BASIC RESEARCH OF THERMAL TRANSFER SIMULATIONS

Vaclav MAREK[1]

[1] MSc., junior researcher, Regional Technological Institute, University of West Bohemia, Pilsen, Czech Republic

Abstract: *The article summarizes basic research into thermal transfer simulations. Problems of thermal influence in mechanical systems are solved there. The first steps focus on matching simple heat-transfer samples with CAE software. Simple cases are performed in a real environment. Thermal values are measured. Cases are also solved using CAE software tools. Solutions are compared. CAE solutions are matched to real values. CAE results are verified or refuted. There are many differences between the options in the solvers, there are steady states and transient-run possibilities, etc. Software tools like Nastran, etc. need many coefficients to solve the problem. This procedure is able to identify specific conditions, fits the solver to the specific sample and performs CAE simulations to get real, verified results. For example, passive radiators heated by an induction heater are used for real tests. Temperature fields are measured by thermal camera and structural deformations by measuring displacement. These values are used in simulations and solved by finite elements method. Simulations are performed in Siemens NX10 software, supported by solvers Nastran, MAYA, and NX Multiphysics. Results are compared and matched in the simulation to acquire a more precise solution in the following steps All these steps are processed to get characteristics of thermal transfer simulation which will be useful in difficult examples of simulation machines, machine tools etc.*

Key words: *heat load, thermal flow simulation, finite element method, convection, conduction.*

1. VERIFICATION OF THERMAL LOAD

A simple simulation of the heat load was performed in the first part of the research. A small iron cylinder was heated by a high frequency induction heater. The cylinder was heated from 25°C to nearly 250°C as one can see on Fig.1. The heat load was turned on for 60 seconds, then it was cooled by radiation and natural convection. The temperature of the cylinder was logged by a thermocouple. The temperature was monitored in relation to time. Thermal fields were monitored by a thermal camera. The thermal camera was used to verify the optimum homogeneous warming. Four measurements were made. Three measurements of a cylinder with diameter 25 mm and 30 mm high. Effective emissivity was guaranteed by paint with guaranteed emissivity ($e = 0.95$).

This effect was simulated. Derivation of the measured curve provided the loading characteristic. The same loading characteristic is used in the simulation. That obtains two views, measured and simulated, as one can see in Fig. 1. The results of the experiments are shown in the graphs Figs. 2 and 3.

Heat load was measured in the experiment. Measuring determined heat load 219 W. For equivalent simulation was estimated heat load 220 W. Then was computed convection heat exchange. Measured exchange was 16.3 W and simulated heat exchange less, about 14 W. Cooling losses were calculated by derivation of curves in Figs. 2 and 3.
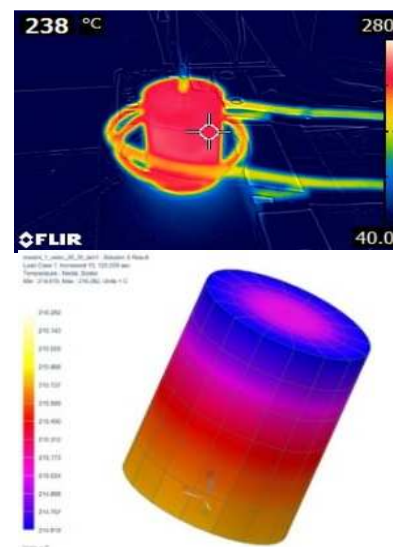

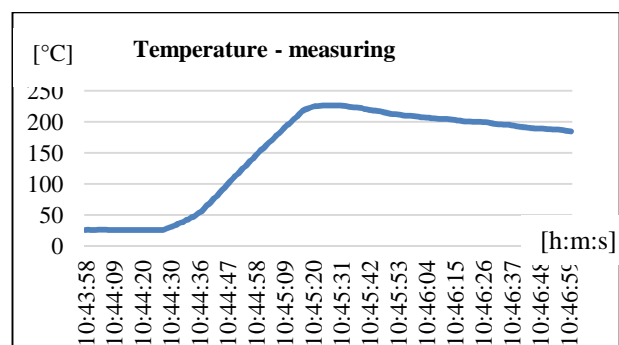**Fig. 1.** Thermal load, measuring and simulation.

Fig. 2. Heat load – measuring, time dependent.

