3D CAD and Simulation-based Analysis Utilization for Halving Person-Hours in System Equipment Development

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Fujitsu has a history of optimizing the design process for server packaging structures and printed circuit boards to foster innovation in the quality, cost, and delivery (QCD) of equipment development. Enhanced and efficient desktop verification and information and communications technology (ICT) application are essential for reducing person-hours in equipment development. To this end, Fujitsu has been applying computer-aided design (CAD) tools capable of handling actual 3D shapes plus simulation-based analysis in upstream design and development to facilitate desktop verification covering equipment design, assembly, and inspection in mass production and maintenance in the field. This paper describes Fujitsu's current efforts in enhancing desktop design verification by consolidating 3D CAD data for electrical and structural systems, which enables the design and production departments to share manufacturing information by embedding it in 3D CAD data, and by applying 3D CAD data in upstream design to design verification and analysis. It also describes the effects of these initiatives and discusses Fujitsu's future plans for further reforms in equipment development.

1. Introduction

Innovations in the development processes of personal computers and cellular phones have previously been introduced in this journal.[1)] This paper takes up innovations in the development process of server equipment, which has a more complex structure than the above products, with more components by two orders of magnitude. Its development has a high level of difficulty combining both electrical and mechanical aspects. Fujitsu server equipment targets high-performance and mission-critical systems, so providing highly reliable high-quality equipment is important to winning the trust of customers.

Competition has become increasingly severe in recent years. In addition to high performance and high reliability, products must now provide added value in the form of power-saving features, lightweight configuration, quiet operation, and low environmental load. They must also be brought to market at just the right time.[2),3)] Against this background, Fujitsu has been actively promoting innovation in the server equipment development process since 2009.

In this paper, we describe our activities to date for shortening person-hours in the development of server equipment and introduce new technologies that we plan to apply in the future toward more reforms.

2. Overview of halving person-hours in server equipment development

To halve the person-hours in the development process (design → evaluation → launch of mass production), we undertook cross-department and cross-process reforms and set as a target a 30% reduction in both development scale (number of test items, frequency of reevaluations) and development lead time. The objectives were to improve design quality in upstream design, optimize data coordination among departments and processes through the use of information and communications technology (ICT) tools, and shorten the time taken for design and verification.

To do this, we attempted to resolve the following three issues.

1) How to make design and verification more efficient by utilizing analysis and verification tools
2) How to judge the quality of manufacturing and maintainability through objective criteria to

reduce design rework

3) How to share verification information across departments and strengthen verification

In particular, to eliminate variation in design quality and design person-hours due to differences in the skills of individual designers, we have been applying the solutions we obtained to the entire development process, from design and design verification to manufacturing, inspection, and shipping while promoting ongoing innovations in the development process. Fujitsu's approach to halving development person-hours and examples of utilizing ICT in this series of activities are shown in **Figure 1**.

3. Reducing person-hours in equipment development by enhancing desktop verification

3.1 Background

In the design of server equipment, an approach that coordinates the enclosure side with the printed circuit board (PCB) side has come into use to deal with the complex spatial configurations inside the equipment as a result of high-density packaging. Checking for any interference between individual structures must be done with high accuracy. Up to now, when combining the enclosure-side and PCB-side structures utilizing a computer-aided design (CAD) system and checking for interference, a difference in quality would later emerge in initial testing with actual equipment due to differences in the skills of individual designers. In other words, even when checking for interference using data representing the same completed unit, the accuracy of that checking would differ between two types of designers: those who took into account actual workflow and operations such as PCB component mounting, equipment assembly, and equipment maintenance and those who checked for interference only for completed equipment in a stationary state.

The need therefore arose for a structure and rule that would enable the states associated with manufacturing, assembly, and maintenance to be visualized so that any designer could comprehend and verify the target structures.

