Jatco

JATCO TECHNICAL REVIEW

No.23

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Introduction to Product

Driving the possibilities of mobility with technology and passion

Tetsuya TAKAHASHI
Fellow

When I was an elementary school student, I almost completely memorized the car guidebook that I got at the Tokyo Motor Show when I went for the first time. I liked to sit on a guardrail and guess the displacement and horsepower of the cars that drove past on the street. And it was a great adventure for me at that time to ride a bicycle that I had just learned to ride, and to go to a strange city by myself.

Time has passed, and now I have a 3-year-old grandchild who fills his toy box with TOMICA and Thomas the Tank Engine, and looks happily at the cars and trains that pass by on the roadways and on the tracks outside. I feel as if I were looking at my old self and feel warm inside.

It goes without saying that “mobility” refers to free movement and transportation, which is a universal human desire. As I grew from infancy, my range expanded. Going to new places and being exposed to different cultures and environments has enriched my knowledge and experience. Wherever I go, I recall that the accumulation of emotional experiences that touched my heart had a great influence on my personal development.

The automobile industry has undergone a once-in-a-century transformation. In order to realize sustainable mobility, it is important to achieve the carbon neutrality target by 2050 and to be compatible with a circular economy society. JATCO must also engage in new value creation in all directions.

In other words, in addition to efforts to reduce CO_2 emissions from the perspective of the entire value chain, it has become essential for sustainable companies to switch to recycling processes based on the premise of resource reuse, such as devising materials and methods from the design stage to facilitate recycling and reuse. Under such circumstances, JATCO’s “MOTTAINAI” culture, which has taken root through the remanufacturing business of automobile transmissions, is one of our advantages.

On the other hand, it is difficult to achieve carbon neutrality of electric vehicles (EVs), which are said to be an environmentally friendly means of transportation, unless the composition of electricity, which is their energy source, is shifted to renewable energy (wind power, solar power, etc.). In addition to the development and production of electric units for automobiles, JATCO needs to actively participate in the renewable energy business, which is indispensable for realizing sustainable mobility, by utilizing our manufacturing capabilities.

In addition, the spread of car-sharing and ride-sharing platforms, which are expected to improve urban transportation systems along with the diversification of transportation methods such as the spread of electric bicycles, will reduce the number of cars owned by individuals and promote the efficient use of resources. While this will increase vehicle life and reduce waste of resources, it will also drastically change the business form of after-sales service, such as simplification of vehicle management and maintenance. In this field, JATCO's expertise in market quality assurance of automotive transmissions will be utilized.

The environment surrounding mobility will transform the social structure itself, affecting not only technological innovation but also the development of new business models that capture the entire value chain.

JATCO, which has grown as a global supplier of automotive transmissions, must utilize its manufacturing capabilities and respond to such changes quickly and flexibly, and thereby contribute to the realization of sustainable mobility.

Under JATCO's corporate purpose, "Driving the possibilities of mobility with technology and passion," we hope to fulfill universal human desires, while also considering the impact on society and the environment, and lead children to a rich life and realize their dreams for the future.

Mobility initiatives

Nobuyuki YONEYAMA* Naohiro YAMADA** Toshiyuki OKAMOTO**
Tomoya SUGIYAMA** Toshihiko TSUDA**

Abstract

It has been said for a long time that we have entered a once-in-a-hundred-years era of transformation. In this document, we will introduce what sort of thinking JATCO should adopt and what actions JATCO should take regarding mobility initiatives given this environment, and what sort of initiatives JATCO should implement based on such thinking.

1. Environmental changes and directionality aims of JATCO

In recent years, there has been demand globally for initiatives from the perspectives of environment, society, economy and companies to achieve a sustainable world. And in particular, it has become important for companies positioned in the manufacturing industry to take great responsibility for carbon neutrality and the circular economy.

Next, looking at the real world, individual trends are forming within each country/region due to moves to prioritize economics and materials/energy policies. And in the automobile market, in addition to electrification, there is a shift to new value such as the experience of using a vehicle rather than the vehicle itself (mobility hardware). Due to such environmental changes, we believe that JATCO has to respond to issues and needs such as the following:

- Contribution to sustainability
- Stable regional supply chains
- Creation of new values
- Electrification response

In response to these, we believe that it is necessary to take advantage of JATCO's strengths developed during the conventional era to address the social issues mentioned above and contribute to the automobile market as we look to the future (Fig. 1):

- Component and system designs
- Production engineering
- Global production and after-sales service

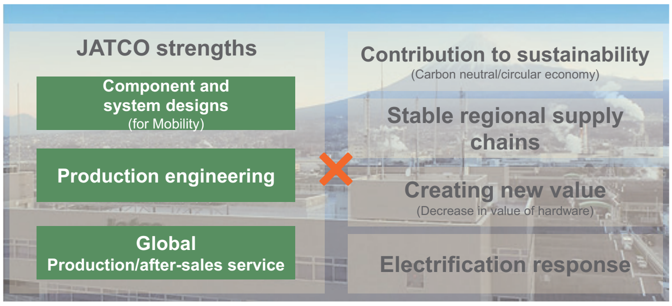

Fig. 1 Directionality aims of JATCO

2. ePT technology trends and initiatives

In the era of electrification in the automobile market, it is necessary not simply to replace the transmissions represented by CVTs with e-Axles and advance planning, development, production, and sales but to take advantage of the aforementioned strengths of JATCO to create new needed values. We will introduce several of these.

In the conventional era, to improve fuel efficiency, approaches such as transmission efficiency improvement and optimization of engine operating points have been realized by CVT. However, with an electric PT, the efficiency of an e-Axle itself is already high and there is no room for significant improvements.

*Innovative Technology Development Department **New Business Development Department

On the other hand, energy wasted as heat is considerable, and improvements in energy efficiency at the vehicle hierarchy level is important in order to efficiently use the limited electric energy stored in the battery and to extend the driving distance, which is a concern for electric vehicles.

Therefore, JATCO has expanded its technological development not only into the development of the e-Axle but also into the energy management field, which is positioned upstream in the V-process.

Focusing on the e-Axle, downsizing and weight reduction are still required as in the transmission era. Therefore, we are aiming at downsizing through higher motor rotation and higher reduction ratio using the gear technology developed by JATCO.

In this way, we have been making initiatives to improve competitiveness of the electric PT, including the vehicle hierarchy. However, with the decrease in the value of hardware itself, it is becoming important not only to sell out goods but also to expand into service businesses.

Therefore, we are also taking on challenges in new areas such as customer experience (CX), aiming at improvement of serviceability through utilization of market data, and user experience (UX) technology, where driver's conditions are detected and incorporated in driving performance.

3. New business initiatives

We have thus far focused on automobiles, but due to major changes in the environment, the value chain that was conventionally completed by automobiles alone has recently become part of a larger value chain (Fig. 2) such as Big Data and infrastructure in the name of mobility. And, in such a value chain, what kind of businesses JATCO takes on in this new value chain has become important.

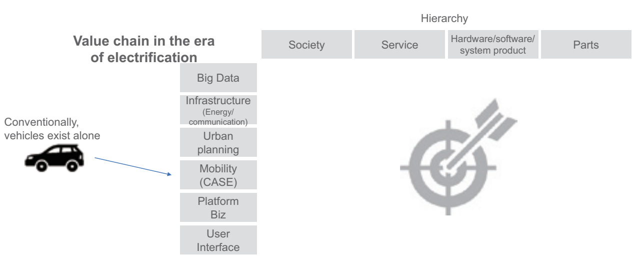

Fig. 2 Changes in value chains

On the other hand, when we jump into a new value chain, we must design the cycles of competencies and assets such as what are our strengths and where we should start to increase our strengths and continue to grow as mentioned above (Fig. 3).

