Simulation Technology to Support the Design of Electric Distribution and Control Devices

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ABSTRACT

Simulation technology for electric distribution and control devices includes structural strength analysis to study case strength, the miniaturization of structural parts, and so forth, and mechanical analysis to improve efficiency of contact switching, handle operation, and so forth. Fuji Electric performs thermal analysis on the case, circuit board, and so on around heat subjects which directly affect the miniaturization of products, and the results are used to optimize the part layout. Other analyses are performed, including electromagnetic field analysis, resin flow analysis, and thermal conduction with electromagnetic field interaction analysis. It is currently possible to determine whether a design satisfies required functionality and specifications using simulations at the concept design stage.

1. Introduction

The transition to use of 3-D CAD in the design of electric distribution and control devices has made it possible to estimate at the conceptual design stage many factors such as product performance and cost, and ease of assembly and quality during mass-production. Development has become increasingly front-loaded, and improving the design quality early on in the development process allows the development to move forward without the need for backtracking.

At the conceptual design stage, the determination of the form in which to fabricate a part is highly influenced by accumulated product data and designer experience; however, simulation technology can now be used to determine whether the design satisfies functional and specification requirements. A designer can use a computer to determine whether his or her own ideas are feasible, and then fabricate a prototype.

This paper describes the simulation technology used in the development of electric distribution and control devices.

2. Simulation Technology

Electric distribution and control devices encompasses magnetic contactors, thermal relays, molded case circuit breakers (MCCB), earth leakage circuit breakers (ELCB), command switches and the like, which are the devices to switch the connection between equipment and an electric distribution system, or to protect the equipment and wiring from overcurrents. These devices have a mechanism for mechanically opening and closing contacts, and the attractive force of an electromagnet or the cumulative force of a spring is used as the driving force of the opening and closing mechanism. Simulation technology is effective for verifying the opening and closing mechanism and the driving force.

2.1 Contactors

For contactors, lower power consumption for driving and smaller size, as well as longer service life of the switching contacts are required. To develop mechanisms that satisfy these requirements, Fuji Electric has been studying using simulations (see Fig. 1).

The electromagnetic force that drives a contactor can be predicted by electromagnetic field analysis. The electromagnet is designed in consideration of the balance between coil power consumption and current with the electromagnetic force. From coupled analysis of a vibrating system that includes the electromagnetic force and the contacts, the contact bounce in a transient state and the like can be predicted, and parameters can be examined to reduce the contact bounce.

Because the impact force affects the contacts when

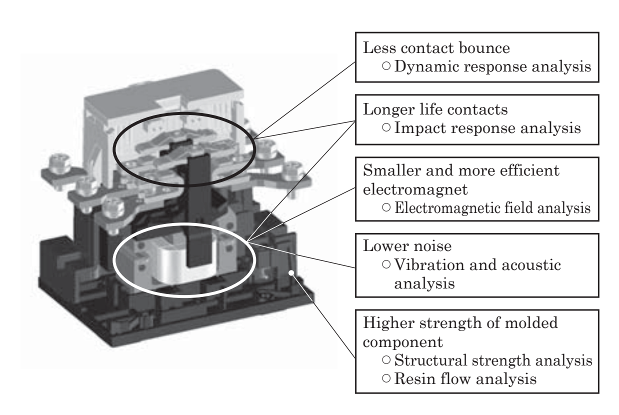

Fig.1 Simulation technology in contactor design

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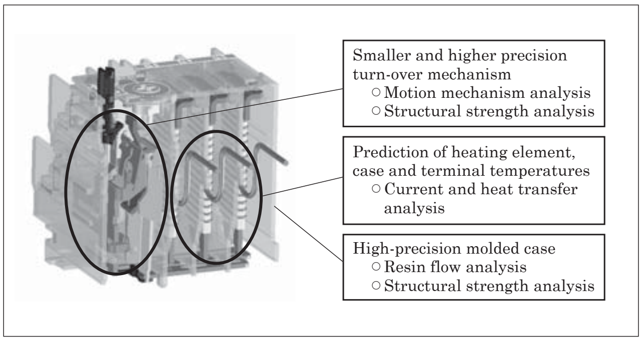

Fig.2 Simulation technology in thermal relay design

the core of the electromagnet collide with the end of the contacts, the effect must be known in advance for longer service life of the contacts. The results of these calculations can also be predicted by the aforementioned coupled analysis.

