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COMPARISON OF METHODS FOR SOLVING THE HEAT TRANSFER IN ELECTRICAL MACHINES

This paper describes the use of modern computational methods for the verification of mathematical equations, to determine the total heat flow transmitted across a certain surface. ANSYS WORKBENCH is choosen as the computational software for this purpose. Calculations are presented for four models. There is a surface, which the total heat flow is transmitted through is considered as: a simple flat plate, comprising with other flat plate, and thin-walled and thick-walled tube. For each case, the total heat flow is calculated using numerical methods and modern computer methods (ANSYS WORBENCH). Performed results of numerical methods are compared with the results of ANSYS software. The numerical methods are considered as a referent. The error of ANSYS calculations in comparison with the the numerical is calculated. The heat transfer by conduction is described for all presented models. Finally, the results of temperature distribution and heat flux distribution for each simulated case are presented.

1. INTRODUCTION

1.1. Simple flat plate

For the numerical solution we have to use Fourier's laws. Fourier's law is an empirical law based on observation. It states that the rate of heat flow dQ/dt, through a homo-geneous solid is directly proportional to the area A, of the section at right angles to the direction of heat flow, and to the temperature difference along the path of heat flow, *dT/dx* i.e. [1].

For simple flat plate applies equation

$$Q_S = \frac{\lambda}{x}(T_1 - T_2)A \tag{1}$$

where Q_s is numerical solution total heat flow transmitted across a certain surface [J], λ is thermal conductivity [W/m.K], x is wall thickness [m], T_1 is temperature of hot wall [K], T_2 is temperature of cold wall [K] and A is heat flow area [m^2] [3].

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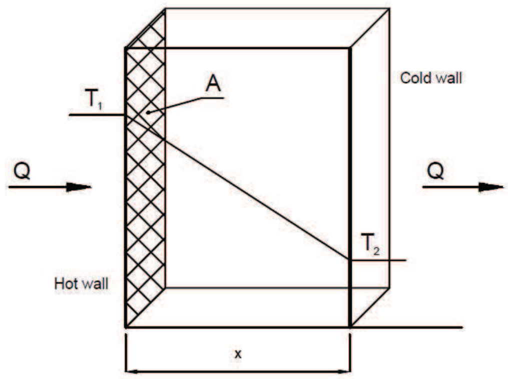

Fig. 1. Case of simply flat plate [2]

1.2. Flat plate comprising with other flat plate

In this case we combined two materials (steel and cuprum) with different thickness.

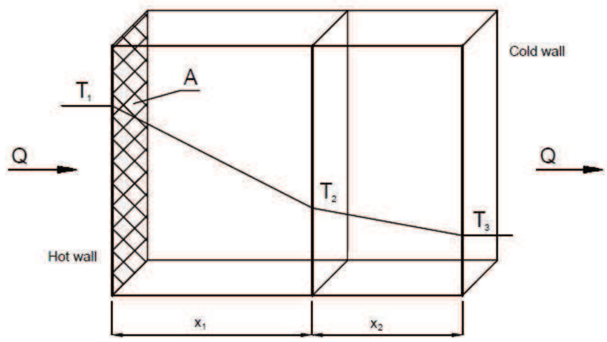

Fig. 2. Case of flat plate comprising with other flat plate [2]

For this case applies equation

$$Q_S = \frac{(T_1 - T_3)}{\frac{x_1}{\lambda_1} + \frac{x_2}{\lambda_2}} A \tag{2}$$

1.3. Thin-walled and thick-walled tube

In this case is important ratio between the radius r_1 and radius r_2. When is this ratio lower than 1.5 (r_1/r_2<1.5) is it thin-walled tube and applies this equation [3]

$$Q_S = \pi \frac{r_1 + r_2}{r_2 - r_1} \lambda . L (T_1 - T_2) \quad (3)$$

where L is length of tube [m].

When is this ratio upper than 1.5 ($r_1/r_2 > 1.5$) is it thick-walled tube and applies this equation [3]

$$Q_S = \frac{2\pi . \lambda . L}{\ln \frac{r_2}{r_1}} (T_1 - T_2) \quad (4)$$

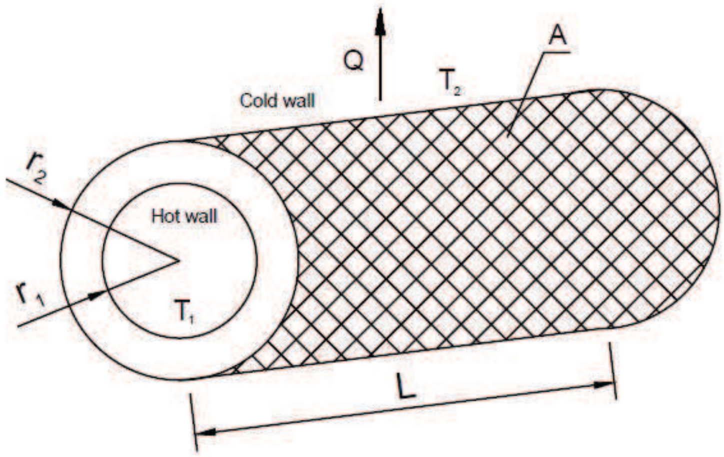

Fig. 3. Case of thin-walled and thick-walled tube [2]

