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# Performance characteristics of the high-speed small power induction motor with core made from different electrical sheets

***Abstract**. The paper presents the performance characteristics of the small power induction motor with core made from different electrical sheets, supplied at 100 and 200 Hz. The calculations were made with the use of circuit models taking into account the nonlinear phenomena and additional core losses. The measured mechanical losses characteristics and the measured for different electrical sheets magnetization and losses density characteristics as a function of a flux density for frequencies up to 2000 Hz were used in the calculations. The computational results have been verified by measurements.*

**Streszczenie.** *W artykule przedstawiono charakterystyki eksploatacyjne silników indukcyjnych małej mocy, o rdzeniach wykonanych z różnych gatunków blachy elektrotechnicznej, pracujących przy zasilaniu napięciem o częstotliwości 100 oraz 200 Hz. Obliczenia zostały wykonane z wykorzystaniem modelu obwodowego, z uwzględnieniem zjawisk nieliniowych oraz strat dodatkowych w rdzeniu silnika. W obliczeniach wykorzystano wyznaczone doświadczalnie charakterystyki strat mechanicznych, a także zmierzone charakterystyki magnesowania stosowanych blach elektrotechnicznych oraz charakterystyki stratności blach w funkcji indukcji magnetycznej wyznaczone dla zakresu częstotliwości do 200Hz. Wyniki obliczeń porównano z wynikami pomiarów. (**Właściwości wysokoobrotowego silnika indukcyjnego z rdzeniem wykonanym z różnych blach elektrotechnicznych**)*

**Keywords:** induction motors, core losses, circuit modelling.
**Słowa kluczowe:** silnik indukcyjny, straty w rdzeniu, modelowanie obwodowe

## Introduction

In the general-purpose induction motors supplied at 50 Hz, under normal operating conditions, losses in the windings of the machine are dominant. According to [3], the average share of losses in the motor windings is estimated about 60 %, basic core losses – about 20 % and mechanical losses – about 7% of the total losses.

The additional losses caused by higher harmonics of the magnetic field and by technological reasons are estimated at about 13% of the total losses. In the high-speed induction motor with increasing frequency voltage these proportions are changed. With increasing frequency, the losses in the core and their share in total losses of the motor become a dominant. Therefore, in order to improve efficiency of the high-speed induction motor, it is appropriate to applied to the motor core the electrical sheets with reduced specific core losses. However, such electrical sheets have a generally worse magnetization characteristic, which affects on the performance characteristics of the motor.

In the paper the performances characteristics of two model small - power induction motors with cores made from different electrical sheets: M600-50A with a thickness of 0.5 mm and NO20 with a thickness of 0.2 mm (produced by Swedish company Cogent Surahammars Bruks AB), supplied at 100 Hz by sinusoidal voltage and supplied from PWM at 100 Hz and 200 Hz, are presented. For a sinusoidal power supply, calculations were made using analytical methods available in the references, with particular determining of the no-load and load additional losses [1, 3, 4, 10,11].

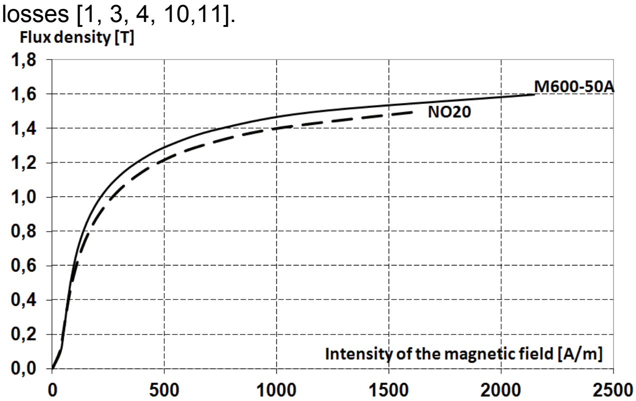



Fig.1. Measured and approximated B/H characteristic for non-oriented silicon steels: M600-50A, and NO20 [9]

The measured magnetization characteristics for both electrical sheets (Fig.1) and measured characteristics of the losses density as a function of a flux density for different values of frequencies (Fig.2 - 4) were used in the calculations [1, 9].