The case strength can be predicted using static and dynamic stress analyses, and by assessing the location of the weld line using resin flow analysis in advance, it can be studied whether the case strength is sufficient.

2.2 Thermal relays

Thermal relays are used in combination with contactors to prevent overloading of an electric motor, for example. A mechanical thermal relay is typically configured from a heater element, a bimetallic strip, contacts and so on. If an excessive current flows in the relay, the bimetallic strip gets heated up and bended. By this motion, the contacts will open and close. Figure 2 shows simulation technology which is used in the design of a thermal relay.

In addition to consideration of the heat generated by the heating element in a thermal relay, a coupled analysis of electric current and heat conduction that includes the bimetallic strip and wiring can be performed to predict the temperatures of the bimetallic strip, heating element, case body and terminals.

A key feature of the structural design is an analysis of the snap action mechanism which drives the contacts when the current exceeds a specified value. Structural analysis that includes elastic analysis of spring and contacts enables the operating characteristics to be predicted with higher accuracy.

2.3 MCCB and ELCB

Other representative examples of electric distribution and control devices are MCCBs and ELCBs. Figure 3 shows the simulation technology used in the design of these devices.

Because a handle is used to open and close the contacts in a MCCB, a key point of the mechanism design is to transmit accumulated spring energy efficiently to a contact lever. The design must be such that a switching action that complies with the specifications can be accomplished with an appropriate handle operating force, and that the mechanism will fit in a limited space. The use of motion mechanism analysis allows a designer's ideas to be visible immediately and quantitatively, and within the range of normal manufacturing dispersion, parametric design to be performed in consideration of their effect on the switching motion.

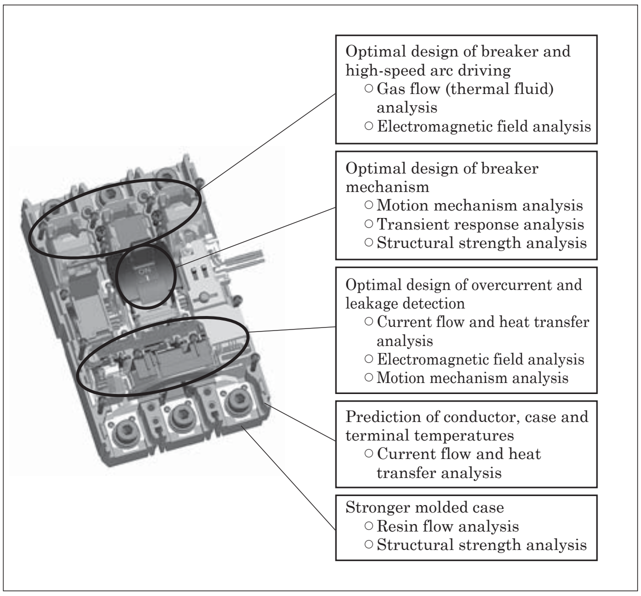

Fig.3 Simulation technology in MCCB and ELCB design

MCCBs and ELCBs are equipped with overcurrent protection and/or earth leakage protection functions, and some of them use bimetallic strips as in a thermal relay, or electromagnetic force. Their structure can also be studied by using thermal analysis and electromagnetic field analysis.

The technical challenge for a circuit breaker is to provide a large current breaking function at the time of a short circuit. The rapid transfer of an arc generated between contacts to an arc chamber, and the extinguishing of the arc are important aspects of the design. To assess this phenomenon, the arc motion can be estimated using gas flow analysis and electromagnetic field analysis.

In recent years, DC circuit breaker technology has been actively developed in response to an increasing need for DC electric distribution. In the case of DC circuit breakers, electromagnetic field analysis is used to determine the optimal location and shape of the electromagnet used for moving an arc in the low current region.

