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KYB

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Foreword

Encouraged by "The Innovator's Dilemma"

SAITO Takashi*

We have enjoyed the opportunity to engage in joint research with the KYB Group since 2018. Thanks to the Group, this joint research has been accumulating a track record beyond all expectations, including a co-written research thesis that won an best paper award [1] last year. The award-winning thesis covers a telescopic mechanism called a clustered convex tape manipulator. This mechanism has a simple structure in which lengths of material like measuring tapes are bundled (Fig. 1), which is apparently an ultra-low-tech product that may not be expected from an university.

When I was asked to write a foreword for the Technical Review, I decided to put together the many twists and turns during our development of the telescopic mechanism and a book behind the meandering path. Please let me tell you my long personal story.

I graduated from the Department of Biochemistry and Engineering at Tohoku University. Since then, I have gone through various circumstances and shifted into a wide range of research involving device development.

When I was in a biophysics laboratory during my last year of university, I researched the decomposition of photosynthetic bacteria to reconfigure photosynthesis capability. In the research using nuclear magnetic resonance spectroscope, a key factor was a component that can photo-irradiate test tubes in a tiny measurement space under a high magnetic field. The component was made by an alumnus of the laboratory for his doctoral dissertation. I realized then that, when you wish to do research on something that does not yet exist in the world, you need to create something new, no matter how small. That event left a big impression engraved on my mind.

During my master's program, I moved to an analytical chemistry laboratory for various reasons. There I was in charge of partly developed spectroscopic equipment (time

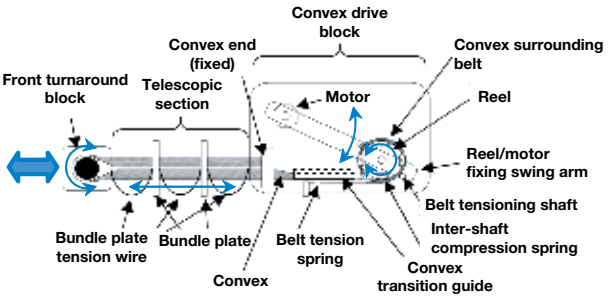

Fig. 1 Clustered convex tape manipulator mechanism

resolved fluorometers). Unfortunately, the equipment did not work at all. Its pulse nitrogen laser light source generated enough electromagnetic noise to shut down the control PCs. Its measuring part was based on trigger specifications different from those for other units to be synchronized even though they were included in a product family from the same manufacturer. I often visited a library to study electric engineering and took various measures including noise control and signal inversion. It took more than one year to finally get the equipment to work properly. This experience enhanced my skill of handling such device, but I wanted to study subjects more related to biomedical engineering. Then, I entered the University of Tokyo as a transfer student for the doctor's program in the Department of Advanced Interdisciplinary Studies.

In the laboratory where I worked, I tried to build an interface to send/receive information to/from nerve cells with the aim of controlling artificial limbs through neural information from a living body. As a result, I discovered that living cells could recover from damage caused by oxidation even if they were perforated with large holes [2], by taking a cue from a failure in an experiment that stimulated neural cells with light. Finally, I earned a Ph.D. for its application in 1999.

During this period, I made various devices myself because I took it for granted that students in a doctoral program should make devices themselves when working

*Professor, Akita Prefectural University

on a novel study worthy of a Ph.D. However, I had many difficulties in obtaining stable data with self-made devices. I eventually wrote a doctoral dissertation with much less data compared to studies by graduate students in other general biology-based departments. I was constantly bothered with a sense of discomfort that there was something wrong with my way of researching.

When I more or less settled down after managing to earn the Ph.D., I had the opportunity to read a book titled The Innovator's Dilemma [3].

This book is a masterpiece in the management field, which may have been read by many of the readers of this Technical Review. Let me give a summary to those who have not yet read it. The book analyzes what happened to companies that fell into decline in various fields, concluding that "they fell into decline because they were excellent". The key points can be summarized as:

[1] An established company cannot meet its growth needs in a small market: A new emerging technology that is apparently at a low level and has many weaknesses can be turned into a small business field if its features not found in any conventional counterparts are demanded by customers. Such a small business field is not attractive to established companies, but it is too late for them to enter the market after its expansion.

[2] Nobody can analyze a market that does not exist: A company with excellent analysis capability will not enter a market that cannot be analyzed. The essential value of a new technology is often not recognized by the supplier itself to begin with. A new technology is usually developed by the supplier and its customers on a trial-and-error basis.

[3] The supply of a technology is not necessarily equal to the demand in the market: Even when products in a technology area have a higher performance, they will not be sold if nobody uses them. Rather, there arises a space for lower-level, lower-cost new technologies, which could meet similar needs, to enter the market.

The author defines these lower-level, lower-cost, but high-potential technologies as "disruptive innovations" and simply-improved technologies as "sustaining innovations". The final part of the book describes how companies should promote their former innovations for their growth.

Actually, I was encouraged by the book because I thought what I was doing could be classified as disruptive innovation, and because I liked history, including the history of engineering, in the first place, the analysis in the book was totally matched with my knowledge of history.

Among the cases introduced in the book, some describe the effects of hydraulics on the excavation equipment industry. According to the book, the shift in excavator engines from steam to gasoline was a sustaining innovation while the shift from cabling to hydraulics was a disruptive innovation.

In parallel with this shift, KYB made a full-scale effort to enter the hydraulic equipment market, as described in detail in the KYB 80-year History [4]. I was really excited about the history when I read it. It is particularly marvelous that the company's accumulated expertise and technology on hydraulics since its foundation contributed to the entry into the market. This is definitely demonstrated by how the KYB Group has developed thereafter.

After that, I became clearly aware that "you can achieve a goal with either low- or high-level technology as long as the goal is essentially correct, and you may see something only after the technology is realized and used." The achievements of our development at that time were Shiroyagi [5] , which is an animal-imitating robot, and a convex-based telescopic mechanism [6]. I jointly developed these products with my colleagues in the laboratory almost as a hobby toward the KAWASAKI ROBOT Festival [7], which is a competition of fighting games among radio-controlled robots. Shiroyagi (literally means white goat) can be positioned as a full-size "artificial body" for animal experiments on neural interfaces. Partly because of this positioning, the robot is intentionally based on a toy-like, link-type leg mechanism with priority placed on speed and mountability and incorporates a mechanism to deflect the thrust by the legs.

Since then, we continued to participate in the Festival every year while riding the wave of digital manufacturing, enhancing our prototyping and development capabilities. However, Shiroyagi had gradually come to be defeated by other robots specially designed for fighting. Under this situation, we implemented an idea about robots that can punch the opponent from a long distance immediately after the start of a game. That is the convex-based telescopic mechanism.

When designing the mechanism, we consulted an existing constituent technology — the soil sampling mechanism of the Mars probe Viking [8]. The sampler has an arm consisting of two bundled convex tapes. The arm was no longer used. Through a search for applications of

the patent, we did not find any arm using reversibly recoverable convex tapes for assumed powerful applications. We estimated that the use of the technology was a blind spot.

I then invented in 2005 a light-weight telescopic mechanism resistant to fighting games which could recover even after its arm was bent. I applied for a patent in 2006 from Osaka University where I was working at that time. It took several more years to complete a prototype that was operable in practice. I started working on a development project for the mechanism on a full-scale basis when I became an independent associate professor in Akita Prefectural University in 2010.

During this period, the technology that helps to prevent living cells from being killed when perforated with large holes through photo-oxidization evolved into a "large-scale cell modification technology" in 2007. This technology was implemented by combining a polymer molded with a dispersed photo-oxidizer and the robot technology, enabling batch processing of sufficient numbers of cells for therapy purposes at low cost. In 2009, I won an award for the technology in the United States [9] and another in Akita Prefecture. These awards served as a direct cue for me to be transferred to Akita Prefecture University.

These days, every time I find an article on the significance of innovation, I remember that The Innovator's Dilemma, which was published a quarter of a century ago, brought a change in awareness to the world and me. I also hope that we will commercialize our telescopic mechanism that has the potential for disruptive innovation together with the KYB Group.

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Greetings

Greetings

KAWASE Masahiro*

I have just taken up the office of Representative Director. Here I would like to state what I think is significant to steer the KYB Group.

1. Growth Strategy

KYB Corporation, as a company with the world's top-class technology for vibration prevention and power control that applies the principle of hydraulics, will promote product development towards the goals of achieving further corporate growth and sustainable social development. For example, electrification of automobiles and construction machinery is one of the measures to realize these goals. I think it is very important to focus on technical development for implementing these measures.

In Automotive Components Operations, we are promoting the improvement of the basic performance of shock absorbers as well as the development of new active suspension systems and next-generation hybrid suspension systems, in order to adapt to the trend of EVs and CASE [Note 1)]

In Hydraulic Components Operations, by leveraging our strength across the product family covering the components (pumps, motors, valves, and cylinders) for the drive mechanisms of construction machinery, we are working on an effort for systemization of the products by adding electronic controls, such as sensing, in order to adapt to the trend of remote control and automatic/unattended operation of construction machinery.

Also, in the Special-Purpose Vehicles Division, by leveraging our technology for concrete mixers for which we have the largest share in the Japanese market, we will develop new products making use of electrification and computerization technologies that can contribute to the creation of a decarbonized society.

Furthermore, as an effort for entering new markets, we are developing a camping car that integrates our proprietary technologies of AC and HC Operations and the Special-Purpose Vehicles Division. Its concept and product display in exhibitions are introduced in this issue of KYB Technical Review.

Note 1) Acronym for Connected, Autonomous Share & Services, and Electric vehicles.

2. Production Innovation for Next Generation

We call our activity to advance Monozukuri (manufacturing) towards the next generation "Ship '30" (Self handing innovation plant 2030). By using digital technologies (DX and AI) as a key solution to minimize "transportation", "inventories", and "operation", we will promote the implementation of unattended self-complete factories. We will roll out this activity on a global basis to optimize the Group-wide production system.

3. Relentless Cost Reduction Activity

Although the business is now on the road to recovery from the spread of COVID-19 infection, the business environment remains severe with surging prices of raw materials, production adjustments at customers due to semiconductor supply shortages, and other issues. Under this social background, the Group is promoting a cost reduction activity on a global basis to stabilize our revenue base. We will also concentrate resources on the core businesses, namely, AC Operations, HC Operations, and Special-Purpose Vehicles Division to transform ourselves into a highly profitable structure.

4. Activities for Sustainability

In order for a global company to achieve continual growth, it is generally indispensable to promote ESG management. KYB Corporation has also established the Sustainability Committee headed by a Representative Director and consisting of general managers of individual divisions and operations. The Committee will introduce specific activities for SDGs and develop employees' awareness of initiatives for carbon neutrality and other issues including reviews on Monozukuri/design specifications, building the company's confidence while responding to social needs.

KYB Corporation has changed its company name in Japanese on October 1, 2023. We would like you to extend continual support to us.

This concludes my greetings as Representative Director. We are committed to promoting reform by all of us and making effort to obtain trust from customers throughout the world.

* Representative Director, and President Chief Operating Officer (COO), KYB Corporation

Technology Introduction

Installation of a Flexible Manufacturing System for Transmission Pumps

MATSUNOSHITA Tomohiro, NISHIDA Hideyuki, YOSHIMURA Takashi

1 Introduction

During the initial stage of the transmission vane pumps (hereinafter "PV") business, we planned to produce a number of PVs for CVT[Note 1)] of the same design/geometry. Then, we built a high-speed, large-lot manufacturing system to reduce the cost of manufacturing.

However, today's customer needs have diversified. To match such a variety of needs, there has been a tendency to manufacture more types of product in smaller quantities (Fig. 1).

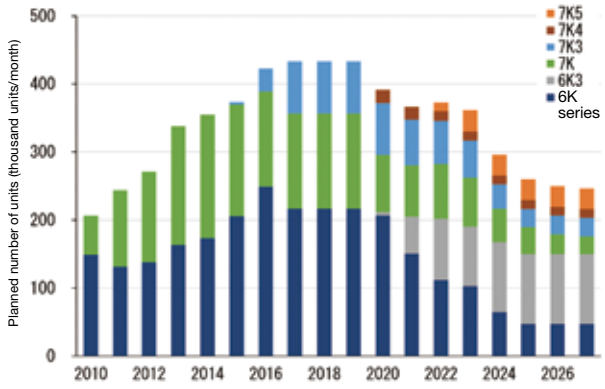

Fig. 1 Global production of CVT PV

If we tried to implement mixed production of the increasing number of product models using the existing high-speed, large-lot manufacturing system, we needed to extensively modify the system, thereby incurring high costs for production preparation. Since it was also difficult to reduce the number of production lines because then only a limited number of models could be subjected to mixed production, lower production efficiency or higher cost of manufacturing was anticipated if we received less orders for the product.

Under this situation of the transmission PV business, we received from a customer an order for a new model that was considered as the last CVT PV. On the other hand, in the course of the activity for "departure from heavy reliance on a single customer", which is one of our business policies, we received for the first time an order from a second customer for a new product, a PV for AT[Note 2)].

Note 1) Acronym for Continuously Variable Transmission.
Note 2) Acronym for Automatic Transmission.

As a result, we became busy with many frequent events while developing a new CVT PV and a new AT PV. In addition, the geometry and machining details of these products were not compatible with their conventional counterparts (Fig. 2), which made it difficult to additionally manufacture them on the existing lines in operation. Then, we needed to add flexible production lines partly because of the necessity of global CVT restructuring.

Fig. 2 Pump geometry

2 Purpose, Targets, and Requirements

2. 1 Purpose

In preparing a manufacturing system for the new models of AT PV and CTV PV, the Production Engineering Dept. carried out activities with the purpose of "establishing a compact, flexible manufacturing system that can accept mixed production of various models and allows labor saving".

2. 2 Targets

While maintaining quality, we set a cycle time of 40 seconds, which is twice the conventional time, based on the number of units of inquiry. The personnel and investment targets were set to 1/2 of the conventional values. The processing cost targets for the three processes of body machining, cover machining, and assembly were set to be no higher than the conventional values.

To implement flexible manufacturing, targets were also set for set-up time and production preparation cost for additional models.

Furthermore, we set space requirements for the installation of process equipment. We aimed to be able to

apply these requirements for enhanced space efficiency to all production sites (Table 1).

Table 1 Targets for production lines

	Body machining	Cover machining	Assembly
Cycle time	40 sec./unit	40 sec./unit	40 sec./unit
Line personnel	One person/shift	One person/shift	Two persons/shift
Operational availability	Not less than 78%	Not less than 78%	Not less than 85%
Set-up time	20 min. or less/ session	20 min. or less/ session	9.5 min. or less/ session
Production space	Three processes to be included in a global PV area (10 m x 28 m)		

2. 3 Requirements

To achieve the targets, the following four requirements were established:

1. A manufacturing system built in a global PV area [Note 3] shall be able to be introduced at any production site.
2. Set-up work shall be able to be conducted efficiently and safely.
3. A traceability system also supporting manual transport shall be established to prevent outflows of non-conforming products and to store quality records.
4. The required contamination level shall be maintained.

Note 3) A unified manufacturing area for all production sites of pump business units.

3 Activities

Related departments discussed the manufacturing processes. They reviewed the processes on the premise that the line transport is manually done by operators with priority placed on the flexibility of the production lines and that automation for ensuring quality and productivity is implemented for each production equipment.

3. 1 Simulation

Through process design reviews (DRs) and repetitive discussions with related departments, we reviewed various combinations of tasks together with the Production Dept. and KPS [Note 4] Improvement Dept. and performed repeated simulation using corrugated cardboard [Note 5] (Photo 1).

Note 4) Acronym for Kayaba Production System.

Note 5) Make simulation equipment from corrugated cardboard and pipes to simulate transport and set-up works.

Photo 1 Simulation using corrugated cardboard

3. 2 Layout Review

Conventionally, the body machining, cover machining, and assembly lines were allocated to separate areas and occupied a layout space of about 2.5 global PV areas.

To build a manufacturing system with a more efficient use of line space and with a high degree of freedom for equipment installation applicable to any production site, we reviewed the layout with the aim of putting three lines in a global PV area (Fig. 3).

We placed importance on flexibility so as to support a variety of product geometries. For this purpose, we decided to select manual transport by operators, instead of the conventional automatic in-process transport.

We allocated a group of operators to the machining zone involving quality concerns and another group to the inspection process and then leveled out the tasks. As a result, the personnel target was achieved even for manual transport, making it possible to build a manufacturing system that can ensure both quality and flexibility.

Furthermore, we worked with the Production Control Dept. to determine the optimal layout of the parts inlet and product outlet chutes, achieving both efficient in-line work of operators and a straight material transport route (Fig. 4).

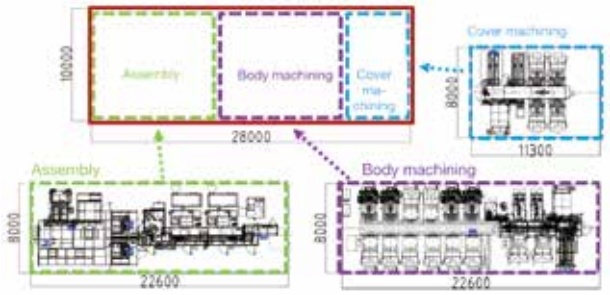

Fig. 3 Layout before review

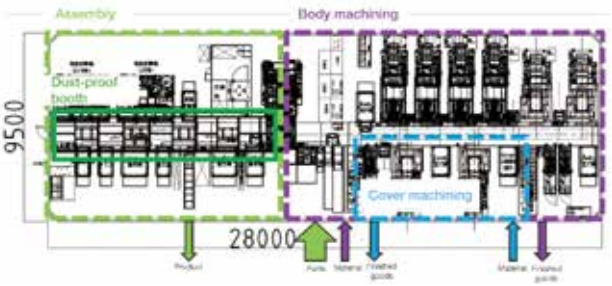

Fig. 4 Layout after review

3. 3 Process Integration

In order to put the three lines in the layout space described above, we conducted process integration for each of the processes as follows, achieving the space target.

3. 3. 1 Process Integration of Machining Equipment

To achieve process integration, we introduced small work clamps as machining jigs. This substantially downsized the machining jigs, achieving a shift from the conventional machining process using flat jigs to a

process using cradle jigs [Note 6] (Fig. 5).

This shift enabled multi-face machining. The conventional six processes needed to accomplish machining were integrated into four processes. The fewer processes helped reduce the time of manual handling work, while the higher degree of freedom of jigs enabled easier set-up changes for other models.

Note 6) A mechanism in which swinging the jig like a cradle will enable machining not only in a single direction but also at different angles.

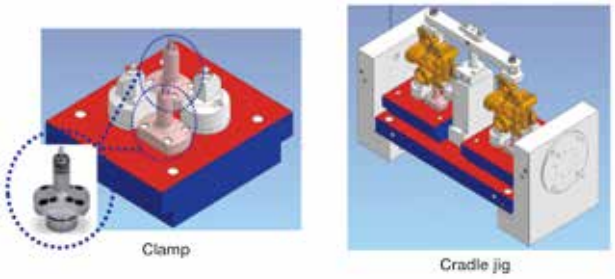

Fig. 5 Machining jig

3. 3. 2 Process Integration of Assembly Equipment

We reviewed the process allocation within the cycle time setting of 40 seconds and decided to integrate two to three processes into a single equipment unit. This integration helped reduce the number of equipment units used and the number of attachments/detachments, contributing to lower processing cost. We also ensured mountability and a wider moving range of the set-up jigs so as to accommodate various product geometries and specifications that vary by model.