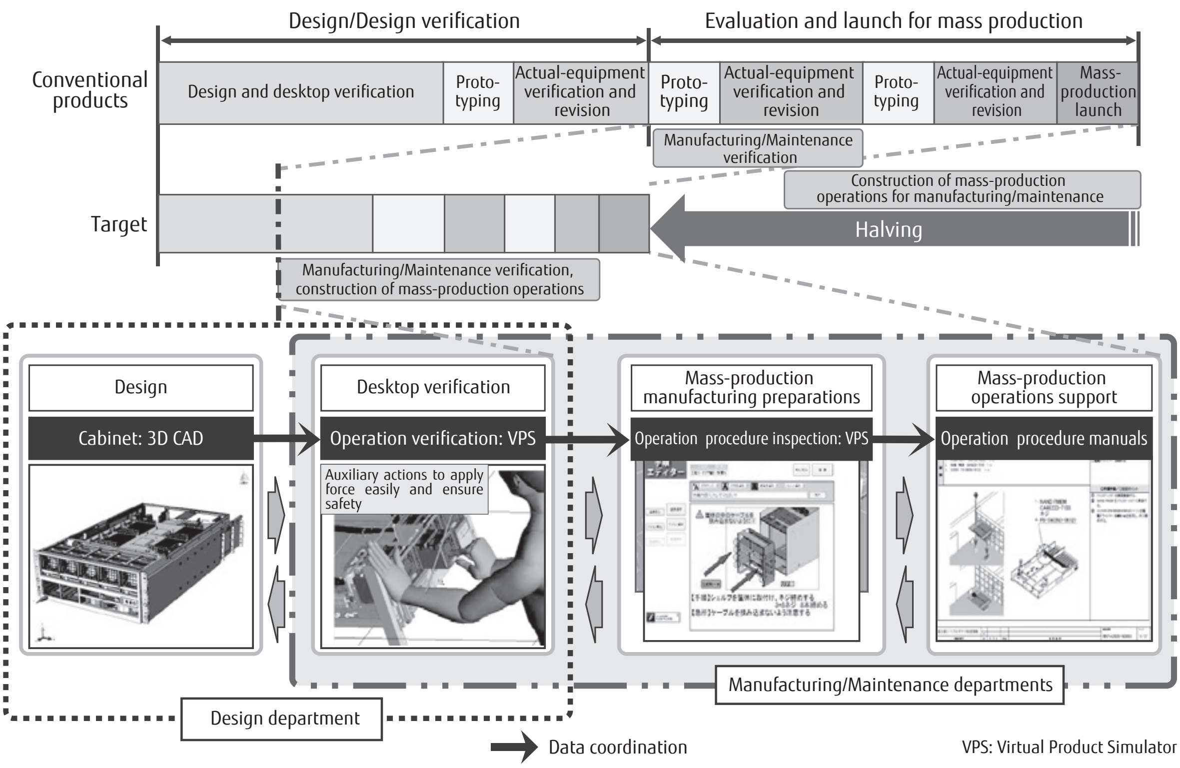

Figure 1
Halving development person-hours (target) and use of ICT.

3.2 Measures

At Fujitsu, we use 3D CAD to design the server enclosure structure and 2D CAD to design the PCBs, including component placement and wiring. We have extended the functions of Fujitsu's Virtual Product Simulator (VPS)—a 3D data viewer conventionally used in verification testing based on digital mock-ups (DMUs)—to enable 3D visualization of both types of CAD data. This approach enables desktop verification that integrates the equipment's electrical and structural systems and provides comprehensive and detailed views.

The following summarizes representative functions and verification methods in this approach.

1) Display state of assembly and check range of component movability in actual assembly procedure. An example of an interference review in a mechanical section when operating a lever is shown in **Figure 2**.
2) Visualize assembly of units and enclosure and range of movability of levers and other components during maintenance operation.
3) Check mating state of components and units in detail with a cross-sectional display.
4) Perform qualitative verification of human response regarding ease of assembly or maintenance using sensory criteria defined for server products.

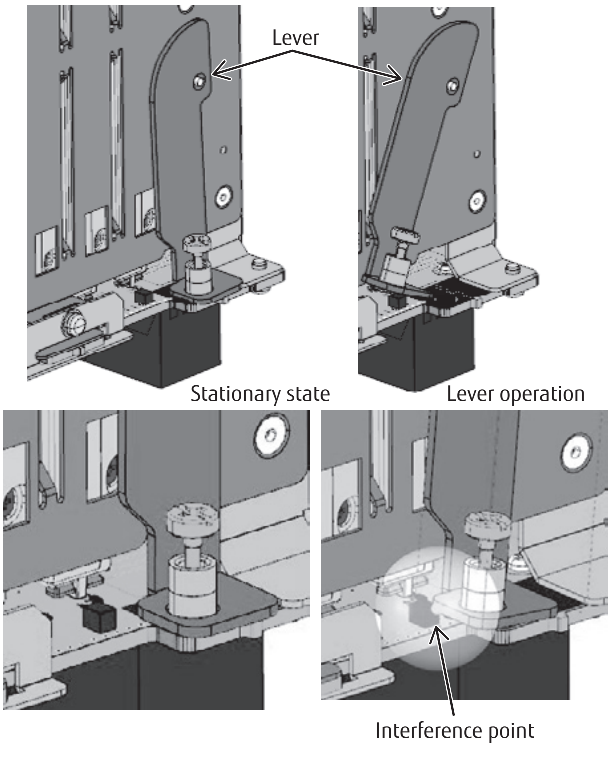

Figure 2
Example of mechanical interference review.

These methods facilitate desktop reviews in all departments including design, manufacturing, assembly, quality assurance, and maintenance before constructing unit or enclosure prototypes, thereby providing valuable feedback to product design.

