Applications of Computational Thermal Simulation in Product Design

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ABSTRACT Computational simulation has become an indispensable tool for research and development. In the past it was often seen as little more than a substitute for experiment, but there are times when it yields information that is difficult to obtain directly from experiments. With progress in software and hardware it has recently become a simple matter to undertake large-scale computations.

Furukawa Electric makes use of computational simulation in any number of fields. The range in which thermal and fluid dynamics simulations are used is very wide, from the development of heat-dissipating devices and various modules to the design of equipment and cases. Here we propose to introduce examples of applications of thermal and fluid dynamics simulation to a variety of products.

1. INTRODUCTION

Computational simulation is being used in all sorts of fields: scholarly research, weather forecasting and architectural and structural design for a start, and everything from finance and the military to regional development. The use of simulation is not limited to specialized disciplines, but as evidenced by the terms "computer-aided engineering (CAE)", it has become a familiar design tool, indispensable to new product development for manufacturing industries. And behind this lies the higher speeds of computers and advances in software.

Simulation software as a design tool has been in existence for several decades, and has long been used in its own ways. But these earlier versions of simulation software needed supercomputers or workstations to run. Their application was also limited to comparatively small-scale models and their operation required highly trained specialists, so that they could not really called a high-productivity tool.

The last few years, however, have seen a dramatic increase in the number-crunching power of the personal computer (PC), delivering performance that was previously available only from mainframes at dramatically decreasing cost. Thus it is increasingly common for simulations to be run on PCs. And with higher PC computing performance, the software, by adoption of the GUI, has become much easier to use, with vast proliferation of function and improvements in computing efficiency.

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This rapid progress in both hardware and software has transformed computational simulation from an arcane activity that was the preserve of the specialist to a convenient tool, easily mastered by any ordinary researcher or technician. Another major change was that it became easy and cheap to simulate large-scale models. In the past the problems of limitations imposed by computer hardware and the excessive time required for computation meant that a large-scale model of complex configuration could not be simulated as is. This required a variety of time-consuming expedients, such as simplification of the model.

Nowadays, however, with the upgrading of computer performance, it has become possible, given just the CAD drawings, to apply computational simulation with virtually no further adjustments. Finally let us draw attention to the previously unimaginable wealth of expressive power that comes from the visualization enabled by software. This means that far from being restricted to a means of replacing experiment, it has become a powerful tool for making presentations of great persuasive power.

2. ADVANTAGES OF SIMULATION

Among the advantages of using simulation the two that are most generally appreciated may well be:

1) It reduces the number of experiments and prototypes, thereby lowering development costs; and
2) It enables estimation of results that would be difficult to confirm experimentally.

For these reasons simulation is particularly useful in cases in which model changes occur frequently and life cycles are short, so that product development must be carried out quickly, or in cases in which the object to be measured is so small or the cost of measurement so prohibitive that conducting experiments is difficult.

But despite the advances that have been made in simulation, it will be difficult to totally eliminate prototyping and experimentation. Although advances in computational technique have resulted in improved accuracy, there are still fields in which accuracy remains inadequate. Furthermore simulation still requires a certain amount of modeling based on human thought. Specifically, since the parameters required for calculation must be entered based on human decision-making, errors of human judgment will still occur. Sometimes a factor that was discarded in the modeling process may manifest itself in unexpected ways in the actual product, giving rise to results that are significantly different from the simulation. It is therefore essential that the measured and calculated results be constantly compared with each other to confirm accuracy.

Then, in addition to the two advantages of simulation mentioned above, we may consider the following:

3) Whenever design changes are made, simulation permits model changes and computations to be implemented in a short time. Design can thus be revised over and over, raising the degree of completeness of the design.
4) Radical designs, which in the past could not be seriously considered because of limitations on the time required, can be placed on the agenda for examination.
5) In experiments, data can only be obtained on a limited number of measurement points, but with simulation, physical values for the total computation domain can be calculated at one time using a one-time calculation. Thus the data obtained is abundant and it is possible to acquire data for any desired point. In this way feeding the results of the simulation back into the design can elicit new ideas.

We believe that if the characteristics of simulation that have been shown here are accurately appreciated, the advantages that simulation offers as a development tool can be maximized.

