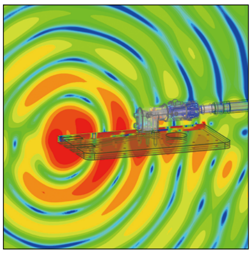

Computer-Aided Engineering Technology Supporting Product Development and Manufacturing

Hidehiko MISHIMA*, Kenichiro TAKAHASHI, Yuichi NAKAMURA, Takemi TERAO, and Shigeki SHIMADA

In recent years, computer-aided engineering (CAE) simulation technology has become indispensable in the manufacturing industry as a part of developing products and optimizing process conditions. CAE supports manufacturing processes and product functions based on physical theories. It stimulates the imaginations of designers and production engineers by visualizing invisible phenomena, such as electromagnetic waves, heat, and stress, and connects to the development of new products and improvements of processes. Furthermore, these days more customers request CAE analysis results in addition to experimental results in adopting new products or manufacturing processes. In order to obtain useful and accurate CAE analysis results under these circumstances, it is necessary to develop advanced CAE technology reproducing experimental results, and high-speed calculation servers. In this work, we have realized CAE analysis that could not be handled previously, by increasing the calculation efficiency and functional performance of the calculation servers. This article gives an introduction to the details of these calculations in various analytical fields.

Keywords: CAE, calculation server, large-scale analysis, coupled analysis, atomistic simulation

1. Introduction

We actively use computer-aided engineering (CAE) for the development of new products and processes, and for evaluating the reliability of mass-produced products. We are aiming to use CAE to reinforce the manufacturing foundation of the entire Sumitomo Electric Group. CAE is a numerical calculation tool that predicts phenomena in processes and the performance of product functions based on theory. If the calculation results are confirmed to show good agreement with experimental results, we can develop new products and optimize the production process without trial products.

Product development in Sumitomo Electric Industries, Ltd. demands more advanced CAE technology for the development of materials and processes and for the improvement of development efficiency. More specifically, the need has greatly increased for advanced CAE technologies, such as (1) large-scale analysis for the entire product; (2) coupled analysis combining multiple physical elements including electrical, structural, and fluid phenomena; and (3) atomistic simulation for understanding the physical phenomena at the atomic level. In addition, more customers request highly accurate CAE analysis results in addition to experimental results in adopting new products or manufacturing processes. In order to obtain useful and accurate CAE analysis results under these circumstances, it is necessary to develop advanced CAE technology reproducing experimental results and high-speed calculation servers.

We have recently improved computational efficiency on the servers by building a batch management system and enhanced functional performance through a strategic custom design. This has made it possible to develop CAE technology with higher precision than ever before, and has enabled us to deepen and expand the utilization of CAE technology to design, manufacturing, and evaluation of reliability in our five business segments: Automotive, Infocommunications, Electronics, Environmental & Energy, and Industrial Materials.

This paper introduces the server installation and operation concept at Sumitomo Electric and describes some case studies including technologies (1) to (3) in several analytical fields.

2. Calculation Server Installation and Operation Concept

The important performance parameters of calculation servers include the number of cores*1 for performing the calculation in CPU*2, the memory*3 capacity for temporarily storing the data and programs, the storage*4 capacity for saving the digital data, and the transmission speed between CPUs. Higher speed and larger scale computations are needed for more advanced CAE technology, and performance improvements are essential. However, there are a wide range of CAE technical fields such as computational fluid dynamics (CFD), electromagnetic, structural, materials design, and optical analysis. The most important parameters for speeding up calculations depend on the field of analysis, such as the number of cores in CFD and the memory capacity in electromagnetic analysis. Therefore, we have introduced originally designed computer servers by tuning the server parameters to maximize the calculation performance in each field. Calculation servers around the world are continually advancing every year, and we also improve the performance of our servers by updating the functions and increasing the capacity every few years.

Furthermore, the calculation servers are connected via a high-speed network so that they can be used from any of our multiple offices (Fig. 1).