As examples of process integration of assembly equipment, the following describes plug and cover bolt tightening processes.

The AT PV uses three plugs of two different types. These plugs need to be tightened in three directions. To accept plugs in different orientations, we provided the plug tightening machine with a cradle mechanism to allow work to swing around the Y-axis and another swing mechanism to allow work to swing around the X-axis, in addition to the regular X-Y axes.

We also installed a socket changer in the equipment to enable automatic socket changes without the need for a set-up change by an operator, making it possible to tighten multiple types of plugs in a single equipment unit (Photo 2).

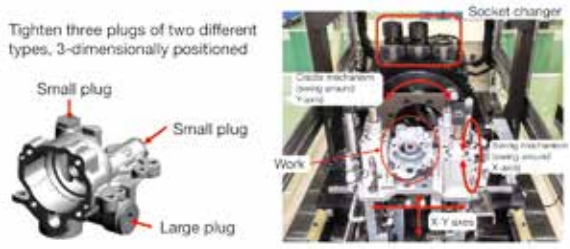

Photo 2 Plug tightening machine

The cover bolt tightening process needed to accommodate different bolt pitches that varied by model. We provided the nut runner with multiple moving shafts to accommodate cover bolts in various positions without mechanical set-up work (Photo 3).

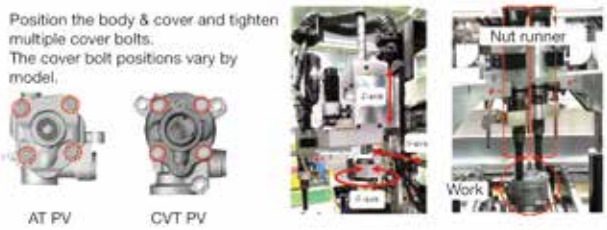

Photo 3 Cover bolt tightening machine

3. 4 Quality Improvement Measures

When building a new manufacturing system this time, we also tried to maintain or improve the quality level of the conventional manufacturing system.

3. 4. 1 Establishment of a Traceability System

We achieved traceability by engraving a serial number for identification on individual body/cover parts in the leading process of the machining line and by reading the serial number of all workpieces with cameras (Photo 4) installed in the processes from machining to assembly.

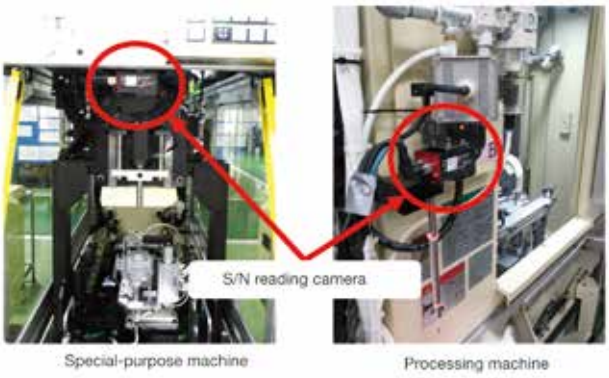

Photo 4 Serial number reading camera

In this system, the serial number read in individual processes is written to the edge PLC [Note 7] along with information about the product model and process progress as well as a timestamp. The next process reads the information from the edge PLC to identify the condition of the previous process, preventing a process skip or outflow of non-conforming products.

Note 7) A programmable logic controller (PLC) for primary processing between the manufacturing system and the server that collects and stores data. It is intended to reduce the server load and increase the processing speed.

Furthermore, quality data output from equipment units is automatically stored in the server, preventing inappropriate behavior such as data falsification (Fig. 6).

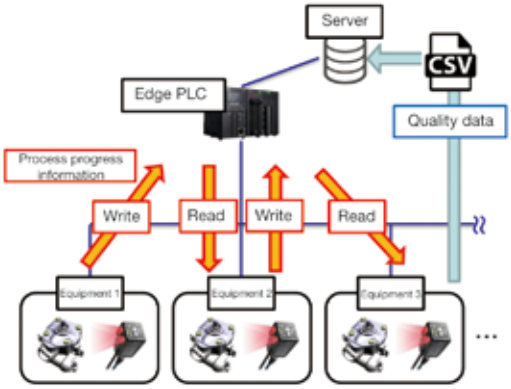

Fig. 6 Traceability system

In the machining process, MT-LINKi [Note 8)] was introduced as an equipment monitoring system. This monitoring system obtains a history of thermal changes per cycle, enabling the prediction of possible causes of lower machining accuracy and determination of the dimensions during dimensional adjustment.

This system has also allowed system users to obtain information about the equipment condition and alarm history during production, thereby enabling non-operating analysis without relying on hearing from operators (Fig. 7).

Note 8) MT-LINKi is a registered trademark of FANUC CORPORATION.

Fig. 7 MT-LINKi screen

3. 4. 2 Contamination Quality Control

While we built a manual transport production system that is totally different from the conventional high-speed, large-lot manufacturing system, we decided to maintain the conventional contamination quality control.

In the machining process, a preliminary cleaning before the inspection and distribution processes removes chips and cutting fluid. This cleaning is intended to improve the inspection accuracy and prevent carry-over of such contaminants to subsequent processes.

To satisfy the contamination standard for the products, we added a palletization process to the last part of the machining process. In the palletization process, an operator puts all parts for a unit of the product into a cleaning pallet to be cleaned immediately before assembly (Photo 5).

Through this process, we prevented the occurrence of missing or excessive parts in the assembly process and improved the contamination level by reducing the work in process after cleaning.

Photo 5 Cleaning pallet

4 Results

We successfully installed the three production lines (body machining, cover machining, and assembly) in a single global area as planned.

Mass production was launched in December 2021 for AT PV and in April 2023 for CVT PV. The production has continued so far with no complaints.

We also achieved the productivity and line personnel targets, namely, a cycle time of 40 seconds/unit and four persons/shift respectively.

The operational availability target was achieved in the machining process, but not achieved in the assembly process on a monthly average basis. Continual improvement is under way to achieve the target (Table 2).

Table 2 Results of newly-installed production lines

	Body cover machining		Assembly	
	Targets	Result	Targets	Result
Cycle time	40 sec./unit	40 sec./unit	40 sec./unit	40 sec./unit
Line personnel	Two persons/ shift	Two persons/ shift	Two persons/ shift	Two persons/ shift
Operational availability	Not less than 78%	84.5%	Not less than 85%	78.9%

5 In Closing

We have successfully built a manufacturing system based on a new concept. This system is now used to manufacture two models of AT PV/CVT PV that have just been designed.

We will manufacture more product models in the new manufacturing system, hoping that the system will be a "flexible manufacturing system" in the true sense of those words.

Finally, we would like to take this opportunity to deeply thank all those concerned who extended support to this project.

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Technology Explanation

Characteristic analysis of high-efficiency hydraulic system

HIRONAKA Tsuyoshi・TSUKUI Ken

Abstract

Exhaust gas regulations for passenger cars have recently become stricter year by year as many countries promote carbon-neutral activities from the viewpoint of the environment and energy saving.

In response, manufacturers have sought the development of transmissions with higher fuel efficiency as one solution as they accelerate their efforts to improve the overall efficiency of their vehicles.

KYB has recently improved the efficiency of the pump used as the power source for the transmission, reaching a level approaching its maximum.

In this study, as a means of confirming the effectiveness and feasibility of this hydraulic system, we modeled the entire system and built simulation technology that enables performance prediction. In addition, by utilizing our simulator we clarified the design parameters that affect the performance and set the prospects for improving the performance of the hydraulic system by coordinating the control of each component.

1 Introduction

Recently, many countries have promoted carbon-neutral activities from the viewpoint of the environment and energy saving. Exhaust gas regulations for passenger cars have also become stricter year by year. In response to this trend, the automobile industry has accelerated its efforts to improve the overall efficiency of vehicles. This means that automobile transmissions are required to deliver higher efficiency.

The transmission uses a pump as its hydraulic power source. Reducing the output from the pump section (specifically, reducing any excessive flow discharged from the pump) will help improve the fuel efficiency. That is why KYB has conventionally promoted efforts to improve pump efficiency. However, there is limited scope for further improvements in efficiency of the pumps alone. Then, to achieve further improvement of efficiency in the pump section, this study focused on a hydraulic system that combines two or more pumps and selector valves and tried to confirm the feasibility.

As a means of confirming the effectiveness and feasibility of this hydraulic system, we established an 1D simulation [Note 1)] technology that enables performance prediction. This paper explains the effort and the results of its evaluation.

Note 1) A method of simulation that expresses phenomena of products and components mathematically and calculates them spanning two or more physical phenomena.

2 Overview of KYB Hydraulic System

As shown in Fig. 1, the hydraulic system that we developed in this study (hereinafter "the KYB hydraulic system") consists of a hydraulic pump driven by an engine (hereinafter "the mechanical pump"), another hydraulic pump driven by a separate electric motor (hereinafter "the electric pump"), and a change-over mechanism consisting of a solenoid and a selector valve. The mechanical pump has two ports: main and sub. These ports can be switched over by the change-over mechanism to deliver two-stage variable discharge.

The following describes the principle of operation of the KYB hydraulic system. Normally, the discharge rate of the mechanical pump changes in proportion to the speed of the engine. In other words, the pump may

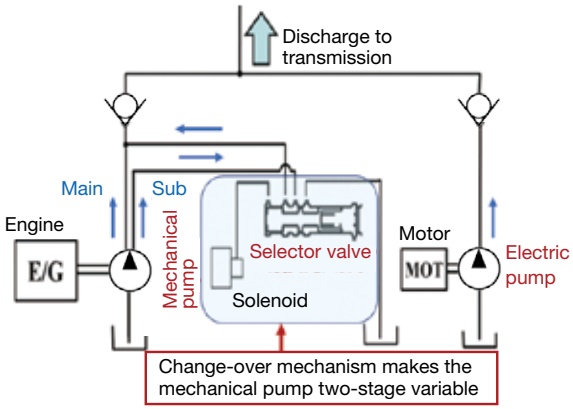


Fig. 1 KYB hydraulic system

discharge more flow than required depending on the operation mode of the vehicle. This increased pump output leads to lower fuel efficiency. The KYB hydraulic system is designed to solve this problem. In an operation mode where the transmission requires a low flow rate, the system diverts the discharge from the mechanical pump (via the sub port) (hereinafter "the sub discharge") to a tank via the selector valve and lets the discharge from the mechanical pump (via the main port) (hereinafter "the main discharge") alone flow to the transmission section, thereby reducing the output of the mechanical pump. In an operation mode where the transmission requires a high flow rate, the solenoid is activated to operate the selector valve to merge the sub discharge with the main discharge, ensuring normal operation of the transmission. Moreover, some operation modes of the vehicle, such as kick down, may quickly require a high flow rate. In this case, the electric pump is activated in addition to the mechanical pump, to compensate for the insufficient flow rate. In this way the KYB hydraulic system can supply the exact amount of flow required to the transmission with fine control. Compared with the system consisting of a single mechanical pump (hereinafter "the single mechanical pump system"), the KYB hydraulic system can be expected to substantially reduce the pump output, namely, improve the fuel efficiency of the vehicle.

3 Feasibility Study

We checked in advance the effectiveness of the KYB hydraulic system by conducting a system performance evaluation using a simplified 1D simulation model. This chapter describes the details of this effort. The 1D simulation model we used was commercially available Simcenter™ Amesim™ software (SIEMENS, Germany).

3. 1 Overview of Simulation Model

The simulation model basically consists of the following three major sections as shown in Fig. 2:

[1] Flow control section (hydraulic system): Uses the engine speed as input and controls the pump flow rate through electronic control of the solenoid and motor.

[2] Pressure control section: Uses two or more voltage/electromagnetic valves to control the discharge pressure from the hydraulic system (hereinafter "the control pressure").

[3] Transmission control section: Controls the transmission gear ratio according to the control pressure.

To determine the effect of pump output reduction in this simulation, driving data (engine speed and control pressure) measured in the automobile's fuel efficiency evaluation mode was taken as input conditions. Then, the pump discharge with these input conditions was calculated. In this study, we modeled two systems: the KYB hydraulic system and the conventional single mechanical pump system. By comparing the pump output calculated in the same operation pattern between the two systems, we checked the effectiveness of the KYB hydraulic system.

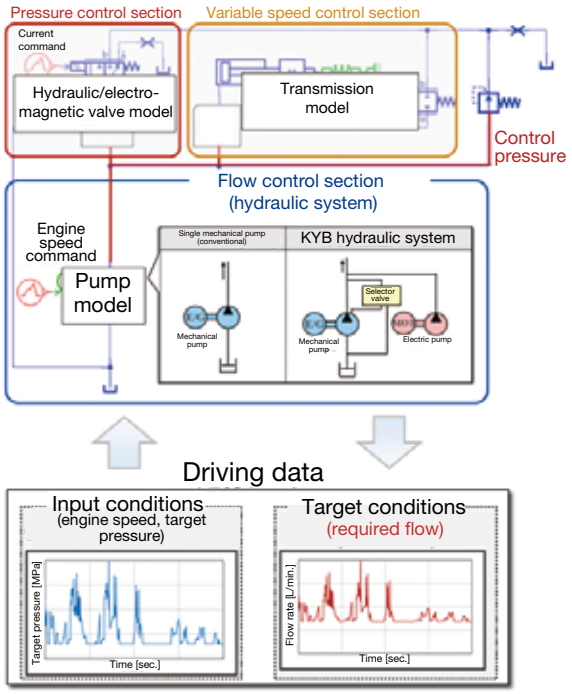
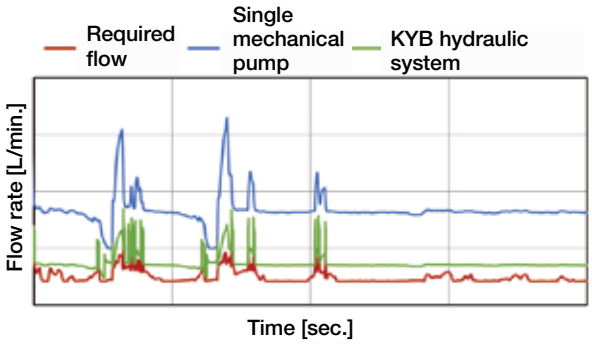


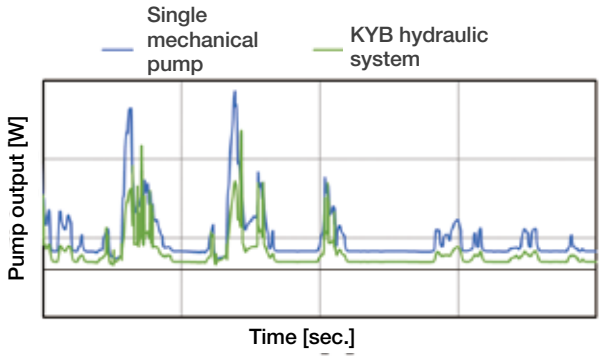
Fig. 2 Overview of simulation model

3. 2 Confirmation of Effectiveness of KYB Hydraulic System

Fig. 3 shows a simulation comparison between the single mechanical pump system model and the KYB hydraulic system model (flow rate and pump output). According to Fig. 3(a), both models meet the flow rate required for the transmission. The Figure also indicates that the KYB hydraulic system successfully curbs the flow rate over a wider range compared with the single mechanical pump system. The KYB hydraulic system achieves this by reducing the discharge from the mechanical pump by directly connecting the sub pump to the tank via the selector valve in the time zones where the single mechanical pump system has a highly excessive flow. Accordingly, the KYB hydraulic system is superior to the single mechanical pump system in reducing the pump output over the entire time zone as shown in Fig. 3(b), showing a pump output reduction rate of 48.3%. Thus, the effectiveness of the KYB hydraulic system was confirmed.



(a) Flow rate

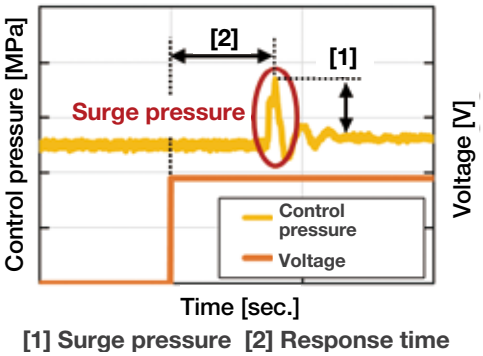


(b) Pump output

Fig. 3 Simulation comparison results

4 Challenges and Countermeasures of KYB Hydraulic System

The KYB hydraulic system is susceptible to a surge pressure occurring when the selector valve is changed over, as shown in Fig. 4. Upon the change-over, the sub discharge will flow into the main line to merge with the main discharge, causing an abrupt change in pressure (surge pressure) in the circuit. This surge pressure appears as a shock-like kick back in the vehicle. It is desirable to reduce the surge pressure as far as possible. We then conducted, against a hydraulic circuit with a selector valve that may cause a surge pressure, a comparative evaluation of simulation and actual vehicles, a parameter study [Note 2)] using the simulation, and optimization [Note 3)] of the valve form. This chapter describes the details.



[1] Surge pressure [2] Response time

Fig. 4 Surge pressure caused by valve change-over

Note 2) To set analytical models and conditions as parameters and repeatedly conduct analysis while changing the parameter values.

Note 3) An approach to find a best parameter value by minimizing or maximizing a design target (an objective function) of a system.

4. 1 Comparative Study of Surge Pressure

Photo 1 shows a valve change-over test machine and Fig 5 shows its hydraulic circuit diagram. The hydraulic circuit for this test has a check valve on the sub discharge line in parallel with the mechanical pump and a selector valve on the sub discharge line at a further position. The sub discharge flows into the tank when the selector valve is open (hereinafter "the selector off") or flows through the check valve to merge with the main discharge when the selector valve is closed (hereinafter "the selector on"). In this test, a surge pressure was measured when the selector valve was operated with the pump running at a certain speed to deliver a certain discharge pressure. We also created a simulation model of the same configuration as that of the actual test machine to compare the simulation results with the test results. In this comparative evaluation of the surge pressure, the magnitude of surge pressure and the response time after the change-over (the time from the issuance of a current command to the occurrence of a surge pressure) were selected as evaluation items.