3. Application Examples

3.1 Structural strength analysis

The resin material typically used in electric distribution and control devices differs from steel in that its elastic region is indistinct. Moreover, resin filled with glass fiber exhibits a low level of plastic deformation. A linear-elastic model is sufficient to study strength qualitatively; however, analysis that considers the elasto-plasticity properties is necessary in order to make a quantitative determination.

The strength can be studied with high accuracy by using values of the mechanical properties of the resin obtained from the results of a tensile test or bend test using a test piece.

Figure 4 reproduces the test piece tensile test by simulation. Simulations now allow such study to continue up until reaching material fracture.

Figure 5 shows an example of the stress analysis of a molded case at the time of a MCCB short circuit. During a short circuit, arc heat causes the internal pressure increase in the case, and the transient stress condition at the time when the entire case expands as shown in the figure was examined. In addition to MCCBs, this type analysis is also used for contactors.

Figure 6 examines the strength of a miniature contactor terminal cover, assuming the pressure which is generated by arcing at the time of short circuit testing of the mini contactor. For the initial design, it was predicted by simulation that the cover would fly off as the pressure increases. Consequently, the shape of the hook on the cover and the like were reconsidered, and a structure that does not fly off at that pressure was adopted.

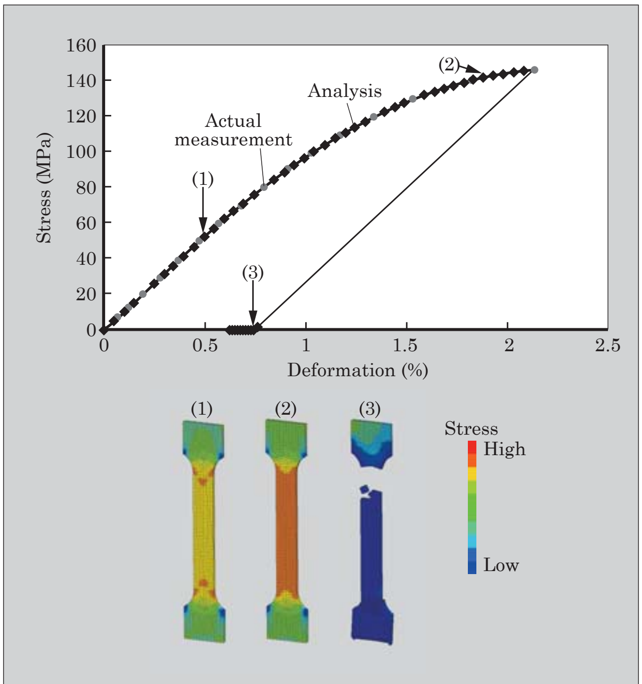

Fig.4 Simulation results of tensile tests

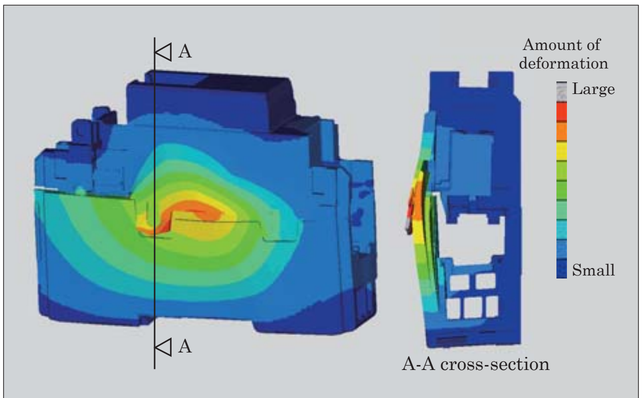

Fig.5 Stress analysis of MCCB at time of short circuit

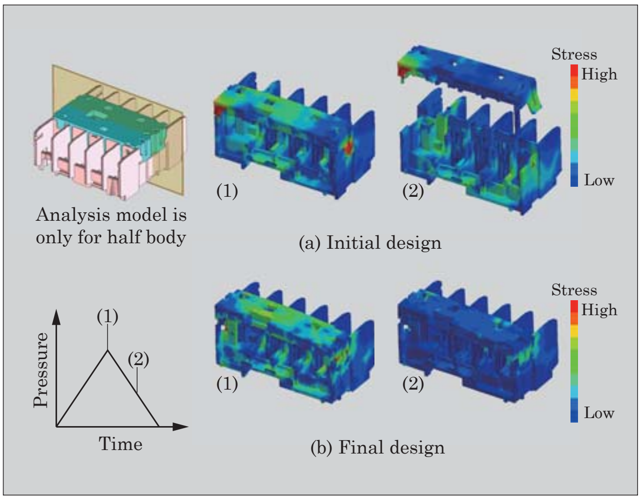

Fig.6 Stress analysis of miniature contactor terminal cover