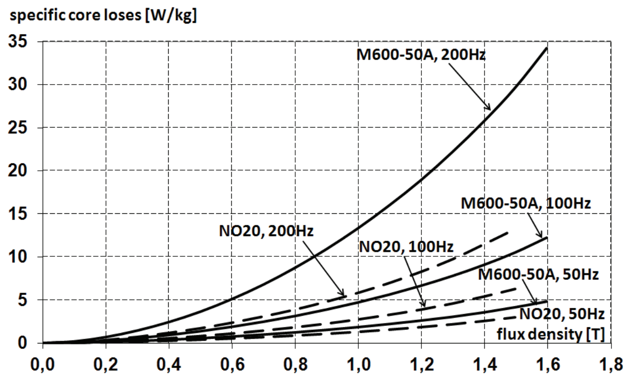



Fig.2. Measured specific core losses as a function of peak magnetic flux density for different values of frequency, for non-oriented silicon steel M600-50A and NO20

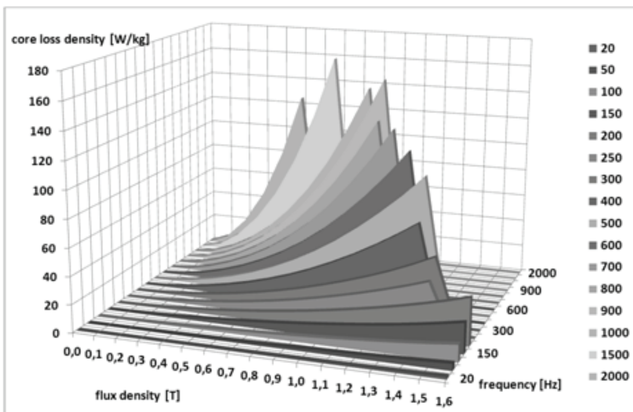



Fig. 3. Measured specific core losses as a function of peak magnetic flux density and frequency for silicon steel M600-50A [1]

The magnetization characteristic of the silicon steel M600-50A is slightly better than the electrical sheet NO20, however, its specific core losses, especially at higher frequencies, is much greater than the specific core losses of the electrical sheet NO20.

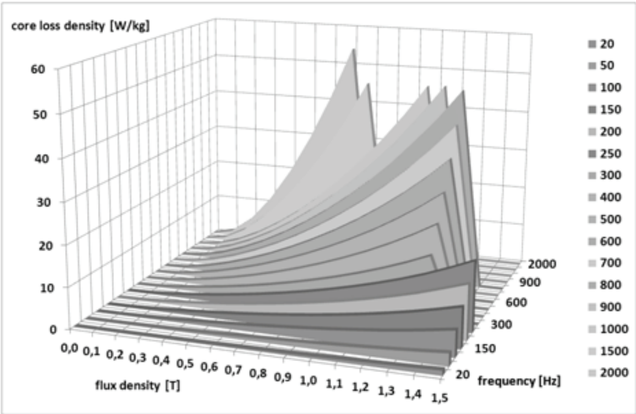



Fig. 4. Measured specific core losses as a function of peak magnetic flux density and frequency for electrical sheet NO20 [1]

### Object of investigation

The two small four-pole energy-saving induction motors with cores made from non-oriented silicon steel M600-50A (motor E) and with cores made from electrical sheets NO20 (motor D) have been examined. For both motors the supply voltage is 400 V at frequency 200 Hz, which – at a constant ratio of voltage over frequency – is equivalent to 200 V at 100 Hz. The stator windings are star connected and the number of turns in series is 156. There are 24 stator slots and 22 rotor slots. The both motors have rotors with closed slots, the same shapes and dimensions of the stator and rotor slots and the same dimensions of the cores.