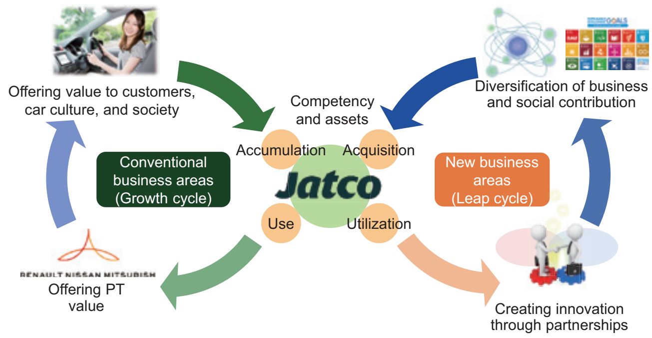

Fig. 3 Competency and asset cycle

In this way, it is important to design businesses that combine changes in the value chain with JATCO's competencies and assets and consider what business paths to take. Therefore, we will draw up visions for the future and business paths that JATCO envisions, such as the following.

- Realize clean energy and its supply to support life
- Realize environmentally friendly, comfortable, and safe mobility and movement
- Provide parts and systems that expand the possibilities of society in the future

Doing so, we will take on new business challenges that leverage our strengths (Fig. 4).

In terms of energy, it is the realization of wind power generation including the reuse of electric vehicle parts. In terms of mobility, it is equivalent to e-Axles of electric vehicles and drive units of electric bicycles. And, it is a form to offer parts and systems to realize them.

Next, we will cover individual products.

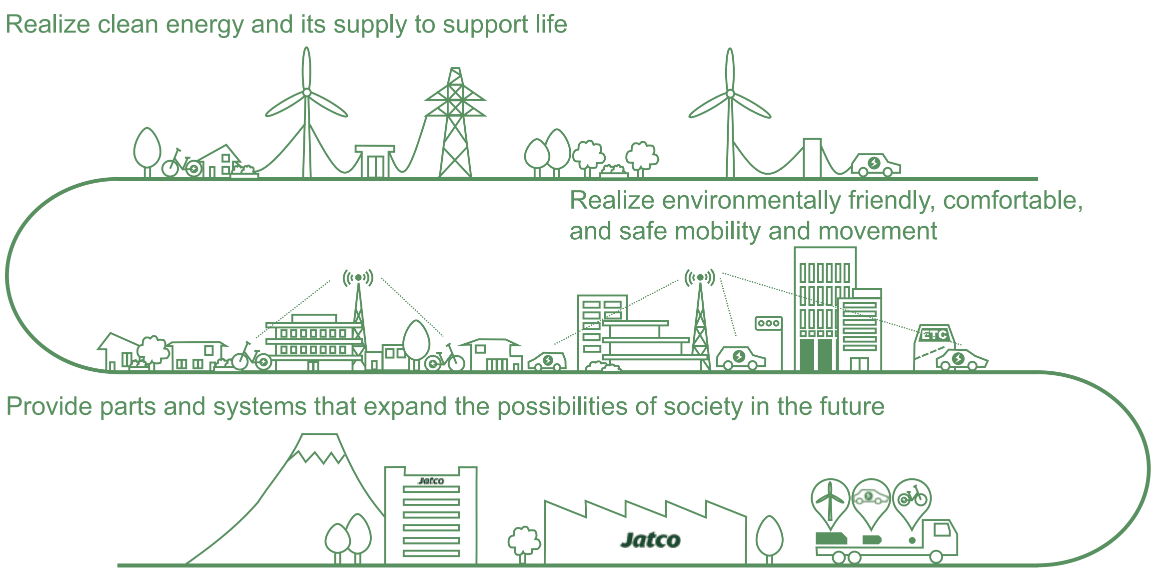

Fig. 4 JATCO's vision for business in the future

4. Mobility initiatives

4.1 Nacelles for medium-sized wind power generators

There is a movement of self-consumption of renewable energy mainly by RE100 member companies and local governments aiming at carbon neutrality. In addition, having experienced Japan's first prefecture-wide blackout due to the Hokkaido Eastern Iburi Earthquake that occurred on September 6, 2018, distributed power supplies have garnered attention from the viewpoint of regional disaster prevention and the rationalization of power transmission infrastructure for remote islands and depopulated areas. These power supplies are installed relatively close to the areas in which people live. Therefore, JATCO is developing a nacelle for a medium-sized wind power generator which is expected to be positively accepted by society.

Business purpose and values

By combining motors of electric vehicle motors with gears (step-up gears) in which JATCO specializes, it is possible to repurpose these motors as generators for medium-sized wind power generators. Doing so helps realize wind power generators with lowers cost, greater reliability, and strong social acceptance. We will contribute to regional disaster prevention and carbon neutrality for companies and municipalities, mentioned above, and contribute to the circular economy by reusing parts from used electric vehicles (Fig. 5).

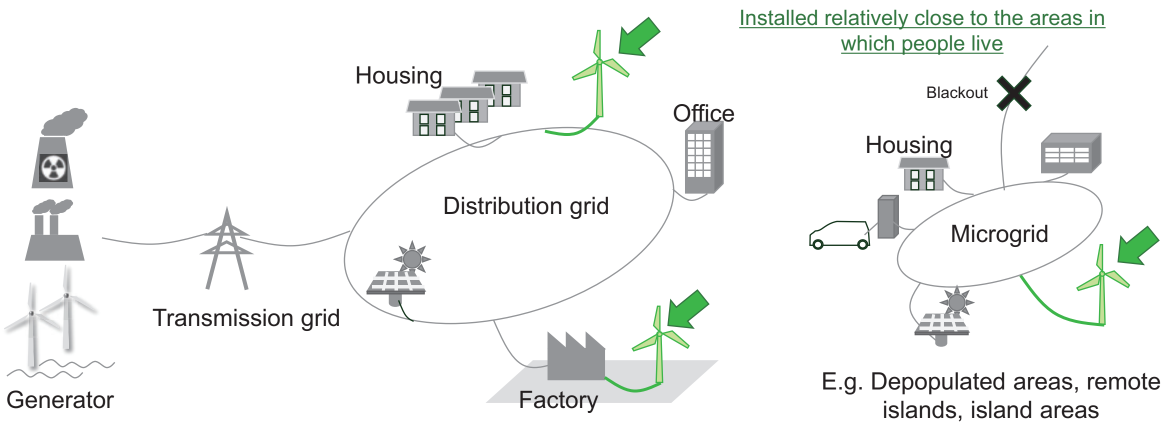

Fig. 5 Assumed markets

This business not only contributes to solving recent social issues but also expands the possibilities of mobility, our purpose.

Product overview (nacelle)

A wind power generator mainly consists of blades, a rotor, a nacelle, and a tower. Wind causes the blades to rotate the rotor, and the nacelle converts the rotation into electricity. JATCO is in charge of the nacelle.

A nacelle is composed of a main shaft which receives the rotor rotation, a step-up gear which transmits accelerated rotation to a generator, the generator which converts rotational energy into electricity, a main shaft brake which prevents rotation during maintenance, a yaw mechanism which changes the direction of the wind turbine according to the wind direction, and a nacelle base on which these components are placed.

The concept of this nacelle is cost reduction and ensuring high reliability by using automotive parts, and these are realized by repurposing electric vehicle motors as generators and adopting gears with high speed increase ratios developed by JATCO for wind power generators. In addition, automotive parts are planned to be used for generator cooling systems, brakes, etc., and used automotive parts are also planned to be used.

Current status and future prospects

We are currently working on verifications using prototype No. 1, which was built in March 2023 (Fig. 6). We are working to achieve further weight and cost reductions, with an aim to start sales in FY 2025. In the future, we aim to achieve sales in FY 2025 (start of new business) and implement field verification using a vending machine.

Unlike our previous product developments, this development will not be completed by the start of sales; verifications and development will be carried out on site and using actual machines, such as by acquiring data from the actual machines sold.

Fig. 6 Prototype No. 1

4.2 Unit for electric-assisted bicycle

Among the various forms of mobility that exist, electric-assisted bicycles are attracting attention as a mean to enable a wide range of users of all ages to travel relatively long distances with low CO_2 emissions relative to the distance traveled. JATCO is developing drive units and smartphone apps for electric-assisted bicycles.

Business purpose and values

An integrated unit that combines a motor and a transmission mechanism that utilizes JATCO's specialty gear and transmission technology will improve the design and convenience of electric-assisted bicycles. In addition, combining this with the use of a smartphone app will provide value in the form of joy from riding and safety.

