EXAMINATION OF HEAT TRANSFER CONDITIONS OF FINNED MOTOR CASE FOR SHELL-HEATED MOTORS

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Research works are performed in connection with the computation and measurement of the heating of electric motors at the Department of Electric Machines, Technical University of Budapest, directed by Dr. Gyula Istvánfy. The examination of the heat transfer conditions of finned motor case is part of these works.

The net-like computation method of heat flow is widely used in the complex computations of heating of electric machines. The continuously distributed parameters are replaced by concentrated ones for the computations. For this purpose the machine under examination is divided into thermally discrete parts [1], [4]. The parts are connected to each other and to the environment via thermal resistances. In the computations it is necessary to know and to analyse in detail the heat transfer relations of the machine parts. The present article deals with the heat transfer conditions of the heat transfer surface — the finned motor case — of motors of protection type IP 44 (closed, shell-heated, without inner circulation).

The heat transfer resistance of the finned case:

$$R=\frac{1}{Y}=\frac{1}{\alpha A}, \tag{1}$$

where α is the heat transfer coefficent and A is the heat transfer surface. For the complicated surface geometry and for the flow in the environment of the surface, the heat transfer coefficent can only be evaluated reliably by measurements [5].

1. Measurement determination of the heat transfer coefficient

The aim of the examination of the heat transfer relations is to improve the computation of the rising motor temperature. The results being applied in the net heating computations of heat flow, the determination of the average heat transfer coefficient is emphasized. The average heat transfer coefficient — α_K — can be determined either by direct model measurements or by averaging the measured local α values.

1.1. *The measurement of the average heat transfer coefficient*

The model applied in average heat transfer coefficient measurement is a motor case without stator core, divided into 3 parts (Fig. 1). There are electric heaters built in on the inner casing of the motor case parts and on the inner surface of the badge plates, providing homogeneous heat transfer. The single parts are separated by heat insulation. The cooling conditions of the model driven by a variable-speed drive motor are just like motors working in real conditions.

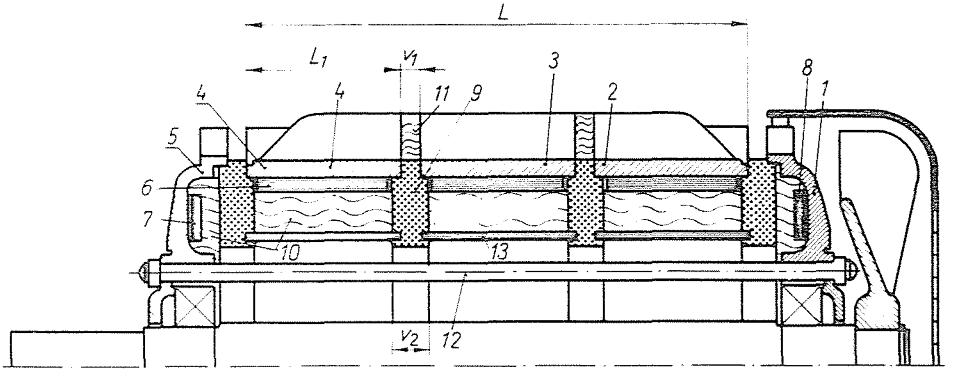

Fig. 1. The structure of the motor case model. 1. Shield on the fan side; 2., 3., 4. Parts of stator case; 5. Shield on the driving side; 6. Case heaters; 7. Heater on the driving side shield; 8. Heater on the fan side shield; 9. Bonamide disk; 10. Glass wool heat insulation; 11. Wooden fin insulation; 12. Steel clamping bar; 13. Pabite bar

Because of the heat insulations, the heat flow between the case parts and to the shaft can be neglected. The heat output of the electrical heaters is transmitted uniformly in the inner casing of the case parts.