---

* Corresponding author: Regional Technological Institute Univerzitni 8 306 14, Pilsen, Czech Republic
Tel.: +420721936147
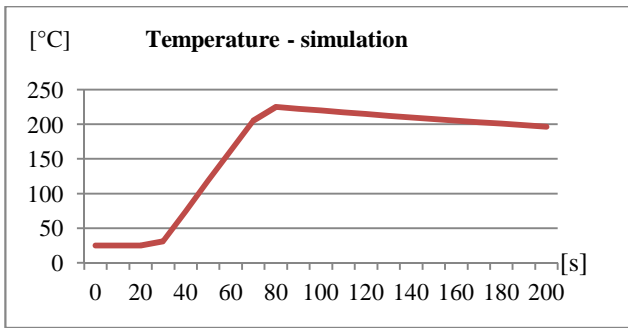E-mail addresses: *marekv06@rti.cz* (V. Marek)

[°C]	**Temperature - simulation**

Fig. 3. Heat load – simulation, time dependent.

2. VERIFICATION OF THERMAL COOLING CAPACITY OF PASSIVE COOLER

The experiment with a passive cooler takes a more precise look at the thermal effects. Thermal effects like free convection and radiation are very difficult to simulate precisely. Results are particularly sensitive to the mesh [6]. Results are also sensitive to the other coefficients. Therefore, it is necessary to perform many experiments to obtain the real coefficients and to acquire information about the basic thermal activity.

The essence of the topic is the harmonization of thermal simulation and real measurement.

A high frequency induction-heating device heats the iron test samples (S235). The main disadvantage of this source is that we do not know the precise thermal input into the sample. It is crucial to find the heating parameters.

2.1. Experiment

An experiment was performed for verification. Experiment was consisted of this setup:
- heat load from high frequency heating device(1);
- cooling by free convection (2);
- thermocouple measuring(3);
- thermal camera monitoring(4).

The experimental setup is presented in Fig. 4.

2.2. Heat loading

Heat load has to be determined and the result is used for the heating of the passive cooler in thermal simulation. This choice is based on the integration of the thermal field in time dependent states. Heating cycles can be seen in Table. 1.
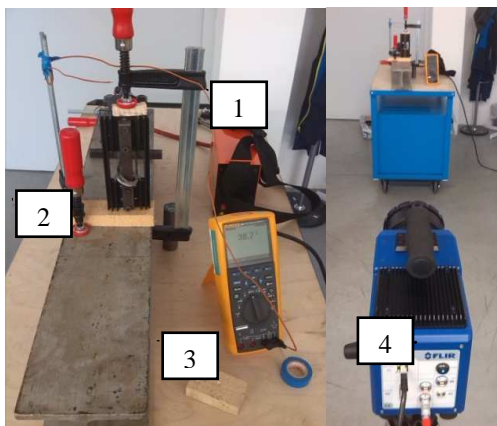

Fig. 4. Experimental setup.

Table.1

Heating cycles

Cycle	Heat load [s]	Cooling [s]	Total time [s]
1	120	180	300
2	90	210	300
3	90	510	600

Heating option, setup and heating cycles are defined with respect to laboratory conditions and measuring possibilities.

2.2.1. Integration area. Figure 5 shows the integration area. Temperatures were measured in this area. Energy states are computed by their integration. The results are the energy states in three periods. It takes the heat load by their differences. Graphs of the temperatures are shown in Figs. 7 and 8. Values, which are represented by graph, are approximated values, because heat conductivity is neglected. It is neglected because of the fast process during 20 s. These results are the input values for the simulation and they will be refined by iterations. Figure 6 represents graphic result of temperature fields of the first iteration.
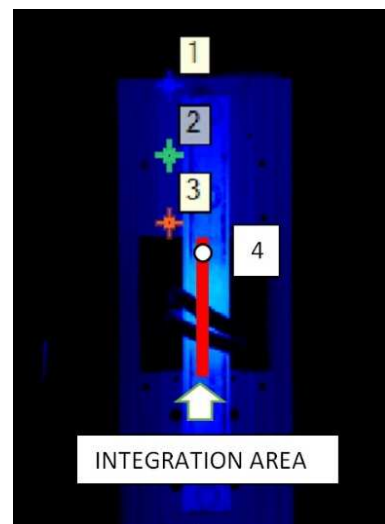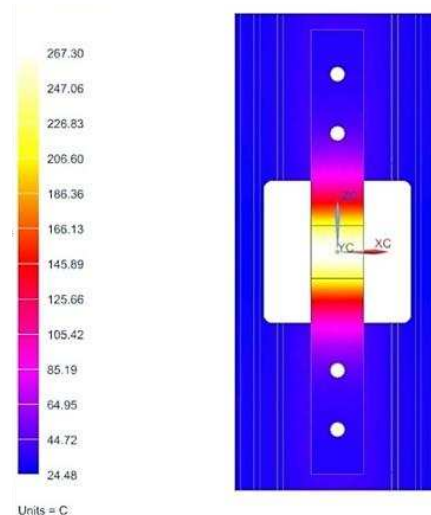