Although it was possible in the past to combine PCB CAD data and enclosure data in equipment verification by using VPS, it was difficult to coordinate data such as verification findings and troubleshooting results. We have since enhanced the VPS Knowhow Share function (a database consolidating the design know-how for server products) to enable the sharing of verification content among multiple departments and to make reviews more efficient.

3.3 Example implementations

1) VPS review of enclosures and units

First, the design department describes the assembly procedure for the enclosure's metal panels and the installation and maintenance procedures for the target units. Next, the persons in charge of manufacturing, maintenance, quality assurance, packaging, and PCB wiring design perform their respective checks by using VPS and input their concerns and items for improvement into VPS Knowhow Share. Finally, this content is checked within the packaging structure department, and a decision is made at a design review on whether countermeasures are needed.

2) VPS review of PCBs including mounted components

To perform a check that focuses on interference between the PCBs and the enclosure's metal panels, we use VPS to overlay mounted-PCB data on panel data. The following summarizes the main verification points.

- Check for interference between structural components, such as enclosure panels and screws, and electronic components, such as wiring patterns and components mounted on PCBs. An example of testing for interference between structural and electronic components is shown in **Figure 3**.
- Check for interference between enclosure panels and component pads, via lands, and wiring

patterns on nearby PCBs when making a PCB or enclosure vibrate.

- Since PCB components may lie outside the worker's view (in blind spots), check if any PCB-mounted components may have been damaged by pressure applied due to handling at assembly time.
- Check whether any component pins, etc. protruding from the backside of a PCB may injure a worker's hands during assembly operations.

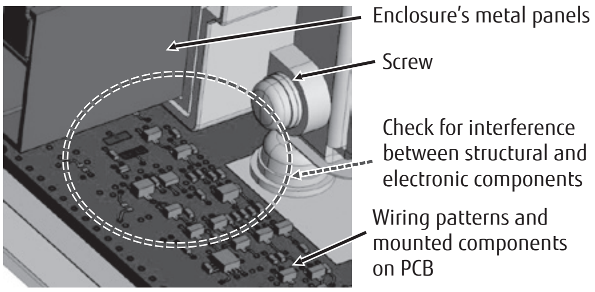

Figure 3
Example of testing for interference between structural and electronic components.

This kind of review can test for interference from a variety of perspectives, which means a higher quality review at the design boundaries between the electrical and structural systems from PCB wiring to enclosure structure. In this way, the time required for design verification has been shortened, and efficient development of equipment with high-density packaging has been achieved.

3.4 Future activities

Progress in the use of 3D shapes is shown in **Figure 4**. In present 3D CAD, a component can only be represented in a simplified shape that shows its width, depth, and height in cuboid form. Such a simplified shape takes on the appearance of a pillar formed from the 2D faces of that component, which may have a complex structure. This simplified shape consequently turns out to be larger than the actual size of the component, which means that the use of simplified shapes in high-density design will create extra space in the actual components, making accurate interference checks difficult. One way of preventing this situation is to create 3D models for actual components from simplified

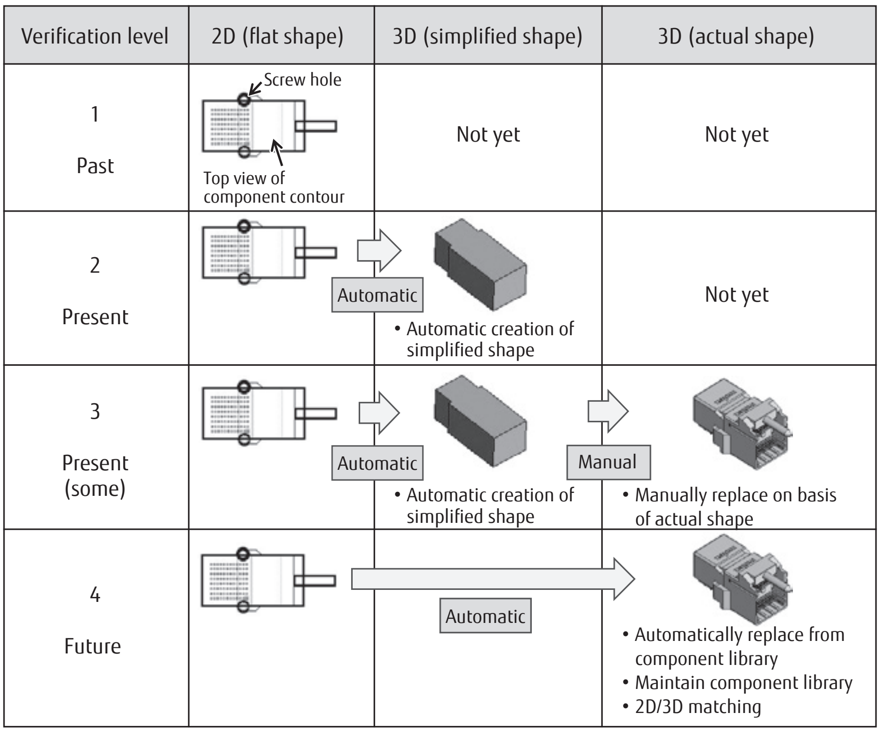

Figure 4
Progress in using 3D shapes.