The heat conduction of the case parts can be determined from the heat output and the temperature difference:

$$Y = \frac{P}{\Delta\vartheta} = \frac{P}{\vartheta_f - \vartheta_0} \quad \left[\frac{\mathrm{W}}{\mathrm{K}}\right] \tag{2}$$

where P is the heating output of a case part, kept at a constant value [W];
ϑ_f the average surface temperature [K];
ϑ_0 the average temperature of the cooling material [K];
Y the heat conduction of the case part [W/K].
From (1) and (2):

$$\alpha = \frac{P}{A(\vartheta_f - \vartheta_0)} \quad \left[\frac{\mathrm{W}}{\mathrm{m^2K}}\right] \tag{3}$$

The surface temperatures of the case parts were measured with calibrated copper-constantan thermocouples. There was one measuring hole formed in every interfin-space in the medium plane of each case part. The average surface temperature is the average of temperatures measured along the circumference of a case part.

Measuring results

Two models have been made for model cases type VZ 112. One of them was a foot-type and the other a flange-type model. Surface temperatures were measured at points indicated by serial numbers in Fig. 2. The temperature fields obtained on the foot-type motor at 24.16 rotations per sec [1/s] are shown in Fig. 3 for the three case parts projected into plane. The serial numbers of the measuring points are shown above the curves in the figure.

The average temperature of the case parts increases with increasing distance from the fan.

Case part No. 2 near the fan exhibits the most uniform temperature distribution.

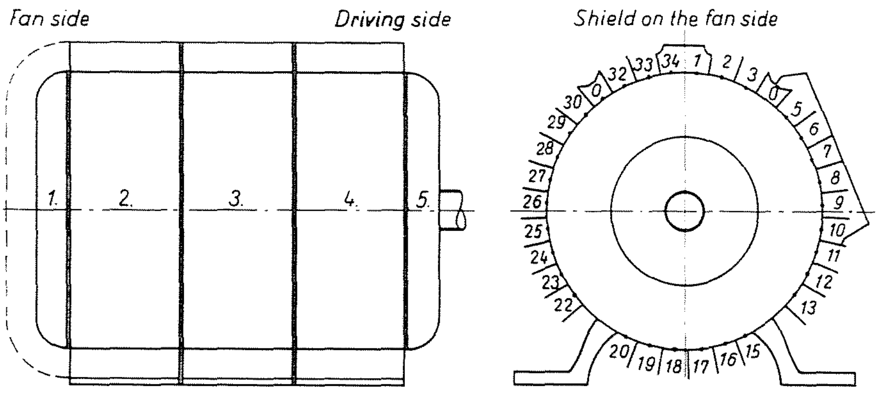

Fig. 2. The loci of thermometry on the motor case

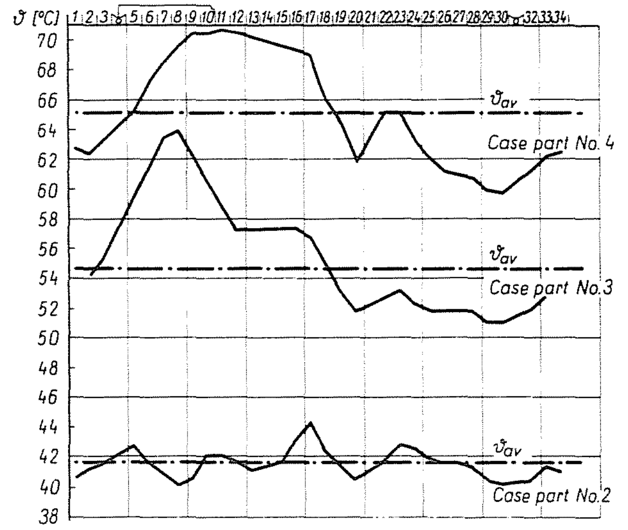

Fig. 3. The temperature field along the circumference of the motor case

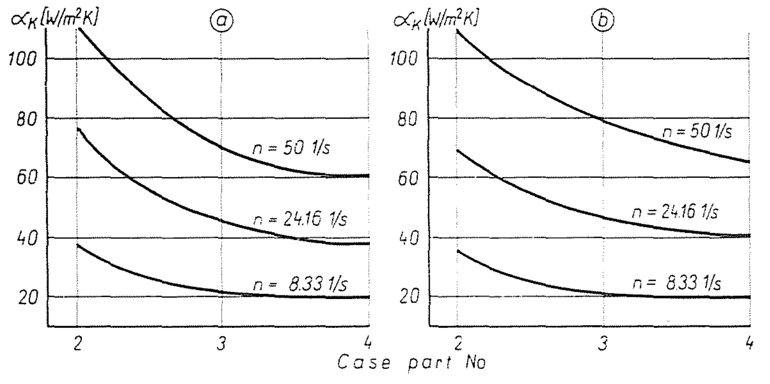

Fig. 4. The average heat transfer coefficient. a. foot-type motor case model; b. flange-type motor case model

The difference between temperatures of the warmest and the coldest points of case parts No. 4 and 3 is significantly greater than for the case part No. 2, mainly due to the disturbance by the terminal board on case part No. 3.