2. CALCULATION PARAMETERS

Each calculation of the numerical and computer solution have set hot wall on value 293.15 K and cold wall on value 263.15 K. Used material in case of Simple flat plate, thin-walled and thick-walled tube is steel with thermal conduction 60.5 W/m.K and in case of flat plate comprising with other flat plate is steel as first material with the same parameters as first case and cuprum as second material with thermal conduction 400 W/m.K.

Thin-walled and thick-walled tube is solved as decomposed simple flat plate.

Simple flat plate, flat plate comprising with other flat plate, thin-walled and thick-walled tube of results is divided into three parts. First (a) is change thickness steel plate in case of simple flat plate and flat plate comprise with other flat plate from 0.1 to 1 m. In case of thin-walled tube we change thickness from 0.05 to 0.3. And in case of thick-walled tube from 0.75 to 1.9 m. Second part (b) is change temperature *T1* from 283.15 to 203.15 K for each model. And third part (c) is change temperature *T2* from 273.15 to 253.15 K for each model.

3. RESULTS

3.1. Simple flat plate

Table 3.1. Simple flat plate, (a) change thickness steel plate, (b) change temperature T_1 and (c) change temperature T_2

Numerical solution	Ansys	Error	Numerical solution	Ansys	Error	Numerical solution	Ansys	Error
Qs [J]	Qfem [J]	[%]	Qs [J]	Qfem [J]	[%]	Qs [J]	Qfem [J]	[%]
a			b			c		
228690,00	228690,00	0,00	50820,00	50820,00	0,00	50820,00	50820,00	0,00
114345,00	114345,00	0,00	63525,00	63525,00	0,00	63525,00	63525,00	0,00
76230,00	76230,00	0,00	76230,00	76230,00	0,00	76230,00	76230,00	0,00
70366,15	70366,15	0,00	88935,00	88935,00	0,00	88935,00	88935,00	0,00
41580,00	41580,00	0,00	101640,00	101640,00	0,00	101640,00	101640,00	0,00
29508,39	29508,39	0,00						
22869,00	22869,00	0,00						