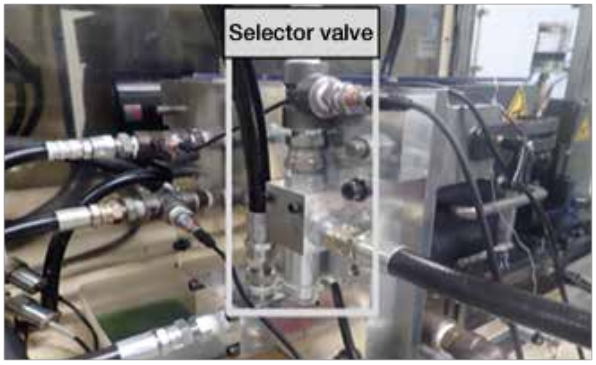


Photo 1 Valve change-over test machine

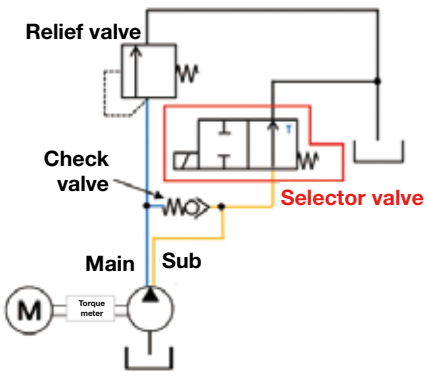


Fig. 5 Hydraulic circuit of valve change-over test machine

Fig. 6 shows a comparison of pressure at the time of change-over between the simulation and the actual machine test. According to Fig. 6, the simulation results closely matched those of the actual machine test with errors within just ±3% for all the evaluation items except response time (the time from the selector on to the selector off) whose error was 8.8%. It was confirmed that the simulation can reproduce the behavior of the actual machine with an accuracy within ±10% for all the

evaluation items.

Thus, the simulation model we built in this study proved its high validity, making it possible to predict the surge pressure upon change-over of the selector valve.

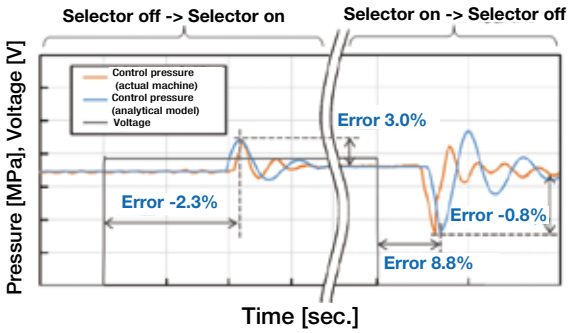


Fig. 6 Comparison of selector valve between analytical model and actual machine

4. 2 Implementation of Parameter Study

To identify design parameters that may affect the surge pressure and/or system response time, we carried out a parameter study using the simulation model created in section 4.1.

Parameter values were adjusted by halving or doubling the design median value. Otherwise, parameter values were changed to an extent that would not hamper the change-over function. We eventually conducted simulation in several tens of patterns. Table 1 shows an example of sensitivity trends of design parameters that affect the surge pressure and/or system response time. The positive (+) and negative (-) signs in Table 1 indicate an increase and a decrease in the relevant performance/ characteristics respectively.

Table 1 Parameter sensitivity for various evaluation items (example)

Target model	Parameter change	Evaluation item			
		Surge pressure performance (Off -> On)	Responsivity (Off -> On)	Surge pressure performance (On -> Off)	Responsivity (On -> Off)
Piping	Diameter up	(+) sensitivity: High	(-) sensitivity: Middle	(+) sensitivity: High	(-) sensitivity: Low
	Length up	(+) sensitivity: Middle	(-) sensitivity: Middle	(+) sensitivity: Middle	(-) sensitivity: Low
	Rigidity up	(-) sensitivity: High	(+) sensitivity: Middle	(-) sensitivity: High	(+) sensitivity: Low
Selector valve	Opening characteristics	Sensitivity: High	Sensitivity: Low	Sensitivity: Middle	Sensitivity: Low
	Spool friction up	(+) sensitivity: Middle	(-) sensitivity: Middle	(+) sensitivity: Low	(-) sensitivity: Low
	Spool diameter up	(+) sensitivity: High	(-) sensitivity: High	(+) sensitivity: Middle	(-) sensitivity: Middle
	Spring force up	(-) sensitivity: High	(+) sensitivity: High	(+) sensitivity: Low	(-) sensitivity: Low
Check valve	Spool diameter down	No effect	No effect	(+) sensitivity: High	No effect
	Lap length down	No effect	No effect	(+) sensitivity: Middle	No effect

From the results shown in Table 1, we obtained insights about the overall sensitivity trend. The surge pressure performance is substantially affected by the piping and check valve while the response time is substantially affected by the selector valve and piping.

In the piping model, the surge pressure performance is higher with lower rigidity, a larger diameter, or a longer length. This is probably because the piping has an increased accumulator effect to be more capable of absorbing surge pressures. In the check valve model, the surge pressure performance is higher with a smaller spool diameter or a shorter lap length. On the other hand, a back flow is more likely to occur when the check valve is closed, which may degrade the robustness [Note 4)] as a system. This issue should be taken into account during design. Description of the selector valve model is omitted here and will be included in the next section.

From the results of the parameter study, we also confirmed that there is basically a trade-off relationship between the surge pressure performance and the responsivity.

Note 4) A property of a system or structure that it is unlikely to be affected by various disturbances.

4. 3 Study on Valve Design Optimization

From the results of the parameter study in section 4.2, we determined that the opening characteristics of the selector valve and the spring specifications (including spring constant and initial load) substantially affect the surge pressure performance and responsivity (see Table 1). In light of this, we optimized the form of the selector valve to enhance the valve change-over performance. The following describes the details of the optimization. Please note that, prior to optimization, we reviewed the valve configuration by simulation and then modified the configuration so as to hopefully deliver even higher change-over performance.

Table 2 shows predictor variables, objective functions, and limiting conditions for optimization. Since there is basically a trade-off relationship between surge pressure performance and responsivity as indicated by the results in section 4.2, the objective function was set so as to optimize the sum of the weighted surge pressure and response time, thereby allowing the valve to have both good surge pressure performance and good responsivity. In terms of limiting conditions, some parameters that cannot help having errors for design reasons, including stroke and spring constant, were given variations. Then, it was judged whether the sub discharge was diverted properly when the valve was changed over. This made the selector valve, which had already been optimized, more robust.

Table 2 Parameters used to optimize the valve design

Predictor variable	Objective function	Limiting condition
- Underlap - Stroke - Spool diameter - Orifice - Spring constant - Initial load - Opening notch	- Evaluation function expressed in surge pressure and response time	- Judgement of the valve's change-over operation with variations in design values

Fig. 7 shows a comparison of surge pressure/response time (the selector off -> the selector on) before and after optimization. It can be confirmed in Fig. 7 that the optimized model shows substantially lower surge pressures and shorter response time than the valve change-over model created in section 4.1. This analysis method was found to be effective for finding optimal design parameters that can improve both surge pressure and response time at the same time.

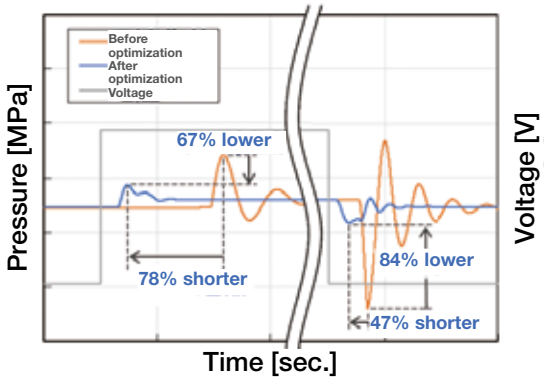


Fig. 7 Evaluation of surge pressure characteristics of optimized model

4. 4 Performance Evaluation of Optimized Selector Valve on Actual Machine

To determine the effect of the optimized selector valve obtained through simulation, we conducted a confirmation test on the actual machine. Fig. 8 shows the surge pressure and response time of the original selector valve in section 4.1 and of the optimized selector valve. According to Fig. 8, the optimized selector valve shows about 80% lower surge pressure and about 40% shorter response time than the original counterpart.

This clarified that the optimized selector valve can also substantially improve both properties in the actual machine in the same manner as for the simulation. We thus confirmed the validity of the simulation and the effectiveness of the optimization program.

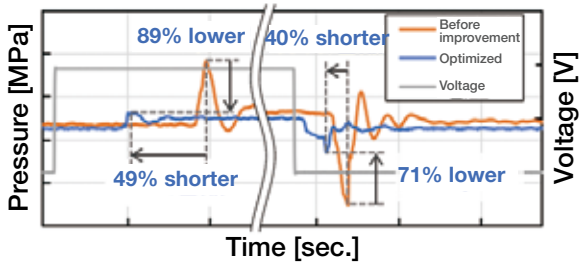


Fig. 8 Comparison of results of surge pressure tests

5 Building of an Electric Pump Model

The KYB hydraulic system model includes an electric pump in addition to the mechanical pump and the selector valve. The electric pump model used in the feasibility study in Chapter 3 was specified to operate without delay according to speed commands. Efficiency and responsivity were not factored into the model design. This study in turn requires a model for the KYB hydraulic system that can determine feasibility and efficiency of the system operation. Therefore, the electric pump, which is one of the system components, also needs to reproduce its efficiency and response time.

Then, we modeled the electric pump, which is one of the components to be installed in the KYB hydraulic system, based on data collected on the actual machine. This chapter describes the details of this effort. The target model accuracy for efficiency and response time was set to within ±10%.

5. 1 Evaluation with Initial Electric Pump Model

Fig. 9 shows the configuration of the actual electric pump. The pump section includes a PMSM [Note 5)] and a vane pump and uses torque maximizing control [Note 6)] and flux weakening control [Note 7)] strategies to control the motor current. The electric motor was modeled using simulation software products MATLAB® and Simulink® [Note 8)], which are often used to build control models, instead of the Simcenter Amesim used to model the hydraulic equipment. By coupling the motor and pump models we had created, we conducted an analysis of the electric pump. In terms of pump operation, the actual speed of the pump motor was fed back and controlled to minimize deviations from the speed commands.

Note 5) Acronym for Permanent Magnet Synchronous Motor. PMSM is driven through synchronization between the motor rotation and the frequency of the AC current flowing into the coil.

Note 6) A motor control method that selects from the same effective current to maximize the output torque.

Note 7) A motor control method that sends a current in a direction that cancels the magnetic flux of the permanent magnet, enabling high-speed operation while reducing the torque.

Note 8) MATLAB® and Simulink® are registered trademarks of The MathWorks, Inc.

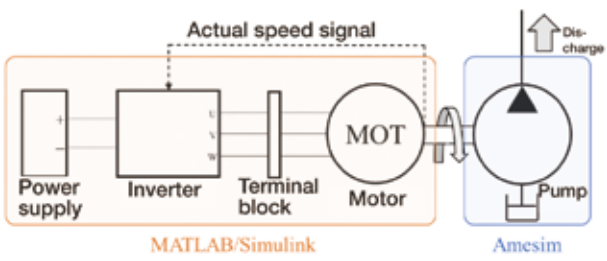


Fig. 9 Configuration of electric pump

Fig. 10 shows equivalent circuit diagrams of the PMSM circuit converted through coordinate transformation to the d-axis (in the direction of the main flux) and the q-axis (shifted from the d-axis by 90˚). In the coordinate transformation shown in Fig. 10, the motor current can be divided into a component I_q that generates a motor torque and a component I_d that causes the rotor to produce a magnetic flux. These current components are individually controlled. Modeling of the electric motor in this study was based on the electric circuit diagrams shown in Fig. 10. Parameter settings for the model used measurements of the actual machine, which is the comparison target, and calculated values from the specifications.

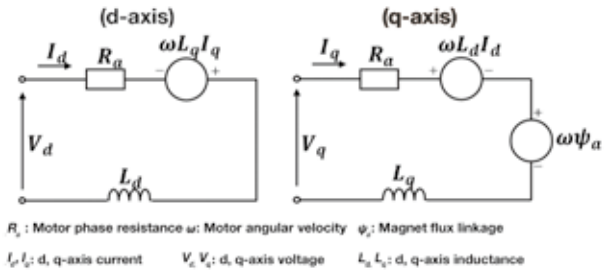


Fig. 10 Equivalent circuit diagrams of motor

Table 3 shows the results of comparative tests of electric pump efficiency between the model and the actual machine. Table 3 indicates that the simulation gives higher efficiency than the actual machine under all the test conditions. This is probably because the motor model was created by considering electrical and mechanical losses, but not considering magnetic hysteresis and eddy currents. The efficiency errors may be attributable to the fact that the dependency of motor inductance on current and temperature was not taken into account. The magnitude of efficiency error is not less than 10% on the whole and over +100% under the high discharge pressure and low speed conditions in particular. Thus, the efficiency of the pump model was found to differ largely from that of the actual machine.

Table 3 Efficiency evaluation of initial electric pump model

	Test conditions (speed and discharge pressure)		
	Low speed, High pressure	Mid speed, Mid pressure	High speed, Low pressure
Model efficiency error	+113%	+12%	+14%

Fig. 11 shows the results of comparative tests of electric pump responsivity between the model and the actual machine. In this study, the pump responsivity was evaluated by the time from the step time of the speed command signal (start time) until the discharge flow reaches 90% of the normal flow rate.

According to Fig. 11, the response time of the analytical model was about twice (about +100% error) that of the actual machine. With such a big difference, it was considered that the model must be improved.

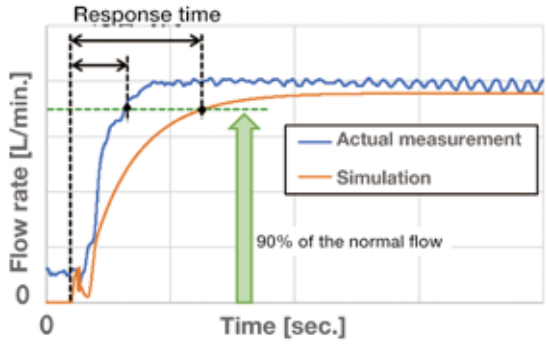


Fig. 11 Evaluation of responsivity of initial electric pump model

5. 2 Improvement of Motor Model

Based on the results in section 5.1, we reviewed the motor model and parameters with consideration given to iron loss. Fig. 12 shows d, q-axis equivalent circuit diagrams with iron loss taken into account [2]. The equivalent circuit diagrams in Fig. 12 express the iron loss caused by rotor rotation in equivalent iron loss resistance R_{cp}. Also, L_{dq} and L_{qd} are used to reflect the d, q-axis mutual inductance. We then created another motor model based on these equivalent circuit diagrams. Since the equivalent iron loss resistance R_{cp} shown in Fig. 12 is a variable parameter relative to I_d, I_q, or the motor speed N, the iron loss obtained in the actual machine test was used to formulate an approximate expression, which was applied to the model. The inductances were set in table data as I_d/I_q-dependent parameters and then subjected to temperature correction before insertion in the equations. The motor temperature was set to a value predicted from the actual machine data.

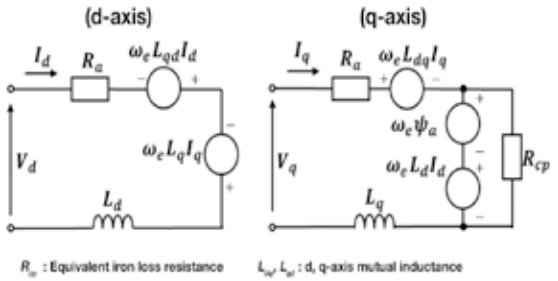


Fig. 12 Equivalent circuit diagrams of motor with iron loss taken into account

Fig. 13 shows the T-N (torque and number of revolutions) characteristics of the actual motor, the motor model in section 5.1 (hereinafter "the initial motor model"), and the motor model in this section (hereinafter "the improved motor model"). In Fig. 13, the horizontal axis indicates motor speed and the vertical axis represents motor torque. The torque-speed (T-N) characteristics are plotted for each of the effective values I_e of the three-phase current.

According to Fig. 13, there are two distinctive sections: a constant torque section and a section where the torque decreases as the speed increases. In this chapter, these sections are called by their current control method: the constant torque section is called the torque maximizing control zone and the slanted graph section is called the flux weakening control zone. When the results of the actual machine are compared with the results of the initial motor model for the various common current values in Fig. 13, the analytical model closely reproduces the graph gradient, namely, changes in torque, but the analysis values are higher than the measurements by about +5% to +10% over the entire torque range. On the other hand, the improved motor model shows motor characteristics with an accuracy as high as within ±3% error for all the current values in the torque maximizing control zone. Also in the flux weakening control zone, the error is limited to within about ±10%. Thus, we successfully built, through improvements including the addition of iron loss, an improved motor model that can reproduce the characteristics of the actual motor with a higher accuracy than the initial motor model.

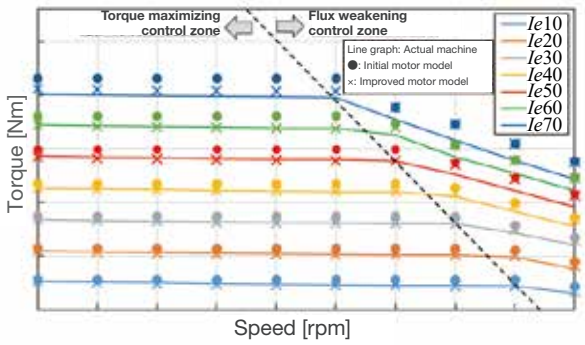


Fig. 13 Evaluation of T-N characteristics of motor models

5. 3 Improvement of Pump Model

Fig. 14 shows an example of measurements of motor speed and discharge flow rate of the actual electric pump. When the actual motor speed is compared with the discharge flow rate in Fig. 14, there is a delay between the start-up of the motor and the start of oil discharge. From this finding, we assumed the following pump behaviors:

[1] After the electric pump is started, the pump vanes remain retracted delivering no flow or no discharge pressure until the pump speed reaches a certain level.

[2] When a certain speed level is reached, the pump vanes extend to produce a flow and build a discharge pressure accordingly.

[3] When the running pump (motor) is stopped, the vanes retract to depressurize the pump.

We designed a pump model that can reproduce behaviors [1] to [3] above for modeling with an operation delay taken into account. On the assumption that the timing for the vanes to extend depends on the angular velocity or angular acceleration of the pump, we determined an equation to obtain the extension timing of the vanes based on the actual machine's data, and then incorporated a mathematical model for calculating the start-up and response times of the pump model. Of course, we could reproduce the response of the pump model by incorporating components including vanes and cam rings. In this study, however, we did not select this approach because:

[1] the calculation load is very high, particularly it takes enormous time to analyze the fuel efficiency;

[2] it is necessary to identify unknown parameters such as the coefficient of friction of the vanes, and;

[3] the contribution of the pump section to the delay of the entire electric pump is low.

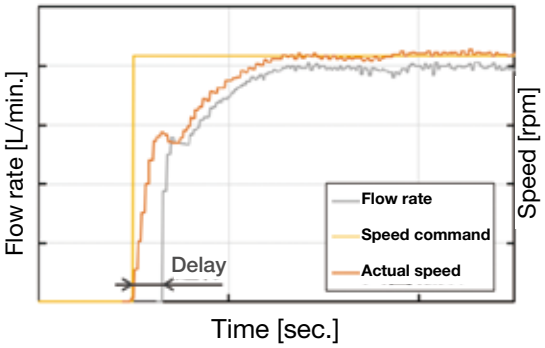


Fig. 14 Actual measurements of pump operation

Fig. 15 shows the pump model we created. By incorporating models for determining the vane state (retracted or extended), we built a pump model that can simulate a delay from the motor start-up until the shift to the hydraulic circuit with the extended vanes, and then incorporated the model into the electric pump model.

5. 4 Evaluation of Improved Electric Pump Model

The combined electric pump model created by incorporating the improved motor model in section 5.2 and the pump model in section 5.3 was evaluated for efficiency and response time.