The average heat transfer coefficient was computed using the heat transfer area, determined from the geometrical sizes, and the weighted average of the temperatures, measured in one case part. The results obtained are shown in Fig. 4 for two models of motor cases with three different revolution numbers. The change of α_K with the speed is the same kind for both types, the heat transfer coefficient tends to decrease with decreasing speed.

Comparing the results obtained for the motor case models of foot-type VZ and flange-type VZP, it can be stated, that the uniform finned circumference of the flange-type VZP is subject to less of disturbances affecting the development of the heat transfer coefficient. The heat transfer coefficient along the length is slower changing in the case of the VZP than the VZ type. The α_K in the central case part and in the case part opposite to the fan are higher the flange-type motor than for the foot type-motor, attributed to the better air flow conditions in the flange-type one.

1.2. *Measurement of the local heat transfer coefficient*

The measurement of the local heat transfer coefficient permits to examine the motor case in details and to map the α-distribution along the surface. The local heat transfer coefficient can be measured by means of instruments equipped with impulse-type sensors [2], or double bridge measuring equipment working with heated measuring tag [3].

The presented results were obtained by impulse-type sensor.

For rotating machines the heat transfer coefficients of the two fins forming an interfin space are different. The interfin space consists of fin sides windward and leeward according to the rotation direction of the fan. The local α values measured on the model of a foot-type motor case, both sides of the interfin spaces in the medium plane of the central case part are shown in Fig. 5. The difference of the α values measured in the sides of the interfin space varies along the length of the case. The difference decreases with increasing distance from the fan. On the 3rd part opposite to the fan the two sided do not differ from this aspect.

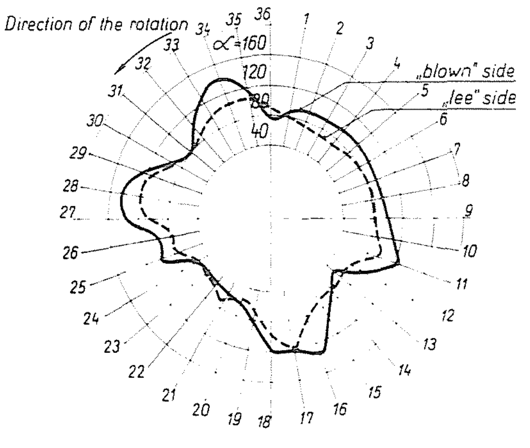

Fig. 5. The peripheral α distribution in the medium plane of the motor case model

It can be explained with the multiple impacts, reflections and eddy equalizations taking place while the cooling air passes in the interfin space.

The average heat transfer coefficient α_{iK} characteristic to the single case parts can be determined from the local measurements using the integrated mean value computations.

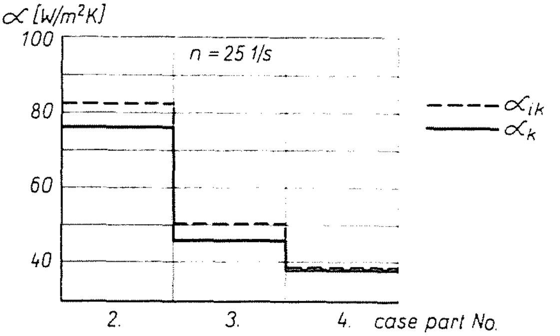

Fig. 6. Average heat transfer coefficient: α_K from direct measurement; α_{iK} from local measurement

The α_{iK} for the three case parts computed from the local measurements, and α_K obtained by average heat transfer coefficient measurement are seen superimposed in Fig. 6. The results correspond to the foot-type motor case model at speed 25 [1/sec].