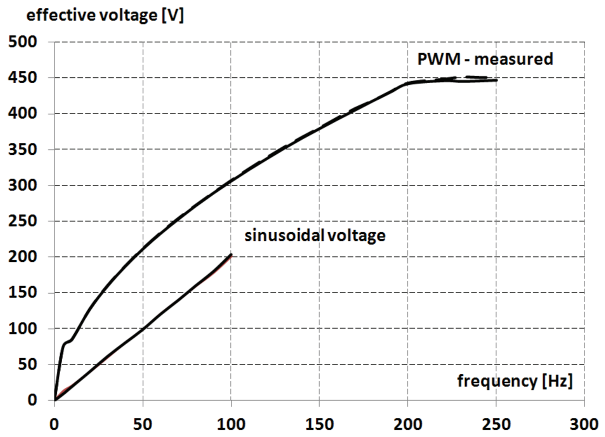



Fig.5. Effective voltage versus frequency for PWM and sinusoidal supply

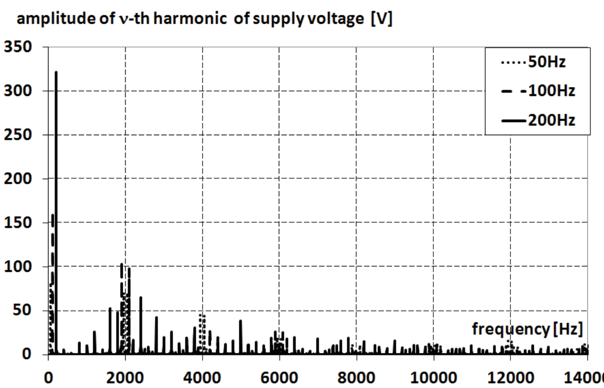



Fig.6 Harmonics amplitude spectrum of the output PWM voltage for different values of effective supply voltage. [1]

The measured mechanical losses characteristics as a function rotor speed of the both motors are given in [1, 4]. Both motors were supplied from PWM at 100 Hz and 200 Hz, and by sinusoidal voltage at 100 Hz. Characteristics of the effective voltage versus frequency for PWM and sinusoidal supply are presented in the Fig.5.

Fig.6 shows harmonics amplitude spectrum of the output PWM voltage for values of effective supply voltage 50, 100 and 200 V.

### No-loading characteristics

For the two tested motors no-load characteristics versus rotor speed in wide frequency range were measured [1, 4, 7]. For the motors supplied by sinusoidal voltage calculations were made with the use of an equivalent circuit model, in which only the first harmonic of the field was taken into account [5, 6, 8]. The higher harmonics of the magnetic field in the air-gap were then considered in the calculation of the additional no-load core loss [1].

The results of these calculations are presented in the Fig.7 and 8.

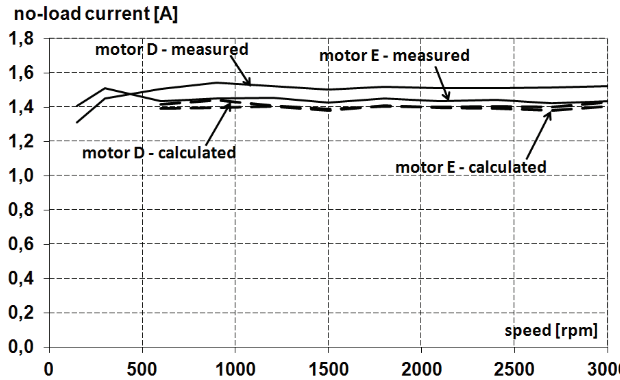



Fig.7. Measured and calculated (with the use of analytical method) no-load current versus rotational speed, for sinusoidal supply at frequency 20 – 100 Hz [1]

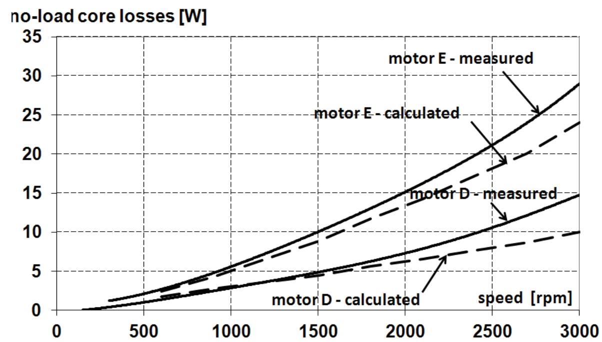



Fig.8. Measured and calculated (with the use of analytical method) no-load core losses versus rotational speed, for sinusoidal supply at frequency 20 – 100 Hz [1]

As can be seen at presented figures the calculated values of the no-load current and no-load core losses are slightly smaller than the values measured. Moreover, the measured and calculated magnetizing current to the motor D is slightly larger than for the motor E, since the core of the motor D is made from electrical steel NO20 with the magnetization characteristic worse than silicon steel M600-50A. Induction motor D has much lower no-load core losses than motor E. For sinusoidal supply at frequency 100 Hz core losses of the motor E are nearly two times higher than core losses of the motor D. The measured no-load current and core losses characteristics versus rotor speed for the motors supplied from PWM are shown in the Fig. 9-10.