This business aims to expand the scope of contributions JATCO's technology can make and create added value not only through hardware but also through software. In cooperation with Fuji City, through this business, we are also looking to take on the service business while contributing to solving local problems through the utilization of bicycles (Fig. 7).

Fig. 7 Creating new values through units (hardware) + software

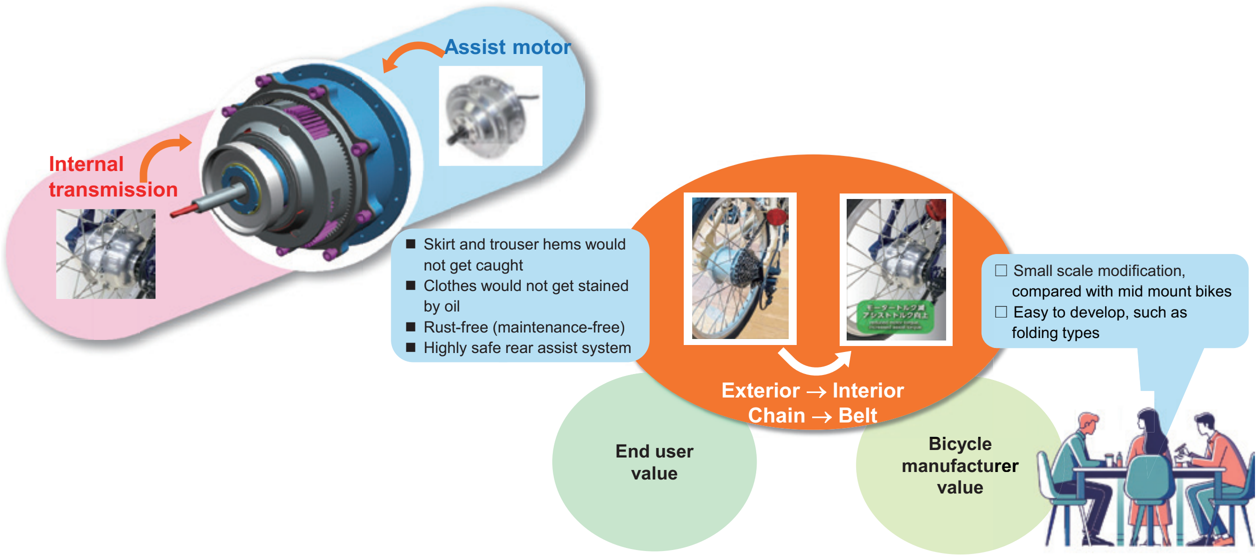

Fig. 8 Unit overview and customer values

Product overview (unit)

This product is a two-in-one unit which integrates the motor assist and transmission functions. An integrated unit with three speeds is an unprecedented industry first product. Since it is not necessary to mount the unit on a pedal shaft like conventional products making visible clearly around the pedal, it is possible to improve bicycle designs and to have the option of belt drive as well as chain drive, thereby meeting various user needs (Fig. 8).

Product overview (smartphone app)

In order to improve value through software, we are also developing apps for smartphones. As specific value improvements through apps, we have been developing products that lead to the values of pleasure, health, and safety for end users, such as the following:

- Ride comfort is adjustable according to preferences of the end users (function to adjust assist force)
- Fat burning mode setting (function to automatically adjust the assist force to make the value of the user's heart rate optimum for burning fat)
- Hazard alarms in areas where bicycle accidents occur frequently and at intersections with poor visibility (utilization of data in cooperation with local governments)

Added user value is created by combining not only the units (hardware) but also smartphone apps (software).

Current status and future prospects

At present, we are carrying out joint development of a unit while communicating with several customers in Japan and overseas. And regarding smartphone apps, we are crafting interfaces and functions required by customers jointly, and we plan to start businesses with these customers and launch them to the market by the end of FY 2024.

The specifications of the unit introduced in the Product Overview (Unit) are such that it is positioned to be an upfront market launch model, and as the first generation, to learn about the market. It can be mounted on bicycles with a wide rear frame, but it is too large to be mounted on city bicycles (so-called mamachari models). Therefore, we are also carrying out advance development of the second generation unit, which can be mounted on city bicycles. We will offer value to more users by integrating what we have learned through the market of the first generation to the second generation. We plan to launch the second generation to the market in FY 2026 or later.

4.3 Conversion EVs

Conversion EVs are expected to be an item that solves social problems such as resource circulation and decarbonization, which are requirements for a sustainable society. As an electric powertrain manufacturer, JATCO is also promoting studies for commercialization of conversion EVs.

Business purpose and values

This business is related to Contributing to a Sustainable Global Environment, one of JATCO's important issues (materiality). Conversion EVs realize reduced CO_2 emissions and the reuse of resources by modifying existing gasoline vehicles into electric vehicles. These initiatives are attracting attention as options that are environment friendly. Compared with the purchase of new EVs, they ensure improved performances while reducing costs. In Japan, the transition to a circular economy is under way based on the initiatives of the 3Rs (Reduce, Reuse, Recycle), which are essential for enhancing the sustainability of business activities of companies. And in Europe, job creation through stimulation of the maintenance, reuse, recycle, refurbish, repair, and used goods markets is garnering attention (Fig. 9).

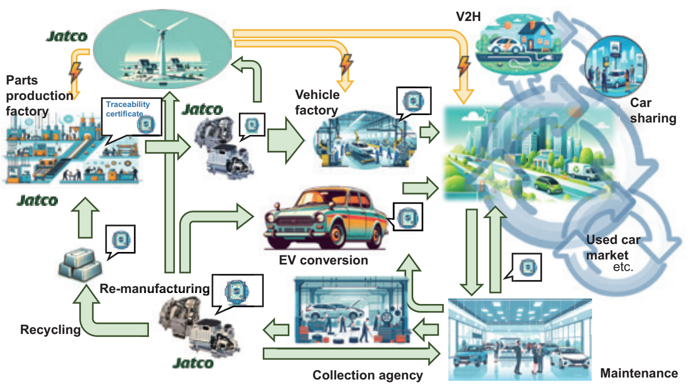

Fig. 9 Conceptual drawing of recycling-oriented society

Product overview

One of the features of JATCO's EV conversion unit is that it uses a transmission. By using a transmission, it is possible to generate higher torque with a smaller motor. This can reduce the use of rare metals and reduce geopolitical risks.

Current status and future prospects

Establishment of a growth-oriented, resource- autonomous economy is a major issue in achieving a circular economy, and ensuring feasibility of business is also an issue in initiatives related to conversion EVs. In particular, it is necessary to promote technological development, including services and software, as well as partner formation, because of the high costs required and the challenges of creating a sustainable market.

4.4 Wheelchair with transfer mechanism

The idea of a wheelchair with a transfer mechanism was conceived three years ago based on the theme of solutions to future social problems making use of JATCO's manufacturing capabilities and entry into industries outside the automobile industry. Up until now, through repeated principle prototyping, acquisition of VOC for actual nursing site, etc., we have been working toward commercialization.

Business purpose and values

The idea of this product was conceived based on a discussion on what to do with JATCO's manufacturing capabilities in the field of nursing given the aging society, which will accelerate at a greater rate going forward.

The hardest work in the nursing field is helping elderly individuals to move from a bed to a wheelchair and from a wheelchair to a bed. Because of this transfer work, more than 80% of caregivers are said to suffer from lower back pain. Sexual harassment is also a potential problem because of the transfer actions involved with holding the elderly person close to a worker's body (Fig. 10).

JATCO is working to realize nursing equipment which reduces mental and physical burdens on caregivers with these problems and which allows elderly individuals who use the equipment to entrust their bodies safely with comfort. This is done by utilizing our ability to improve, which has been developed at manufacturing sites, and the advanced control system used in CVT.

Fig. 10 Physical burden using transfer assistance

Source: Industrial safety information website (the Ministry of Health, Labour and Welfare)

Product overview

Wheelchair with a transfer mechanism is an innovative form of mobility in which the transfer and movement functions are packaged in one. This function lifts the waist of an elderly person who is sitting on the bed off the bed surface using the transfer mechanism in the front, and allows the elderly person to sit on the wheelchair by setting the seat surface of the chair. It is a form of mobility that makes movement in a wheelchair as is possible.