Furukawa Electric also actively uses computational simulation, and besides establishing a specialized organization for undertaking sophisticated analysis, we are applying it broadly in the development workplace and design workplace, in forms that are closely related to product development.

Taking a look at the areas in which simulation is used, we find an extremely wide variety—thermal and fluid dynamics analysis, as well as structural design, electromagnetic field analysis, acoustics and vibration analysis, optical design, analysis of chemical reactions and processes, design of molecular materials, and so on. In this paper we have chosen products that are thermal-related in the broad sense, and present examples in which simulation is used in close integration with their development.

3. THERMAL-RELATED PRODUCTS FROM FURUKAWA ELECTRIC

Although we blithely use the phrase thermal-related products there are a variety of types, from those that actively utilize and control heat (power generating equipment, for example) to products for which a compromise solution has to be reached for heat that is generated as an unavoidable consequence. Generally speaking, it would seem that the cases of the latter type, in which unwanted heat has to be disposed of in some manner, are much more common, and to respond to these needs, Furukawa Electric has developed a wide range of heat-dissipating devices such as heatpipes and heatsinks. Photo 1 shows some typical micro heatpipes, and Photo 2 shows a typical heatsink using heatpipes.

Photo 1 Typical micro heatpipes.

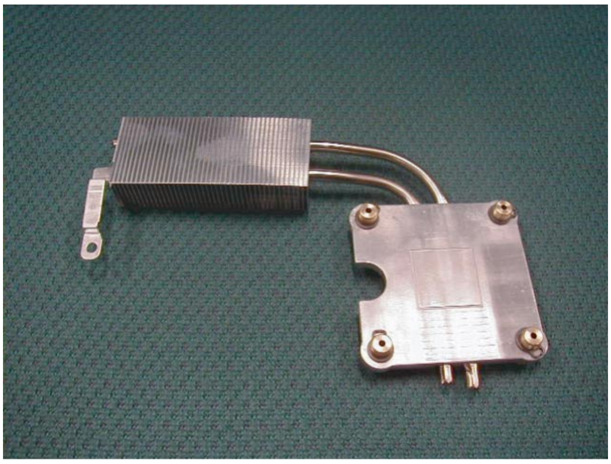

Photo 2 Typical heatpipe-heatsink.

Next are modular products incorporating cooling components such as heatpipes or Peltier devices, or heaters or other heating components, exemplified by temperature control type optical modules and case cooling devices. There are also products like reflow ovens, which actively make use of heat.

Finally, as examples of products that require measures to deal with heat that has unavoidably been generated we may mention communications equipment, cases and optical transmission devices incorporating highly exothermic devices or modules.

Heat dissipating devices are developed based on detailed thermal design in order to obtain the desired thermal performance. Not only that, thermal design is becoming indispensable even for modular components, equipment and packages that are more compact or more exothermic. Accordingly full design consideration using thermal and fluid dynamics analysis is being given in the development process.

Table 1 Thermal management problems in various types of products.

Type of product	Thermal management problem
Heat-dissipating device	Thermal resistance reduction; Downsizing; Height reduction; Noise reduction
Modular product	Power consumption reduction; Temperature stabilization; Downsizing; Output power enhancement; Enlargement of working temperature range
Equipment and units	Power consumption reduction; Downsizing; Noise reduction; Elimination of heat spot

Table 1 summarizes the objectives for which thermal design is being done for each of the types of products described above. We can see that the efficient dissipation of unwanted heat to control temperature is the problem common to all these products, but there are also developmental problems that differ according to the type of product. The accuracy required of the simulation also differs according to the type of product.

In this paper we have selected a number of examples to illustrate the advantages of thermal simulation: from among heat-dissipating products, a heatsink for a desktop PC and a heatsink for an optical amplifier; from among modular devices, a laser diode module; and as an example of equipment and units, optical transmission equipment.

4. APPLICATIONS TO HEAT-DISSIPATING DEVICES

Heat-dissipating components that Furukawa Electric has brought to commercial production are many and varied, including heatpipes, power plates, vapor-chamber, Crimped fin®, heat transfer sheets, coated aluminum sheets for heat dissipation, metal core circuit boards, and so on. Of these the most representative is the heatpipe. The heatpipe is a phase change heat transport device, and because of its outstanding heat-equalizing properties and high reliability it is used in a wide range of applications, from cooling power semiconductors to heat dissipation for small electronic devices. Notebook PCs are particularly impacted by advances both in smaller size and in greater CPU heat generation. Thus the need for heatpipes is increasing most rapidly in products for mobile applications [2]. In future, it is anticipated that usage in desktop PCs will increase [3]. Since heatpipes are fundamentally heat-equalizing devices, they are generally used in the form of heatpipe-heatsinks, joined to heat-dissipating fins.