shapes, but this requires manual work. In addition, to reproduce the movement of movable components, reviews must include elements such as component weight and center of gravity. Reviews that include such information can also facilitate the evaluation of the ease of actual assembly and maintenance work.

In light of the above issues, the plan is to automatically replace simplified shapes with 3D models of actual components on an integrated platform now under development. This will make it possible to perform desktop reviews at design time with shapes that approximate actual components. This capability will enable us to aim for higher densities of equipment packaging and elimination of reworking by achieving a 3D model that requires no revisions in equipment reviews.

4. Reducing person-hours in equipment development by enhanced design data coordination

In this section, we introduce a new standard method of 3D modelling and drawing for achieving further reduction in person-hours and reliable advanced verification utilizing 3D CAD as well as enhanced coordination of 3D data and various types of analysis tools.

4.1 Background

At Fujitsu, we have been promoting the use of 3D CAD in the development of server equipment since 1995 to make development work more efficient and improve design quality. We have also linked 3D data to a variety of analysis and verification tools and constructed a mechanism for coordinating design reviews, design verification, prototyping, and mass production (involving the improvement of tools and creation of procedures). In this way, we have made design work more efficient, decreased development lead time, and reduced development scale.

At the same time, design by 3D CAD has become mainstream even in the electronics and automobile industries having a large market scale, but regardless of the manufacturing process in both industries, 2D drawings that contain manufacturing know-how accumulated over many years are still easier to work with. Since the number of person-hours required to create 2D drawings generally makes up about 30% of total design person-hours in the case of ICT products, it is essential that the number of person-hours spent creating 2D drawings be reduced in order to control design person-hours and improve added value.

We are thus working on restructuring the design process through the use of a new 3D model, 3D Annotation (3DA). Product manufacturing information (PMI) needed for manufacturing is conventionally described in 2D drawings. The PMI includes dimensions and tolerances, text annotation, surface finishing, and materials specifications. The use of 3DA will enable PMI to be embedded in 3D models. This, in turn, will enable us to eliminate 2D drawings and make development and manufacturing more efficient. In relation to this, the Japan Automobile Manufacturers Association, Inc. (JAMA) and Japan Electronics and Information Technology Industries Association (JEITA) have been investigating the creation of 3DA operation rules that address the need for design and manufacturing coordination using 3D data.

4.2 Expected effect of 3DA at Fujitsu

We have begun to introduce 3DA in the development of server products and to engage in early 3DA-related activities while taking the above operation rules into account.

In fiscal year 2014, we studied the JEITA 3DA guidelines, examined market trends, and performed a functional verification with 3D CAD, and, as an initial activity, conducted a trial to check the effectiveness of 3DA with small-scale components.

Figure 5 shows the differences in the flow of design information from design to manufacturing between conventional design based on 2D drawings and 3DA as implemented by Fujitsu. In conventional design, 2D drawings are created from 3D models, dimension-related information is added to those drawings, and that information is delivered to the manufacturing and inspection departments in either paper form or as digital data in PDF format. However, when embedding special design conditions in a 3D model and using a 3D viewer to verify those conditions and component dimensions in each process, there is a need for a process that can deliver that information via the 3D model. Fujitsu 3DA delivers 3D models with embedded PMI to the manufacturing and inspection departments for production transition. Compared with conventional design using 2D drawings, it is sufficient for the PMI

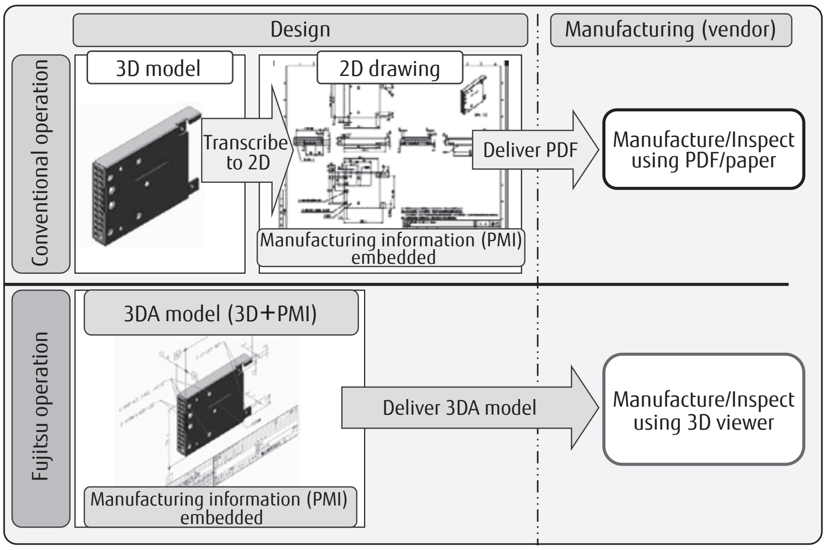

Figure 5
Operation of 3DA.