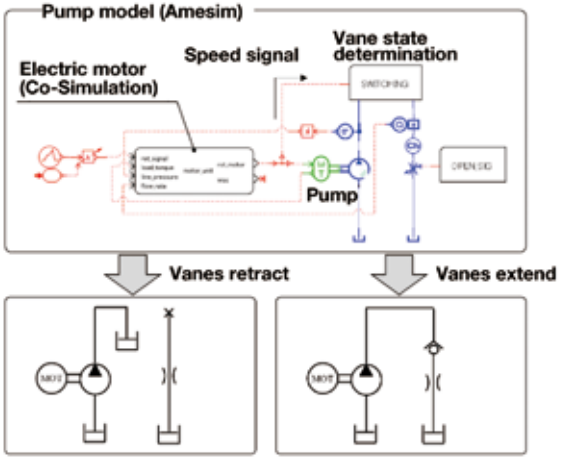


Fig. 15 Pump model with vane behavior taken into account

Table 4 shows a comparison of efficiencies during operation of the electric pump. It should be noted in Table 4 that the efficiencies of the overall assembly (electric pump) are actual measurements calculated from the actual pump output, while the efficiencies of various components are estimates calculated from theoretical equations.

The efficiency error of the entire assembly is within ±10% under any of the conditions. In particular, the error for the mid-pressure and mid-speed operation or the low-pressure and high-speed operation is within ±3% not only for the entire assembly but also for all components, proving a very high model accuracy. For the high-pressure and low-speed operation, the entire assembly has -5.5% error, but some components show around 10% error. These quite big errors are probably because the model accuracy is low for rotary motion of components "between the motor and the pump" downstream of the electric pump system.

Thus, the model still needs to be improved, but was confirmed to reproduce the pump with high accuracy particularly for the entire assembly with an efficiency error of about ±5%.

Table 4 Evaluation of efficiency of improved electric pump model

		Operating conditions		
		High pressure, Low speed	Mid pressure, Mid speed	Low pressure, High speed
Model efficiency error	Between the power and the inverter	−3.0%	−1.2%	−0.1%
	Inside the inverter	−9.4%	−2.5%	0.5%
	Between the inverter and the motor	0.2%	1.0%	1.2%
	Inside the motor	−4.1%	−1.7%	−2.1%
	Between the motor and the pump	12.8%	2.0%	2.6%
	Inside the pump	−0.8%	−0.2%	0.0%
	Entire assembly (electric pump)	−5.5%	−2.7%	2.0%

Next, we evaluated the response time of the electric pump model. The response time of the pump is affected not only by the discharge pressure and pump speed but also by the P control gain [Note 9)] setting for motor speed, which was added to the test conditions. In the testing, the P control gain setting for speed control was adjusted at three levels: low, middle, and high.

Fig. 16 shows a comparison between the actual machine and simulation regarding the response time of the electric pump under high-speed, low-pressure operation with the high P control gain setting. Fig. 16 reveals that the simulation almost reflects the response time as well as the flow rate waveform including the timing of the rising edge of the flow rate and the process to reach the steady state.

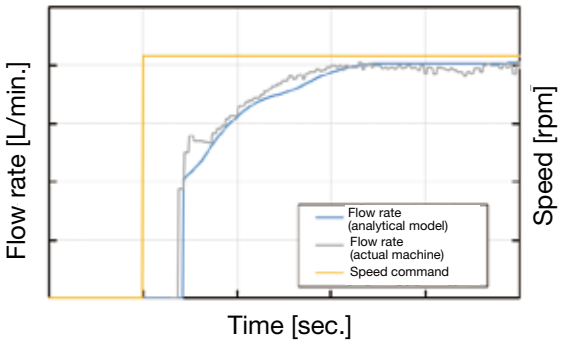


Fig. 16 Electric pump discharge flow rate over time

Note 9) A control gain for adjusting the control input in proportion to the difference between the target and current values of the controlled object

Table 5 shows the response time of the analytical model under various test conditions compared with the actual machine. According to Table 5, the response time error is within ±10% with the P control gain set to high. On the other hand, it is between about 10% and 30% with the P control gain set to low. This is probably because a lower P control gain leads to a smaller difference between the motor torque and the load torque in the transient state, resulting in a relatively stronger impact of the motor torque error of the model on the rotary action.

Table 5 Evaluation of responsivity of improved electric pump model

Operating conditions	P control gain	Response time error
Low pressure, High speed	Low	12.8%
	Mid	-12.0%
	High	2.0%
High pressure, Low speed	Low	21.6%
Mid pressure, Mid speed	Low	7.1%
	Mid	4.3%
	High	-7.9%

In this way, we successfully built an electric pump model that can reproduce efficiency and response time with the target accuracy by setting the P control gain for pump speed to a high value. Note that the KYB hydraulic system described in Chapter 6 uses a high P control gain setting for performance evaluation.

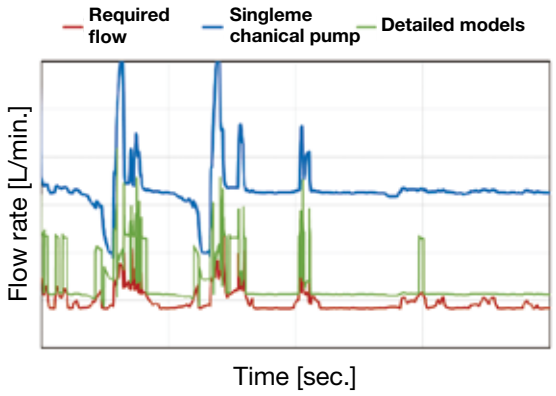
6 Performance Evaluation of Hydraulic System

We combined the models built in the previous chapter (hereinafter "the detailed models") into a whole hydraulic system and evaluated the performance through simulation in order to determine whether the system is effective.

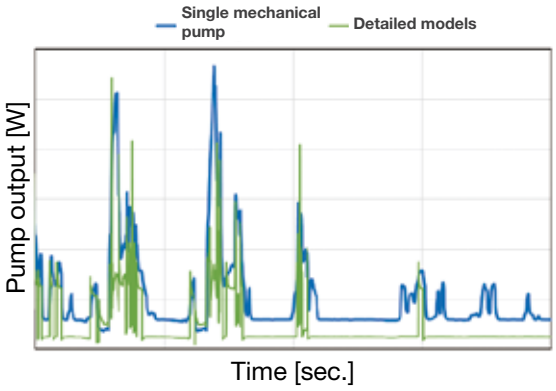
6.1 Performance Evaluation of Hydraulic System

This section describes the results of system performance evaluation of the detailed models which was conducted in the same manner as for Chapter 3. Fig. 17 shows the results of the simulation. Fig. 17(a) shows the pump discharge flow rate, indicating that the pump meets the required flow rate. This graph also reveals that the detailed models discharge at a lower flow rate as a whole than the single mechanical pump system, implying that any excessive flow has been reduced.

The pump output of the detailed models is lower than that of the single mechanical pump system model over the entire range as shown in Fig. 17(b). The output reduction rate is 48.3%, proving the effectiveness of this system.



(a) Flow rate



(b) Pump output

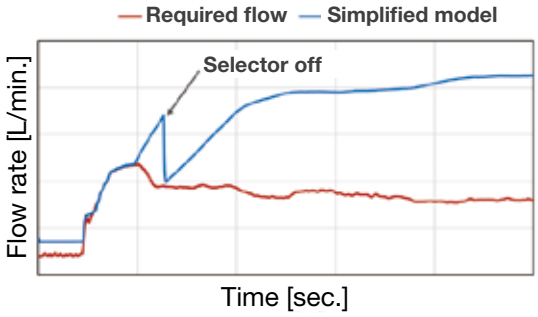
Fig. 17 Results of simulation

6. 2 Stability Evaluation of Hydraulic System

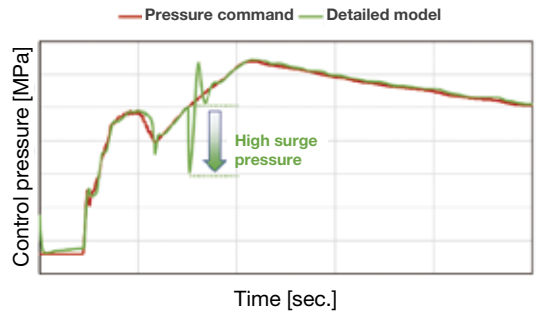
This section describes a simulation of an operation pattern that needs instantaneous high flow rate and control pressure, such as kick down (hereinafter "KD"), to determine the follow-up performance.

Fig. 18 shows the results of analysis of flow rate and control pressure. Fig. 18(a) indicates that the required flow rate is mostly satisfied over the entire operating range. Fig. 18(b) indicates that the control pressure follows the pressure command, except for high surge pressures with the selector off.

As described above, the surge pressure causes a shock to the entire vehicle, leading to lower ride comfort. This issue might be resolved by cooperative control of the selector valve and the electric pump. Then, we took a simplified measure for reducing the surge pressure, which is described in this section.



(a) Flow rate



(b) Pump output

Fig. 18 Follow-up performance during KD

Fig. 19 shows an overview of the cooperative control logic. The KYB hydraulic system is conventionally controlled to merge the main discharge with the sub discharge if the main discharge alone is not sufficient to provide the required flow. If this is not enough to meet the required flow, the electric pump is started up to compensate for the flow. This is a control logic only intended to satisfy the required flow. In this case, a surge pressure is likely to occur when the sub discharge is turned on/off with the selector valve, as shown in the upper section of Fig. 19. Then, we decided to add surge pressure reduction control to the cooperative control logic as shown in the lower section of Fig. 19. This control system is intended to prevent abrupt changes in flow in the whole hydraulic system by decreasing/increasing the discharge of the electric pump in response to an increase/decrease in sub discharge upon change-over of the valve.

Fig. 20 shows the results of the analysis of control pressure in the KD evaluation using the model including the surge pressure reduction control. It was confirmed that the addition of this control can reduce the surge pressure that occurs upon change-over of the valve by about 50%.

In addition to the stability improvement verified in this section, a further study on cooperative control will enable us to reduce the frequency of change-overs, implement a

robust operation design, and improve the effect of pump output reduction.

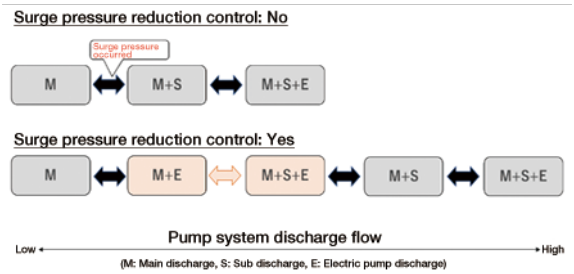


Fig. 19 Cooperative control logic

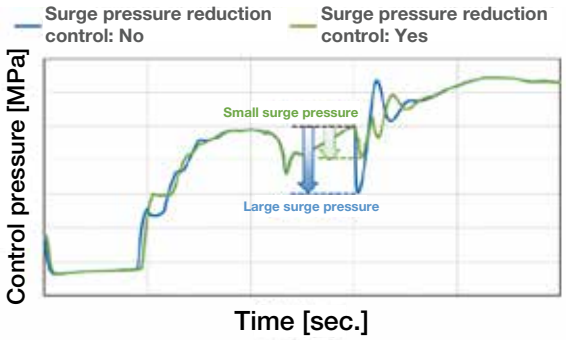


Fig. 20 Effect of surge pressure reduction by cooperative control

7 Concluding Remarks

We have established a simulation technology that enables performance prediction as a means of confirming the feasibility of a high-efficiency hydraulic system and obtained the following findings:

(1) We modeled a KYB hydraulic system consisting of a mechanical pump, an electric pump, and a selector valve to enable prediction of the system performance with high accuracy. We then confirmed the effectiveness of this hydraulic system.

(2) We carried out a parameter study using the model built to identify parameters affecting the stability, clarifying the design indices with which surge pressure and responsivity can be controlled.

(3) We successfully set the prospects for improving the performance of the hydraulic system by coordinating the control of each component according to operation mode.

The results obtained make it possible to accelerate the development with less frequent prototyping of actual machines and design a hydraulic system with priority placed on the main machine.

From now on, we will study optimal equipment specifications and/or cooperative control suited to operation modes required by customer specifications, with the aim of maximizing the system performance/quality. We will also apply the technology to the prediction of the lubrication/cooling system for eAxle (an integrated structure of the motor, reducer, and inverter) that is growing in demand in the automobile industry.

References

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2) KANO Yoshiaki, KOSAKA Takashi, HOJO Yoshihisa, OHMORI Yoichi: "Novel d-q equivalent circuit model of IPMSM for accurate torque control", Joint Workshop on Motor Drives/Home and Consumer Appliances on March 1, 2022, pp.115-124 (March 2022)

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Technology Explanation

Research on strength prediction technology for fiber-reinforced plastic injection-molded products

OGURA Shogo

Abstract

In anticipation of the introduction of global CO_2 emission regulations, there is a growing need to reduce the weight of transportation equipment. Fiber-reinforced plastic (FRP) is attracting attention as a lightweight material. FRP injection-molded products have the potential for both weight reduction and cost reduction. However, it is difficult to predict and control strength because the fiber orientation changes depending on how the products are made, and this has a significant impact on physical properties. Therefore, development has been conducted on a trial-and-error basis, and optimization of part geometry and processing methods has not been studied. In this study, we use simulation to develop a strength prediction technique that considers the anisotropy of physical properties due to fiber orientation. This enables us to realize development without rework and to construct a technology that can optimize the design.

We quantified the fiber orientation in plastic parts, which has been difficult in the past, and improved the prediction accuracy of fiber orientation by resin flow analysis. Based on the predicted fiber orientation information, the physical property anisotropy of fiber-reinforced plastic parts was predicted. A material model for structural analysis was created, and structural analysis considering fiber orientation was performed to improve the accuracy of strength prediction for plastic parts.

It was also found that this technique can be used to predict the fracture behavior of actual plastic part geometry, confirming the importance and effectiveness of studying material strength, including the manufacturing process, when designing fiber-reinforced plastic parts.

1 Introduction

1.1 Background of the Research

In anticipation of the introduction of global CO_2 emission regulations and market launches of electric vehicles, there is a growing need to reduce the weight of transportation equipment. To respond to the weight reduction need, studies are in progress to replace metallic parts with plastic components that are lighter and easier to process. Since plastic is inferior in mechanical properties to metal, fiber-reinforced plastic (FRP) such as plastic reinforced with glass or carbon fibers is attracting attention as a low-density, high-strength material. FRP is used as structural members in a wide range of fields today.

1.2 FRP Processing methods and its Characteristics

Fig. 1 shows the mechanical properties and productivity characteristics of FRP for various processing methods [1]. FRP varies in mechanical properties and productivity by fiber length. Continuous fibers are superior in mechanical properties but inferior in productivity, so they have limited applications in aircraft, sporting goods, luxury cars, and others. On the other

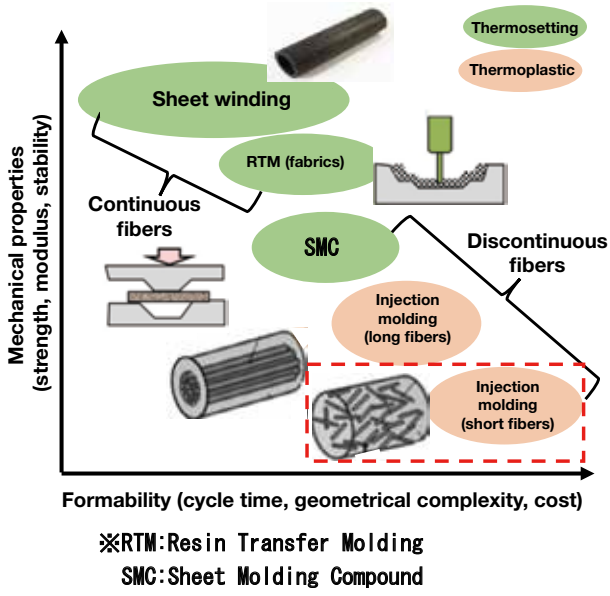


Fig. 1: FRP characteristics for various processing methods

hand, discontinuous fibers that can be injection-molded have a good balance between mechanical properties and productivity, thereby having the potential for both weight reduction and cost reduction. This research focuses on FRP injection-molded products.

1.3 Anisotropy of Physical Properties of FRP Injection-Molded Products

FRP injection-molded products have a distribution of fiber orientation and/or fiber length due to the shear stress and elongation flow that occur when resin flows in the mold during injection molding. Because of its higher reinforcement in the direction of fiber orientation, FRP shows anisotropy of modulus, strength, coefficient of linear expansion, and other properties according to the fiber orientation distribution during injection molding. This poses the problem that it is difficult to predict the strength, rigidity, and warpage of molded parts. For example, molded parts may fracture before reaching a required load if their anisotropy of modulus or strength have not been considered. In another case where anisotropy of the coefficient of linear expansion is not considered, molded parts may go out of dimensional tolerance due to warping.

That is why it is difficult to predict the quality characteristics of FRP injection-molded products. Mold changes have been repeated on a trial-and-error basis, resulting in longer development periods and higher development costs. Furthermore, the part geometry has not been optimized since the anisotropy of physical properties due to fiber orientation cannot be exactly predicted. Some parts have been produced using more resin material than necessary in order to ensure quality.

Fig. 2 shows the current and target development flows for FRP parts. The target development flow will allow us to predict the anisotropy of physical properties due to fiber orientation and the mechanical properties of molded parts, thereby enabling the optimization of the part geometry and mold design on the desk. This will contribute to higher development efficiency.

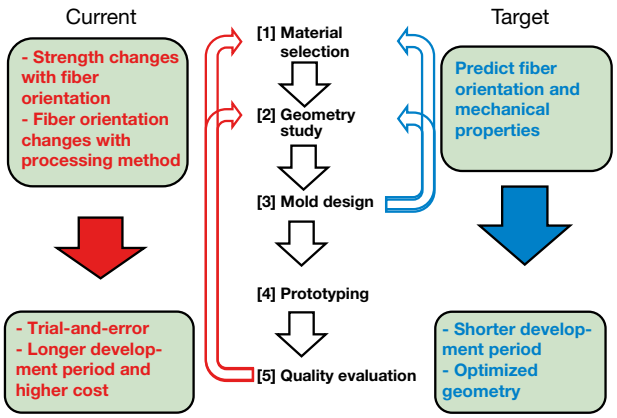


Fig. 2 Current and target development flows

2 Overview of Prediction Technique

In this development study, we predict the anisotropy of physical properties from the fiber orientation generated in the injection molding process and then carry out a structural analysis that considers the anisotropy, improving the accuracy of strength prediction for FRP parts. Fig. 3 illustrates the concept of the prediction technique.