Regarding the transfer mechanism, by combining the motions of two actuators, a rising and sitting trajectory that reduces the physical burden on the elderly individual is derived, allowing for the trajectory to be controlled by a robot (Fig. 11).

Fig. 11 Transfer mechanism motions

Current status and future prospects

At present, the third generation prototype is being trialed by elderly individuals through the cooperation of a care facility in Fuji City, and the facility has also expressed their considerable hopes. However, there are many issues such as making it compact and reducing costs in order to actually use it.

We would like to focus on solving these problems and making our products better by incorporating the opinions of our customers. Prioritizing to bringing the products to market, we plan to launch them to the market in FY 2024.

4.5 Application to parts

JATCO has been working to develop not only electrified units but also parts targeting electrification.

Downsized 48V motor winding structure for an EV powertrain

Recent initiatives for carbon neutrality have increased the need for electrification of vehicles. At the same time, the increased cost of electric vehicles must be controlled.

When we consider the use of low voltage systems for cost reductions, a large current would be required to achieve the target outputs. In order to realize the high power and low voltage system, a 48V system was examined as an example.

However, as it is a low voltage system, sufficient attention is necessary for the winding wire structure of the motor, which can handle the large electric current required for the high motor outputs. In this development project, a motor parallel winding wire structure has been adopted in combination with the transmission, and by exerting sufficient suppression effect and suppressing motor enlargement, installation to the vehicle was made possible.

Development of steel materials and manufacturing methods for gear at high rotation conditions

Miniaturizing is required for e-Axles from the viewpoint of aerodynamic performance and collision safety to vehicles.

To miniaturize e-Axles, it is necessary to miniaturize the motors. Therefore, reduced torque as a result of miniaturization is compensated for by higher speed rotation to ensure output.

As the motor rotates at higher speeds, the reduction gears also rotate at higher speeds, which may result in insufficient lubrication and a poor lubrication environment. In a poor lubrication environment, sliding surface metal contact portions increase, meaning there is a risk of seizure occurring.

Therefore, we developed a seizure preventative method which is less expensive than the existing seizure resistance method.

We report specific cases as follows.

1)Development of a nacelle for a medium-sized wind power generator

2)Downsized 48V motor winding structure for an EV powertrain

3)Development of steel materials and manufacturing methods for gear usable at high rotation conditions

■ Authors ■


Nobuyuki YONEYAMA


Naohiro YAMADA


Toshiyuki OKAMOTO


Tomoya SUGIYAMA


Toshihiko TSUDA

Development of a nacelle for a medium-sized wind power generator

Satoshi WATANABE* Tomohiko GONDA** Yoshihiro KURAHASHI***
Makoto MAEDA** Takeshi YAMAMOTO****

Abstract

In order to reduce environmental burdens through carbon neutrality, a circular economy, and so on, it is important to produce and consume energy locally and to create new value by utilizing reused parts. Among measures to realize these is a plan for a medium-sized wind power generator that reuses automotive parts and is connectable to the power grid. In order to participate in the Environmental Technology Verification Program by the Ministry of the Environment and contribute to resolving social issues, we have launched the development of a nacelle for this medium-sized wind power generator, the first nacelle to be produced in Japan.

1. Introduction

As demand for renewable energy is increasing, there is a plan for a medium-size wind power generator with a 50 kW-level power generation output, which assumes a self-consumption type power supply and which can be connected to a power grid, in order to disseminate distributed electric power and reduce investments in infrastructure in sparsely populated areas.(1) This output is equivalent to that of an EV, and the system consists of an increaser and a generator. We have also forayed into the electric PT field, and aim to provide inexpensive and high-quality components in a short period by utilizing this core technology and reusing automotive parts.

2. Overview of the development of the nacelle for a medium-sized wind power generator

2.1 Development concept

As described earlier, the power generation output was set to 50 kW, which can be connected to low-voltage power grids in Japan, assuming a self-consumption type power supply. The size of the generator was designed to a scale suitable for the site of a business office (Fig. 1), and the price was also set to a level economically operable for a single business owner. In addition, considering the fact that the wind turbine is to be installed in living area, we decided to ensure quietness to prevent noise problems. And in order to reduce both costs and environmental burdens, we decided to reuse automotive parts and build a circular system.

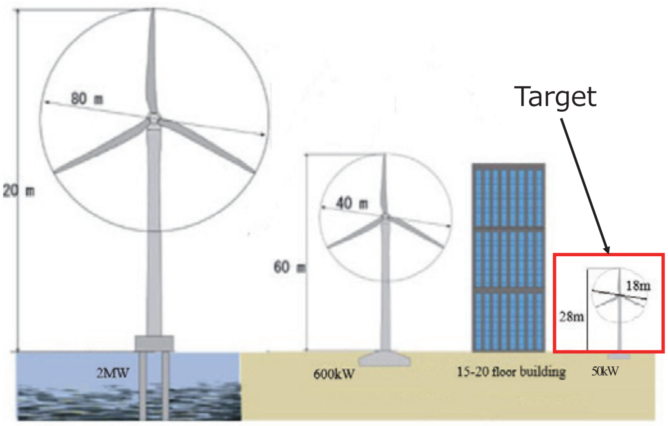

Fig. 1 Power generation and wind turbine size

2.2 Overview of the specifications of the medium-sized wind power generator

As an example, the main specifications of the demonstration wind power generator actually produced are shown below.

*Hardware System Development Department **Innovative Technology Development Department ***Control System Development Department
****Project Management Department

1) Overview of the wind turbine
- Rated output: 50 kW (target, rated speed of main shaft: 60 rpm)
- Rated wind speed: 11 m/s
- Cut-in and cut-out wind speeds: 3.0 - 25.0 m/s
- Tower height: 18.9 m
- Rotor diameter: 18.2 m

For reference, Fig. 2 shows the definition of the general output characteristic that will help understand the performance of wind power generators.

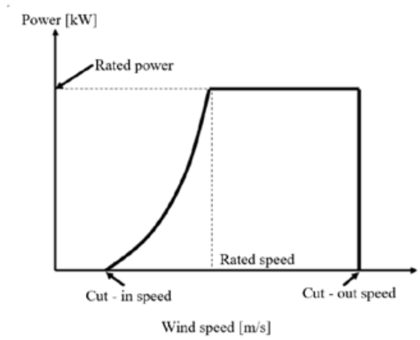

Fig. 2 Power curve of wind turbine

2) Overview of the nacelle (Fig. 3)

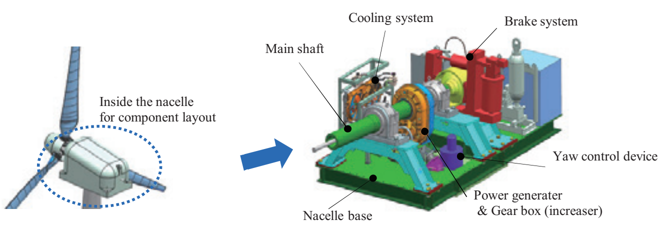

Fig. 3 Inside the nacelle

Generator: Mechanical-electrical separate type (generator for commercial automobile reused)
Increaser: Parallel 5-axis type
Cooling system: Water cooling control type (cooling system for commercial automobile reused)
Main shaft brake: Non-excitation actuated type drum brake
Yaw control device: Phase-driven motor provided with a brake
Size of nacelle: 4.4 m (L) × 2.2 m (B) × 2.4 m (H) (size excluding cowl: 3.0 m (L) × 1.7 m (B) × 1.2 m (H))
Mass of nacelle: 5,212 kg

3. Development process and key technologies

3.1 Development process

We decided to apply to this development process the system engineering (SE) we have established over the years. Applying SE enables us to design the linkage of requirements between the sub-system, the nacelle, and the wind turbine and each system level, their functions, and components for the nacelle for wind power generation, a new area of development in which we lack experience without omission. Furthermore, establishing a V-process evaluation system and planning verification at each level allowed us to perform efficient experimental verification without introducing large-sized equipment.

The sections that follow will show specific examples and key technologies.

3.2 Hardware system design

We analyzed the requirements from the higher-order wind turbine system to the nacelle system based on a use case diagram (Fig. 4). As mentioned above, the reuse of used automotive motors and inverters is important for this development in order to realize a power generation output as a self-consumption type power supply and reduce environmental burdens.