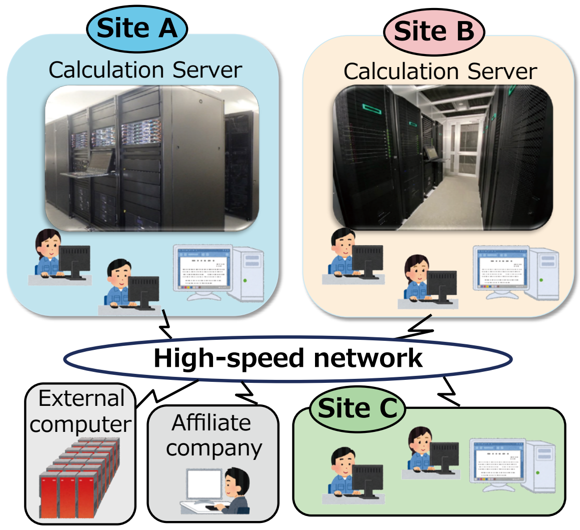

Fig. 1. Operation of calculation servers via high-speed network

In order to enable a large number of people to simultaneously access the calculation servers from various offices, a batch management system using calculation job management software was designed and put into operation. In order to use calculation servers efficiently, we designed this system to allocate new jobs with optimal CPUs by automatically evaluating analysis software and simulation size.

3. Development of CAE Technology for Various Analysis Fields through Server Installation

We have been promoting the development of CAE technologies utilizing high-performance computer servers, which has enabled us to take on challenges in areas and methods that were previously impossible, such as large-scale analysis and coupled analysis. The following gives an introduction to some examples.

3-1 Structural analysis (stress analysis)

The structural analysis makes it possible to evaluate the magnitude of deformations, the strength of a structure, and service life, and it is used in all kinds of fields. In recent years, demand for further precision has been growing, with an increasing need for larger-size models. And also demand for coupled analysis, such as between heat, fluids, and electromagnetic fields, is also growing. So we have striven for technological development, and now introduce an example of using structural analysis for the design of a multi-core optical fiber connector that has multiple cores*5 and is expected to greatly increase transmission capacity.

In order to reduce the connection loss of optical connectors that join optical fibers together, it is necessary to make physical contact between the cores with the designated force applied. For conventional single-core optical fibers, this is not a particular problem since there is only a single core at the fiber center, and it is sufficient to make contact within a radius of around 10 μm at the center of the fiber connection point (Fig. 2 (a)). In contrast, since multi-core optical fibers have multiple cores, the contact needs to be made over an area with a radius of over 50 μm in order for all of the cores to touch (Fig. 2 (b)). Therefore, it was necessary to develop connecting simulation technology that is able to predict the contact radius by using structural analysis to optimize the connection parameters of the connector.

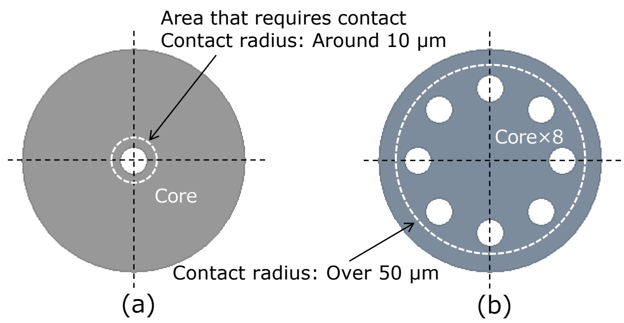

Fig. 2. Comparison of contact radius between (a) single-core optical fiber and (b) multi-core optical fiber

The contact radius depends on variable design parameters including the shape of the optical fiber end surface and the relative position with the optical connector. Therefore, finding the optimal design parameters requires a massive number of connecting simulations with combinations of design variables. These simulations must also be carried out in a short period of time, and it has been made possible through high-performance calculation servers, although this was previously impossible.

Figure 3 shows an example of connecting simulation results for an 8-core multi-core optical fiber. This confirms that the contact radius is obtained from the high-pressure regions. Through this simulation, we succeeded in finding the ideal parameters that can sufficiently suppress the connection loss of 8-core optical fiber. We also succeeded in confirming low connection loss with a mean value of 0.07 dB or less through the evaluation of trial production.[(1),(2)]

In this field, progress is being made not only in the context of determining manufacturing parameters as in this example, but also in the development of technology for evaluating structural strength and service life. Furthermore, progress is also being made into integration with automatic optimization technology that is able to greatly reduce the design time.