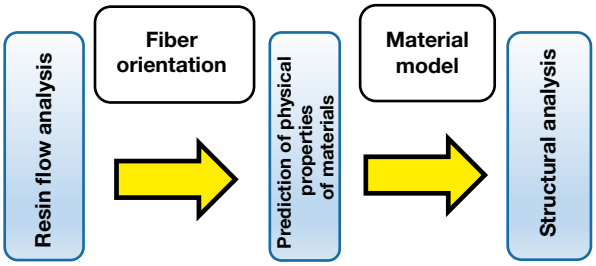


Fig. 3 Concept of strength prediction technique

The first step is to conduct a resin flow analysis and then predict the fiber orientation of injection-molded parts. The next is to create an anisotropic material model based on the predicted fiber orientation. The final step is to carry out a structural analysis using the anisotropic material model, enabling prediction of mechanical properties with the fiber orientation taken into account. Implementation of this technique involves challenges:

[1] Quantitative evaluation of fiber orientation
[2] Improvement of fiber orientation prediction accuracy through flow analysis
[3] Improvement of structural analysis accuracy with fiber orientation taken into account
[4] Improvement of prediction accuracy for strength reduction rate of welds

The following chapter describes what we have addressed to resolve these challenges.

3 Accuracy Testing with Element Specimens

3. 1 Quantitative Evaluation of Fiber Orientation

Photo 1 shows an X-ray CT image of an injection-molded product.

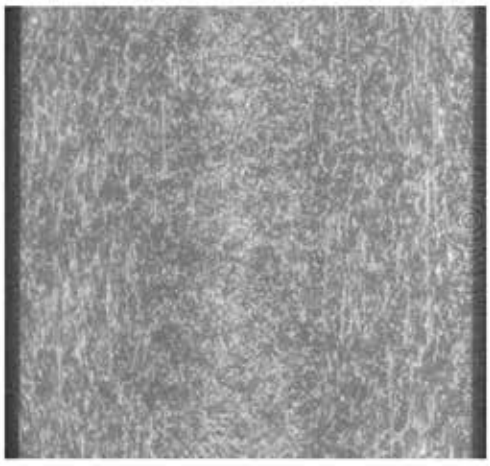
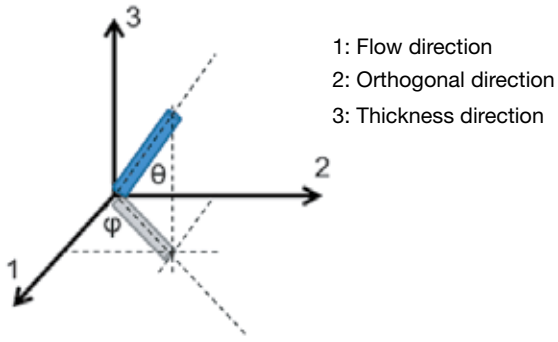


Photo 1 X-ray CT image of FRP

Glass fibers appear in white and plastic in gray. This injection-molded plastic product contains about 30% to 50% fibers of a thickness of about 10μm. Since the fibers are three-dimensionally distributed, it is usually difficult to quantify the fiber orientations. Then, we have conducted joint research with Kanazawa Institute of Technology (KIT) to quantify the fiber orientations from X-ray CT images using the cylinder-model fitting approach [2].

The following describes how to identify glass fibers using the cylinder-model fitting approach. First of all, a cylinder model is placed over each of the fibers obtained in the X-ray CT images. The angle and length of the cylinder models are adjusted so that the models match the actual fibers well, which will determine the parameter values. Calculating the angle of individual cylinder models will quantitatively evaluate the fiber orientation. Next, the part thickness is divided into 21 layers at all observation points and the degree of fiber orientation in each layer is determined. The definition of the degree of fiber orientation is illustrated in Fig. 4. The angle of fibers is indicated by the in-plane orientation angle Φ and the out-of-plane orientation angle θ. The orientation tensor in each direction has been calculated using equations 1) to 3). "N" indicates the number of fibers. The orientation tensor is "a11" in the flow direction (MD), "a22" in the direction orthogonal to the flow direction (TD), and "a33" in the thickness direction (ND) at all observation positions.



Φ: In-plane orientation angle (Flow direction: 90°)
θ: Out-of-plane orientation angle (Thickness direction: 0°)

Fig. 4 Definition of the degree of fiber orientation

$$a11 = \frac{1}{N}\sum_{i=1}^{N}(\sin\theta_i \cos\varphi_i)^2 \quad (1)$$

$$a22 = \frac{1}{N}\sum_{i=1}^{N}(\sin\theta_i \sin\varphi_i)^2 \quad (2)$$

$$a33 = \frac{1}{N}\sum_{i=1}^{N}(\cos\theta_i)^2 \quad (3)$$

It is now possible to three-dimensionally quantify the fiber orientation, which has conventionally been difficult (Fig. 5).

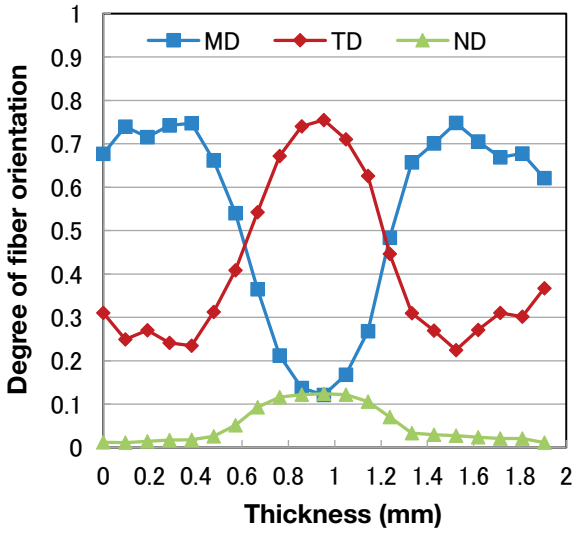


Fig. 5 Quantitative evaluation of fiber orientation

3. 2 Improvement of Fiber Orientation Prediction Accuracy through Flow Analysis

To achieve a structural analysis that considers the anisotropy of physical properties due to fiber orientation, it is necessary to predict the fiber orientation taking place during injection molding. Then, we predict the fiber orientation by analyzing the material flow in injection molding and compare the prediction with the results of the quantification of actual fiber orientation stated above, in order to verify the prediction accuracy.

Fig. 6 shows a flat plate specimen used in testing. The specimen is made of PA66 containing 30 wt% glass fibers.

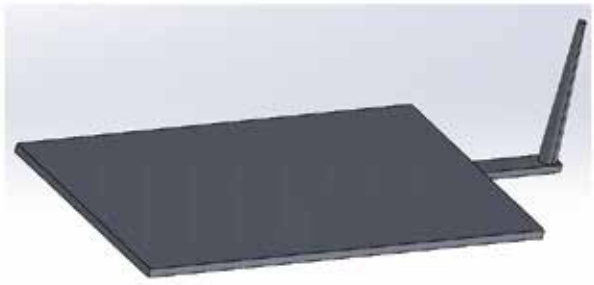


Fig. 6 Overview of specimen geometry

The flow analysis was made with an injection molding software (CoreTech System Moldex3D®). As a prediction model for fiber orientation, the Folger-Tucker model [3], which is a model for predicting orientation behavior of ellipsoids in high-concentration solutions, was used in combination with the iARD (Improved Anisotropic Rotary Diffusion) model[4] to also allow consideration of interference among fibers.

Fig. 7 shows a schematic diagram of the fiber orientation mechanism. In injection molding, the molten material is instantaneously cooled to solidify in the areas where the material has come into contact with the mold. Inside these areas, the molten resin still continues flowing in general cases. There arises a velocity gradient between the solidified layer and the molten layer. It is generally considered that the difference in velocity causes a shear

stress to make the fibers position in the direction of the resin flow. In this research, specimens were prepared with two injection speed levels (high and low) since the injection speed greatly affects the thickness of the solidified layer. Then, fiber orientation was compared between the actual test results and the analysis results.

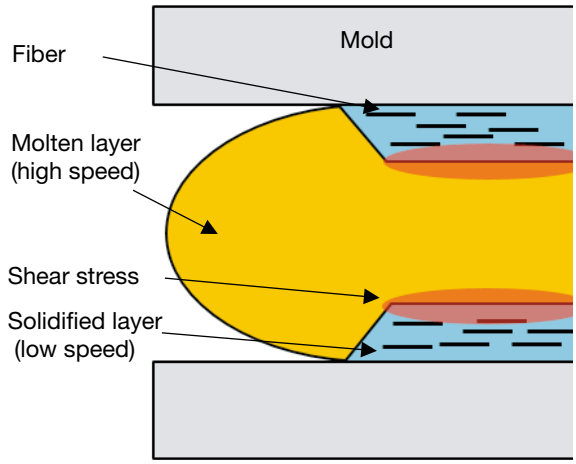


Fig. 7 Schematic of fiber orientation mechanism

Figs. 8 and 9 show the comparison of fiber orientation distribution between the actual test and the analysis. These Figures indicate that the analysis results generally reflect the actual fiber orientation distribution, which has been achieved by adjusting the flow analysis parameters to improve the prediction accuracy for fiber orientation. The Figures also reveal that the trend of fiber orientation distribution varies with injection speed. Specifically, slower injection produces a thicker layer in the direction of the molten resin flow (MD) close to the wall of the mold. This is probably because the solidified layer close to the wall is more likely to grow with slower injection and the shear stress occurring between the solidified and molten layers applies even at its center. Thus, it is possible to reproduce through analysis the fiber orientation distribution for varying injection speeds.

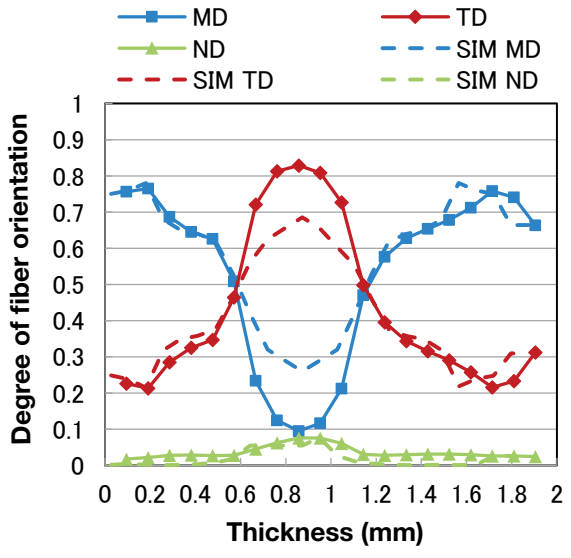


Fig. 8 Comparison of fiber orientation distribution between actual test and analysis (high speed injection)

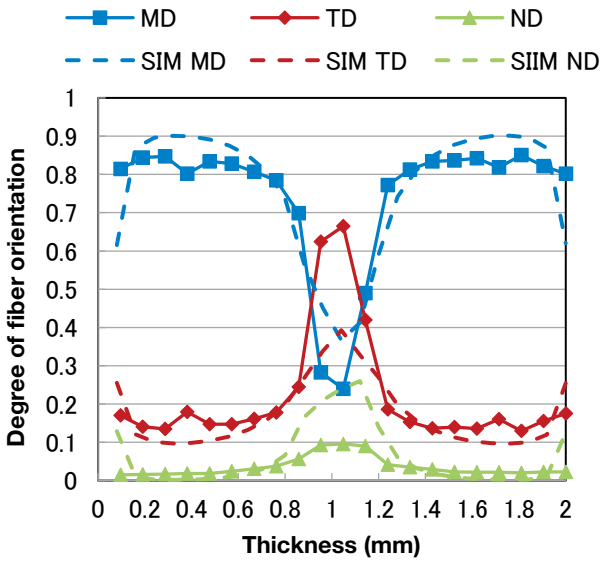


Fig. 9 Comparison of fiber orientation distribution between actual test and analysis (low speed injection)

3.3 Improvement of Structural Analysis Accuracy with Fiber Orientation Taken into Account

This section carries out a structural analysis considering the fiber orientation distribution predicted through flow analysis and verifies the analysis accuracy. A non-linear, multi-scale material modeling software Digimat® (e-Xtreame) was used to predict anisotropic physical properties of the material, and homogenized with the Mori-Tanaka model[5]. Digimat uses the mean field approximation approach. This approach handles the geometry and orientation of glass fibers approximately as ellipses and calculates the strain and stress applied to the resin matrix and glass fibers, determining the total physical properties of the composite containing glass fibers. The mean field approximation approach focuses on the micro stress-strain characteristics of a material to calculate its macro physical properties with its microstructure taken into account. Featuring high-speed calculation, the approach can be combined with the finite-element method to calculate and solve equations.

The structural analysis accuracy has been verified with dumbbell-shaped specimens cut out from the flat plate specimen which was produced in section 3.2, at different angles (0˚, 45˚, 90˚) to the direction of the resin flow (Fig. 10). These specimens were subjected to a tensile test. The resultant stress-strain (S-S) curves were compared with the analysis results. In general, fibers contained in an injection-molded part are likely to be predominantly oriented in the direction of the resin flow. It is therefore considered that the strength of the specimens depends on the anisotropy of their physical properties due to fiber orientation. Specifically, specimens cut out at 0˚ have a high strength while those cut out at 90˚ have a low strength. The following verifies that these behaviors can be simulated by analysis.

In section 3.2, we already confirmed that changes in injection speed affect the fiber orientation distribution and that the phenomenon can be reproduced by analysis. To determine the impact of changes in fiber orientation due to variations in injection speed on the physical properties, both a strength evaluation and a comparison with analysis results have been carried out at two injection speed levels: high and low.

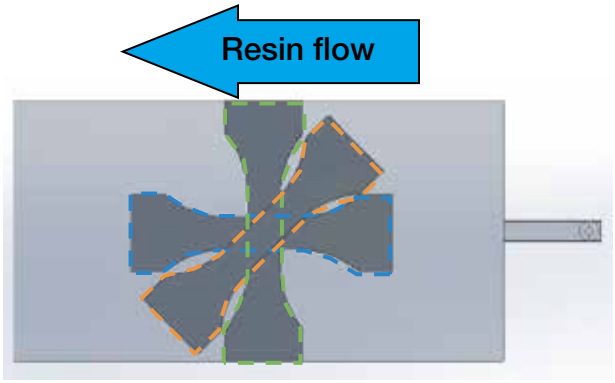


Fig. 10 Locations from which strength test specimens were cut out

Figs. 11 and 12 show the test results. These Figures reveal that the analysis model can reproduce the behavior of the actual specimens. The end point of the S-S curves represents the timing when the specimen fractured. Fracture was determined according to the Tsai-Hill 3D transverse criterion. By considering the breaking strain for each fiber orientation, the analysis model also reproduces fracture timing with good accuracy.

The results also show that the slower the injection speed, the larger the anisotropy with high strength at 0˚ and low strength at 90˚. This is probably attributable to the finding in section 3.2 that a higher degree of fiber orientation is found in the direction of MD for low injection speed. In other words, the injection molding method impacts the fiber orientation, which further affects the physical properties. We have verified that these changes can be reproduced with good accuracy by an analysis model that considers fiber orientation.

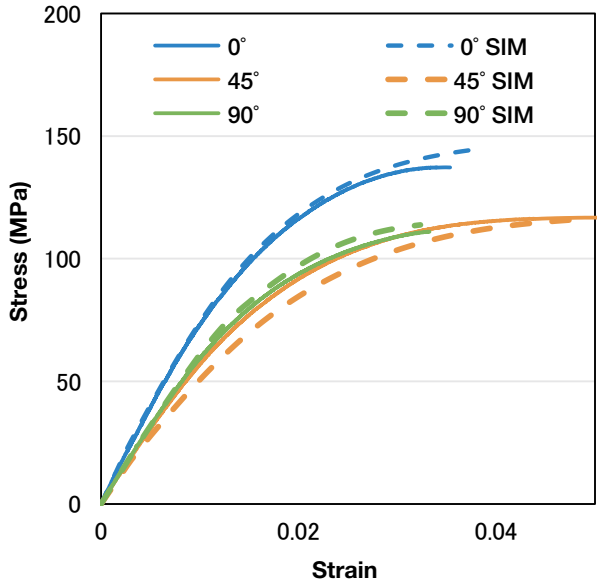


Fig. 11 Structural analysis accuracy for various cut-out angles (high speed injection)

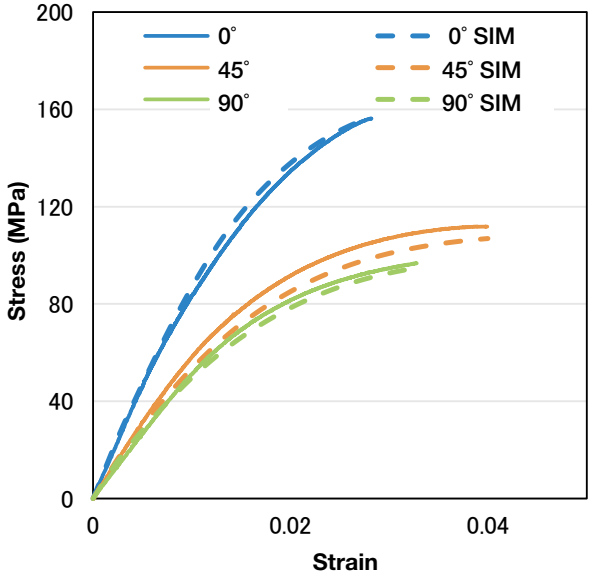


Fig. 12 Structural analysis accuracy for various cut-out angles (low speed injection)

3. 4 Improvement of Prediction Accuracy for Strength Reduction Rate of Welds

When a flow of molten resin meets another flow of molten resin during injection molding, a weld line is formed. The weld line substantially degrades the strength of the composite because of the local change in fiber orientation and the existence of a fusion interface (Fig. 13). In fact, it is difficult to completely eliminate the formation of weld lines in injection molding of actual products. Therefore, it is essential to carry out analysis with weld lines taken into account, in order to improve the strength analysis accuracy.

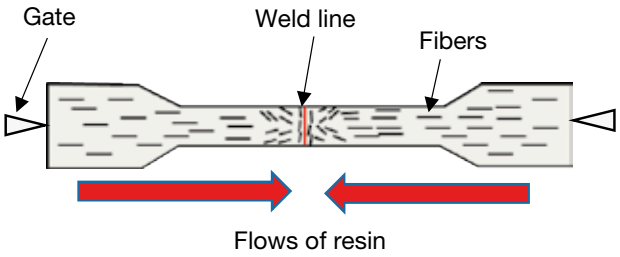


Fig. 13 Schematic of weld line

As stated above, welds may have lower strength due to a local change in fiber orientation and the existence of a fusion interface. Photo 2 shows an X-ray CT image of the fiber orientation distribution of a weld. In the portion where the flows of resin merge, fibers are densely positioned in the direction perpendicular to the direction of the flows of resin. In this way, the weld is the place where there is a local change in fiber orientation and is likely to be a source of fracture partly because of the existence of the fusion interface. By predicting the fiber orientation at the resin merging point by flow analysis and then including the lower strength due to the fusion interface as an analysis variable, we have successfully improved the prediction accuracy for strength of the welds (Fig. 14).