Now that elasto-plastic analysis that includes an analysis of transient phenomena is carried out, product design can be implemented with a high degree of accuracy even in the early stages of design.

3.2 Motion mechanism analysis

Figure 7 shows analysis models of the contact mechanisms in a multi vacuum circuit breaker (multi-VCB) and a MCCB. Now that motion mechanism analysis is used, necessary parameters for the design, i.e., the handle operating force, contact switching speed, trip load, etc., can be predicted using a PC. Such motion mechanism analysis is also used in the design of shifters and differential mechanisms for thermal relays and the like, as well as in the design of switching mechanisms.

Figure 8 shows a shifter and a differential mechanism of a thermal relay. The thermal relay transmits the amount of bend of a bimetallic strip which has been heated by a heater element to a turn-over mechanism. In the case of overcurrent protection only, the shifter structure serially transmits the amount of bend of the 2-phase bimetallic strip to the turn-over

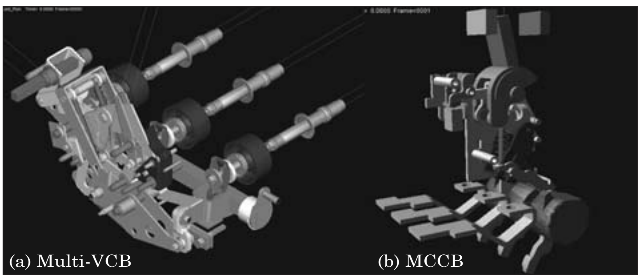

Fig.7 Example of motion mechanism analysis model

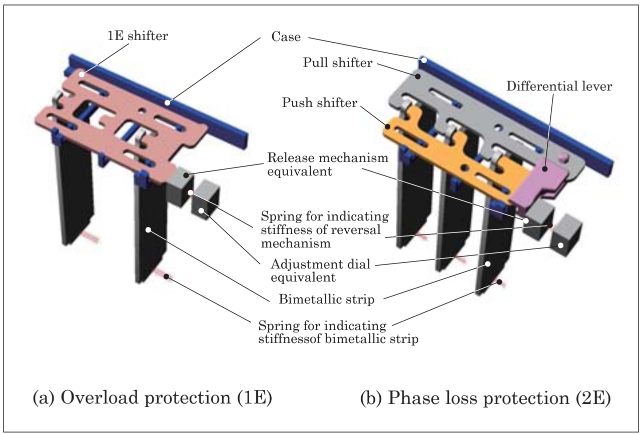

Fig.8 Motion mechanism analysis model of thermal relay unit

structure. On the other hand, in the case of phase-loss protection, because current stops flowing in one of the three phases, the bimetallic strip will be in a non-bend state, and a differential shifter is used to transmit the difference to the turn-over mechanism. The amount of curvature of the bimetallic strip is affected by many parameters including the stiffness of the bimetallic strip itself, the location of support of the shifter, resistance due to friction, the effect of stiffness of the turn-over mechanism, and so on. By using motion mechanism analysis, the part of the shifter causing resistance can be identified visually, thereby enabling the design of a shifter with low dispersion and good efficiency.