Photo 3 shows a typical Crimped fin® heatsink for cooling the CPU of a desktop PC. Desktop PCs are subject to fewer restrictions on power consumption and space than notebook PCs, with the result that CPU heat generation in desktops is increasing at a faster pace than in notebooks.

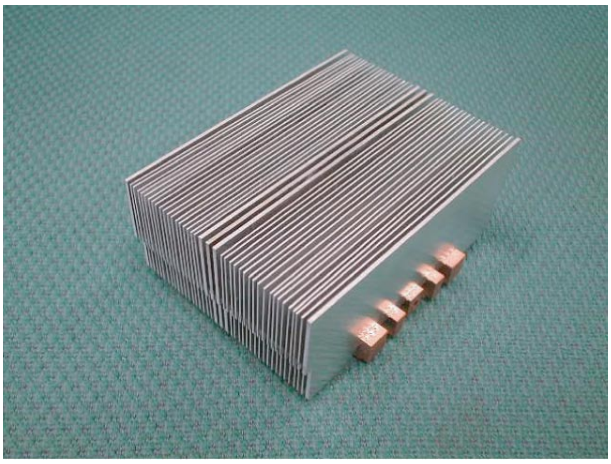

Photo 3 Crimped fin® heatsink for desktop PC.

In the past CPU heatsinks have been of the aluminum extrusion type or the soldered type. At present, however, with the quantity of heat generated reaching near 100 W, it is becoming difficult to satisfy specifications for thermal resistance with the conventional heatsinks. The Crimped fins, which Furukawa Electric has recently developed to cope with higher heat generation, constitute a Crimped fin heatsink in which the fin base and fins are joined by crimping, achieving a low level of heat resistance that was difficult in conventional heatsinks.

Figure 1 shows simulated temperature contours for a Crimped fin heatsink for a desktop computer. Features of the Crimped fin heatsink include fins of a slim profile difficult to achieve with the extruded heatsink, and greater ease in achieving high-density fin arrangement. Another feature is the freedom with which the shape and materials used for the base and fins can be designed. Accordingly the aim in this project was to make adjustments to the shape of the base, thereby achieving compatibility between lighter weight and heat-dissipating properties. Simulation was also applied in discovering the optimum base design.

Figure 2 shows the airflow between the fins and fin temperature contours for a Crimped fin heatpipe-heatsink. We consider that when base width was too great the airflow from the fan was obstructed by the base and was

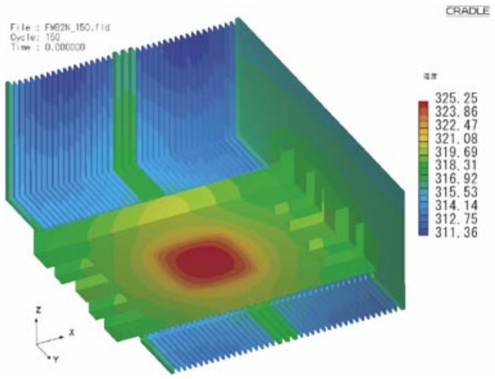

Figure 1 Simulated temperature contours for Crimped fin heatsink.

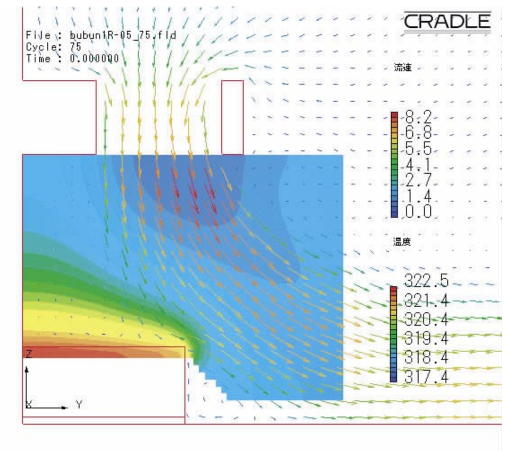

Figure 2 Airflow and fin temperature contours for a Crimped fin heatpipe-heatsink.

diverted to the outside, so that inadequate air flowed between the fins and heat resistance increased. When, on the other hand, the base width was too little, the heat from the heat source was not adequately transmitted to the tips of the fins, fin resistance was reduced, and the heat-dissipating characteristics were degraded. We were able to realize a design in which, by setting the base width at an optimum value, the airflow from the fan was discharged between the fins unimpeded by the base, so that heat was adequately transmitted to the tips of the fins.