Fig. 5. Heat load – thermal camera.
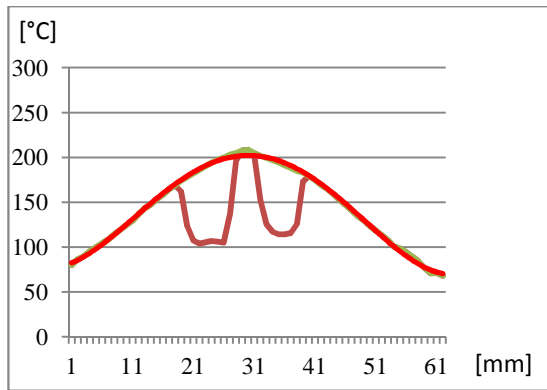

Fig. 6. Thermal load – simulation.

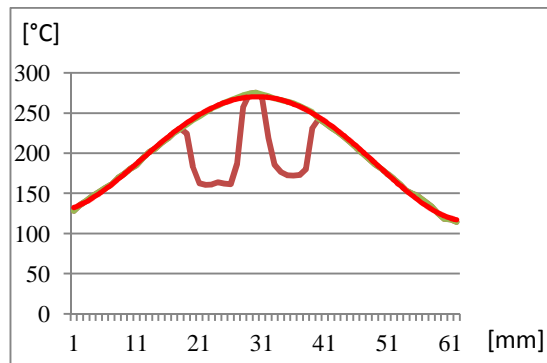**Fig. 7.** Temperature profile dependent on dimension,
at time 20 s.

Fig. 8. Temperature profile dependent on dimension,
at time 30.s.

Average heat load was estimated to be 347 W by difference of energetic states defined by graph in Figs. 7 and 8.

2.3. Thermal simulation

Simulations are performed in Siemens NX10 with a palette of solvers. Three options of heat loading states were used in the simulation.

2.3.1. Simulation of heat loading and verification. Simulations and measurements present the states of thermal behavior during heating and cooling time. States are solved by a pallet of the provided solvers. Solved states are shown in Table 2.

2.4. DATA for comparison

All data for procession are given bellow. Data are represented by four sets:

A) NX Thermal NASTRAN

The simplest way is to use NX Nastran solver. Environment provides easy option of boundary condition.

B) Solver NX Thermal/Flow – Thermal solution

More sophisticated solver is Thermal/Flow solver included in NX. It supports more options to specify real states. However, in this case can be used only thermal solver and convection can be defined merely by coefficients.

C) Solver NX Thermal/Flow – Coupled Thermal/Flow solution

Last performed options are full thermal/flow solution. This option respects many properties of heat and flow effects [2]. One can see the result in Fig. 9.
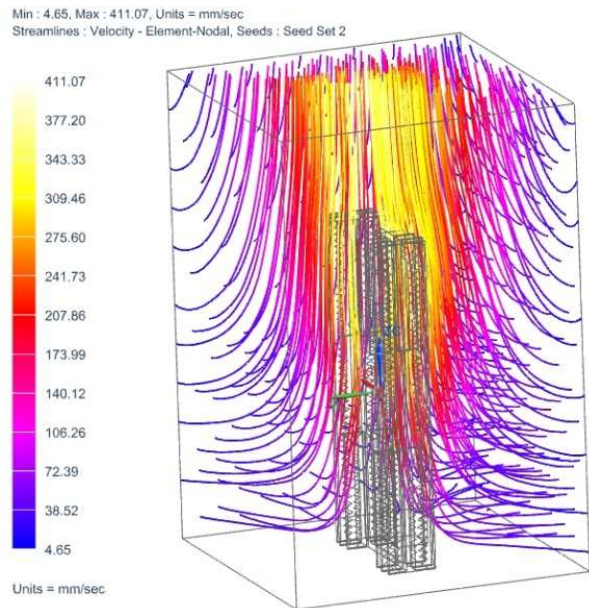

Fig. 9. Free convection, speed of the airflow.