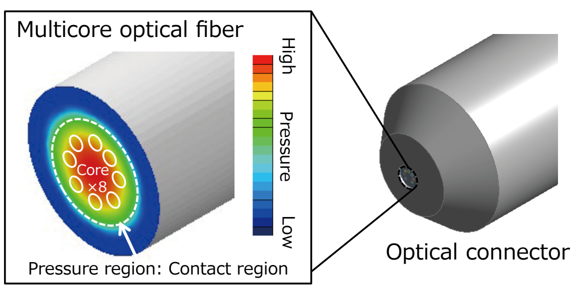

Fig. 3. Contact radius results by connection simulation

3-2 Computational fluid dynamics (CFD)

CFD is able to evaluate the flow of gases or liquids and the heat that accompanies them, and is used in many fields. This type of analysis is suitable for parallel processing, in which the calculation speed is increased by using multiple cores. For example, although the speed reaches the limit with around 10 to 20 cores in structural analysis, in large-scale CFD the speed is increased by virtually 1000 times with 1000 cores. This is therefore being used in a wide variety of design situations. Furthermore, there is also an increased need for coupled analysis in various scenarios such as chemical reactions and electrical current in semiconductor fabrication devices, ion diffusion, and electrochemical reactions in electroplating devices. As an example, we have developed CFD technology coupled with electrical current and ion diffusion analysis for predicting the electroplating thickness of flexible printed circuits. These circuits are used in cutting-edge electronic and information devices, such as smartphones, as a wiring material, and are formed via copper foil on an insulating film.[3]

In order to achieve uniform thickness in electrolytic plating, it is necessary to suppress the electrical current distribution and local decreases in metal ion supply. So we have developed technology for predicting the plating thickness by macro analysis of the entire product (scale: 100 mm order) and micro analysis of through holes, etc. (scale: 10 to 100 µm order). In terms of macro analysis, we have developed technology that can predict the macro plating thickness distribution of an entire product from the electrical current distribution by considering the product, electrodes, and surrounding materials. However, micro analysis requires complex calculations (coupled analysis) that give consideration to the mutual effects of plating fluid flow and electrical current distribution. Furthermore, in order to perform such complex coupled analysis calculations and use them to determine manufacturing parameters, it is necessary to obtain analysis results in a short period of time.

In this work, we established technology for predicting plating thickness that quickly obtains results with high precision by using the installed calculation servers. Figure 4 shows the micro analysis. The change in growth with time in the plating thickness, as shown in Fig. 5, was visualized by simultaneous coupled analysis of plating fluid flow and electrical current distribution, and the actual plating shape was successfully reproduced. The development of this technology makes it possible to predict circuit thickness in all areas, from the micro to the macro. We are improving the quality of products with it.

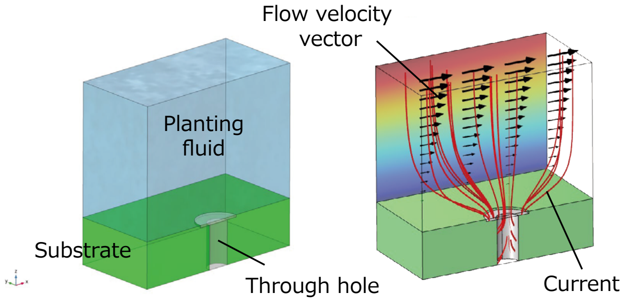

Fig. 4. Coupled analysis of plating fluid flow and electrical current distribution

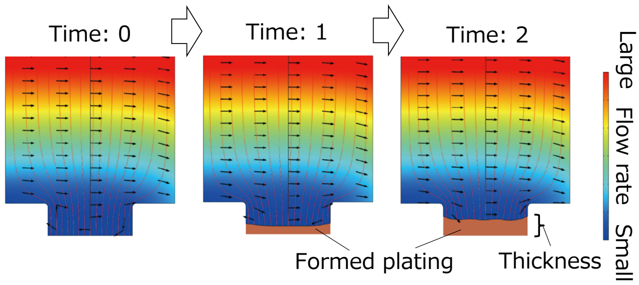

Fig. 5. Temporal change in plating thickness

3-3 Electromagnetic analysis

The electromagnetic analysis is a method that is able to evaluate high-frequency signal integrity (electromagnetic waves) by solving all four of Maxwell's equations, which govern electromagnetic fields. The high-frequency analysis is a field that requires design by CAE because the signals cannot be seen. The signals also may not arrive due to various issues such as slight changes in a circuit at higher frequencies or radiation into space as noise. In recent years, the need to develop high-speed transmission technology for autonomous driving and 5G has been increasing, and utilization of this analysis is growing rapidly in our company.