Photo 4 Typical heatpipe-heatsink for optical fiber Raman amplifier.

Photo 4 shows a typical heatpipe-heatsink for an optical fiber Raman amplifier. Figure 3 shows the simulated temperature contours for the HP-HS for a Raman amplifier shown in Photo 4. By making use of a heatpipe in this way, we were able to realize a heatsink with a slimmer profile that in the past, and at the same time cope with devices generating large amounts of heat.

5. APPLICATIONS TO MODULAR PRODUCTS

Thermal simulation is useful not only in developing heat-dissipating devices themselves, but also in designing modular products incorporating heat-dissipating devices. Here we would like to introduce an example of the use of thermal simulation in designing a laser diode module used in a wave-division multiplexing (WDM) system, a type of device used in optical fiber communications.

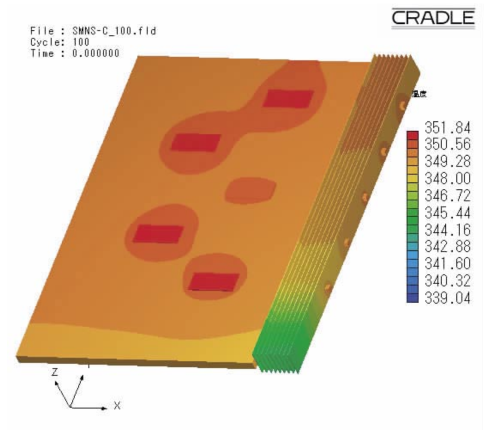

Figure 3 Simulated temperature contours for HP-HS in Photo 4.

WDM is a method for achieving high-speed transmission by sending optical signals of different wavelengths simultaneously over a single optical fiber, and at present is the method in general use on trunk lines and other long-haul transmission paths. In order to avoid interference by signals of adjacent wavelength, the carriers used require the severest wavelength stability. Since the wavelength emitted by the laser diode, which acts as the light source, is temperature-dependent, a thermoelectric cooler (TEC) must be built into the module to provide temperature control.

Figure 4 is a schematic showing a laser diode module, in which the diode chip, together with a thermistor, is mounted on a TEC module for temperature control. In some cases components may also be mounted to monitor the wavelength of the light emitted by the diode chip.

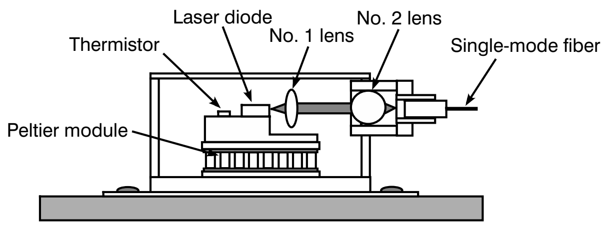

Figure 4 Schematic of laser diode module.

Figure 5 shows the result of a simulation of the dependence of TEC power consumption on LD module case temperature. The heavy dependence of power consumption on case temperature is due to the fact that as case temperature increases the load on the TEC becomes greater, resulting in a dramatic increase in TEC power consumption. Also, if the case temperature exceeds a given value, it becomes impossible to control diode chip temperature.

Next, Figure 6 shows the result of a simulation of the dependence of diode chip temperature on case temperature. The fact that chip temperature is dependent on case temperature despite the use of temperature con-

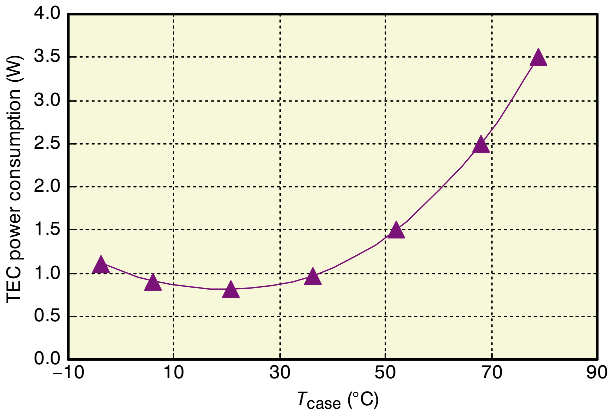

Figure 5 Simulated dependence of TEC power consumption on LD module case temperature.