D) Measuring

Measuring provides experimental data, which are used to verification of computed results.

Four points on the body were verified. Three points are situated on the aluminum cooler (see Fig. 4) and one is situated on the heated iron sample. The evaluation is presented below. For heating in the first iteration was used heating schema as shows Table 2.

Table 2

Heat load – Iteration 1

Cycle	Heat load [W]	Heat load timing [s]	Cooling [s]	Total time [s]
1	350	120	180	300
2	350	90	210	300
3	350	90	510	600

Table 3

Temperatures comparison 1 for point 1

Solver	C1- max temp [°C]	C2- max temp [°C]	C3- max temp [°C]
Nastran	109.1	82.06	82.6
Thermal-Flow: Thermal	130.4	105.1	105.2
Thermal-Flow: Coupled	127	98.2	98.05
Measuring	154.17	97.5	104.7

Table 4

Temperatures comparison 2 for point 1

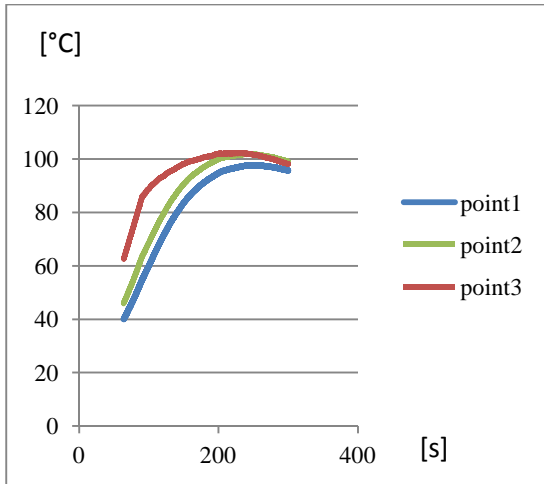| Solver	C1- finish temp [°C]	C2- finish temp [°C]	C3- finish temp [°C]
Nastran	88.03	79.22	66.37
Thermal-Flow: Thermal	113	90.1	66.4
Thermal-Flow: Coupled	106.8	76.6	49.38
Measuring	151.01	95.6	73.9

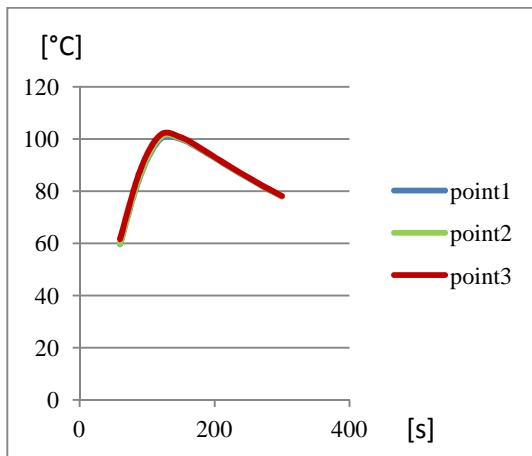**Fig. 10.** Measured temperatures dependent on time.

Fig.11. Simulated temperatures dependent on time.

Comparison. Tables 3 and 4 present measured temperatures. As can be seen in Figs. 10 and 11, differences in the default simulation with perfect contact are substantial. The large difference in maximum temperature is obviously caused by a more powerful heat load. A useful parameter is the temperature of point 4 on the iron sample. Points 1, 2 and 3 show the effects of face contact between the iron sample and the aluminum cooler. The heat transfer coefficient is a characteristic quantity of convection [3]. Values of point 4 before solver settings are given in the Tables 5 and 6.

Measured points can be seen in Fig. 12 made by thermal camera. Simulated temperature fields are presented in Fig. 13.