Moreover, in the development of thermal relays, the abovementioned motion mechanism analysis can be coupled with the thermal analysis described in section 3.3 to predict characteristics from current input to turn-over motion.

3.3 Thermal analysis

The heat sources in electric distribution and control devices include the Joule heat arising from current flow, contact resistance, the heater element, and the like. Because miniaturization directly affects thermal characteristic, the temperature distribution of a product must be known in advance.

Figure 9 shows an example of the thermal analysis of a thermal relay. In products connected to wiring, modeling of the wiring is important since inflows and outflows of heat from the wiring are not negligible. Modeling of this part based upon previous actual measurement data improves the accuracy of prediction.

Through performing thermal analysis, in addition to predicting the temperature distribution of the bimetallic strip itself, the temperature of a compensating bimetallic strip, the terminals and the case can also be predicted. As a result, a determination as to whether the assumed structure is appropriate can be made at the evaluation stage, and development can proceed without redoing.

Many types of electric distribution and control devices contain integrated electronic parts, and thermal analysis is also applied to these various electronic parts. Figure 10 shows an example of thermal analysis carried out for the miniaturization of the printed circuit board of a contactor. The area of the printed circuit board of the new structure has been reduced to approximately 75% of the size the previous product. In miniaturization achieved simply by shrinking the previous layout, the effect on heat sensitive components such as capacitors and varistors would have been a concern. Therefore, thermal analysis was used to predict the temperature distribution and to determine an optimal layout.

3.4 Electromagnetic field analysis

Various types of AC and DC electromagnets are used in electric distribution and control devices. At present, small electromagnets that have low loss and high performance can be designed using electromagnetic field analysis. Electromagnetic field analysis is used not only for designing electromagnets, but also for predicting the behavior of tripping devices that sense overcurrents and earth leakage, small transformers for pilot lamps, the electromagnetic repulsion on contacts and arcing that occur when an overcurrent flows, and the like.

Figure 11 shows an example of the electromagnetic analyses performed in consideration of the arcing behavior in a 1,000 V DC-applicable breaker. The placement and size of the electromagnet shown in the initial design results in a weak Lorentz force for driving the

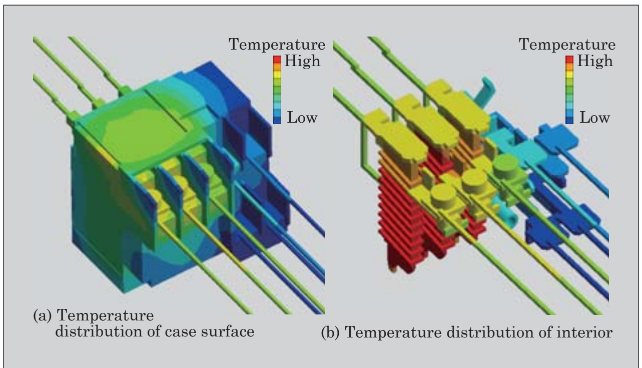

Fig.9 Thermal analysis of thermal relay

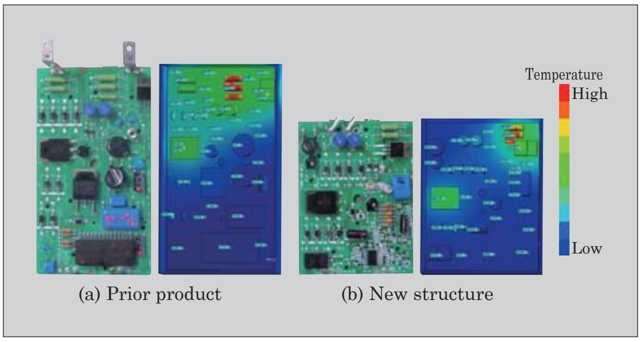

Fig.10 Thermal analysis of printed circuit board

arc; however, the final design clearly shows that a Lorentz force sufficient for driving the arc can be obtained. Accordingly, it has been possible to design low-loss, high-performance electromagnets.