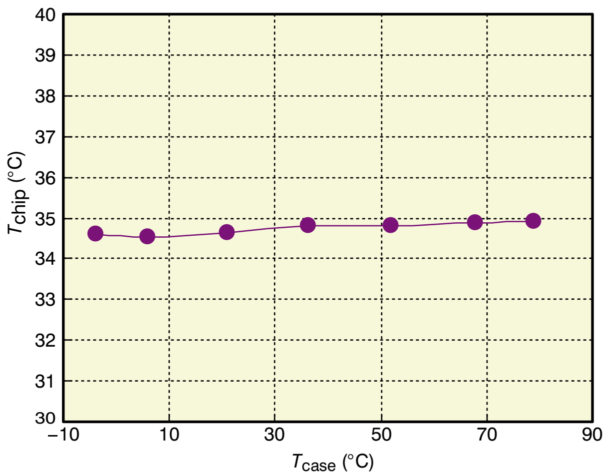

Figure 6 Simulated dependence of diode chip temperature on case temperature.

trol is because of the temperature difference between the thermistor that measures temperature and the other components. The thermistor itself is always kept at a set temperature, but the other components are in fact influenced by the ambient temperature. In practical terms it is extremely difficult to measure experimentally the temperatures of components inside such a small module. By contrast the use of thermal simulation makes it easy to calculate the temperature at each part of the module. Also, when the design is changed, it is possible to examine quickly and at low cost the way in which the temperature of each part has changed.

6. APPLICATIONS TO EQUIPMENT DESIGN

Furukawa Electric offers a range of equipment for telecommunication, including routers, fiber-optic transmission devices, and so on. Every time a model change is made on such equipment, size becomes smaller and performance higher, so that devices emitting more and more heat must be mounted at greater and greater density, requiring countermeasures that become ever more difficult.

Figure 7 shows an example of simulated airflow distribution inside the case of an optical communication unit. Accurately measuring this kind of airflow distribution inside equipment with an electronic circuit board of complex configuration and a complicated arrangement of heatsinks is well nigh impossible, but simulation makes it child's play to grasp in a moment the flow of air inside the equipment.

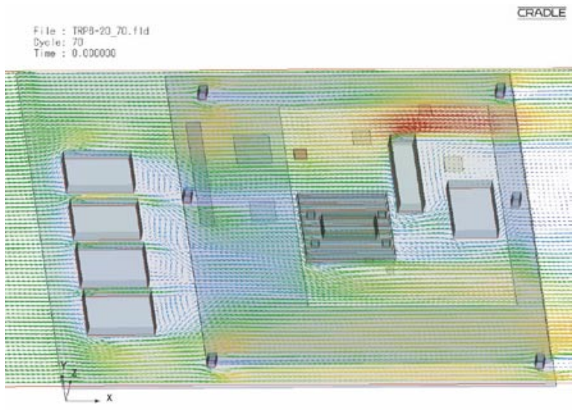

Figure 7 Simulated airflow distribution in optical communication unit.

If the airflow inside the equipment can be understood, countermeasures can be taken, such as disposing hot devices where airflow is favorable, selecting the appropriate fans and fins to use, or providing channeling vanes to control the flow of air. If it were desired to study device placement by experimenting on actual objects, it would be necessary to go to the trouble of fabricating circuit boards, and this would take a large amount of time and money. But with simulation, changes in device placement would need only minor corrections of the model, and a wide variety of layouts could be tried in a short time.

7. CONCLUSION

Furukawa Electric has made wide use of computational simulation in developing its products, and simulation has already taken its place with experimentation as an indispensable technique. In this report we have introduced examples of the use of thermal and fluid dynamics simulation of a variety of products in the area of heat.

The advantages of simulation are becoming widely understood in Furukawa Electric's corporate culture. We intend to further promote information sharing and technological interchange among different departments, thereby dealing with the important task of simulation in the development workplace.

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