Table 5

Temperatures comparison 1 for point 4

Solver	C1- max temp [°C]	C2- max temp [°C]	C3- max temp [°C]
Nastran	265.9	222	222
Thermal-Flow: Thermal	252.7	219.3	219.7
Thermal-Flow: Coupled	248.8	214.7	176.9
Measuring	–	307	325.1

Table 6

Temperatures comparison 2 for point 4

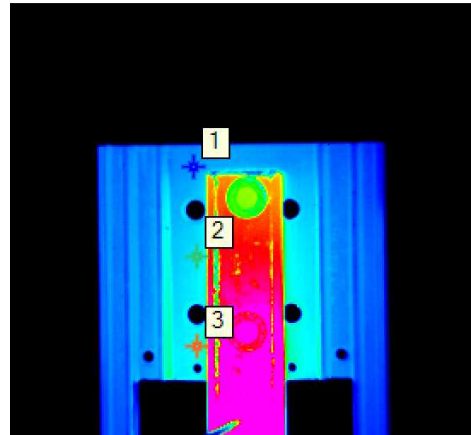| Solver	C1- finish temp [°C]	C2- finish temp [°C]	C3- finish temp [°C]
Nastran	117.39	86.4	86.4
Thermal-Flow: Thermal	116.4	92.15	67.5
Thermal-Flow: Coupled	109.5	78.85	50.46
Measuring	–	131	84.4

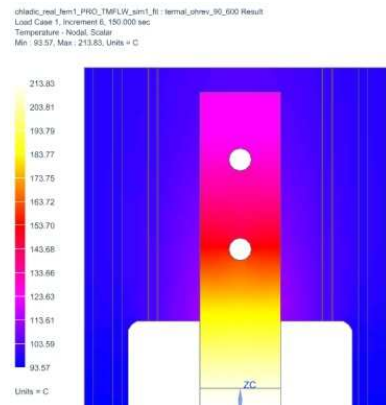**Fig. 12.** Thermal camera, time 150 s.

Fig. 13. Simulation, time 150 s.

Matching. There are a few options for improving the results of the simulations. As can be seen, the differences are more than 20%. Globally, good accuracy of thermal simulations is about 10–15 %.

Main factors in thermal simulations are below:
- face contact between objects (thermal resistance);
- effective emissivity – radiation;
- roughness of the walls
- flow effects – turbulent/laminar flow, etc.

2.5. Match solvers

Values provided by three solution setups were verified by the measuring. Solution setups/solvers are given below:
- NX Thermal NASTRAN;
- solver NX Thermal/Flow – Thermal solution;

- solver NX Thermal/Flow coupled – This is a coupled thermal and flow solution.

Computation was processed with these boundary conditions:

- contact resistance 0.75 C/W [4]; this temperature change is known as the thermal contact resistance [5];
- heat load 375 W.

Table 7 shows experiment input values in three cycles. Figure 14 shows graphic comparison of cycle 2. Graph shows measured and simulated point 4. Measuring was performed by thermocouple. The graph in Fig. 14 represents temperatures dependent on time and influence of contact resistance. Tables 8 and 9 show results of the second iteration of simulation.

Figure 17 represents matched solution of the simulation. Figure 16 shows thermal camera measuring, which verifies the simulation.

Table 7

Heat load – Iteration 2

Cycle	Heat load [W]	Heat load time [s]	Cooling [s]	Total time [s]
1	375	120	180	300
2	375	90	210	300
3	375	90	510	600

Table 8

Correlated values of point 1

Solver	C1- max temp [°C]	C2- max temp [°C]	C3- max temp [°C]
Thermal-Flow: Thermal	120.78	101.8	109
Thermal-Flow: Coupled	118	91.75	95.9
Measuring	154.17	97.5	104.7

Table 9

Correlated values of point 1

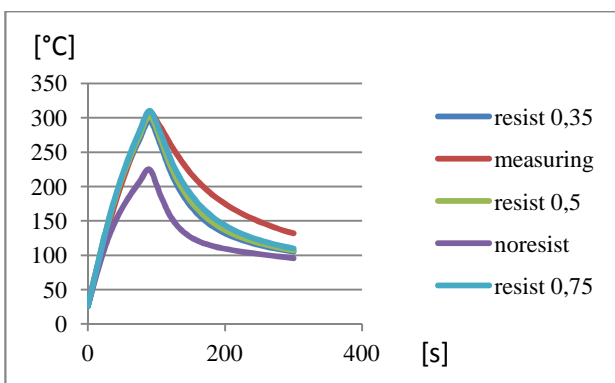| Solver	C1- finish temp [°C]	C2- finish temp [°C]	C3- finish temp [°C]
Thermal-Flow: Thermal	117.18	97.67	76.7
Thermal-Flow: Coupled	112	81.35	56.2
Measuring	151.01	95.6	73.9

Fig. 14 Results for variation of contact resistance [C/W].