input into Fujitsu 3DA to be limited to information such as reference positions, locations requiring tolerance, and special work instructions, which means less data to input.

Including all required information in 3D data enables uniform management of design information. It facilitates sharing of information from design to manufacturing with all concerned parties including manufacturing vendors while reducing person-hours spent preparing drawings and shortening manufacturing lead times.

4.3 Future activities

In addition to working on the preparation of 3DA procedure manuals and operation tools, we are currently cooperating with post-design departments such as manufacturing, inspection, and quality assurance to set up 3DA browsing methods and tools for application to new server products. At the same time, we must keep up to date on all 3DA tools. We are currently relying on CAD vendors via JEITA for functional extensions in tools and new functions as well to make 3DA creation more efficient.

Enhanced data coordination between manufacturing vendors and Fujitsu plants is needed to accelerate the deployment of 3DA, so we are promoting cooperation between them with regards to manufacturing facilities and systems.

To achieve a development environment that can transform the structure and rules of Monozukuri (Japanese way of manufacturing), we need to minimize the PMI created by 3DA and effectively coordinate the sharing of 3DA information among the various processes, including manufacturing and inspection. We also need to incorporate geometric tolerances to accurately convey the intention of a design to the manufacturing side. At Fujitsu, we are studying methods for defining geometric tolerances based on advances in this area at JEITA. Going forward, our plan is to reduce person-hours in the creation of 3DA and create a mechanism for data coordination that includes the manufacturing and inspection departments and vendors as well.

5. Utilization of analysis to improve upstream design quality

Fujitsu has been using various types of analyses in server equipment development since 1993. In the beginning, the focus was on design issues and problem solving, but with the subsequent appearance of highly convenient analysis tools in parallel with the spread of 3D CAD, the utilization of analysis in equipment development has taken hold.[4] In this section, we describe the effects of various types of analyses in improving the development of server equipment and introduce future Fujitsu initiatives in this area.

5.1 Reducing manufacturing analysis person-hours

Key issues in server design include the reliability of mating connectors between PCB units and of solder joints between electronic components and PCBs. There is also concern about deformation associated with thinner and lighter panels or caused by maintenance operations and about damage caused by stress. It is therefore necessary at the design stage to identify and solve these problems to shorten design lead times. However, the structural analysis of servers is essentially the analysis of an integrated piece of equipment having a complex combination of many components. As a result, such analysis has traditionally required more than ten days to complete. There is therefore a need for making the work of analysis more efficient. For this reason, we have simplified mesh partitioning in the modeling process from 3D CAD shapes while maintaining dynamic consistency. A problem here, though, is that variation in manually performed modeling can affect analysis results. To address this problem, we have extracted modeling know-how accumulated by analysis engineers and saved it in database form for sharing purposes. In particular, we have been automating the shape processing of 3D CAD data and creating rules for modeling at the enclosure level with a focus on fasteners, and we have passed on these developments to design engineers while continuing to use analysis from analysis engineers.

An example of our efforts in halving person-hours in deformation analysis is shown in **Figure 6**. We have shortened the time needed for analyzing deformation of server enclosures from about 10 to 5 days for a model with about 500 components and 3 million mesh cells and achieved uniformity in modeling quality.

At Fujitsu, we have undertaken the development of a large-scale solver, "FS-Solver" (FS: "flexible scale"), for in-house use to enable many more jobs to be submitted for the analysis of integrated equipment. We are also pursuing server equipment development through an integrated environment of CAD and analysis tools with the aim of shortening the execution time of analysis jobs. In future studies, we will explore ways of reducing person-hours in analysis work, envisioning a further increase in the number of components.