2. Variation of the heat transfer properties of the motor case as a function of the fin parameters

Examining the heat transfer properties of the motor case, both the heat transfer and heat conductivity properties of the fin are to be taken into consideration. The model of the fin consists of two nodes and thermal resistances (Fig. 7). The tangential and the radial thermal resistances R_2 and R_1, R_3 respectively, can be computed, using symbols in Fig. 7, as follows:

$$R_1 = \frac{V_h/2}{\lambda_v bh}; \quad R_2 = \frac{l/2}{\lambda_v V_h h}; \quad R_3 = \frac{V_h/2}{\lambda_v b_K h} \tag{4}$$

The thermal resistance of the interfin space:

$$R_{bk} = \frac{1}{\alpha_K h b_K} \tag{5}$$

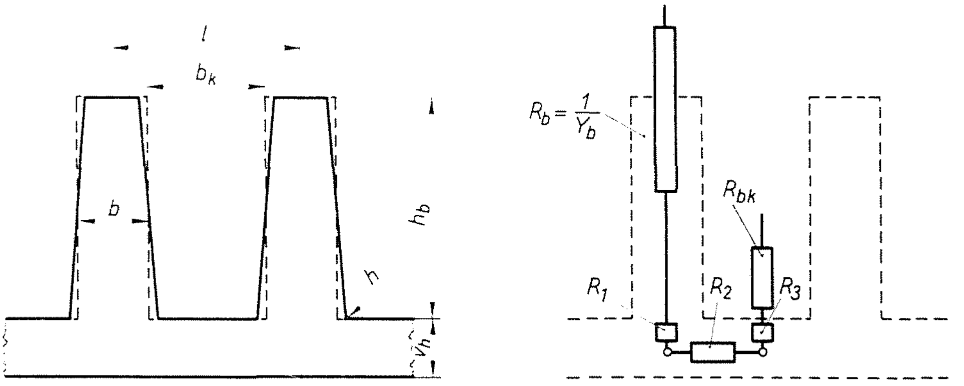

Fig. 7. Fin of the motor case a. symbols; b. representative model

The heat conduction of the fin can be computed taking the continuous heat distribution along the fin into consideration:

$$Y_b = \frac{1}{\rho h_b} th(\rho h_b) \cdot Y_{bp} \tag{6}$$

where

$$\rho = \sqrt{\frac{2\alpha_K}{\lambda_v b}}; \qquad Y_{bp} = \alpha_K 2 h_b h$$

The formula (6) includes the heat conduction of the fin casing and the finite heat conduction of the iron stuff of the fin.

In these formulae:

α_K heat transfer coefficient along the surface of the fin and of the case in contact with the air, regarded to be constant (average value);

λ_v heat conductivity of the iron;

b average width of the fin;

h_b height of the fin;

Y_{bp} heat conductivity of the fin casing.

The heat resistance R_2 is negligible compared to the heat conduction and heat transfer of the fin. Thus the resultant heat conduction from the node in the middle of the fin spacing to the environment:

$$Y = \frac{1}{R_1 + \frac{1}{Y_b}} + \frac{1}{R_3 + R_{bk}} \tag{7}$$

The resultant heat conduction of the full case part having a number Z of fins is:

$$Y_e = ZY \tag{8}$$

In the computations the variation of three characteristic dimensions such as height, width and number of fins were examined. To make the results comparable, the computations always referred to the same tangential dimension. The fin spacing derives dividing the given circumference dimension by the number of fins on it, this way the fin spacing and the number of fins correspond to each other. In the diagram presenting the computational results the dependent variable is the resultant heat transfer of the finned case part, the independent variable is one of the fin characteristics. An additional fin characteristic is used as parameter. (The use of more variables would make the results confused.)

In the examination of a single variable the other characteristics were set to mean value.

Length of the motor case	$L = 100$ mm
Circumference of the motor case	$K = 200$ mm
Mean heat transfer coefficient	$\alpha_K = 100$ W/m²K
Thickness of case	$V_h =$ 10 mm
Number of fins	$Z = 5$, *10*, 15
Height of fin	$h_b = 10 \ldots 50, \ldots 100$ mm
Width of fin	$b = 2, \ldots 6, \ldots 10$ mm

Rather than relative units, fin values approximating dimensions of fins in the practical ones have been assumed in the computations.