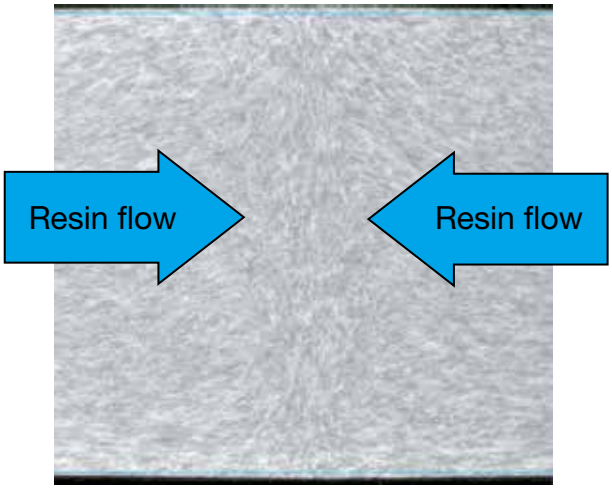


Photo 2 Fiber orientation in the weld

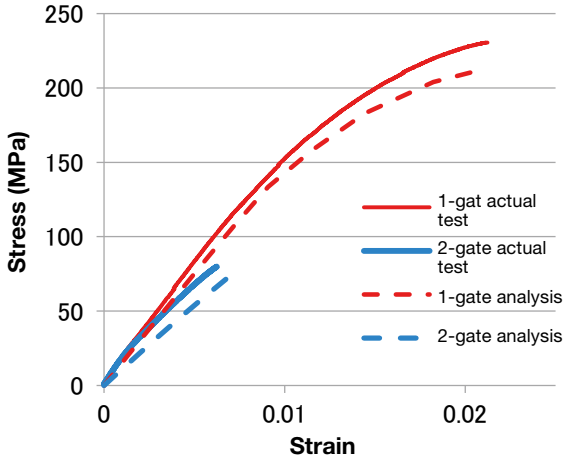


Fig. 14 Prediction accuracy for strength of welds

Through these efforts, we have established an analysis technique with consideration given to the fiber orientation and weld line that substantially affect the physical properties of FRP injection-molded products.

4 Prediction Accuracy Verification with Actual Part Geometry

4. 1 Confirmation of the Effect with Actual Part Geometry

Since it is now possible to carry out the strength analysis considering the fiber orientation and weld line, this chapter verifies the effect of the analysis by using actual parts. An example for plastic bump stoppers for shock absorbers is introduced as follows. The plastic bump stopper is press-fitted into the outer. When the stopper with geometry [1] was press-fitted into the outer, a fracture occurred. Then, the part design was modified on a trial-and-error basis to have another geometry [2], which eventually eliminated the fracture problem (Fig. 15). We then tried to verify that this phenomenon can be reproduced by analysis.

First of all, we examined the flow behavior of resin through resin flow analysis. The examination revealed that the resin flow behavior varies according to the part geometry, resulting in different areas where the weld line is formed. We then conducted a structural analysis that considers the fiber orientation and a lower strength of the weld line. As a result, the analysis successfully reproduced the behavior that the part with geometry [1] fractured while that with geometry [2] did not (Fig. 16). Thus, we confirmed that, when designing FRP parts, it is important and effective to study how to ensure the material strength, including the influence of the manufacturing method.

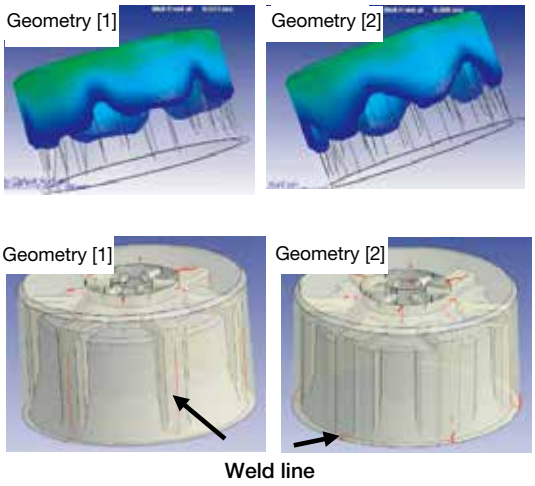


Fig. 15 Weld lines formed in different locations

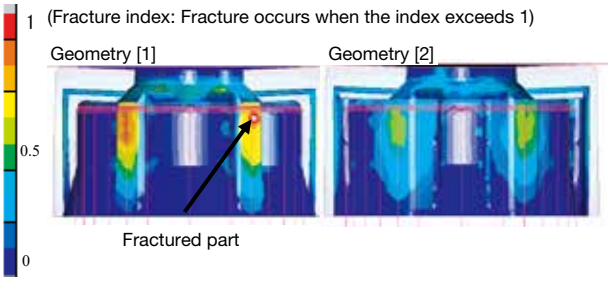


Fig. 16 Analysis of fracture index during press-fitting into the outer

5 Concluding Remarks

FRP injection-molded products have anisotropy or distribution of their mechanical properties due to fiber orientations and/or weld lines generated during the molding process. We have developed a structural analysis technique that considers fiber orientation and welds in the molding process, improving the prediction accuracy for physical properties of plastic parts. It has also been found that the technique can be used to predict the fracture behavior of actual parts of different geometries. We have confirmed that, when designing FRP parts, it is important and effective to study material strength, including the influence of the manufacturing process.

6 Future Prospects

This technique has improved the strength prediction accuracy for plastic parts. We will apply the technique to various actual parts to improve the development efficiency and optimize the part geometry for cost and weight reduction, contributing to higher competitiveness.

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Product Introduction

Development of KCH-8 High Pressure Cylinder for Construction Machinery

KOBAYASHI Toshio

1 Introduction

KYB manufactures and sells cylinders for construction machinery including hydraulic excavators as its main products. Among these, hydraulic excavators of an operating mass of the 20 to 40 ton class are high in demand and can be often seen in various places throughout the world from urban construction sites to mines. KYB has continued manufacturing cylinders for hydraulic excavators of the class stated above (hereinafter "KCH") for about 50 years. However, the company is now exposed to a very competitive environment due to the globalization of hydraulic excavator manufacturers, and the emergence of competitive cylinder products. Particularly in terms of price competition, it is difficult for us to find a competitive edge.

To improve this disadvantageous situation, we have developed a new model (KCH-8: Kayaba Cylinder High pressure model-8) that is not bound by the existing structure. This paper introduces the existing product we focused on this time, its technical challenges, and the newly developed product.

2 Hydraulic Cylinders

2. 1 What is a Hydraulic Cylinder?

A hydraulic cylinder uses hydraulic fluid supplied by a pump as a means to apply a pressure to its pressure area, which will thereby generate a thrust. A hydraulic excavator uses the thrust and expansion/contraction of its hydraulic cylinders linked to a bucket to accomplish various tasks including digging, transport, and lifting of heavy soil (Fig. 1).

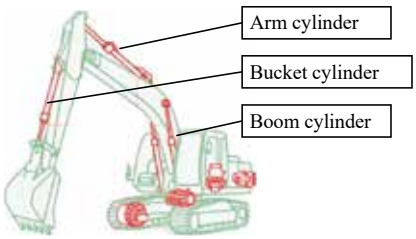

Fig. 1 Example of use of hydraulic cylinders in construction machinery

2. 2 Major Cylinder Components

A hydraulic cylinder consists of less than 50 kinds of parts, which is fewer than other hydraulic components (such as pumps and valves). The mechanical structure of a hydraulic cylinder is rather simple. Although a detailed introduction of cylinder parts is omitted here, Fig. 2 shows an overview of a hydraulic cylinder and Table 1 shows its typical functions.

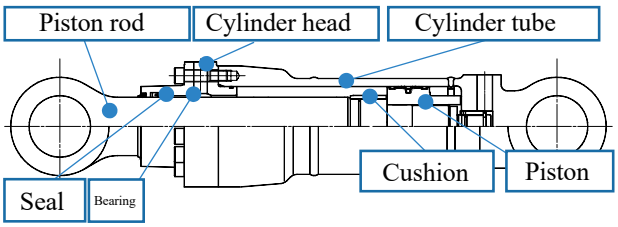

Fig. 2 Cylinder model

Table 1 Components and typical functions of a hydraulic cylinder

Component	Typical function
Cylinder tube	Structure, sealing
Piston rod	Structure, sliding
Cylinder head	Structure, sealing, bearing retention
Piston	Structure, bearing retention
Seals	Sealing, pressure resistance
Bearings	Structure, sliding
Cushion	Buffering

2. 3 Characteristics of Hydraulic Cylinders

Hydraulic cylinders used in a hydraulic excavator play the twin roles of performing the required exterior work and accommodating the counterforces and external forces applied to the excavator. They can deliver various functions related to workability/operability of the hydraulic excavator including sealing of hydraulic fluid for ensuring thrust generation, slidability for smooth expansion/contraction, and buffering with cushions at the stroke ends. At the same time, many of the cylinder components serve as structural members to bear the pressure of hydraulic fluid, tensile/compressive loads, bending, buckling, and vibration as well as holding the structure themselves.

The major dimensions of cylinders are decided by the thrust and stroke required by the hydraulic excavator. Since many cylinder products are long and narrow, their components are required to be long in the direction of the cylinder axis.

3 Development Challenges and Improvement Points

3. 1 Clarification of Challenges

KCH is exposed to severe price competition as stated in the Introduction. Cost reduction is the top priority. To clarify the challenges, we conducted a cost analysis on the cylinder. The analysis revealed that the material cost of cylinder tubes accounted for the largest proportion of the cylinder cost (piston rod material is the second largest). These long parts are dominant cost contributors (Fig. 3). Therefore, it can be expected that thinning the walls of these long parts will substantially reduce the cylinder cost.

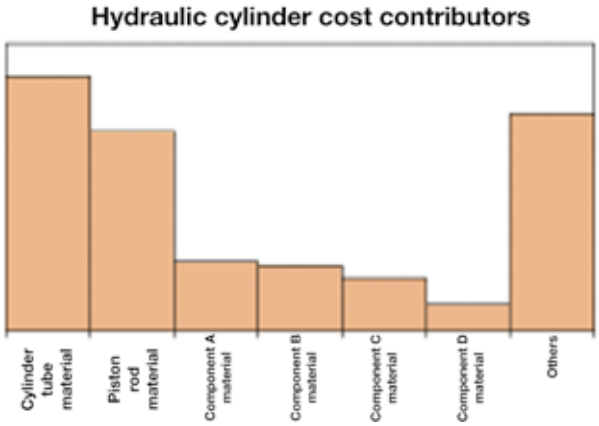

Fig. 3 Cylinder cost contributors

3. 2 Properties and Technical Hurdles of Cylinder Tubes

Examples of hydraulic cylinders used in a hydraulic excavator (Fig. 1) include boom, arm, and bucket cylinders. Since the way in which cylinders are used depends on where they are installed, the load applied to the cylinders naturally depends on their location. Therefore, the required strength varies by cylinder, so cylinders are specifically designed to attain their own relevant strength. Fig. 4 shows the cylinder tube assembly, which is one of the components of the hydraulic cylinder, and its configuration. Our conventional cylinder tubes are designed to have an appropriate wall thickness selected from up to four thickness levels, in order to attain an optimal design for the required strength.

The wall thickness of the cylinder tube can be reduced as long as it has adequate strength. We analyzed the rate of change in various properties of a cylinder tube with a wall thickness 20% less than the conventional thickness and determined whether the cylinder tube met the required strength (requirements). The results are shown in Table 2.

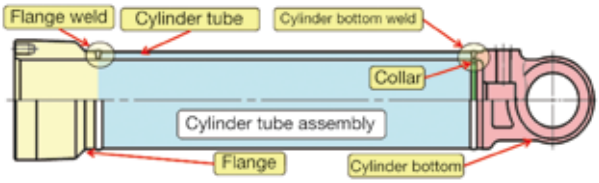

Fig. 4 Existing cylinder tube assembly model

Table 2 Major mechanical properties of cylinder tube with thinner wall

Property	Rate of change	Requirements
Endurance strength	-57.0%	Not acceptable
Strength against external force	-24.7%	OK
Compressive strength	-18.5%	OK
Pressure deformation	-16.0%	OK
Rigidity	-4.3%	OK

Among the various properties, the endurance strength decreased at the highest rate. The analysis implies that simply thinning the wall of the cylinder tube will not meet the requirements. Particularly, the cylinder bottom weld (Fig. 4) is the weakest point, posing a strength bottleneck. You might question why thinning the cylinder tube wall should affect the endurance strength of the cylinder bottom weld. However, endurance strength is inversely proportional to stress concentration. The endurance strength of the cylinder bottom weld is proportional to the wall thickness of the cylinder tube. A strength analysis (using the Finite Element Method; hereinafter the "FEM") showed, through a trial calculation, that thinning the cylinder tube wall would increase the stress in the weld and lower the endurance strength.

It should be noted here that the cylinder bottom weld is a welded joint between the cylinder tube and the cylinder bottom and has a dramatic change in geometry in contrast to the straight cylinder tube. Due to this geometry change, stresses are concentrated in the weld. Moreover, the weld, which is directly connected to the cylinder tube, has a higher mean stress in proportion to the lower wall thickness of the cylinder tube. Thus, the already stress-concentrated weld has an even higher stress.

In the light of these characteristics of the cylinder bottom weld, we thought that, if the stress concentration in the cylinder bottom weld was suppressed, a cylinder tube with a thinner wall could maintain a conventional endurance strength, in spite of the increased mean stress of the cylinder bottom weld caused by thinning of the tube wall.

Then, we set a challenge of "thinning the cylinder tube wall by improving the endurance strength of the cylinder bottom weld" and decided to work on the improvement of the weld.

3.3 Conventional Cylinder Bottom Weld Structure and its Characteristics

Fig. 5 shows various cylinder bottom variants (four

geometries) that have been used so far. These geometries have been developed to ensure the necessary functions of the cylinder bottom weld, including pressure resistance, endurance, and coaxiality of the cylinder tube and the cylinder bottom.

The cylinder bottom weld geometry before the development of KCH-8 was Type 4.

Type 1: The initial geometry of the hydraulic cylinder tube assembly. Type 1 features the simplest design, lower number of parts, and a rather good production yield. But the endurance strength is the worst among the four types.

Type 2: Compared to Type 1, the weld is farther away from the cylinder bottom to reduce the stress concentration, delivering better endurance. Type 2 consists of the same number of parts as Type 1, but shows a lower production yield.

Type 3: Designed to reduce the stress concentration in the cylinder bottom weld by considering deformation due to hydraulic pressure applied to the cylinder bottom section. Type 3 shows better endurance than Type 2. Uses the same number of parts, but involves complex machining to cut a circular groove in the bore of the cylinder bottom.

Type 4: To further reduce the stress concentration due to hydraulic pressure applied to the cylinder bottom, a three-piece structure has been introduced. Type 4 is constructed to weld the cylinder bottom to the cylinder tube using a collar (a part equivalent to a back board). Type 4 delivers the best endurance among the conventional types. The production yield of the cylinder bottom section has been improved from Type 3.

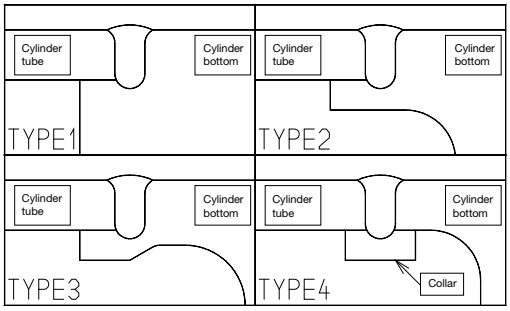

Fig. 5 Bottom weld geometries that have been used so far

4 How to Improve Weld Endurance

4. 1 Structural Study

We studied how to improve the endurance of the cylinder bottom weld by modifying the geometry of the weld section. The farther the weld is from the cylinder bottom, the lower the stress. This is a typical stress reduction measure, but unavoidably extends the total length of the structure, posing a configuration disadvantage. Then, we conducted an FEM analysis to look for an optimal geometry (Fig. 6). Various configurations were analyzed, including different wall thicknesses of the cylinder tube, the presence/absence of a collar, and different machining geometries of the cylinder bottom section. From the results of the analysis, we predicted that forming a groove-like cavity inside the bore of the cylinder bottom weld section would enable the stress concentration to be suppressed without modifying the conventional configuration. We thought that the presence of the groove would allow the axial load to be evenly distributed to the structure, and not intensely applied to the stress concentrated part, thereby enabling improvement of the endurance strength (Fig. 7)

4. 2 Confirmation of Effectiveness

The geometry variants of the cylinder bottom weld subjected to the stress analysis were narrowed down to six good candidates, which were further subjected to endurance tests. We checked whether the candidates exceeded the endurance strength requirements and whether they showed the endurance strength as analyzed. As a result, assuming that the endurance test result of the conventional cylinder tube was 1.0, the finally selected geometry variant showed about 1.1 even with a reduced wall thickness. Thus, we confirmed a higher than conventional endurance strength for the selected variant. Also, an endurance test on a cylinder tube assembly with conventional tube wall thickness with only the cylinder bottom geometry modified showed an endurance strength twice that of the conventional counterpart, proving that the geometry change adequately improved the strength (Fig. 8).

In addition to endurance, machinability and workability were added to the test evaluation items to build a geometry variant that also considered productivity.

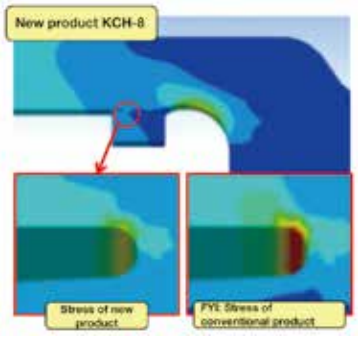

Fig. 6 Stress distribution around the weld

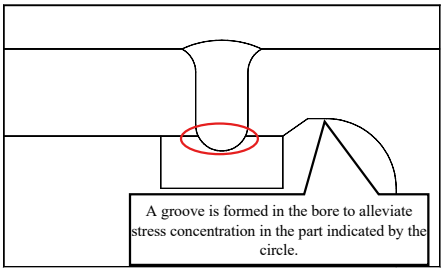

Fig. 7 Geometry of bottom weld of newly developed KCH-8

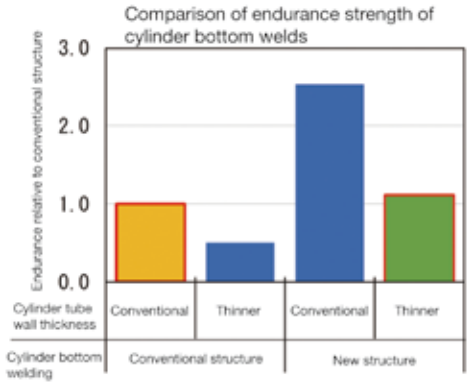

Fig. 8 Comparison of endurance strength

5 Concluding Remarks

In this development project, we were told by our predecessors that this type of product is difficult to improve. However, we have kept the conventional geometry and successfully improved the endurance strength of the cylinder tube assembly even with the thinner tube wall. I am pleased with this achievement.

Based on the outcome of this development project, I will continue my efforts as part of the team developing new hydraulic cylinders.

Finally, I would like to take this opportunity to cordially thank all those concerned from the construction machinery manufacturers, related corporate partners, and related KYB departments who extended cooperation to the development of this product.

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Product Introduction

KYB Camper Concept

TANAKA Kazunori

Photo 1 Full view of KYB booth at Tokyo Auto Salon 2023

1 Introduction

The core product of the KYB Special Purpose Vehicles Div. is concrete mixer trucks, which have the top share in the domestic market. Concrete mixer trucks are long, heavy vehicles used to transport ready-mixxed concrete. Unfortunately, concrete demand is on a downward trend for the medium-to-long term. The number of concrete mixer trucks owned in Japan is also on a downward trend accordingly.