However, electromagnetic analysis for high-speed transmission faces two major problems. The first is the problem of computational scale. Since the number of meshes in the finite element method*6 grows roughly in proportion to the cube of the frequency, when the frequency increases 10 times, the computation size increases 1000 times. Furthermore, since direct interactions occur by electromagnetic induction not only with neighboring sites, the electromagnetic analysis uses more complicated equations and requires a larger amount of memory than structural and fluid analyses for the same model size. In the installed calculation server, the memory has been greatly increased for electromagnetic analysis, making it possible to meet the need for developing this rapidly advancing high-speed transmission technology.

The second problem is the effect of differences between designs and the actual shape. Since the wavelength of the propagating signal becomes shorter inversely with the transmission speed, small variations in the shapes of components have a larger effect on transmission performance as the frequency increases. As a consequence of this, the CAE results diverge from the experimental results. To solve this problem, we established a shape design method that creates the analysis model*7 by the shape information from X-ray CT images instead of from the design.

As an example, we introduce the case of a vehicle-mounted high-speed transmission connector. Although CAE was previously used to design them, the CAE results diverged from the experimental results for transmission performance as the speed of in-vehicle transmissions increased when using the conventional method of creating the analysis model from the designs. For example, Ethernet, which has been installed in vehicles in recent years, is around 100 to 10,000 times faster than conventional CAN transmission*8,(4) and the wavelength of the propagating signals is 100 to 10,000 times shorter. The top of Fig. 6 shows the difference in shape between the plans and actual measurements (X-ray CT images), which confirms that there are changes in the shape due to, for example, deformation or stretching from the connector crimping, and insertion misalignment. Although the number of component elements greatly increases and the computational cost increases since it is necessary to consider finer details of the shape as the frequency increases, the installed calculation servers realize this shape design method. The graph at the bottom of Fig. 6 shows the results of evaluating the characteristics of each part of the product from the response state of the input signal.

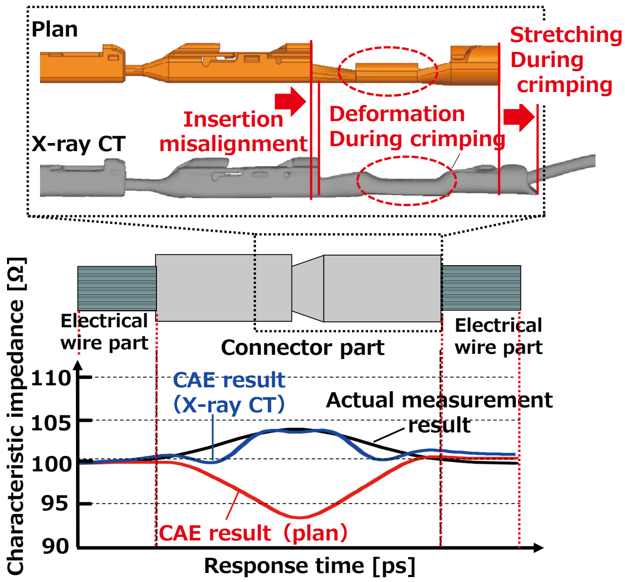

Fig. 6. Vehicle-mounted connector shape comparison and comparison of CAE with experimental results of transmission performance (characteristic impedance)

This confirms that although the characteristic impedance obtained by the conventional method of using the design does not reproduce the experimental results, the results of the newly developed method match those of the experimental results and thus the analysis precision has been improved.

The same design development is also actively spreading outside of high-speed transmission connectors, and in the future we will promote both infrastructure installation and technological development to match the need for higher frequencies.

3-4 Atomistic simulation

Atomistic simulation provides understanding and prediction of atomic-level phenomena and material design by using computers to solve physics equations. These methods are being used in a wide variety of fields with the recent growth of computer technology. However, calculating the behavior of a massive number of atoms requires high computational cost, and increasing spatial and temporal scale. We have overcome these problems using the installed calculation servers, and the following shows the development of technology for simulating the age-hardening of aluminum wire.