The bearing between the motor case and the stator iron core was assumed as 100%, thus the resultant heat conduction is Z-fold of a single fin (7), where Z means the number of circumferential fins.

The computation results have been plotted in Figs 8, 9, 10.

The fin width corresponding to a given fin height is the numerical value at the maxima of the curves in Fig. 8. The heat transfer efficiency of the fins decreases with increasing height. In Fig. 9 the fin height is the independent variable and the number of fins is the parameter.

Increasing the fin height the heat conduction increases significantly in the beginning, later negligibly.

The computations assumed a mean heat transfer coefficient even if the variation of the fin height was examined. Actually the value of the heat transfer coefficient varies with increasing fin height. Hence the results obtained are suitable only to qualitative analysis, to optimalize the fin dimensions, the variations of the characteristics regarded here as constant, are to be taken into consideration.

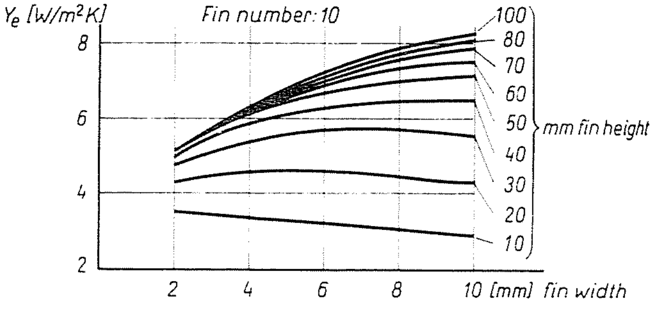

Fig. 8. Resultant heat conduction *vs.* fin width

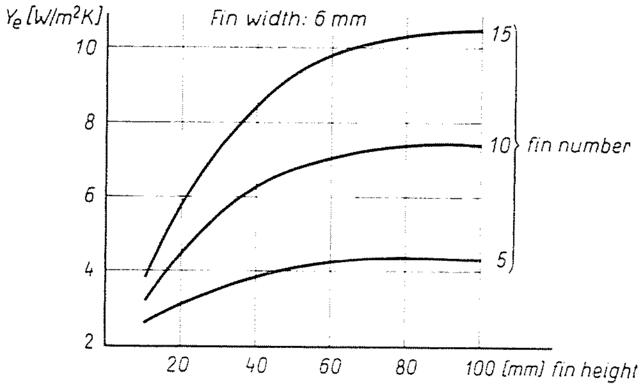

Fig. 9. Resultant heat conduction *vs.* fin height

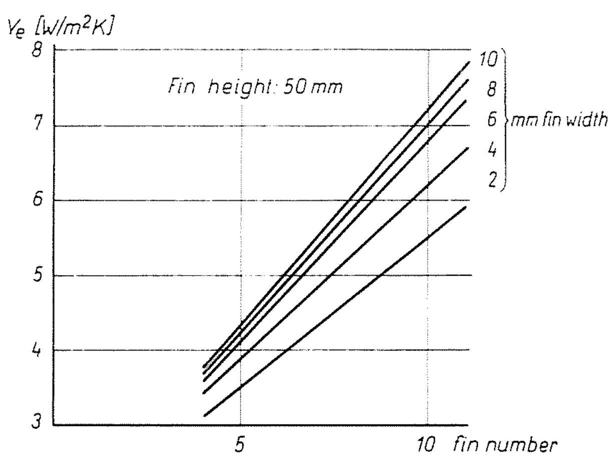

Fig. 10. Resultant heat conduction *vs.* fin number

The presented computing method is suitable for further analysis.

Extending the thermal model to several fins, the variation of the tangential bearing can be taken into consideration.

The examination of the variation of the characteristics regarded here as constant, permits to determine the optimum fin size for heat transfer for a given fan characteristic.

Summary

The basic relationships of a computing method of heat flow are presented. A method is described for measuring the heat transfer coefficient necessary for the computations. An approximate computing method is suggested for determining the optimum fin size for shell-heated motors.

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