation (overload, blocked rotor, too frequent or long acceleration, application of different duty cycles) are discussed. The time constants of the thermal model and other technical aspects causing deviation of the thermal model algorithm are explained. Other topics covered in this article show that detailed information contained in the motor data sheet and coordination between the protection engineer and the motor supplier lead to the proper selection of the motor thermal protection parameters.

According to two different centers investigating the causes of damage to electrical machines, IEES and EPRI, the share of factors related to the impact of the environment in which the machines operate is estimated at 38.7% and 32%, respectively. Of this, the impact of too high temperature, too low or too high relative air humidity and improper ventilation of motor winding insulation is as much as 12.7% (Venkataraman, 2005).

The influence of temperature on the aging strength of the insulation system determined in laboratory conditions is presented in the publication (Szymanec, Plutecki, 2012). The research results show that the best insulation life for the tested composition was obtained at a temperature of 160°C.

The literature (Szymaniec, Plutecki, 2012) provides research results on thermal-flow phenomena that occur in equilibrium between working electrical machines and external environmental conditions. The research was conducted in industrial operating conditions, measuring: air temperature, radiation temperature, air velocity, relative air humidity and dust level. In addition, selected measurement results of quantities describing the size of partial discharge emissions, which were performed using the on-line method, were presented.

In the publications (Krok, 2018; Krok, 2019) a model for calculating power losses and efficiency of a closed-type induction motor was presented, taking into account the influence of the ambient temperature. The developed thermal network allows for calculating the temperature of individual components of the induction motor and the power losses generated in them at a given ambient temperature.

Methodology

For research purposes, the following questions were formulated:

Q1: How do temperature changes affect the efficiency of electric motors?

Q2: How does temperature affect the mechanical characteristics of electric motors?

The answers to the research questions were contained in two hypotheses:

H1: The efficiency of electric motors depends on temperature. An increase in temperature causes a decrease in the energy efficiency of motors.

H2: Temperature changes affect the mechanical characteristics of motors.

Four DC motors (theoretical models) with parameters presented in Table 1 were selected for the tests.

Table1

DC motor parameters

Motor	I [A]	U [V]	M [Nm]	Pm [W]	ɳ	n [rpm]
PMDC-1	0.5	48	0.1	12	0,52	1173
PMDC-2	15	220	3.2	3065	0,92	9141
SWDC-1	1	48	0.2	14.5	0,28	692
SWDC-2	5	220	4.5	1073	0,98	2279

Source: own work

The PMDC (Permanent Magnet DC) motor is a brush DC commutator motor with permanent magnets that replace the field winding. The SWDC (Series Wound DC) motor is one type of commutator DC motor.

The rated parameters of the motors given in Table 1 are:

1. I[A] – rated current
2. U[V] - rated voltage
3. M[Nm] - torque
4. Pm[W] - mechanical power
5. ɳ - rated efficiency, defined as the quotient of mechanical power Pm and electrical power Pe
6. n[rpm] - rated rotational speed

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The following temperature of motors values in degrees Celsius were assumed:

-20, -10, 0, 10, 20, 30,

and a reference temperature of 20°C, for which the rated parameters listed in Table 1 apply.

Using advanced Simcenter Amesim software tools to visualize simulation results, the following graphs were generated for the full temperature range from -20°C to 30°C:

1. Efficiency as a function of shaft torque η=f(M).
2. The relationship between speed and torque, i.e. mechanical characteristic n=f(M).

Important characteristic parameters were read from the graphs for each engine temperature:

- maximum efficiency

- rated efficiency

- maximum speed

- rated speed.

The stiffness of the mechanical characteristics (relative change in the rotational speed of the electric motor) was calculated using the formula:

$$\triangle n = \frac{nmax - n}{nmax} 100\%$$

Where:

△ n - mechanical characteristic stiffness

n - rated speed

nmax - maximum speed

PMDC electric motor tests

The tests were carried out on a PMDC motor model with the parameters set in Table 1. The measurements and graphs were recorded using mechanical and electrical power, torque and speed sensors (Figure 1).