5.2 Application of tolerance analysis

Server equipment development requires highly accurate positioning in connector mating between PCB units and in assembly work. Accordingly, in the assembly of components having large variation in dimension tolerance, we check the quality of mating while calculating total variation in tolerance. Particularly, in assembly work using jigs, we determine optimal

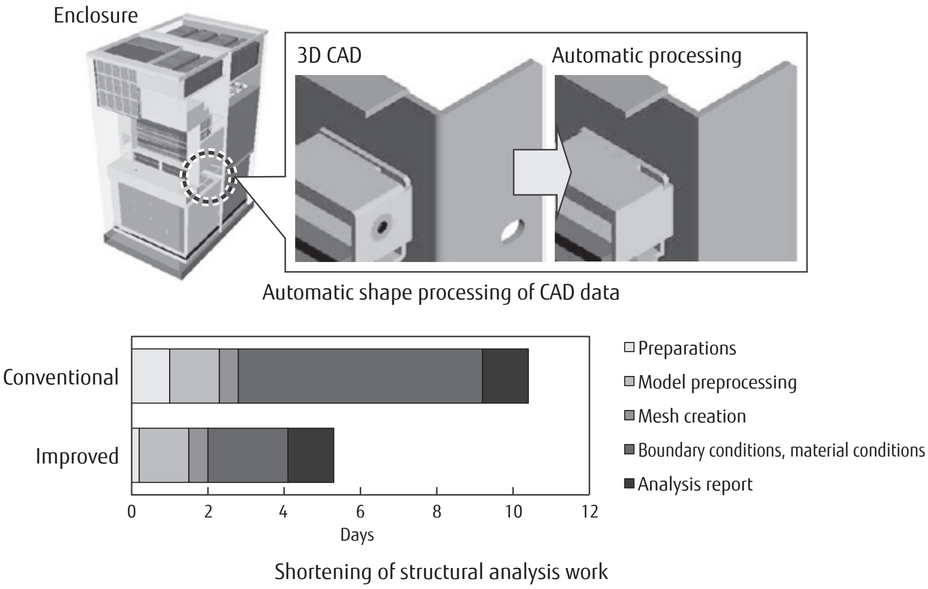

Figure 6
Example of halving person-hours by deformation analysis.

tolerances while promoting the visualization of what types of tolerance including rotation and movement have the greatest effect.

The process of verifying the positioning accuracy of a power supply connector when inserting the main PCB is shown in **Figure 7**. In initial design, dimension tolerance on the PCB side was large, and cumulative variation in the Y-axis direction was likewise large. However, by rotating the angle of the connector mating section by 90°, it was possible to decrease dimension tolerance by switching to cumulative variation in the X-axis direction. In addition, by enabling the visualization of connector mating and interference between components at the design stage, we are decreasing the amount of reworking due to problems uncovered in the equipment assembly process at plants.

With conventional techniques, tolerance analysis itself required two months for 50 components and separate verifications for each of the X, Y, and Z translation axes. In contrast, the use of a specialized tolerance analysis tool enables tolerance analysis to be completed in as little as 5 days for 50 components and a total of 6 axes (the X, Y, and Z translation axes and the 3 rotational directions around those axes). This improves the efficiency of verifying the accuracy of connector mating and component assembly.

The specialized tolerance analysis currently in use cannot incorporate deformation of equipment components, so deformed shapes must be created using CAD. We plan to link tolerance analysis and deformation analysis to improve the accuracy of verifying interference between equipment components.

5.3 Vibration analysis

Vibration in server equipment can give rise to a variety of problems. These include damage to fasteners between enclosure frames, disconnected connectors, and damage to the solder joints of electronic components due to an increase in stress. To prevent such problems from occurring, some form of analysis is needed prior to actual vibration testing as a means of verifying deformation modes and stress during vibration.

Conventional vibration analysis focuses on measures for decreasing stress in fasteners between members of the rack frame. However, with the coming