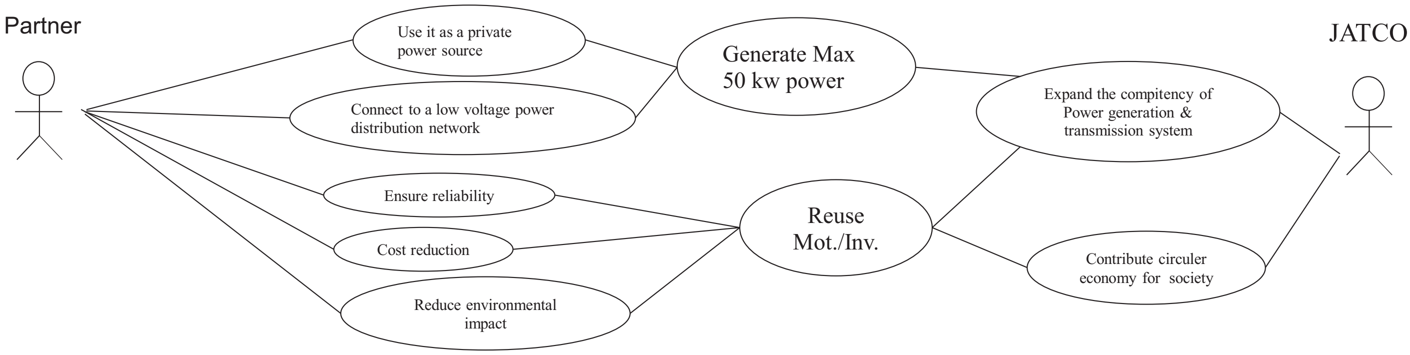

Fig. 4 Use case diagram for wind turbine system

Next, in order to extract all functions and constituent elements of the nacelle without omission and to determine the necessary prerequisites for the design of each element, we elucidated the five main functions the nacelle system will assume, and the IN-OUT physical quantities between them and the constituent elements and the peripheral elements using a context diagram based on a small-sized wind power generator available on the market (Fig. 5).

[Function 1] Generating power → Power generation increaser

[Function 2] Yawing → Yawing system

[Function 3] Stopping the main shaft rotation → Main shaft brake system

[Function 4] Maintaining power generation performance → Cooling system

[Function 5] Monitoring and communicating the condition → Cooling system control unit

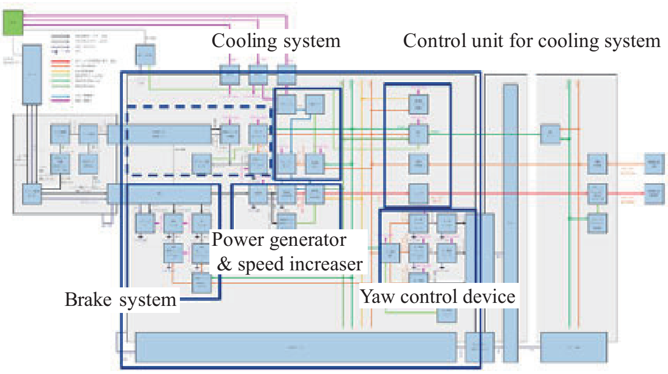

Fig. 5 Context diagram

Then, we defined the requirements of each element, allocated target values, and implemented detailed design. For the power generator, the main component, we reused a motor and an inverter for an automobile available on the market, whose regenerative output was close to the target value. In addition, we set the speed of the main shaft to 60 rpm to ensure quietness, and designed the motor to run with maximum efficiency by adjusting the gear ratio of the increaser to 102.8. Table 1 and Fig. 6 show the specifications of the power generation increaser designed in this way.

Table 1 Function and specifications for wind power

Request (R)	Function (F)	Specifications (L)
Generate electricity	Generate electricity	Motor regeneration output *Kw
		Voltage 240~400V
	Transmit power (Determine the motor operating point)	Speed increase ratio 102.8
	Transmit power (Ensure reliability)	Spindle maximum input torque 7,958 Nm
		Spindle maximum speed 70 rpm
Ensure quietness (Main shaft speed 60rpm)	Reduce transmission loss	Transmission efficiency *%
Operate continuously	Control inverter water temperature	Water cooling mechanism (for commercial vehicle use)
	Lubricate gearbox parts	Built-in electric pump

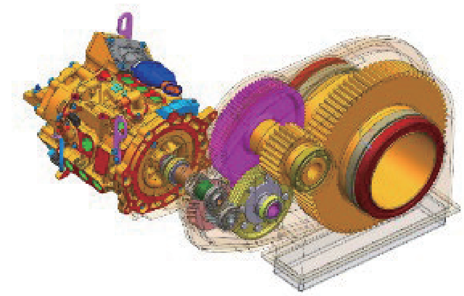

Fig. 6 Exterior of power generator & increaser

The nacelle system designed in this way consists of more than approximately 130 parts, and we applied many reuse designs to realize the development concept of this medium - sized wind power generator, referring to automobiles and industrial equipment. Reused automotive parts accounted for approximately 30% of all parts of the demonstration wind power generator, and the reuse rate is expected to further increase ahead of mass production (Table 2).

Table 2 The reuse rate of automotive parts

		Prototype	Mass production
Nacelle ASSY		**29%**	**Approximately 40%**
	Power generator & increaser	**38%**	**Approximately 50%**
		Motor	←
		Inverter	←
		Lubricating oil pump	←
		Sensor	←
		Lubricant fluid	←
			Gear
		O-rings, etc.	
	Nacelle system	**12%**	**16%**
		Cooling system	←
		Coolant	←
			Sensor

3.3 Control system design

Looking at the systems for the entire wind power generator, we undertook to control (1) through (4), below, to maintain and manage the generator.

(1)Control of the operating volume for the water cooling auxiliary equipment of the generator

(2)Lubricant amount control and temperature monitoring of the increaser

(3)Startup and stop control of auxiliaries based on commands from the higher-order system

(4)Request to the higher-order system to stop when an abnormal state is detected

Figure 7 shows the scope of control development.

Since a wind power generation system is an unknown field to us and the wind power generator manufacturer, who was a joint development partner, was operating in a different cultural area from the automobile industry, the clarification and consistent sharing of the required specifications was an important issue. Thus, by using timing charts and other SE tools, we were able to share the specifications inside and outside the company. Figure 8 shows an example of a timing chart when an agreement was reached with the joint development partner on control specifications.

For the control development process, we adopted the Model Based Development (MBD) process, which we adopt as a standard process. This enables us to utilize the company's control model library and flexibly assign personnel in charge of control development. It also offers such advantages as the feasibility of front loading for verification using Model In the Loop Simulation (MILS) and Hardware In the Loop Simulation (HILS) even when actual hardware is still incomplete.

This time, we adopted a Programmable Logic Controller (PLC), which is a general-purpose controller for industrial use. However, an MBD development environment using our standard C language base was not prepared for the PLC. For this reason, we constructed an MBD development environment for PLCs and performed the in-house development of basic software to be implemented in PLCs.