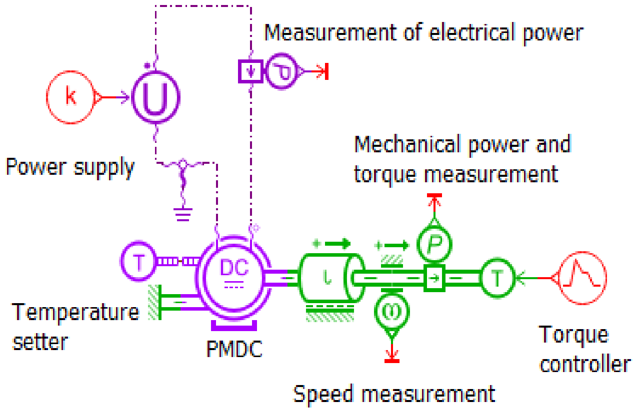

Figure 1. Simulation model of the PMDC motor in Simcenter Amesim

Source: own development based on Simcenter Amesim (2020), *Motors and Drives Library- Users Guide*

Figures 2-4 present comparative analyses of the test results of PMDC motors.

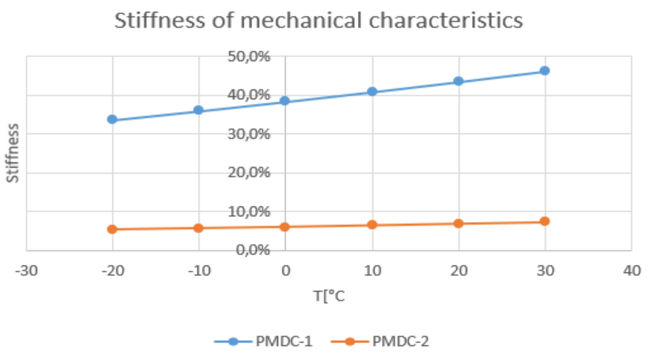

Figure 2. Comparison stiffness mechanical characteristics of PMDC-1 and PMDC-2

Source: own work

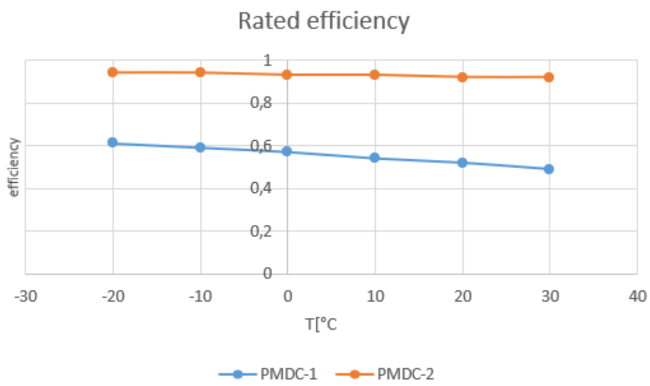

Figure 3. Comparison PMDC-1 and PMDC-2 rated efficiency

Source: own work

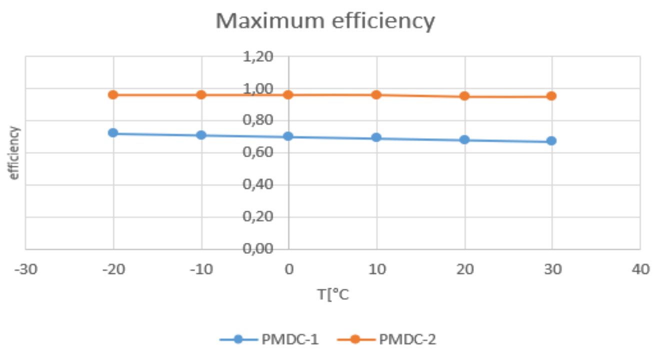

Figure 4. Comparison maximum efficiency of PMDC-1 and PMDC-2 motors

Source: own work

Conclusions from the comparative analysis of the effect of temperature on the operation of PMDC motors.