Aluminum wire mounted in vehicles, where the need for weight reduction is growing, can be strengthened through age-hardening process by adding specific elements. The age-hardening is a phenomenon where additive element atoms aggregate and are precipitated as time passes, with the material properties determined by the state (size, shape, density) of the precipitate. In order to determine the best age-hardening conditions by controlling the state of the precipitate (10 to 100 nm), it is important to accurately evaluate the state of the clusters in the initial stage of the aggregation (around 1 nm) and clarify the aggregation mechanism. However, clusters are so small that they cannot be easily observed by analytical equipment. To deal with this issue, we have developed technology for simulating the age-hardening by first-principles calculations*9 that are able to visualize the transitional of the clusters.

Since the calculation of the age-hardening requires high computational cost due to treating the behavior of a large number of atoms and vacancies, the calculations have been limited to several hundred atoms and have been difficult to make practical use. The newly installed server and faster calculation program have made it possible to calculate tens of thousands of atoms. Figure 7 shows the behavior of the atoms of the additive element as found by age-hardening calculations for aluminum wire. This shows that the atoms agglomerate to form clusters through the age-hardening process.

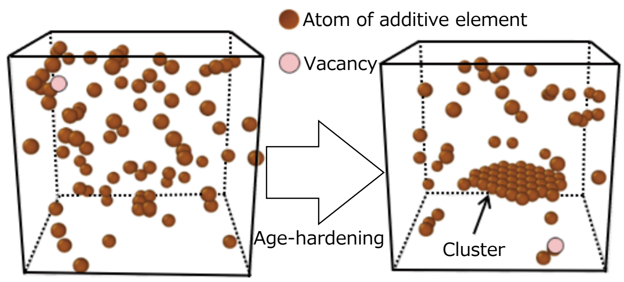

Fig. 7. Age-hardening calculation of aluminum wire (aluminum atoms are not shown)

We are using this simulation technology for improving product performance by optimizing the age-hardening parameters and searching for effective additive elements.

3-5 Analysis of powder motion

Analysis of powder motion is used for investigating the parameters of various manufacturing processes and for designing equipment that uses powder, including food, clothing, and electronics materials. We also manufacture products by powder metallurgical methods such as sintering, in which fine powders of multiple metals are compression-molded and then heated. We use it in the optimization of this manufacturing process. In this field, we have no choice but to make simplifications such as assuming that the powder particles are all spherical or that the size is uniform in order to calculate the motion of a massive number of powder particles. However, this results in low analysis precision.

Although methods such as evaporation deposition with a large number of particles placed in a rotating drum are used to form a thin film on the surface of powder particles, particles that are buried within a clump and are not exposed to the surface do not form a film. Therefore, the particles within the drum need to be uniformly mixed such that no clumps remain. Since it is difficult to understand the behavior of a large number of particles experimentally, we have been working on creating CAE technology using the distinct element method*10, which is able to track the behavior of each particle. In previous stirring simulations, since the computational cost for treating the motion of a huge number of particles (10 million or more) would be enormous, approximations, such as not considering the actual particle size distribution or the coarseness of particles, have been used. As a result, however, the accuracy of the analysis was low and particle behavior could only be evaluated qualitatively. To overcome this issue, we utilized the installed computation servers to realize a highly accurate powder agitation simulation that takes the particle size distribution into account.

Figure 8 shows the tracking of each particle when the drum is rotated, and visualizes its behavior. We developed a program for calculating the time over which particle surfaces are exposed without being buried inside particle clumps and also established a method of predicting the thin film thickness of each particle from these analysis results. We found that the experimental results were reproduced when the distribution of thin film thicknesses formed on the particle surfaces was evaluated.

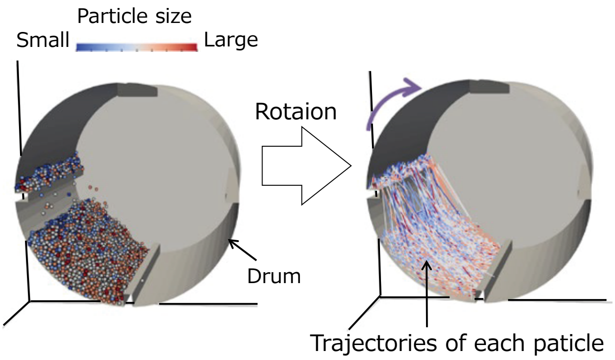

Fig. 8. Analysis of powder motion that has a particle size distribution

We use this method for investigating the optimal stirring parameters and designing equipment with the aim of increasing the quality and reducing the cost of products.