On the contrary, the demand for camping cars is brisk, mainly among families and senior households. Through the COVID-19 pandemic, camping cars have found a variety of applications: some people enjoy their own personal time, while others use them for remote work. The market has thus enjoyed increasing sales volume. The total accumulated number of camping cars owned in Japan reached 136,000 vehicles in 2021, which is 107% compared to the previous year. The total sales volume has expanded three times from 10 years ago (Figs. 1 & 2, Reference: White Paper on Camping Cars 2021/2022). The recent annual number of newly registered camping cars is 430,000 in the U.S., 230,000 in Europe, 45,000 in

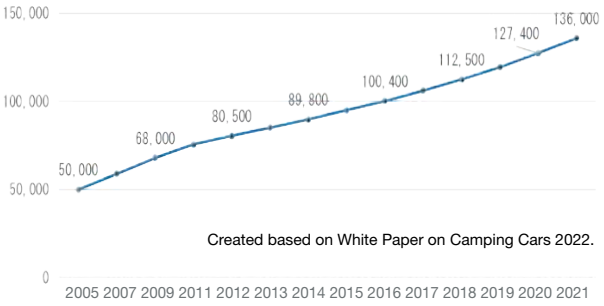

Fig. 1 Accumulated number of camping cars owned in Japan

Fig. 2 Domestic sales of camping cars

Australia, and 8,000 in Japan. The number of RV parks and auto campgrounds is 16,000 in the U.S., 11,000 in France, and 300 in Japan. Compared to foreign countries, the Japanese camping car market is relatively small, but has room to grow.

This paper reports one of the attempts by the Special Purpose Vehicles Div. to address another potential market in the course of a study on next-generation products. The Special Purpose Vehicles Div. has little experience in B2C business and has seldom developed commercial products for general consumers. Still, KYB has sought what it can do for the expanding market, including human resource exchanges with other departments and development through cross-functional activities as a company-wide project.

2 Concepts

We had a questionnaire survey for camping car users to figure out what they want camping cars to be and compiled the answers into a matrix of complaints and points that appeal to users (Table 1).

The survey revealed that users of tall camping cars have concerns about driving stability, such as the risk of tipping over due to, for example, wobbling on the highway, crosswinds at tunnel exits or on bridges, or a sloping road with a reverse camber. It was easy to imagine they were not satisfied with the ride comfort. They also complained about the comfort of the vehicle when parked, such as the vehicle tilting during sleep or the vehicle rocking due to passengers' movement. Many of these problems that are related to the vehicle's suspension seem to be able to be solved with our suspension technology. Several comments on the vehicle's convenience were also collected, including the difficulty to find a parking lot, inability to drive on a road with height limitations, and hesitation to use a drive-through. These complaints may be resolved with our vehicle fitting technology.

Table 1 User complaints and appealing points

	Complaint	Scene	Damping force adjustment	Vehicle height adjustment	Suspension lock	Structure
Safety	Wobbling on highways	Highways	•			•
	Being caught by crosswind	At tunnel exits, on bridges, when overtaken by trucks	•			•
	Concern about tipping over	Highway ramps, road surfaces with a reverse camber	•			•
Comfort	Poor ride comfort	Use of tires with a high spring constant, high tire pressure setting	•			
	Rolls and twists	Entering/exiting convenience stores, driving on unpaved uneven roads	•			
	Vehicle tilting	During parking		•		
	Vehicle rocking	During parking (due to passengers' movement)			•	
Convenience	Freely adjustable by user by hand (via smart phone or tablet)		•	•	•	•

Considering the points that appeal to users, we aimed to create a camping car (camper) implementing the following concepts, among various candidate ideas.

[1] A camper for two people, able to smartly move around in tourist spots, driving on narrow roads and using small parking lots in daytime and offering comfortable, relaxing nights when parked at a campground.

[2] A camper for outdoor lovers to enjoy outdoor activities from morning to night, driving on narrow mountain roads, crossing streams, fishing until sundown , and staying inside safe and comfortable even after dark.

[3] A top-quality, high-end camper with which active outdoor lovers can approach nature in a way that they could not experience with a conventional camping car and can even enjoy driving itself.

3 Vehicle Configuration

To implement the appealing points and concepts stated above, we decided against building a camper by van conversion [Note 1)], which is popular in the market but has a lower degree of freedom, preferring instead cab conversion [Note 2)] based on a truck vehicle frame with a cab. Cab conversion was selected because we can make use of our vehicle fitting technology.

To solve the complaints attributable to the vehicle height such as concerns about driving stability and vulnerability to crosswinds, we worked out a hydraulic pop-up mechanism to implement a low center of gravity, low-height vehicle. This mechanism allows users to raise or lower the vehicle height by 600 mm. Setting the vehicle height at a low level during driving enables stable running not affected by wind. Cab conversions from a 1.5 ton small truck with a standard roof can park at major parking lots for regular passenger cars. A prototype we made has driving dimensions of a total length of 4970 mm, a total width of 1850 mm, and a height of 2150 mm and can be parked at any coin-operated parking lot with no particular restrictions, drive-throughs of fast food restaurants, and even underground parking lots with a ceiling height of not less than 2300 mm, making it smart and great for trips . The room height can be 1900 mm with the vehicle expanded so that occupants can stand up and move around comfortably and enjoy cooking with ease.

The vehicle is narrow enough to enable driving on narrow roads in old cities and forest roads along mountain streams without worry. To enable space expansion, a 400 mm slide-out mechanism is provided on the right side of the vehicle, ensuring sufficient room even after installing sleeping accommodation. We made a wooden mockup (Photo 2) to help portray the indoor atmosphere. After experiencing the livability with the mockup, the design process began.

When expanded with the pop-up and slide-out

mechanisms, the cabin space is about twice the capacity during driving (excluding the equipment) (Photos 4 & 5).

Photo 2 Cabin mockup

The world's smallest class micro piston pump (Photo 3) and cartridge valves manufactured by Takako Industries Inc., one of the KYB Group companies, are used to implement smooth hydraulic operation.

Photo 3 Micro piston pump

The cabin may be expanded only in the height direction during a mini break so that passengers can stand up and move around. In places where care about neighboring cars is needed, the driver may choose not to expand the slide-out.

Photo 4 Side face of contracted vehicle during driving

Photo 5 Side face of expanded vehicle during parking

Note 1) Van conversion: A minivan-based conversion in which principally the interior has been stripped out to install camping equipment.

Note 2) Cab conversion: A camping car based on a truck with a cabbed chassis.

4 Manufacturing of Body

The main body of the vehicle fitting consists of a combination of a steel sub frame with sufficient rigidity and sandwich panels made of aluminium and insulating foam. This body is mounted on the chassis to provide a thermally insulated cabin. The pop-up shell and slide-out section also consist of hard shells made of the sandwich panels, delivering sufficient thermal insulation, sound insulation, vehicle security, and a guard against animals during both driving and parking with the vehicle expanded.

For the room expansion functions, we decided to install an electro-hydraulic unit on one side of the chassis frame under the floor to operate three hydraulic cylinders for the pop-up mechanism and one for the slide-out mechanism (Fig. 4).

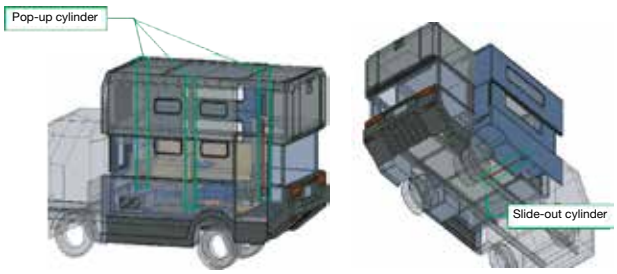

Fig. 4 Cylinder layout

The high-rigidity sub frame contributes not only to easy driving but also to the smooth operation of the pop-up and slide-out mechanisms.

We selected a SUV-like rugged exterior design and installed a rear bumper as seen in passenger cars, emphasizing the departure angle (Photo 6). There is a honeycomb section in the middle part of the rear face to serve as an air outlet of the fan, accentuating the design.

Photo 6 Rear design emphasizing the outdoor characteristics

A water tank is installed in the lower part of the left side to enable water change outside the vehicle. A fuel tank and diesel exhaust fluid tank are located on the right side and can be accessed easily.

5 Installation of Suspension

To improve the running stability, solenoid damping-force adjustable shock absorbers (hereinafter "damping adjustable SAs") have been installed. These adjustable SAs allow the user to adjust the damping force from inside the vehicle, achieving stable, comfortable driving suited to the road surface and running conditions.

In addition, we prototyped a shock absorber with a vehicle height adjustment function that keeps the vehicle level even on a slope and a leveling & suspension lock function that prevents vehicle rocking during being parked (hereinafter "height adjustable SA") (Photo 7).

This paper does not cover the details of the suspension development, which we expect to be introduced in an upcoming issue of the Technical Review.

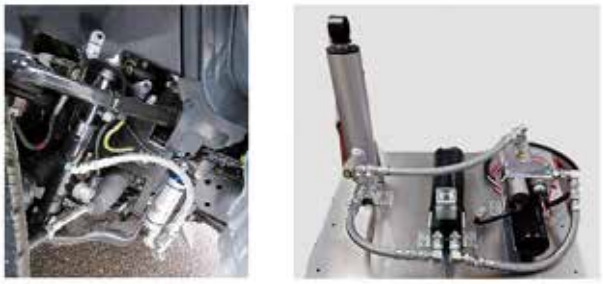

Photo 7 Damping adjustable SA for front wheels, height adjustable SA for rear wheels

6 Interior and Exterior and their Operation

The interior and exterior wrapping was designed by void. Co., Ltd. With the cabin concept of a "shelter" for active people, the interior has been decorated to create a dignified space (atmosphere), giving the camper an upscale image, different to a typical luxury car. While the interior is decorated in classy, chic colors, the exterior is wrapped in earth colors expressing the transition from the ground to the sky in the natural world using contour lines and latitude & longitude lines, to match the "Nature" theme of the exhibition booth (Photo 4, Fig. 5).

A tablet PC or a smartphone can be used to operate the expansion/contraction of the vehicle, adjust the damping force, ensure leveling, operate the suspension lock mechanism, and operate the fan. The application screen has an earth-color based chic design in harmonization with the vehicle design (Fig. 6).

Fig. 5 Interior design

Fig. 6 Smartphone app

7 Requirements for Camping Cars

The newly developed camper comes under the application category of "camping cars" for motor vehicle registration in Japan. The camper should meet the below requirements for the registration as well as related laws and regulations:

- The number of persons sleeping in the camping car shall be not less than 1/3 of the riding capacity.
- The equipment footprint shall be not less than 1/2 of the floor area.
- The storage capacity for clean and waste water shall be not less than 10 L each and tap water shall be readily available.
- Cooking shall be possible with a stove and ventilation shall be available.
- A working surface for food preparation shall be available.

The prototype has a riding capacity of three persons and is equipped with sleeping accommodation that also serves as a living room sofa, a kitchen, clean and waste water storage of up to 20 L each, portable butane stove, a refrigerator, lithium-ion batteries, solar panels, an air-conditioner, and a fan.

8 Exhibition in Tokyo Auto Salon 2023

While the Tokyo Motor Show and other events were canceled due to the COVID-19 pandemic, Tokyo Auto Salon was held to provide a place for automobile manufacturers to announce their new products. With its diversity of exhibits, Tokyo Auto Salon was considered as a good opportunity for us to hear opinions from car lovers. Then, we selected Tokyo Auto Salon as the place

to announce the concept of the KYB camping car (Photo 1).

At Tokyo Auto Salon 2023, we exhibited how a number of project members from various departments worked together to build the car under the theme KAYABA ALL HANDS and used videos to show how we deliver our advanced technology, safety, and security (Fig. 7).

Fig. 7 Image movie

The improved steering stability achieved by the damping adjustable SAs was presented by images and simulation videos. We demonstrated the operation of the hydraulic pop-up & slide-out mechanisms to expand the cabin through a tablet PC and the leveling and suspension lock function (Photo 8). We also demonstrated how to use smartphones to adjust the damping force with the damping adjustable SAs. To demonstrate the effect, we made in advance an actual device that allowed the audience to experience the effect of the suspension by operating a manual lever, highlighting the changes in damping force that might be difficult to recognize in the exhibition booth.

In these ways, we successfully presented the maximum appeal and advancement of the KYB camping car by leveraging our hydraulic and vibration technologies.

9 In Closing

The prototype has been designed as a vehicle for the exhibition and manufactured after much trial and error. We know some engineers may want to give some comments about the prototype. I hope that we will improve and perfect the camping car.

Photo 8 Demonstration at Tokyo Auto Salon 2023

At the Tokyo Auto Salon 2023, our camper gained great popularity among a lot of visitors. We received many comments praising our attempt to develop such a camping car. However, trying to enter a new market as a latecomer will involve various difficulties. We need to consider not only quality but also cost, sales channels, and after-sales service. We will promote product marketing by seeking a style that suits us best.

I would like to thank void.Co.,Ltd. that supervised the exhibition and designed the interior & exterior of the camping car, corporate partners, internal project members, and all those who extended cooperation to the exhibition and interviews.

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Essay

Essay from Expatriate in Germany

KIM Yong Tae

1. Introduction

I was assigned to KYB Europe GmbH (hereinafter "KEU") in Germany in February 2021. I experienced many things as an expatriate for about two years until returning to Japan in December 2022. KEU is a sales base of commercial shock absorbers (hereinafter "SAs") for western Europe. I was in charge of purchasing operations during the expatriation.

I had never imagined that I would live in Europe, and it had been about 10 years since my father and I had travelled to Germany when I was a university student, so I was deeply moved when we arrived at Frankfurt Airport. Given that the memories of ten years ago have led to the present, you can hardly know where there will be a turning point in your life.

The following introduces some of the short but very valuable experiences I obtained both on business and in private life during the two-year stationing.

2. Life in Germany

Germany (the Federal Republic of Germany), with a population of 84 million and a total area of 350,000 square kilometers, is a federal republic located in Central and Western Europe.

Düsseldorf, where I was stationed, is located on the banks of the Rhine River and has a population of approximately 620,000 and an area of 217 square kilometers. With these figures, Düsseldorf may look like a small- to medium-sized city but is well known in the economic and artistic fields. Economically, several global companies are headquartered there. In the arts, the Düsseldorf Academy of Fine Arts is located in the city.

Geographically, Düsseldorf is easily accessible from the Netherlands and Belgium. Many Japanese companies have their bases in Düsseldorf and around 5000 Japanese people live there. One of the attractions of Düsseldorf is that you can experience Asian culture in spite of being in Europe.

I have written only good things about Düsseldorf, but one of the difficulties was the cold due to the extremely low amount of sunshine during winter. In winter, when the solar radiation drops to an extreme level, it was dark both when I reported to work in the morning and left each evening. The decrease in sunshine affects people's lives to the extent that there are reports of an increase in the suicide rate due to depression in Germany. In fact, winter was like a long tunnel. During my first winter in Germany, I took extra care to keep my spirits up both on business and in private life as far as possible. I also tried to go out and move my body even when it was cold.

In addition, COVID-19 hit all of Europe immediately after I was sent to Düsseldorf. In Germany at that time, the daily number of people infected with COVID-19 exceeded 60,000 and all shops except supermarkets were shut down. It was almost impossible for people to go out accordingly. I continued a round trip between work and home every day. Naturally, all restaurants were closed, so I had to cook my own meals every day, even though I was expatriated abroad. This was the first time in my life that I had been stationed overseas, but I was not allowed to go out, which was a hardship at the beginning of my expatriation.

Photo 1 Masks for protecting yourself

3. Work in Germany

As mentioned above, I was in charge of purchasing operations during my expatriation in Germany. KEU is a commercial product sales base whose main distribution channel is stock sales to the European market and has about 30 employees in Germany. The main businesses are purchasing and inventory control of commercial SAs, coil springs, and mounting kits, which are primarily purchased from the KYB Group's production sites and outsourced suppliers.

The purchasing operations cover a wide spectrum including ordering of commercial SAs, following up on suppliers' delivery dates, appropriate inventory management, improvement of order fulfillment rates, and new development work. I had never experienced any of these operations, so I had a very difficult time at first. The work of forecasting demand based on sales forecast data and deciding on order quantities while maintaining a balance between stock levels and fulfillment rates requires the exchange of information and collaboration with factories and other departments. I experienced firsthand how important communication in the workplace was. In particular, salespersons or customers complained to me, as the person in charge of purchasing, when product delivery was late for instance. But, I learnt a lot by listening to the real voices of the market and sincerely responding to customer requests through such complaints and advice. I was also able to build a relationship of trust with them. These were my big achievements.

Beside these, the external influences during the expatriation included the COVID-19 problem. The infection spread throughout the world from 2020 and hit each production site, sharply lowering order fulfillment rates at times. However, the team worked as one to recover the fulfillment rate by steadily following up on production and shipping plans every month. We had meetings every day, spending days under a constantly tense atmosphere. Looking back, however, that was a very valuable experience for me.

Photo 2 KEU purchasing team

4. German Cuisine

It is no exaggeration to say that meat and potatoes are the chief staple of Germany. Immediately after arriving in Germany, I thought that German food was simple at first glance and the menu was poor in variety. But, soon I noticed that, when you take German food and beer together, you can taste just the right balance of flavors.

The most famous German food is probably the German sausage, but there are several traditional dishes other than sausages. One of the most typical traditional German dishes is Schweinshaxe, which is, in brief, roasted pig's feet. It is a dish in which pork shanks are roasted until the skin is crispy and served with potatoes, giving it a unique texture.

Photo 3 German dishes (Schweinshaxe on the left)

Besides the above-mentioned Schweinshaxe, another famous traditional German dish is Schnitzel. It is a meat dish that is widely eaten not only in Germany but also in Western Europe. Its taste is very similar to that of Japanese pork cutlets. However, it is not deep-fried in as much oil as Japanese pork cutlets, so the taste is softer. You can taste a deeper flavor if the schnitzel is accompanied with oven-baked potatoes, French fries, or potato salad. It may seem a simple dish, but it is certainly an addictive one.

Photo 4 German dish (Schnitzel)

5. German Beer

What's indispensable to the dishes stated above is definitely German beer. Particularly in Germany, local beer brewed at regional breweries, rather than beer produced by the major beer manufacturers, is very popular. Therefore, there is a wide variety of beer categories. The beer seems to be generally classified by region and color.

Photo 5 Local beer (Kölsh) in Cologne

For example, the northern area of Germany has mainstream beers called "ale", many of which have a long-lasting rich flavor, whilst the southern area has a mainstay called "lager", which is characterized by a refreshing taste. German beers also vary in taste by color and can be roughly divided into three types: Weissbier (pale beer), Schwartzbier (black beer), and the normal type often seen in Japan.

Photo 6 Weissbier (pale beer) in Munich

In this way, you can enjoy a variety of delicious beers in Germany and have the pleasure of comparing them. In the busy days as an expatriate, a glass of beer on the weekends was a treat for myself.