Because a zero point does not exist for the electric current flowing in a DC circuit, the arc generated between contacts must be transferred within a short time to an arc chamber where the arc is stretched and cooled so that the arc voltage gets higher than the power supply voltage, and the current flow is cut off. In the case of a large current, the arc moves as a result of the magnetic field of the arc itself or by gas flow generated by a high-temperature arc; however, in the low voltage region, this effect cannot be expected and therefore the electromagnetic force of a permanent magnet is used.

In the early stage of development of a 1,000 V DC-applicable breaker, a study was carried out using electromagnetic field analysis, and the results have enabled a significant reduction of prototypes fabricated and have shortened the development term.

3.5 Resin flow analysis

Because resin material is used in many components employed in electric distribution and control devices, war page and shrinkage after molding, weld locations and the like must be checked in advance.

Figure 12 shows an example of the crossbar of a low-voltage circuit breaker for which high dimensional accuracy is required. The crossbar is a component that transmits the deformation of a bimetallic strip or solenoid arising from overcurrent or earth leakage sensing to switching mechanism, and requires a certain degree of accuracy that corresponds to the warpage deformation. Because a large deformation after molding was predicted in the initial design, the thickness of the crossbar was equalized to lessen the warpage deformation.

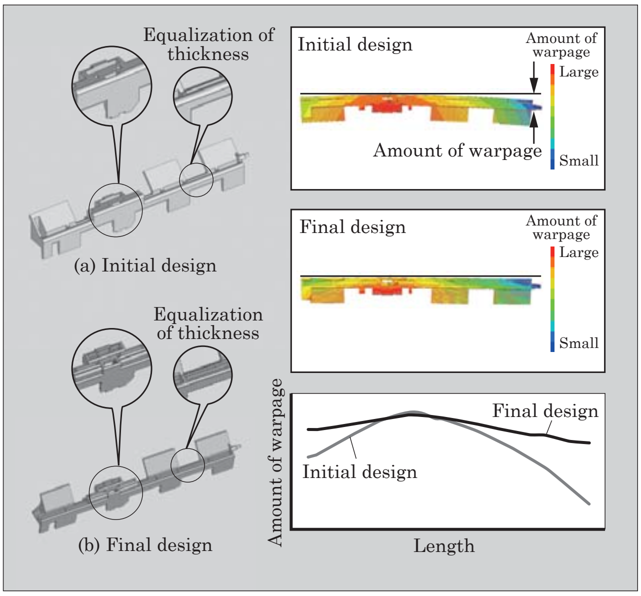

Fig.12 Resin flow analysis of crossbar

The problems of warpage and shrinkage after molding can be overcome in some cases by changing the gate location or molding conditions, but usually a design change is required. For this reason, performing resin flow analysis at the early stages of the design is important for shortening the development period.

3.6 Coupled analysis of thermal flow and electromagnetic fields

For electric distribution and control devices, predicting and controlling the behavior of arcing that occurs when the contacts are opening or closing are important challenges. Fuji Electric has previously responded to these challenges by using thermal fluid analysis of arc ablation and Lorentz force analysis of the arcing based upon electromagnetic field analysis. To increase the accuracy of predictions, Fuji Electric has developed arc behavior simulation technology that