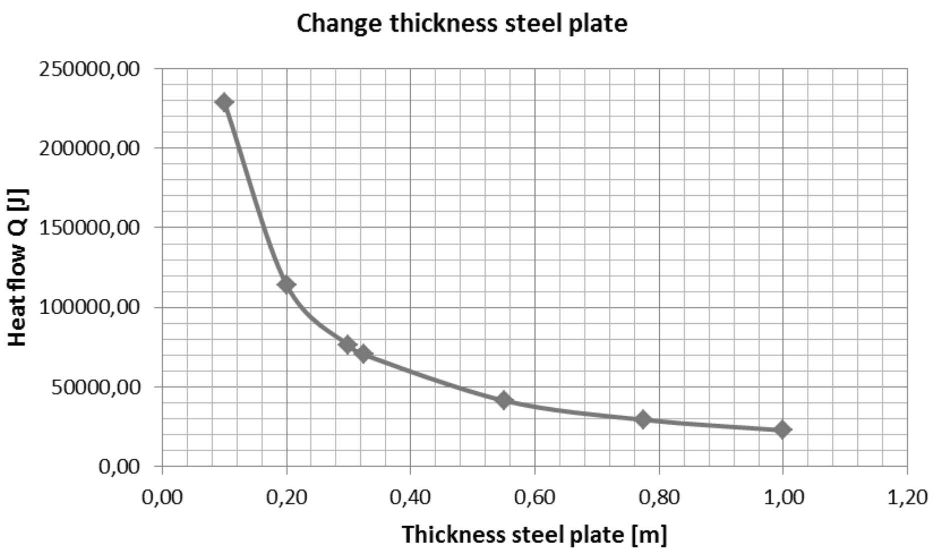

Fig. 4. Change thickness steel plate for simply flat plate

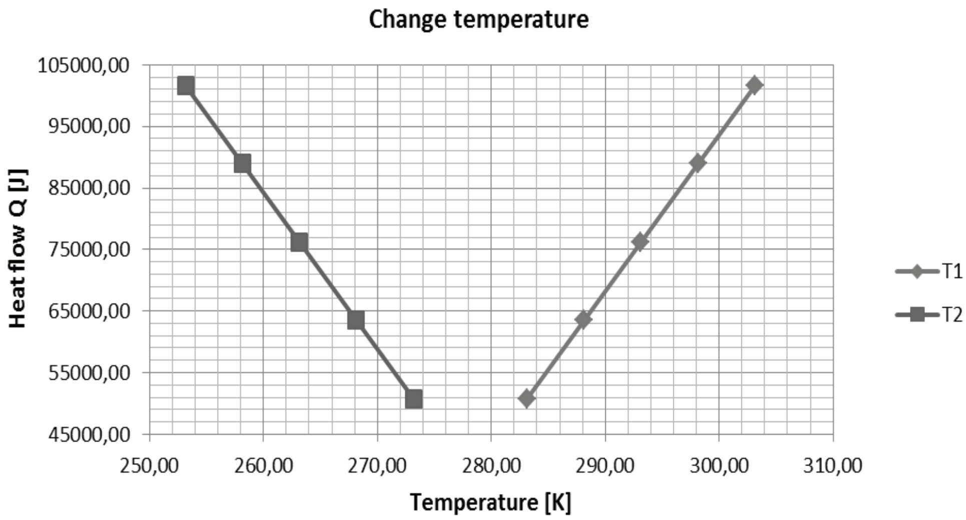

Fig. 5. Change temperature T_1 and T_2 for simply flat plate

3.2. Flat plate comprising with other flat plate

Table 3.2. Flat plate comprising with other flat plate, (a) change thickness steel plate, (b) change temperature T_1 and (c) change temperature T_2

Numerical solution	Ansys	Error	Numerical solution	Ansys	Error	Numerical solution	Ansys	Error
Qs [J]	Qfem [J]	[%]	Qs [J]	Qfem [J]	[%]	Qs [J]	Qfem [J]	[%]
a			b			c		
130214,95	130155,16	0,05	40588,35	40579,60	0,02	40588,35	40579,60	0,02
82971,43	82947,06	0,03	50735,44	50724,49	0,02	50735,44	50724,49	0,02
60882,53	60869,34	0,02	60882,53	60869,39	0,02	60882,53	60869,39	0,02
57083,31	57071,75	0,02	71029,62	71014,29	0,02	71029,62	71014,29	0,02
36553,85	36549,07	0,01	81176,71	81159,19	0,02	81176,71	81159,19	0,02
26884,94	26882,33	0,01						
21261,13	21259,48	0,01						

3.3. Thin-walled tube

Table 3.3. Thin-walled tube, (a) change thickness steel plate, (b) change temperature T_1 and (c) change temperature T_2

Numerical solution	Ansys	Error	Numerical solution	Ansys	Error	Numerical solution	Ansys	Error
Qs [J]	Qfem [J]	[%]	Qs [J]	Qfem [J]	[%]	Qs [J]	Qfem [J]	[%]
a			b			c		
161474,50	163660,41	-1,35	170973,00	172860,77	-1,10	170973,00	172860,77	-1,10
199468,50	202107,47	-1,32	213716,25	216074,55	-1,10	213716,25	216074,55	-1,10
256459,50	259291,15	-1,10	256459,50	259291,15	-1,10	256459,50	259291,15	-1,10
351444,50	351037,87	0,12	299202,75	302502,11	-1,10	299202,75	302502,11	-1,10
541414,50	543338,54	-0,36	341946,00	345732,84	-1,11	341946,00	345732,84	-1,11
1111324,50	1112993,02	-0,15						

3.4. Thick-walled tube

Table 3.4. Thick-walled tube, (a) change thickness steel plate, (b) change temperature T_1 and (c) change temperature T_2

Numerical solution	Ansys	Error	Numerical solution	Ansys	Error	Numerical solution	Ansys	Error
Qs [J]	Qfem [J]	[%]	Qs [J]	Qfem [J]	[%]	Qs [J]	Qfem [J]	[%]
a			b			c		
19024,06	18819,90	1,07	27406,88	26843,86	2,05	27406,88	26843,86	2,05
27406,88	27036,03	1,35	34258,60	33554,67	2,05	34258,60	33554,67	2,05
41110,32	40265,48	2,06	41110,32	40265,48	2,06	41110,32	40265,48	2,06
58104,91	56165,18	3,34	47962,04	46976,28	2,06	47962,04	46976,28	2,06
82220,63	80848,72	1,67	54813,76	53687,09	2,06	54813,76	53687,09	2,06
121256,51	118811,32	2,02						

4. CONCLUSION

When changing thickness of the material in case is obtained simple flat plate difference between the values calculated using the numerical method and ANSYS Workbench 0% (in fact, this difference is about 1x10-6%). In the second case for flat plate comprising with other flat plate is obtained the difference between the values calculated using the numerical method and ANSYS Workbench maximum 0.05%. In this case we can see the effect of two materials with different thermal conductivities. In the third case for thin-walled tube is the difference maximum -1.32%. And in the last case for Thick-walled tube maximum error was 3.34%. All results show that with increasing thickness of the material decreases nonlinearly heat flow.

When changing temperature T_1 or T_2 we can see linear change in heat flow with temperature.

All errors between the numerical solution and the computer came out small, so we can say that ANSYS Workbench is a suitable solution to these problems.

ACKNOWLEDGEMENTS

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