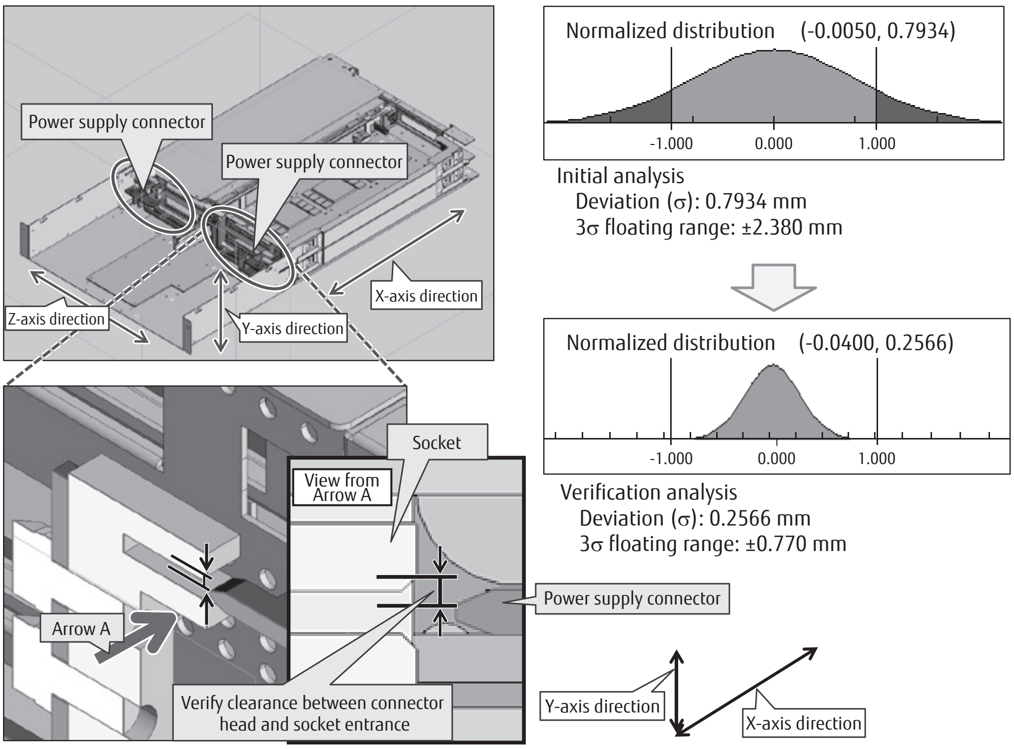

Figure 7
Example of tolerance analysis.

of high-density packaging, the number of components and units has been increasing as has the number of fasteners, so it has become necessary to analyze not only fasteners between members of the rack frame but also the state of the unit fasteners. Against this background, we have adopted techniques for searching out low-order vibration modes and inferring vibration modes conducive to the detaching of connectors through analysis based on detailed models of enclosures and units. As shown in **Figure 8**, it was found that low-order vibration modes are closely related to connector detaching. These techniques can thus clarify the behavior of fasteners due to vibration in a way that past analysis could not.

Vibration analysis of this kind has so far been put to practical use in the area of ICT products and particularly in devising countermeasures to dropped smartphones. However, vibration analysis has also become applicable to servers as equipment that consists of a large number of components, and the detection rate of behaviors that would likely appear in vibration tests has improved at the analysis stage.

In future studies, we plan to clarify which items should be part of vibration tests at the level of actual equipment having several hundred components while also working to improve the efficiency of vibration testing and verification. Specifically, we seek to improve the quality of vibration testing by focusing on locations where problems are likely to occur according to vibration analysis and determining where best to position accelerometers for measuring acceleration in vibration tests. Furthermore, to make vibration analysis practical to use while speeding up processing, we will consider the creation of libraries consisting of rack models, etc. to shorten the person-hours taken up by modeling and thereby reduce analysis person-hours by half or more (such as from two months to two weeks).

5.4 Composite analysis between structural and thermal phenomena

One issue in improving cooling performance is how to decrease contact thermal resistance when connecting a heat sink to an LSI package, especially since the amount of heat generated by LSI devices is on an upward trend. Factors governing contact thermal resistance are variation in the material properties and

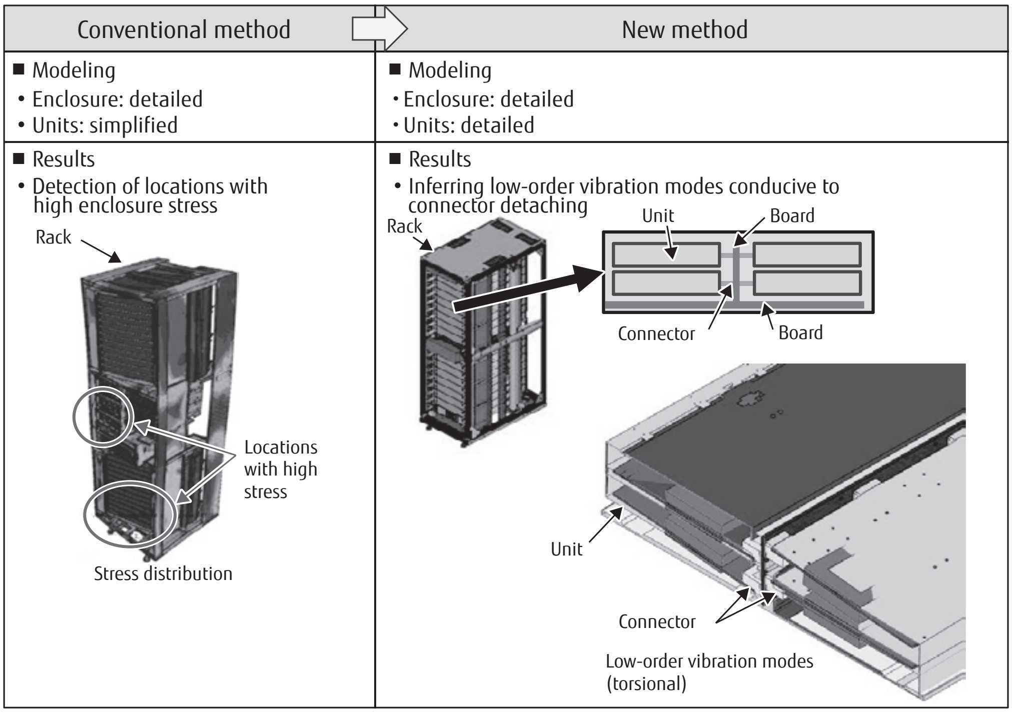

Figure 8
Example of vibration analysis in equipment.