Stiffness of mechanical characteristics:

– in the PMDC-1 increases with increasing temperature in the range from 33.6% to 46%;
– in the PMDC-2 increases with increasing temperature in the range from 5.3% to 7.2%.

Rated efficiency:

– in the PMDC-1 decreases with increasing temperature in the range from 0.61 to 0.49;
– in the PMDC-2 changes little over the entire temperature range and remains at a level from 0.94 to 0.92.

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Maximum efficiency:

- in the PMDC-1 decreases with increasing temperature in the range from 0.72 to 0.67;
- in the PMDC-2 changes little over the entire temperature range and remains at a level of 0.96 to 0.95.

In the low-power PMDC-1 motor, larger ranges of changes in efficiency and stiffness of the mechanical characteristics occur under the influence of temperature.

Discussion of the results of SWDC electric motor tests

The tests were carried out on a SWDC motor model with the parameters set in Table 1. The measurements and graphs were recorded using mechanical and electrical power, torque and speed sensors (Figure 5).

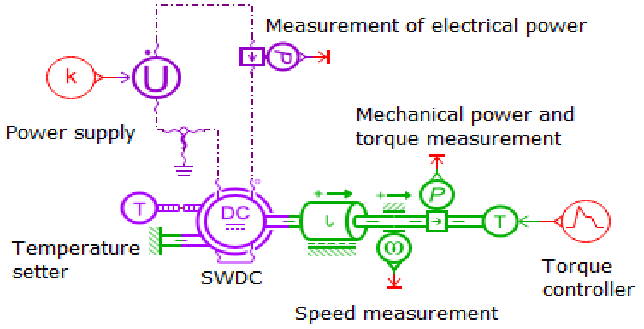

Figure 5. Simulation model of the SWDC motor in Simcenter Amesim

Source: own development based on Simcenter Amesim (2020), *Motors and Drives Library - Users Guide*

Figures 6-8 present comparative analyses of the SWDC motor test results.

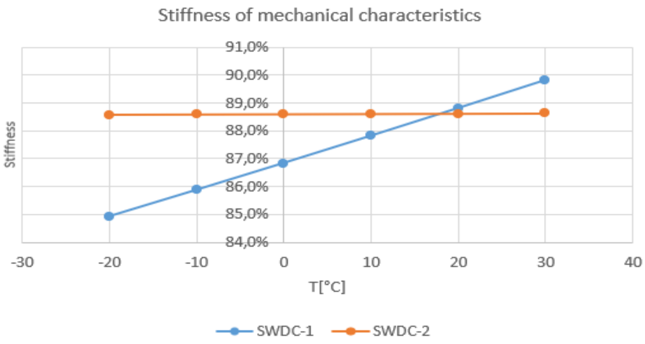

Figure 6. Comparison stiffness of mechanical characteristics of SWDC-1 and SWDC-2