Figure 15 shows matched solution of thermal simulation in graph. Graph shows temperature of point dependent on time. Measured temperature fields are shown in Fig. 16. Similar temperature fields are obtained by simulation in Fig. 17. Temperature fields are similar, small differences could be neglected.
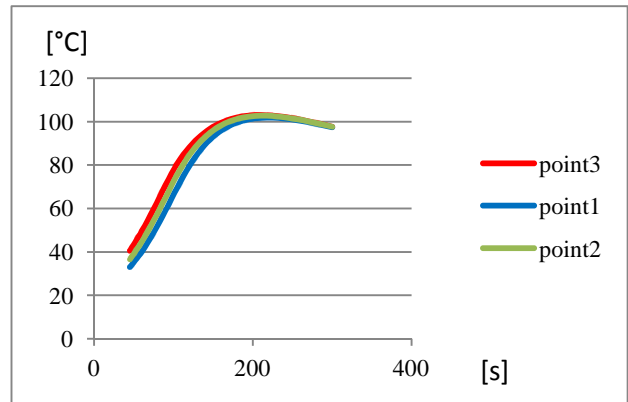

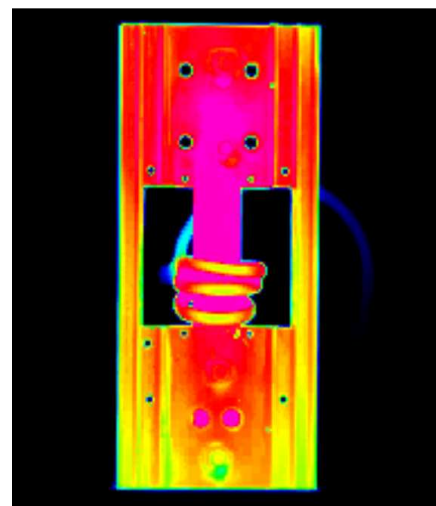**Fig. 15** Matched solution, heat resistance of face contact 0.75 C/W.

Fig. 16. Measured temperature fields at time 300 s.
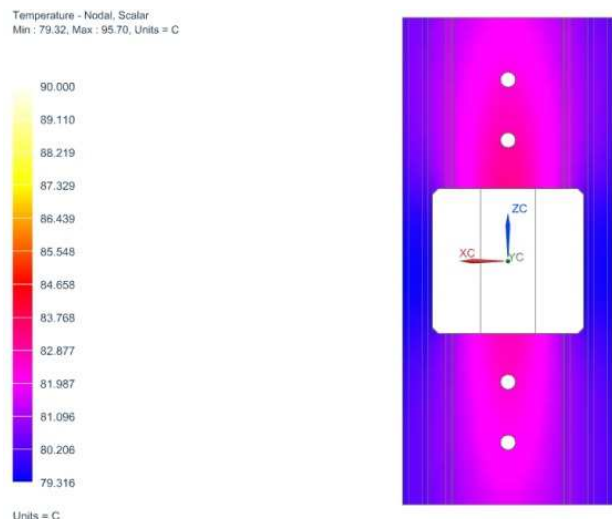

Fig. 17. Simulated temperature fields at time 300 s.

3. COOLING CAPACITY SIMULATION

This part of the article shows how to use the acquired data. Two methods for computing the theoretical cooling capacity were performed. Heat loading process was designed with a heat load of 20 W and 50 W. The cooling process was designed with a free and forced convection cooling. Final computation is processed in two ways. The first computation was processed with Nastran simple thermal simulation. Second computation was processed in Thermal/Flow environment for two conditions - free and force convection. If the fluid is made to move by the action of a pump, a fan, or a blower, we have a case of forced convection [6].

Results of a flow simulation are represented in Figs. 18 and 19 and Table 10. Results of thermal/flow environment are more detailed. Computation is able to analyze fluid temperatures, flow directions and temperature of parts.