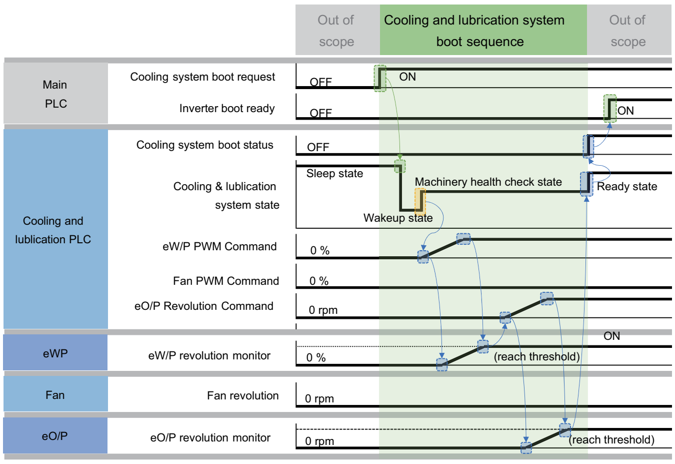

Fig. 8 Timing chart

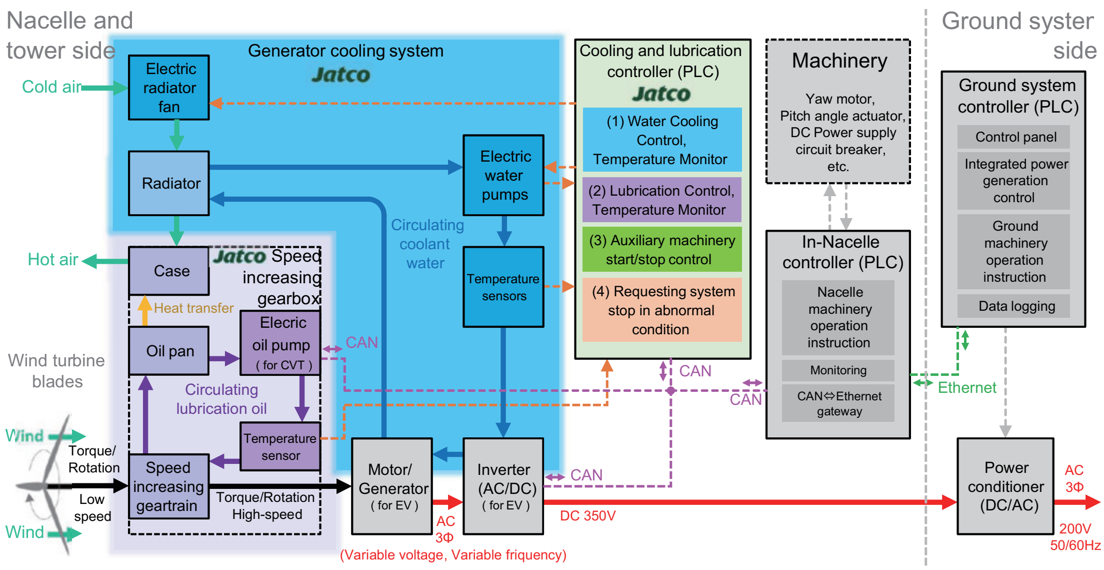

Fig. 7 Concept block diagram

Figure 9 shows an overview of the MBD development environment for PLCs and the software structure.

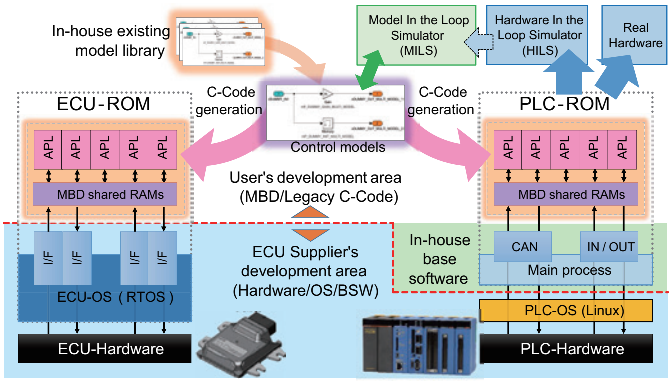

Fig. 9 Overview of MBD development environment and software structure

In addition, Fig. 10 shows the core part of the control model actually developed through the MBD process. Although this figure does not include processing such as input and output and shows only the core application part, we can see that the functional layout complies with Fig. 7.

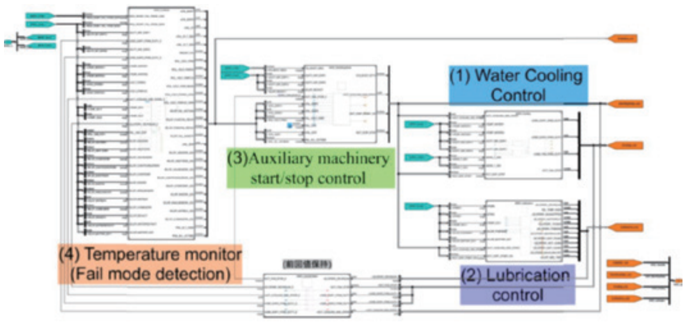

Fig. 10 Control model diagram (core part)

In the MILS verification, we performed operational verification at an early stage with a plant model connected to this core part. And in the subsequent HILS verification, we performed verification using an actual PLC by joining the core part to the basic software part of the PLC concurrently developed and to communication and input/output models into execution form. We thereby confirmed before the experiment that the control functions worked without problems within the scope of the assumed behavior of sensors and actuators.

We successfully reduced the development period through the utilization of an existing model library, development through the flexible organization of teams, and the front loading of the verification by applying MBD to these PLCs and operating MILS and HILS. In addition, as a side effect, we were able to form the foundation for the development scheme that applies MBD and reuses the control model library for automobiles also in PLC control development using our production equipment.

3.4 Experimental verification

We also applied the V-process, which is used for automobile development processes, to experimental verification as is the case with design. We were able to reduce the risk that issues would be detected in subsequent processes because in the V- process, we follow the steps of detecting issues in each process and taking measures against them before moving to the next process. This time, we set three separate processes, namely sub-system, nacelle, and wind turbine, and verified the required specifications in each process.

Table 3 shows the relationship between the respective processes and main verification items.

As the first step, we verified the sub-system. We verified the basic performance and reliability of the wind turbine, such as the power generation capacity and cooling water and oil temperatures, and its reliability with the generator and the increaser combined.

Next, we verified the nacelle. We operated the nacelle in various patterns by combining the generator and the increaser with peripheral units, and verified the impact of mutual interference, functions such as the startup and stop sequences, and reliability. As the final step, we are currently verifying the overall performance, functionality, durable reliability of the wind turbine in its assembled state.

Table 3 Relation between each process and testing items

Process	Performance verification	Functional verification	Reliability verification	Durability verification
Sub-system	○		○	
Nacelle		○	○	
Wind turbine	○	○	○	○

Here, the verification system for the sub-system is shown in Fig. 11. Since the maximum torque produced by the sub-system reaches as high as approximately 8,000 Nm, it is impossible for existing equipment for verifying automotive components to deal with it. However, if new equipment is introduced for performing verifications, there is concern it may cause a heavy cost to be incurred by introducing it and, what is more, the development schedule will be delayed due to a long delivery period. For this reason, we connected two prototypes, one of which was to be used for driving and the other for power generation, in this verification to build a verification system. As a result, it became possible for us to significantly reduce the cost of introducing the verification system, and we also performed the verification without hindering the development schedule.

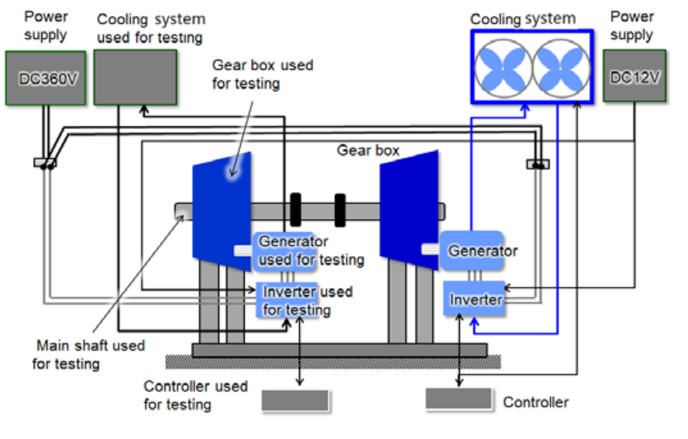

Fig. 11 Test system of sub-system

Next, the verification system for the nacelle is shown in Fig. 12. The nacelle is composed of multiple units such as a main shaft, its peripheral units, a turning unit, and other units. However, since the rotor of the wind turbine was not installed, we could not perform a verification while rotating the main shaft with wind or another external force. Thus, we operated the nacelle using the generator as the drive unit. As a result, we were able to verify the impact of mutual interference and functions, such as the startup and stop sequences.