Source: own work

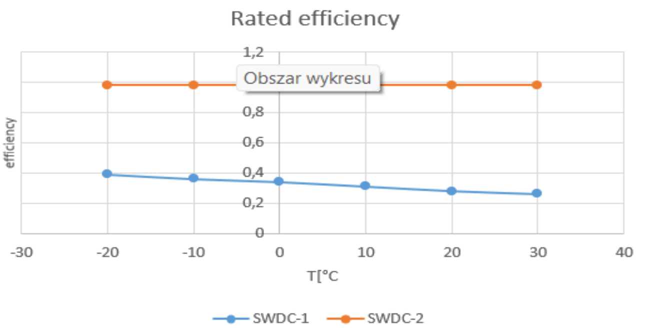

Figure 7. Comparison SWDC-1 and SWDC-2 rated efficiency

Source: own work

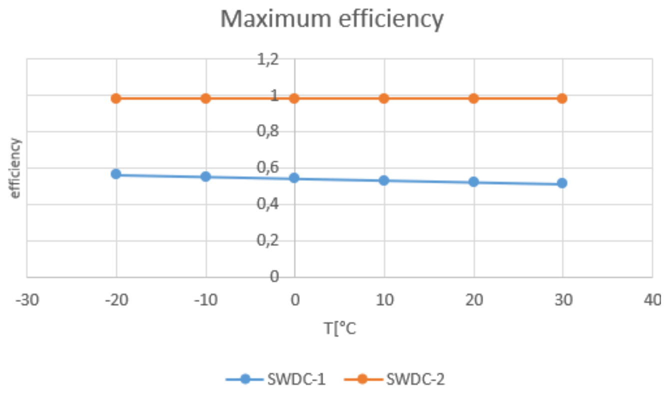

Figure 8. Comparison maximum efficiency of SWDC-1 and SWDC-2

Source: own work

Conclusions from the comparative analysis of the effect of temperature on the operation of SWDC motors.

Stiffness of mechanical characteristics:

- in the SWDC-1 increases with increasing temperature in the range from 84.9% to 89.8%;
- in the SWDC-2 does not change with temperature changes and is 86.6%.

Rated efficiency:

- in the SWDC-1 decreases with increasing temperature in the range from 0.39 to 0.26;
- in the SWDC-2 does not change with temperature changes and is 0.98.

Maximum efficiency:

- in the SWDC-1 decreases with increasing temperature in the range from 0.56 to 0.51;
- in the SWDC-2 does not change with temperature changes and is 0.98.

In the low-power SWDC-1 motor, changes in the analyzed parameters, i.e. efficiency and stiffness of the mechanical characteristic, occur under the influence of temperature. No changes were observed in the higher-power SWDC-2 motor.

Conclusions

Detailed conclusions:

1. PMDC motors

a) Efficiency of the motors, both in nominal operating conditions and maximum, depends on temperature. Increase in temperature causes decrease in engine efficiency. Hypothesis H1 was confirmed.
Greater changes in efficiency with temperature occur in the low-power PMDC-1 motor.

b) Temperature changes affect the parameters of the mechanical characteristics. Temperature changes occur in the idle speed and rated speed of the motors, which increase the stiffness of the mechanical characteristics. Hypothesis H2 was confirmed.
Greater changes in the stiffness of the mechanical characteristics with temperature were observed in the low-power PMDC-1 motor.

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2. SWDC motors

Efficiency of the motor, both in nominal operating conditions and maximum, depends on temperature. Increase in temperature causes decrease in efficiency. Hypothesis H1 was confirmed for low-power SWDC-1 motor.

a) Efficiency of the motor, both in nominal operating conditions and maximum, does not depend on temperature. Temperature increase does not cause efficiency to decrease. Hypothesis H1 was not confirmed for the higher power SWDC-2 motor.
b) Temperature changes affect the parameters of the mechanical characteristics. Temperature changes the idle speed and rated speed of the motors, which increase the stiffness of the mechanical characteristics. Hypothesis H2 was confirmed for the low-power SWDC-1 motor.
c) Temperature changes do not affect the parameters of the mechanical characteristics. It can be assumed that the changes in the idle speed and rated speed of the motors under the influence of temperature are minimal and do not affect the stiffness of the mechanical characteristics. Hypothesis H2 was not confirmed for the higher power SWDC-2 motor.

General conclusions:

1. A significant effect of temperature on the operation of micromotors, both PMDC and SWDC, with a power of several watts, was observed. An increase in temperature causes unfavorable phenomena consisting in a decrease in the energy efficiency of the motors and a decrease in rotational speed, which affects the course of mechanical characteristics (its stiffness changes significantly).
2. No effect of temperature on the operation of the 3 kW SWDC motor was observed. The efficiency of the SWDC motor, both in nominal operating conditions and maximum, is practically independent of temperature. Temperature changes also do not affect the parameters of the mechanical characteristics of the motor.
3. The efficiency of DC micromotors is lower than the efficiency of higher power DC motors of the order of 1-3 kW. The decrease in efficiency is influenced by the higher resistance of the micromotor windings.

However, despite the results obtained, there is a need for further research, especially to determine more detailed aspects of the effect of temperature on different types of electric motors.

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