Table 10

Cooling capacity

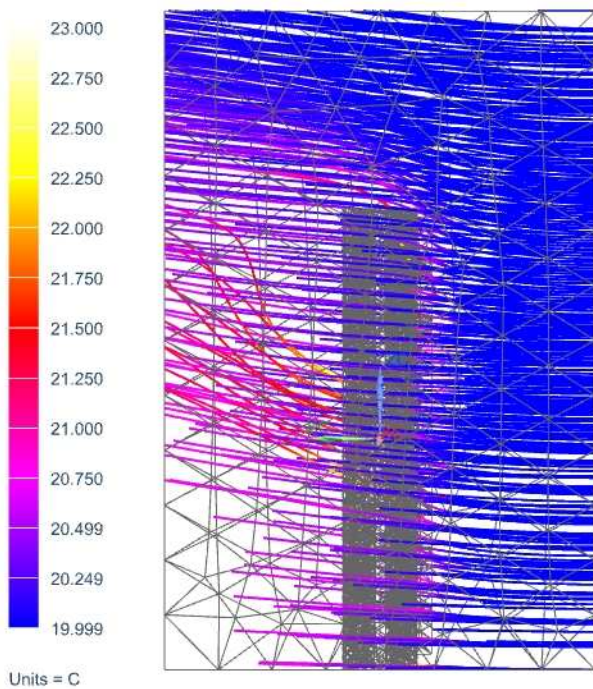| Solver	Heat load [W]	Heat load timing [s]	Max temperature [°C]
Thermal-flow - Steady state	20	Until steady	86.33
Thermal-flow - Transient	50	600	143.8
Thermal-Flow Forced convection – Steady state	20	Until steady	74.81
Thermal-Flow Forced convection – Transient	50	600	143.85

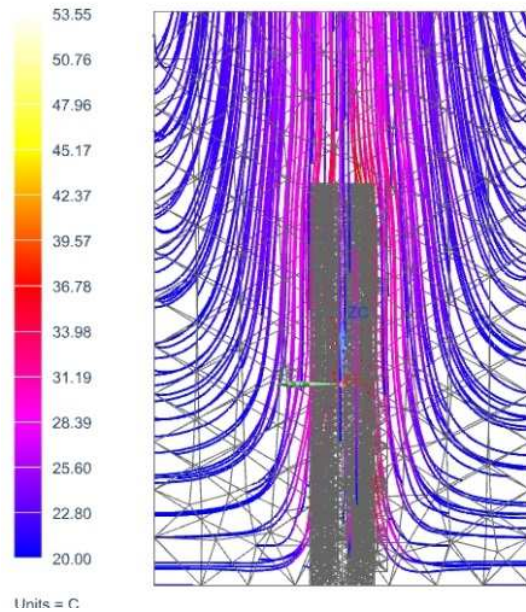**Fig. 18.** Flow temperature – forced convection.

Fig. 19. Fluid temperature – free convection.

4. CONCLUSIONS

Vital issues in thermal transfer simulations are the unknown thermal transfer coefficients and the unknown precise definition of the environment condition. These facts mean that the results are not very precise. Difficult transfer cases have to be supported by simulated and simply measured cases, which can help us to find the boundary conditions and to identify the coefficients. This article shows how to identify conditions and refine the results. Next research will show how to simulate thermal transfer in bearings, transmissions or other important nodes in machines.

REFERENCES

[1] T.G. Alexandru, T.A. Mantea, C. Pupaza, S. Velicu, *Heat transfer simulation for thermal management of electronic components,* Proceedings in Manufacturing Systems, Vol. 11, No. 1 (2016), pp. 15–26.

[2] P. Goncharov, I. Artamonov, T. Khalitov, *Engineering Analysis With NX Advanced Simulation,* Lulu Press, Inc., 2014.

[3] D. Anaratone, *Engineering heat transfer*, Springer, New York, 2010.

[4] R. Balmer, *Thermodynamic tables to accompany modern engineering thermodynamics*, Elsevier, Amsterdam, 2011.

[5] T.L. Bergman, F.P. Incropera, *Fundamentals of heat and mass transfer*, 7th ed. / Hoboken, NJ: Wiley, 2011.

[6] E. Baskharone, *Thermal science: essentials of thermodynamics, fluid mechanics, and heat transfer*. McGraw-Hill, New York, 2011.