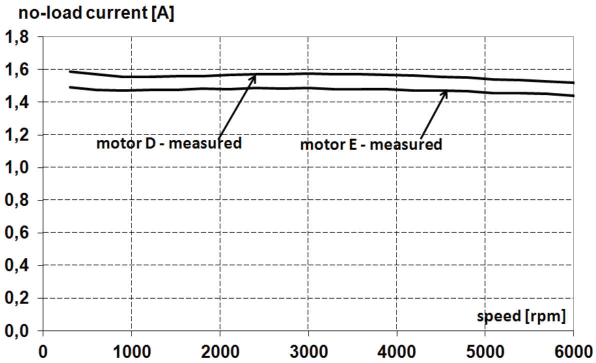



Fig.9. Measured no-load current versus rotational speed, for PWM supply at frequency 20 – 200 Hz

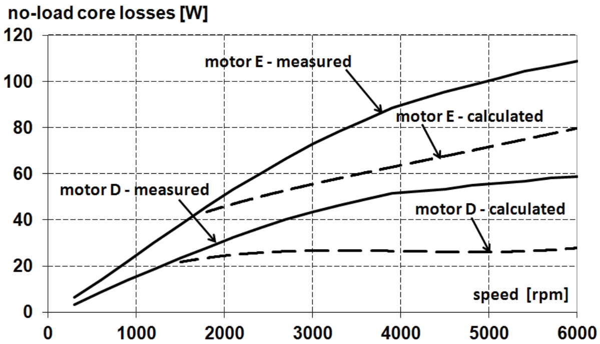



Fig.10. Measured and calculated with the use of circuit model no-load core losses versus rotational speed, for PWM supply at frequency 20 – 200 Hz

Presented in Fig.10 the results of the calculation were made with the use of circuit model for the sinusoidal supply of the motors for the effective value of the supply voltage designated for the real voltage generated by the inverter. Calculated in this way, the core losses are much smaller than the measured, and the discrepancies of results depend on the participation of higher harmonics in the curves of the voltage generated by PWM. The accurate results can only be obtained using the field-circuit model taking into account the real voltage generated by PWM.

Using the circuit model to determine of the core losses in the motor supplied from PWM would be calculate a loss for the dominant voltage harmonics, obtained in result of the distribution of the PWM output voltage on a Fourier series and sum the core losses obtained for each harmonic.

## The load characteristics

Figure 11 shows the measured and calculated with the use of circuit model characteristics of efficiency for both motors versus output power, for sinusoidal supply at frequency 100 Hz.

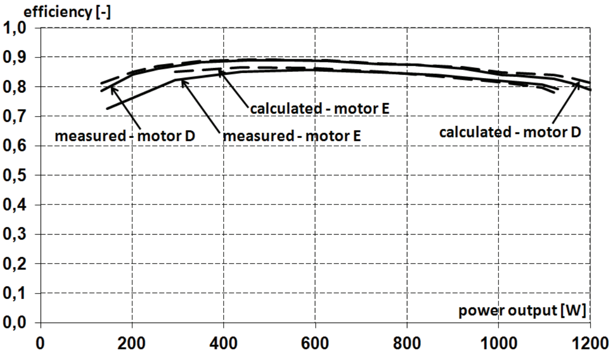



Fig.11. The measured and calculated with the use of circuit model characteristics of efficiency for both motor versus output power, for sinusoidal supply at frequency 100 Hz.

The calculations were made for the temperature of the stator windings 115 °C, and of the rotor windings 140 °C. For more precise results, calculation should take into account the change in temperature of the motor windings for the different measuring points. The other measured and calculated load characteristics for both induction motors for the sinusoidal supply at frequency 100 Hz are presented in [2, 7].

Based on the characteristics shown in Figure 11 can be concluded that the use of electrical steel NO20 for the core of the motor supplied by sinusoidal voltage at 100 Hz gives increase of efficiency of about 5% in relation to the efficiency of the motor with a core made from silicon steel M600-50A.

Figure 12 shows the comparison of measured and calculated with the use of circuit model characteristics of efficiency and total losses for both motors supplied from PWM of rated voltage at frequency 200Hz .