6. World Cultural Heritage and Traveling in Germany

As one of the most historic countries in Europe, Germany has numerous cultural heritage sites. Among these, Cologne Cathedral, the largest Gothic building in the world and a World Heritage Site, is one of the most popular tourist attractions in Cologne, which is a big city in western Germany. The Cathedral was built over around six centuries from its start of construction in 1248 to its completion in 1880. Standing in front of the building, you are overwhelmed by the huge scale of it.

The city of Münster located in the northwestern area of Germany is a beautiful place that has flourished around its cathedral since ancient times. It is one of the most popular tourist spots in the country because of its historical architecture and universities. Particularly, Münster Abbey, which is a masterpiece of the transitional period between Romanesque and Gothic architectures, has been registered as a World Heritage Site and is a typical sightseeing spot visited by many tourists.

7. Traveling in Europe

The neighboring countries of Germany include France, the Netherlands, and Belgium, which are only a two-hour drive away. I often visited these countries on weekends. Crossing a border by car was new to me, so it was a very surprising experience. Particularly, I often travelled to Amsterdam in the Netherlands, which is my most

Photo 7 Cologne Cathedral

Photo 9 National museum of the Netherlands

Photo 8 Inside of Münster Abbey

Photo 10 House museum of Rembrandt, the leading Dutch painter

favorite city in Europe, by car for about two hours from Düsseldorf as if I was just taking a drive. Amsterdam, which is also known as an "art paradise" in Europe, has various tourist attractions including the Rijksmuseum (the national museum of the Netherlands) and the Rembrandt House Museum (Rembrandt van Rijn was a leading Dutch painter). You can fully enjoy Dutch art in the city.

8. In Closing

I would like to express my gratitude and appreciation through this report for the warm support of my supervisors, senior engineers, expatriates, and local staff who helped me to complete my stationing in Germany for nearly 2 years without any problems. At the same time, I am convinced that the experience I obtained in this expatriation will provide me with the base and confidence to work on future operations. Thanks a lot for giving me such a valuable opportunity.

Author

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Essay

Essay from Expatriate in Thailand

WATANABE Yoshizou

1. Introduction

I was an expatriate in Thailand for five years and 10 months from April 2017 through February 2023.

In Thailand, I worked at a production site of KYB Steering (Thailand) (hereinafter "KST") that manufactures power steering pumps and CVT pumps.

Since I originally learnt design only, my life as an expatriate began with expectation and anxiety about the work at the production site. I definitely experienced various things during the stationing. The following introduces some of them.

Photo 1 Members of supporting departments (at the KST lobby)

Photo 2 Management members (at the KST lobby)

2. Meals

Before the expatriation, the first thing that came to mind from the words "Thai cuisine" was only the typical spicy dishes like gapao rice and tom yum kung. Fortunately, I liked spicy food, so I was not so nervous.

At the welcome party, the local staff took care of me and prepared non-spicy dishes at first. I thought Thailand had some non-spicy dishes as well, but soon the spicy dishes started to gradually appear.

I managed to eat up all the dishes while drinking beer with ice in it, which is specific to Southeast Asia, to cool my mouth. Then, I asked a question about the dishes. They said the dishes that appeared in the latter half of the party were so spicy that even some Thai cannot eat them. They tested me in the trial (welcome party) to see that I am OK with a little bit spicier dishes than those acceptable to ordinary Thai. I was eventually judged as a person who can eat any Thai food.

As an aside, I was surprised to find that there were some Thai who could not eat spicy food at all although most Thai dishes are basically spicy.

Thanks to the results of the test, everyone recommended a variety of foods to me, including spicy dishes, at dinner parties, which kept me satisfied with delicious things to eat.

Among their recommendations, one was a fruit at which I was very surprised. That was *noina* in Thai, about the same size as an apple. The surface is like crocodile skin, looking a little scary. In spite of the appearance, ripe ones are soft and fluffy enough to be broken open by hand and eaten. They are very sweet and delicious. When I heard its English name (custard apple), I was convinced that this tells exactly what it is.

Since I was expatriated alone, I usually ate out or bought food at supermarkets during the first year. After around the second year, I started to cook for myself a little, starting with a simple breakfast (scrambled eggs) on weekends. I gradually expanded my repertoire to include stir-fries, baked goods, and Thai food (gapao rice, moo grob, or fried pork). I finally became able to cook simple dishes for myself, although I could not make complicated ones.

The cooking experience helped me a lot during the long days off caused by the COVID-19 pandemic. I easily killed time when I was locked in my house.

Photo 3 Cuisine

Photo 4 Noina

3. Events

Thailand is a tropical country with an annual average temperature of nearly 30˚C. It is particularly hot in April when the world-famous water festival is held. I used to participate in the festival before the COVID-19 pandemic. When I dropped by a water spot, numerous street vendors selling water pistols and buckets full of ice water were lined up in rows on the roadside. The city was fully prepared for visitors to be able to splash water on each other even if they came to the festival with nothing.

There were such water spots here and there. Some were moderate spots for families and some others were popular among foreigners (tourists?) who liked vigorous water splashing. I also found a spot where people were painting flour dissolved in water on each other in addition to water splashing. I enjoyed hopping between such unique water spots.

To prevent trouble, some water spots were guarded by police officers standing alongside, which made me a little bit nervous. When I was taking pictures of the festival from the roadside, a police officer standing nearby came and told me "I can take pictures for you", probably because he thought I was a tourist. That gave me the impression that police officers in Thailand were working not only for security but also to help people enjoy the festival. I thought "That's how the land of smiles does it!"

During the water festival, while such public events are held on the street, private companies may hold their own unique events, such as calling monks to have a Buddhist ceremony or distributing sweets to employees before the holidays. KST holds an interesting event on the last day before the holidays at which the management, including the President, are asked to sit down in front of the entrance of the company building and be splashed with water by all staff members.

At my first year, I was told to come over to the entrance having first left my smartphone and wallet in my locker. When I was sitting on the ground puzzling why I had to do things like this, the event was started. Somebody splashed some water over my hands at first and the splashing gradually escalated to my legs, body, and head. Finally, a bucket of water was poured over my entire body, making me feel like I had become scrubbed of sin.

Leveraging the experience in the first year, I brought water pistols to the second year's festival. That was my turn to let them become scrubbed of their sin. However, they were a cut above me: They brought a big water hose to scrub me of sin even more carefully than the first year, since I got along with them very well and it was my second year. Anyway, that experience brought me peace of mind in part and made me recognize that we had established a relationship in which we could be in close contact with each other without hesitation.

KST also held a Sports Day and Futsal Competition. There were two kinds of Futsal Competition: One was a competition among three teams inside KST and the other a competition among three Thai teams (KYB Thailand, KYB Asian Pacific, and KST). The winner of the three Thai teams would get the chance to participate in a sport competition in Japan in addition to monetary rewards. Everybody in the teams was playing like mad.

I sometimes played futsal with staff members after work partly because I used to be a futsal player in Japan. So, I knew how they were normally playing. In the competition, however, they were playing with new aggression. When I found them moving in a totally different way from usual, I felt keenly that people's passion really affects their performance.

Although KST's hope of winning the competition did not materialize during my expatriation, I realized that moving forward together with colleagues toward one thing fosters a sense of esprit de corps not only for hobbies but also for work, leading to higher work efficiency. I hope that the competitions in Thailand will be resumed this year as we have recovered from the COVID-19 pandemic.

Photo 5 KST Competition

Photo 6 Competition of the three Thai companies

4. Languages (English and Thai)

I was originally not good at English. Before expatriation, I took a language training course and was a little relieved to be able to have a little English conversation. But, I was devastated from the start as soon as I was transferred to Thailand.

First of all, I had a hard time understanding what Thai were saying in English with their unique pronunciation and accent (Thaiglish). For example, a word sounded like "kover". I did not get the meaning and asked them to say it again and again... then, I finally understood they had said "cover". I gradually learnt that they basically pronounce English according to Roman letters. I felt somewhat guilty when I asked them to say it again many times, but the experience deepened my understanding of Thaiglish while the local staff deepened their understanding of my Japanglish. This interaction enhanced the communication level and we eventually became able to communicate with each other.

Soon after that, I became able to say what I wanted to in English. When I finally had some confidence in my English capability, I got involved in a job working with an American. At a meeting where I was excited about using my "fluent" English in discussion, I could not understand what he was saying at all because both my tongue and ears had already been tuned to Thaiglish. I ended up being devastated again. Still, I managed to get through the situation by employing the strategy of asking him to repeat the words over and over again and fortunately he spoke very slowly. Based on that experience, I can always deal with similar difficult situations by employing the same strategy, which is now patterned, although it may not be good depending on the other party or topic. Anyway, this can still be used as a good countermeasure.

There was one thing that I thought was interesting with English. When Thai people were talking about work, they mixed in 10% to 20% English, not 100% Thai. According to a book, Thailand has had to rapidly accept many different cultures from the outside world and cultural advance has outpaced language advance. As a result, words that did not exist in Thai came into existence. They seem to speak in English under some specific circumstances including business. I realized that Thailand was that kind of country. As a Japanese, I felt intimacy with Thai people because I noticed that we also have many Japanized English words whose corresponding Japanese could not come to mind.

Totally apart from English, I memorized only a minimum of Thai words including numbers and food. Of course, I heard daily conversation in Thai during work, but I did not learn Thai in the classroom. However, as I had heard Thai over six years, I became able to roughly understand what Thai people were speaking about on the topic of work. Ears may learn the language themselves.

When I understood the direction of their discussion or whether they were saying a good thing or a bad thing, although I did not understand the details 100%, I abruptly joined them at some midpoint of the conversation in some cases, which dramatically surprised them. This was a very effective and helpful skill that could be applied to cases where staff members had difficulty in a scene I did not notice or when they could not promote an activity well.

5. Work

KST is a small factory with about 250 employees, but there are various departments, including factory sales, pump parts procurement, cost management, accounting, and human resources. I had only experience in design work, so I was very anxious about what I could do at the factory and whether I would be able to communicate with the staff.

In the first year, I managed a transfer project from Japan and worked on quality issues, some of whose elements were similar to those of design work. I ran this

way and that in an unfamiliar place and business, but partly because it was a product transfer from Japan, I was able to complete the transfer with the support of various people including the members of the related departments of KANAYAMA Plant in Japan.

After that, I was assigned to cost management in the second year, factory sales in the third year, and work responsible for procurement of pump parts in the fourth year.

In cost management, I was given base data for setting targets for cost reduction activities and actual projects from cost planning and procurement of Gifu North Plant, and manufacturing and production engineering of Kanayama Plant, which were very useful in deciding how to manage and promote KST activities.

In terms of factory sales and pump parts procurement, the related sales and procurement personnel in Japan gave us information about the situation in Japan, past activities, and procurement policy. The provision of this information enabled us to add one-step more advanced operations to KST's factory sales and pump parts procurement, thereby strengthening the functions of the departments.

6. In Closing

Looking back, I realize anew that I was able to make various improvements at KST thanks to the support of so many people during my six years of expatriation in Thailand.

I would like to take this opportunity to thank all those concerned in Japan, all the expatriates at each office, and the local staff at KST who helped me during my stay in Thailand.

I would also like to acknowledge the opportunities I had to experience so many other things that could not be reported in this article.

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Glossary

Injection Molding of Fiber-Reinforced Plastic

Refer to “Research on Strength Prediction Technology for Fiber-Reinforced Plastic Injection-Molded Products” (page 20)

OGURA Shogo
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1 What is Injection Molding?

Injection molding is a process for forming parts by heating resin and injecting the molten material into a mold. This process enables the stable production of parts of complex geometry at a high-speed cycle. Plastic parts manufactured by this process are used in a variety of fields.

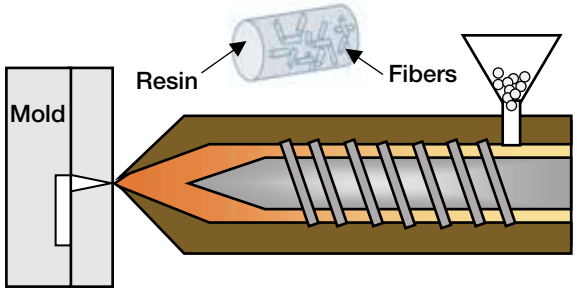

Fig. 1 Schematic of injection molding

2 Features of Injection Molding of Fiber-Reinforced Plastic

The plastic used for structural members is reinforced with glass or carbon fibers to be fiber-reinforced plastic (hereinafter “FRP”) with improved physical properties. Injection-molded FRP is made from resin pellets mixed with three-dimensionally distributed fibers of a length of about 100 µm. Like normal plastic, FRP can also be formed into complex geometries by injection molding (Fig. 1). However, FRP injection-molded parts have fiber orientations (fibers positioned in different orientations) that depend on how the molten resin flowed during the molding process (Fig. 2). FRP is more reinforced in the direction of fiber orientation. This means that the physical properties in the direction parallel to the fiber orientation are different from those in the direction perpendicular to the fiber orientation. This is called “anisotropy of physical properties” and makes it difficult to predict the final quality of parts.

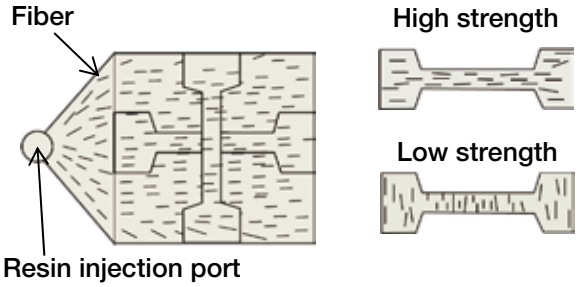

Fig. 2 Overview of anisotropic physical properties

3 Prediction of Anisotropy of Physical Properties

To predict the physical properties of a composite of resin and fibers, an approach called “homogenization” may be used. Homogenization can be used to predict the physical properties of a composite from the physical properties and geometry information of the individual materials, i.e., fibers and resin in this case. Homogenization is thus a concept necessary for predicting the quality of composites. Furthermore, for composites containing a number of distributed short fibers, as seen in injection-molded products, it is necessary to define how many fibers exist in which directions. To this end, a concept called “fiber orientation tensor” is used. Fiber orientation tensor is expressed in three major directions of fiber orientation and the ratio of fibers oriented in the respective directions. For example, a fiber orientation tensor closer to one (1) along an axis indicates that more fibers are oriented aligned along that axis. Thus, fiber orientation tensors can be used to quantitatively define the orientation of a number of fibers distributed in the plastic, thereby enabling the prediction of anisotropy of physical properties of FRP injection-molded parts.

Glossary

PMSM[1)]

Refer to “Characteristic Analysis of High-efficiency Hydraulic System” (page 10)

SHIBAHARA Daichi
Electronic engineering Sect, Basic Technology R&D Center, Engineering Div.

1 What is PMSM?

1. 1 Acronym and Structure/Operation

PMSM is an acronym for Permanent Magnet Synchronous Motor. This is a motor that uses magnetic field flux created by permanent magnets to run in synchronization with an alternating-current (AC) power source. PMSMs are classified as AC motors.

1. 2 Classification by Configuration

PMSMs can be divided by magnet arrangement into Surface-mounted PMSM (hereinafter “SPM”) and Interior PMSM (hereinafter “IPM”). These types of PMSM deliver different characteristics from each other depending on the combination with current control methods as described below.

The SPM is suitable for low-speed, large-torque design and can smoothly run with low torque ripples Compared to the IPM, the SPM can deliver liner torque responses against a current and be more easily controlled.

With its higher degree of geometry design freedom, the IPM can be designed to provide specific characteristics tailored to the application. The range of speed at which the IPM can be rotated is higher than that of the SPM.

1. 3 Characteristics

PMSMs can commonly deliver high power efficiency over a wide operating range and output a high power even with small-sized designs. On the other hand, they requires microcomputers and permanent magnets that use rare earth elements, which make PMSMs more expensive than the induction motors widely used in industrial applications. Therefore, PMSMs are suited to applications where downsizing and efficiency enhancement are needed.

2 Varying Properties Depending on Control

2. 1 Control Methods

The PMSM control methods can generally be divided into V/f control (open-loop control) and current vector (hereinafter just “vector”) control (closed-loop control). The former is used in cost-oriented applications and the latter used in performance-oriented ones. This section describes the latter control method.

2. 2 Current Vector Control

On the plane of the d-axis corresponding to the direction of magnet flux (≈ physical angle of the magnets) and the q-axis orthogonal to the d-axis, current components of a three-phase motor are regarded as a vector. A method of controlling the magnitude and angle (= current split ratio between the d-axis and the q-axis) of these components is vector control. The vector can be determined by several approaches including MTPA control and weak field control described in the following.

2. 3 Maximum Torque Per Ampere Control

MTPA control determines the current split ratio so as to achieve the highest possible torque on the assumption that the vector is constant (= constant motor current). This is a basic motor control strategy applied to cases with no limited by voltage or current.

2. 4 Weak Field Control

In a high range of revolutions, the reverse induced voltage increases to reduce available current. Then, a negative d-axis current can be used to cancel the magnet flux, lowering the reverse induced voltage. This expands the range of speeds to drive the motor. This weak field control strategy is applied to cases in the presence of voltage limit.

Reference

1) MORIMOTO Shigeo, INOUE Yukinori: “Basics and Design Method of Drive System for Energy Saving Electric Motors” Kagakujyoho Shuppan Co., Ltd. (November 4, 2019)

Editors Script

This is my first time to be a member of the editorial board of the Technical Review, a great honor for me as an engineer. It reminds me of the days when I myself was working on research and development, writing an article for the Review and being pressed by deadlines. Compared to those days, the world has become even more complex and engineers must be struggling day by day in a situation where it is difficult to foresee the future. Under these circumstances, this issue focuses on prediction technology using simulation. This technology involves a significant theme on how we provide new value to customers by modelling real-world systems and processes with high precision based on rules and principles and applying them to products. As an engineer and editor, I will continue making effort to provide valuable information to readers, in order to create new technologies and solve social issues with them. (FUJINAMI)

I have been involved in the editing of the Technical Review since last year. As a non-scientific administrative staff member, I am mainly in charge of editing essays and also request staff to write articles. Recent returnees from overseas stationing have had difficulties in dealing with COVID-19 infection in foreign countries. When I asked them to write an essay, some of them said that they had no story to write because the pandemic meant they only had a round trip between work and home every day during their expatriation. I guess that they had a lonely and difficult time. Although the current situation is sometimes referred to as "with Corona" or "after Corona", I believe that it is my important responsibility to share with you not only the work (work stories) of expatriates in their destination countries, but also the joys, difficulties, and attractions outside of work in each location. We hope that you will continue to contribute your experiences. (AMANO)

As COVID-19 has been downgraded to a category 5 infectious disease, regulations on COVID-19 have been loosened and holiday resorts have begun to region their former liveliness. On the other hand, we have been having extremely hot days as the rainy season has not yet ended, and the heatwave is so intense that I feel like I might melt, hesitating to go out. This reminds me that global warming is progressing without any doubt. With the reduction of CO_2 emissions regarded as a global standard today, it brings me peace of mind that this issue contains articles on technologies for energy saving such as weight reduction and efficiency enhancement. I am grateful to the engineers who are continuously working on research and development while anticipating future possible environmental changes. I also expect them to address the challenge of elevating KYB's engineering expertise to new heights. (HAGIDAIRA)

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