thickness of a thermal interface material and variation in screw tightening load at the time of assembly. In addition, the trend is for contact thermal resistance to make up a greater percentage of the total thermal resistance in the cooling system.

In the past, it was necessary to perform time-consuming testing with actual equipment to analyze the composite effects of structural deformation on contact thermal resistance. To enable such testing to be performed on the desktop, we have undertaken composite analysis that reproduces the mutual interaction between various structural and thermal phenomena.

To deal with many design verifications by composite analysis in a short period of time, there is a need for automatic cooperation between structural and thermal analysis tools. At Fujitsu, we have developed a coupler function that serves as an automatic cooperation tool between structural analysis and thermo-fluid analysis. This function associates the extent of deformation of thermal joints with thermal resistance by using a bidirectional coupling process (repeated calculations until temperature becomes constant). This process is shown in **Figure 9**. In addition, we performed a design verification by inserting a thermal sheet as the thermal interface material between the LSI package and heat sink and estimating by analysis the temperature of the LSI package when applying a screw tightening load. For a scale of about 1.5 million mesh cells for structural analysis and 9 million mesh cells for thermo-fluid analysis and 15 cases to be analyzed, the proposed technique could perform design verification in about 9 days compared with a month or more with conventional techniques. The results of analysis agreed with actual measurements and demonstrated that a thermal joint can peel under high torque. With these results, we were able to determine the allowable screw-tightening torque.

This screw-tightening torque will eventually be reflected in work procedures at assembly plants. We also plan to perform analyses that take into account factors that affect variation in thermal resistance and their rate of contribution, such as the assembly process at plants and the thickness and properties of thermal joints, with the aim of shortening verification tasks in thermal design.

In addition to promoting cooperation between structural analysis for manufacturing and thermal analysis, we will expand the field for simulation application in order to analyze more diverse phenomena in the future. We are presently developing a cooperation function in parallel with the development of FS-Solver specialized for in-house use. Our aim is to speed up design feedback and reflect it in the design of cooling structures for LSI packages to keep them within their specified temperature range. Looking to the future, our aim is to construct a composite analysis environment in the fields of electrical circuits, electromagnetic fields, optical waveguides, thermal fluids, and thermal stress.

6. Conclusion

In this paper, we introduced technologies for reducing person-hours in design verification of PCBs and server enclosures and described their application. These technologies utilize 3D CAD and diverse analysis tools in upstream development to perform desktop verification that can handle actual component shapes from manufacturing and assembly to maintenance.

Our plan for future activities is to enhance design verification by making maximum use of 3D CAD and various types of analysis tools and to integrate CAD and

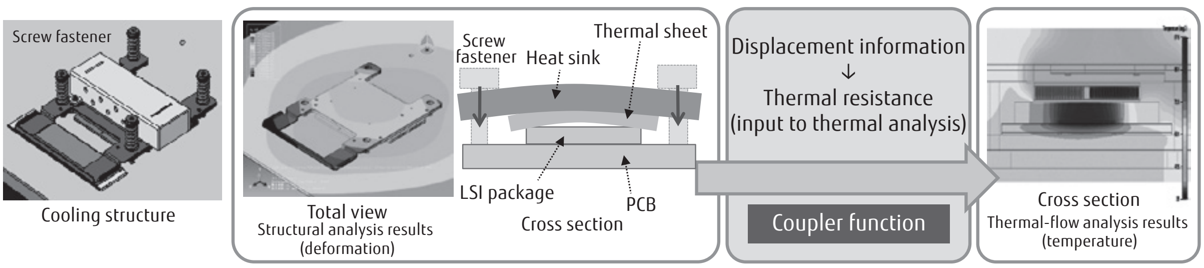

Figure 9
Example of composite analysis flow (manufacturing/thermal linking).

simulation data to achieve further gains in efficiency. For example, we can envision a fully automatic modeling system that generates simulation data without the need for processing CAD data. In short, we will energetically pursue improvements in design quality and design lead times through the utilization of 3D CAD and analysis tools with an eye to fostering innovations in quality, cost, and delivery (QCD) and expanding our server business.

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