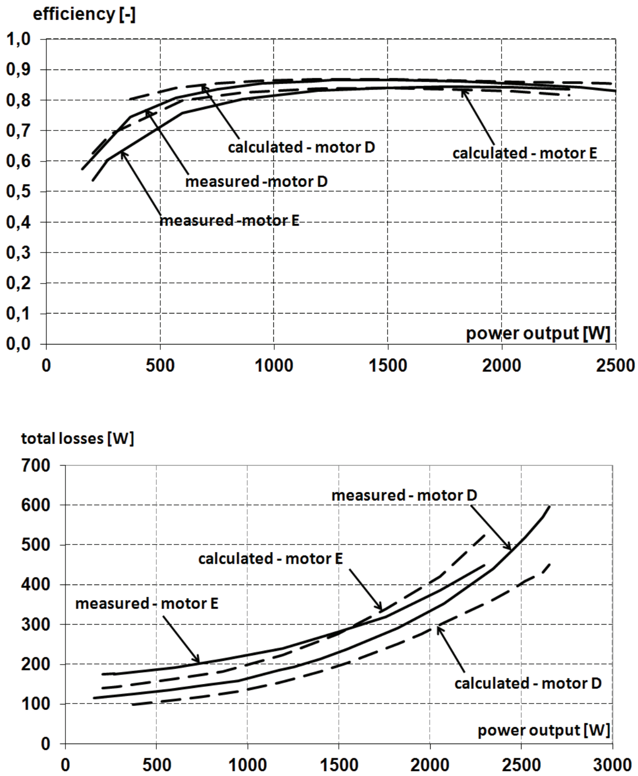
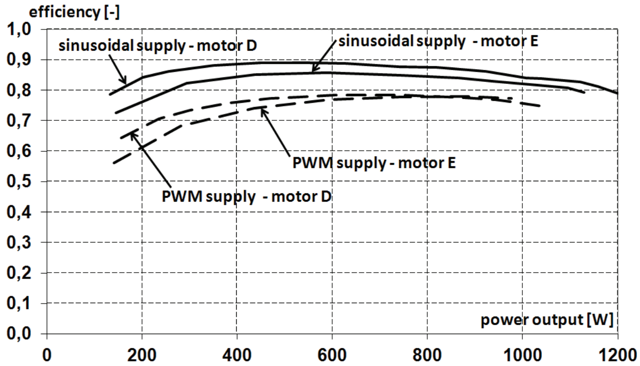



Fig. 12 Measured and calculated with the use of circuit model efficiency and total losses versus output power for PWM supply of rated voltage at frequency 200Hz.

As shown in Figure 12, applied in the motor D the electrical sheet NO20, already at a frequency of 200 Hz gives increase efficiency in relation to the engine E, despite that the core losses in the motor D is in the case of the order of 15% of the total losses. These proportions can change as well as design of the motor, to increase the use of magnetic core and at the same time reduce the use of the windings and losses in the windings.

In the Fig. 13 the measured characteristics of efficiency and total losses for both motor versus output power, for sinusoidal and PWM supply at frequency 100 Hz are presented.

On the basis of the presented characteristics can be state that for the motor supply from PWM can be observed significant increase of the total loss and decrease of efficiency, in comparison to the sinusoidal supply of the motor.



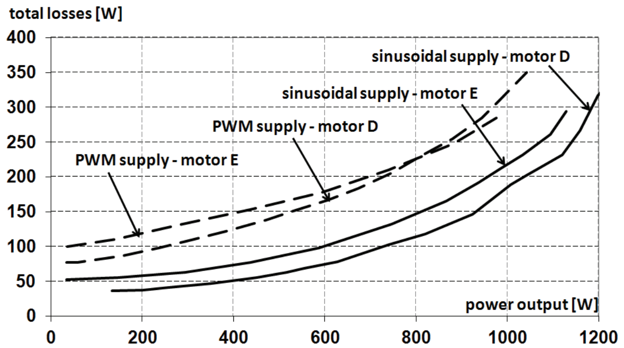




Fig.13. The measured characteristics of efficiency for both motor versus output power, for sinusoidal and PWM supply at frequency 100 Hz.

**Conclusion**

The paper presented the influence of the electrical sheets properties, using for stator core material, on the performances characteristics for small power induction motor supplied by sinusoidal and PWM voltage with frequency of 100 and 200 Hz. Increasing the frequency of the supply voltage, especially with the use of PWM inverters causes an increase in losses in the machine core.

Achieving high efficiency therefore requires the use of magnetic materials with improved properties, especially smaller specific losses. Significantly less specific losses than conventional electrical steel are characterized by amorphous material, but they are definitely worse magnetization curve, which necessitates increasing the dimensions of the engine. An important limitation of the use of amorphous metal is also the lack of efficient technology of production cores with amorphous materials.

For this reason, the paper presents the effects of the application of induction motor core made from electrical sheets NO20 0.2 mm thick. With lower specific losses, this sheet allows for a better performance than using a sheet of 0.5 mm, without creating technological problems.

Calculation of motor parameters was performed using a circuit method modified accordingly for the supply from inverter.

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