4. Conclusion

CAE has become essential, not only at our company, in design, trial production, experiment, and verification during product development, process improvement, and evaluation of reliability. It is the key competitiveness to develop and utilize CAE technologies customized to the products and the production process. To build up this ability, it is necessary to proceed with the following two items in a well-balanced way: One is to build high-precision computational models such as large-scale analysis, coupled analysis, and atomistic simulation, and the other is to install high-performance calculation servers to perform the necessary calculations. This paper introduced some examples of these developments. In these studies, which are also linked to Digital Transformation, it is essential for the business, development, and analysis divisions to work together, and at the same time, it is important for all divisions to be able to use CAE on a daily basis. We will set up an environment for the use of CAE and pursue a stronger foundation for manufacturing.

Technical Terms

*1 Core: The area that performs the actual computation processing inside the CPU. In recent years, “multi-core” CPUs have become mainstream. They have multiple cores in a single CPU and process multiple streams of data at the same time.

*2 Central processing unit (CPU): This component processes all of the instructions received from peripheral devices and software.

*3 Memory: A component that temporarily stores the data and programs processed by the computer, and that mainly has the role of increasing the processing speed of the computer.

*4 Storage: The devices and systems for saving and recording digital information such as the data and programs processed within the computer. It stores large amounts of data and allows for long-term recording.

*5 Core (optical fiber): The waveguide in which light propagates. An optical fiber consists of cores in the center and cladding that surrounds them. The cores are designed with a higher refractive index than the cladding, and the propagating light is contained within the cores by the phenomenon of total internal reflection.

*6 Finite element method (FEM): An analysis method that performs numerical analysis of a structure divided into multiple finite elements (also called a mesh). The elements have a large effect on the calculation precision, although making the mesh finer gives results that are closer to the theoretical solution. This also increases the number of elements, which increases the computational load.

*7 Analysis model: A model of the analysis target object divided into elements (a mesh) with simplified shapes for calculation on a computer that is needed for finite element method calculations.

*8 Controller Area Network (CAN) transmission: This is a standard that is mainly used for transmission between electronic control units in vehicles. The maximum speed of transmission is 1 Mbps.

*9 First-principles calculations: Method of finding various physical quantities purely by theoretical calculations using laws based on quantum mechanics without relying on empirical rules.

*10 Distinct element method (DEM): Analysis method for solving the time evolution of the motion of many solid particles based on the equations of motion for the translation and rotation of each particle.

References

(1) T. Morishima, K. Manabe, S. Toyokawa, T. Nakanishi, T. Sano, and T. Hayashi, "Simple-Structure low-loss multi-core fiber LC connector using an align-by contact method." Optics Express, Vol. 29, Issue 6, pp. 9157-9164 (2021)

(2) T. Morishima, Y. Saito, K. Manabe, S. Toyokawa, T. Nakanishi, and T. Hayashi, "Simple-Structure Low-Loss Multi-Core Fiber LC Connector," SUMITOMO ELECTRIC TECHNICAL REVIEW, No. 93, pp. 13-18 (2021)

(3) T. Kasuga, Y. Oka, Y. Okuda, Y. Tsuda, Y. Uchita, and J. J. Park, "Thinner Flexible Printed Circuits with Nano-conductive Paste," SEI TECHNICAL REVIEW, No. 80, pp. 8-11 (2015)

(4) T. Kawauchi, A. Iwata, H. Urayama, T. Izumi, T. Hagiwara, and Koichi Takayama, "Physical Layer Simulation Technology for Automotive Ethernet," SEI TECHNICAL REVIEW, No. 88, pp. 22-26 (2019)

Contributors

The lead author is indicated by an asterisk (*).

H. MISHIMA*
• Group Manager, Analysis Technology Research Center

K. TAKAHASHI
• Group Manager, Analysis Technology Research Center

Y. NAKAMURA
• Group Manager, Analysis Technology Research Center

T. TERAO
• Doctor of Engineering
Group Manager, Analysis Technology Research Center

S. SHIMADA
• Director, Analysis Technology Research Center