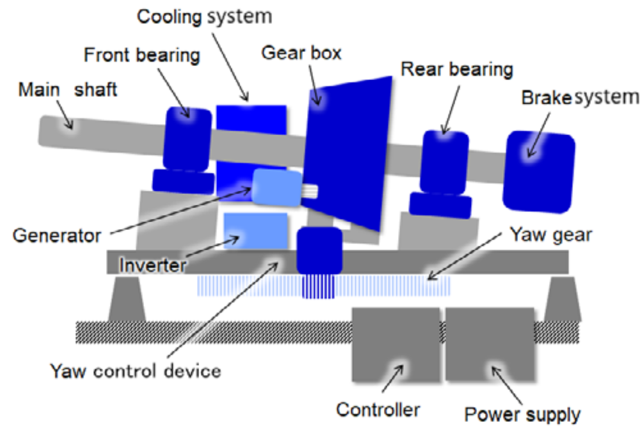

Fig. 12 Test system of nacelle

4. Verification results

Table 4 shows part of the verification results of the sub-system and the nacelle. As shown in Table 4, the required specifications were fulfilled in each verification.

Table 4 Testing results

Process	Items	Verification results
Sub-system	Rated power	○
	Rated speed	○
	Rated torque	○
	Efficiency	○
	Maximum coolant temperature in generator	○
	Maximum oil temperature in gear box	○
Nacelle	Sequence operation of start-stop	○
	Rotating operation of main shaft	○
	Operation of brake mounted on main shaft	○
	Yaw turning operation of nacelle	○

Here, the verification results of the efficiency of the generator and the increaser, which is one of the main indicators of the performance of the wind turbine, are shown in Fig. 13. The results confirm that setting an appropriate gear ratio for the increaser ensures the use of an efficient region of an automotive motor and contributes to realizing satisfactory power generation efficiency.

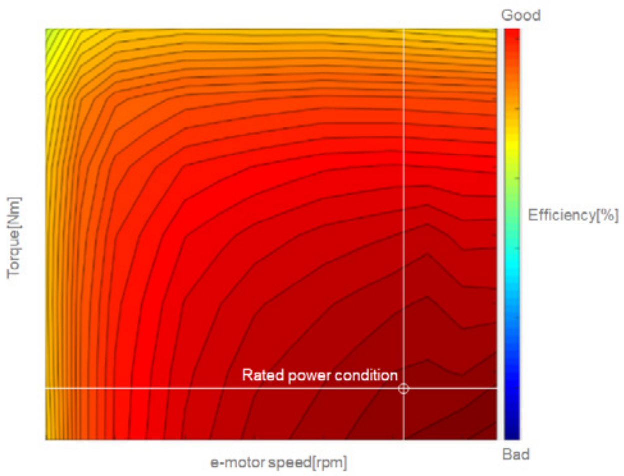

Fig. 13 Efficiency testing result

Next, the evaluation results of temperatures during continuous operation are shown in Fig. 14. This time, the nacelle was equipped with a PLC implemented with new control logic for the purpose of applying automotive cooling devices, such as a radiator, to the wind turbine, and both the temperature of the motor and that of the inverter were below the allowable range. This verifies that the wind turbine is capable of operating continuously without problems for a long time as is required for wind turbines.

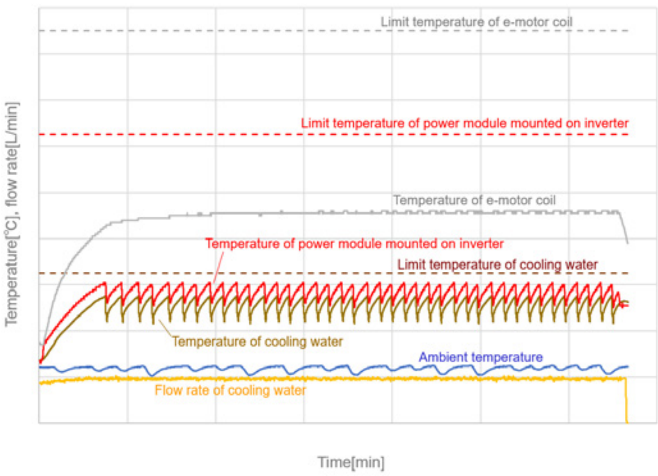

Fig. 14 Temperature testing result

The nacelle thus produced for the actual unit test was incorporated into the wind power generation tower for the demonstration experiment. Figure 15 shows the nacelle, and Fig. 16 shows the wind power generator.

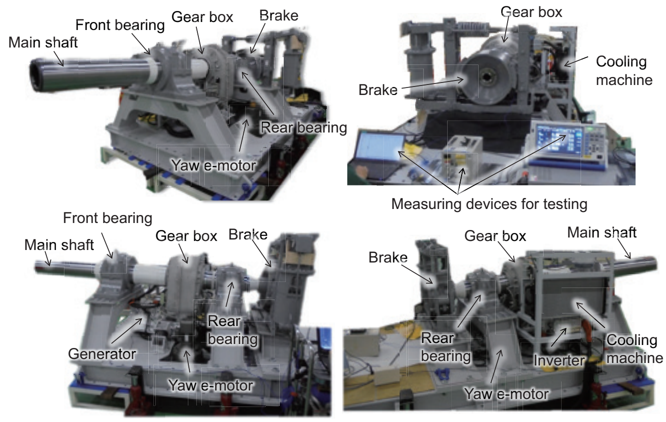

Fig. 15 Nacelle used for testing

Fig. 16 Wind turbine generator

5. Summary

We took on the challenge of developing Japan's first nacelle for 50-kw wind power generation under commission from the Ministry of the Environment and completed the prototyping of the demonstration wind power generator. Reductions of development periods and costs can be expected from the reuse of many automotive parts. In particular, we were able to verify the power generation performance and reliability of an actual generator by using a motor and an inverter for a car available on the market for the generator. In this verification, we confirmed the feasibility of the reuse of automotive parts. The SE we have established through the development of ATs and CVTs is also effective for this development.

6. Afterword

In the future, we aim to develop a technology for controlling power generation, charging, and the electric power supply by connecting a battery to the nacelle system (electric power management). By acquiring this technology, which means connecting a motor, an inverter, and a speed reducer to a battery and operating them (driving an EV) as desired, we will be able to open up a new vista as a system supplier (Tier 0.5).

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■ Authors ■


Satoshi WATANABE


Tomohiko GONDA


Yoshihiro KURAHASHI


Makoto MAEDA


Takeshi YAMAMOTO

Downsized 48V motor winding structure for an EV powertrain

Daiki TANAKA*　Akira SUWABAYASHI*　Junichi ASAMA**

Abstract

Activities to achieve carbon neutrality in recent years have heightened the necessity of electrified vehicles. At the same time, the increased cost of electrified vehicles must be suppressed.

Considering low voltage systems for cost reduce, high current is needed to achieve target output. In order to realize a high power low voltage system, we studied the 48V system as an example.

However, because of the low voltage system, a motor winding structure is required that can accommodate the high current needed for achieving higher motor output. In this development project, a parallel motor winding structure was adopted in combination with the transmission, thereby sufficiently suppressing the increase in the motor size to enable vehicle installation.

This paper describes the technology applied to achieve a parallel motor winding structure.

1. Purpose

Activities to achieve carbon neutrality in recent years have heightened the necessity of electrified vehicles. At the same time, the increased cost of electrified vehicles must be suppressed. One means of accomplishing that is to adopt a 48V system that can be installed at relatively low cost. However, because of the low voltage of a 48V system, a motor winding structure is required that can accommodate the high current needed for achieving higher motor output. In this development project, a parallel motor winding structure was adopted in combination with the transmission, thereby sufficiently suppressing the increase in the motor size to enable vehicle installation.

This paper describes the technology applied to achieve a parallel motor winding structure.

2. Development aim

The motor to be developed this time is expected to be installed in small vehicles.

Targeting for an output power equivalent to that of convensional small car , and using high-rotation speed motor in order to make it even more compact.

The performance values required of the motor and inverter were therefore defined as follows:

- Adoption of a 48V power source
- Maximum inverter current of 905 Arms
- Adoption of a double-star connection with a maximum phase current per star connection of 452 Arms
- Motor output of 32 kW or more
- Maximum motor speed of 20,000 rpm
- Target motor torque of 32 Nm

2.1 Technical issues to be addressed and their solutions

The following issues had to be addressed in developing a motor to achieve the performance requirements noted above.