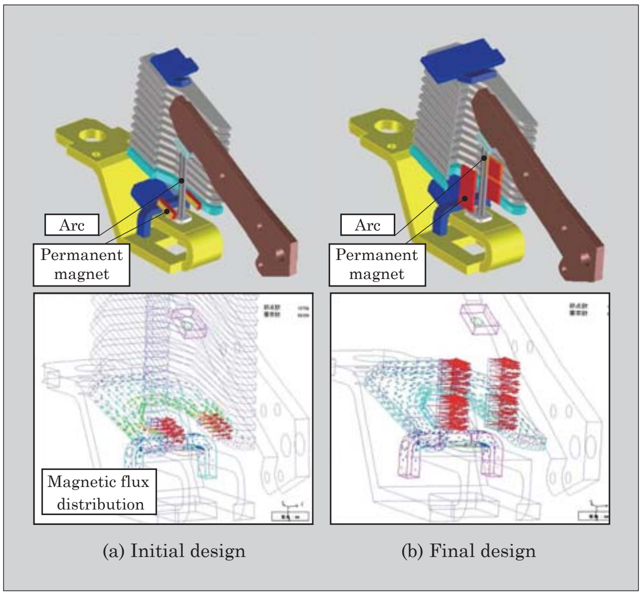

Fig.11 Electromagnetic analysis of MCCB cutoff part

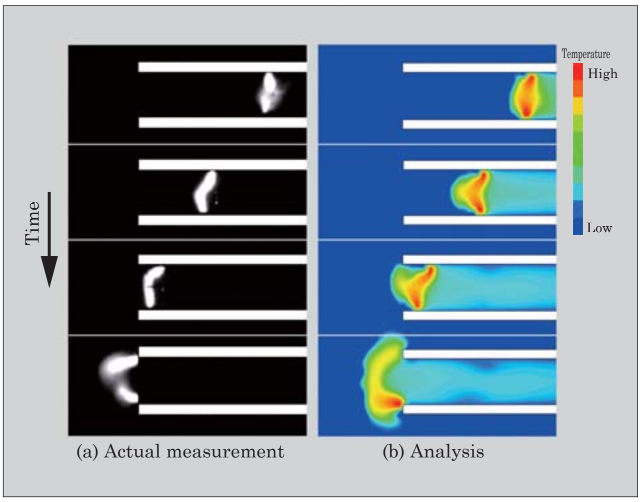

Fig.13 Simulation of arc behavior

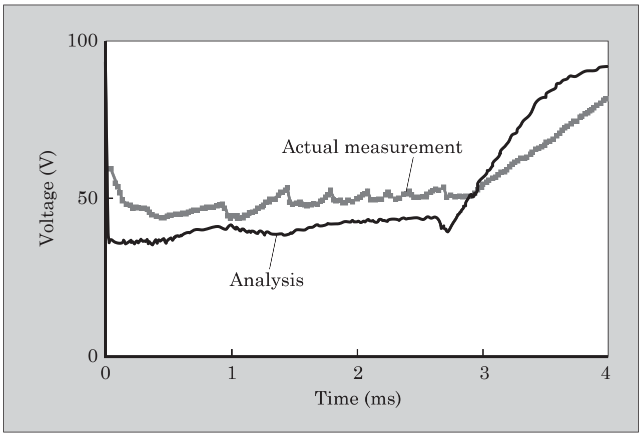

Fig.14 Comparison of arc voltage

couples thermal fluid analysis and electromagnetic field analysis.

Figure 13 is an example, reproduced through simulation, of the arcing behavior of parallel conductors. A current of 100 A is flowed between conductors spaced apart by 10 mm to generate arcing, and the arcing behavior and voltage levels at that time are compared.

Figure 14 compares the analysis and actual measurement values of the arc voltage. By using this analytic technique, the magnetic and electric fields that generate arcing, as well as the gas flow caused by arc heating, can be taken into account and therefore the effect that includes the magnetic field and pressure of the extinguishing chamber, and the influence of an external magnetic field from a permanent magnet, can also be evaluated.

In the future, after further study, this analytic technique will be applied to actual electrodes.

4. Postscript

Since simulation is a technology built upon a simplification of physical phenomena, it cannot reproduce all actual phenomena. However, in the product design stage, simulation technology is an extremely effective means for quantifying and visualizing the effects of various parameters. Prior to applying this technology as a tool, the physical phenomena that make up the product must be understood and the limits to which verification by simulation is possible must be known.

As a result of the higher level of performance of PCs and more sophisticated pre- and post-processing capabilities, simulation technology that previously could have only be implemented by analysis experts is now readily available for use by designers. In the early stages of development, the ability of designers themselves to run simulations of their own ideas is expected to create to good products.

Based on the data and knowhow acquired to date, Fuji Electric intends to contribute to the fabrication of even higher quality and higher performance products by advancing further the simulation technology available to designers.