*Innovative Technology Development Department　**Faculty of Engineering, National University Corporation Shizuoka University

(1) Maintaining the current density of the motor coils so as to accommodate the increased current needed for higher motor output would require increasing the cross-sectional area of the coils and also making the area of the slots larger. In that case, the stator volume would also become larger, thus degrading vehicle mountability. Moreover, increasing the current density while keeping the stator volume the same would result in larger heat generation, thereby degrading thermal performance.

In this project, it was necessary to maintain the motor size on account of the vehicle mountability requirements. Therefore, a method was needed for suppressing the current flowing per unit area while keeping the current density the same as before.

(2) Owing to the compact, high-speed motor design, there was concern about large iron loss when the motor was driven in the high-speed range. There was also concern about the possibility of a sharp increase in the motor temperature because of its smaller thermal capacity on account of the compact design.

2.2 Selection of winding specifications for resolving the technical issues

2.2.1 Defining the number of motor winding turns

Winding specifications were examined in this project based on a previously developed high-output motor. When a two-turn specification was applied to that motor, the required output was not attained because induced voltage larger than the battery voltage occurred at low operating speeds. On the other hand, with a one-turn specification, the maximum current exceeded 1,000 Arms, which was an unacceptable current value for the motor in this project.

Therefore, a study was made of an intermediate 1.5-turn specification. The required motor output was obtained, but the coil arrangement with the 1.5-turn specification caused the coil filling factor in the slots to vary. Accordingly, four 1.5-turn windings in series were changed to two 3-turn windings in series in a double-star connection.

With the adoption of a double-star connection, the target output per star connection was set at 16 kW, enabling the target motor output of 32 kW to be attained while suppressing the current density (Fig. 1).

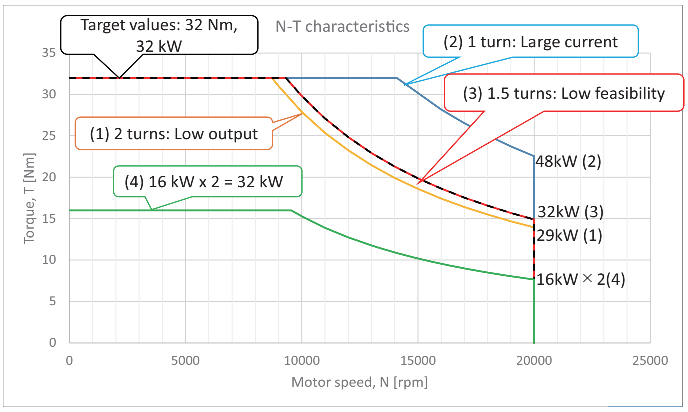

Fig. 1 Relationship between number of winding turns and motor output

2.2.2 Measure against iron loss in high-speed area

Double-layer, short-pitch distributed windings were adopted to reduce iron loss in the high-speed area. One advantage of short-pitch distributed windings is that the induced voltage waveform more closely resembles a sinusoidal wave. As a result, it leads to a reduction of high-harmonic components and reduces iron loss. In addition, shortening the coil pitch also reduces the copper wire length, which can be expected to reduce copper loss as well.

Combined with the use of double-layer windings in this project, the coil circumference was further shortened for an additional reduction of copper loss.

3. Parallel Winding Structure Issues and Their Solutions

This chapter considers double-layer, full-pitch, 3-turn windings in a double-star connection. Owing to the odd number of turns, they are divided between 2-turn slots and 1-turn slots. Because no more than three turns can be put in one slot, coils are inserted in same-phase slots between the double star connection in combinations of two turns and one turn or one turn and two turns. The magnetomotive force distribution is proportional to the number of turns of the coils in the slots, so the maximum value occurs between slots with 2-turn coils.

As shown in Fig. 2, a comparison based on the V-phase reveals that the slots with 2-turn coils of v1 and v2 windings differ, causing a phase difference in the magnetomotive force distribution. As a result, it produces an induced voltage waveform like that shown in Fig. 3 in which there is a phase shift equal to one slot. A phase difference occurs between the magnetic flux generated by the v1 winding and that generated by the v2 winding, giving rise to a possibility that mutual magnetic interference might occur when controlling the motor. As a measure to prevent that, the induced voltage waveforms of the v1 and v2 windings between the double star connection must be in the same phase.

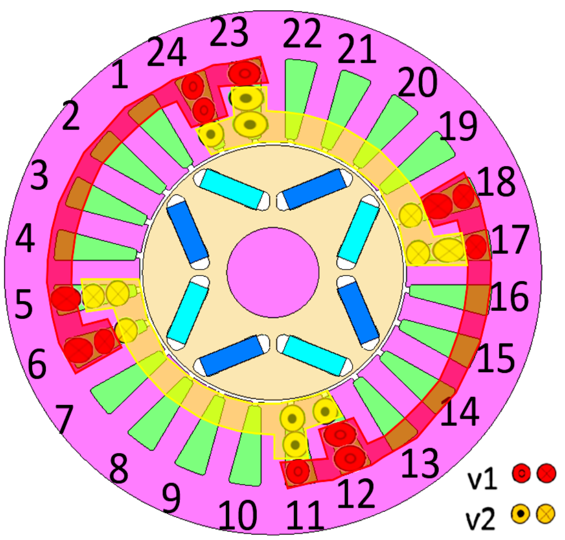

Fig. 2 Winding diagram for double-layer, full-pitch distributed windings

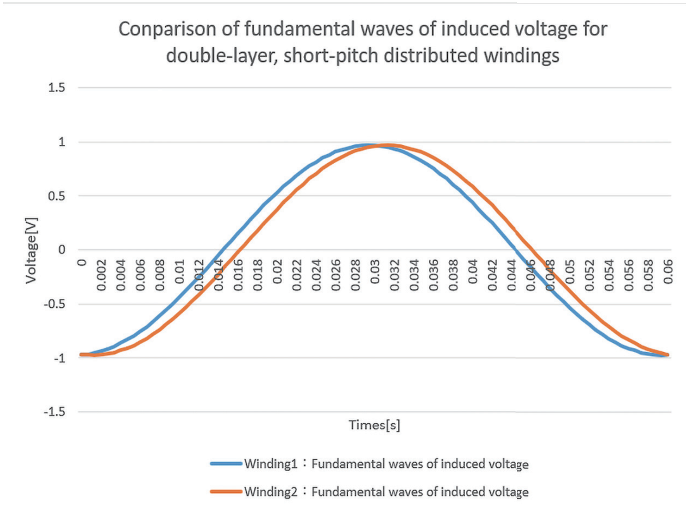

Fig. 3 U-phase induced voltage waveforms for double-layer, full-pitch distributed windings

In this project, short-pitch windings were adopted to change the winding arrangement, and a winding method was applied that shortened the coil pitch. As a result, in relation to the positions where the 2-turn and 1-turn v1 windings were placed, the v2 windings were arranged in the same way at positions shifted by 6 slots and an electrical angle of 180 ° el. As a result, the same phase was obtained for the induced voltage of each phase (Fig. 4).

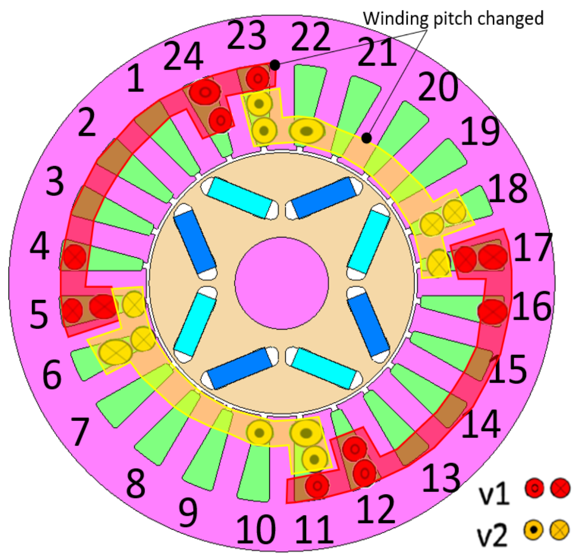

Fig. 4 Winding diagram for double-layer, short-pitch distributed windings

As shown in Fig. 5, the winding changes described here made it possible to achieve the same phase for the induced voltages of the v1 and v2 windings.

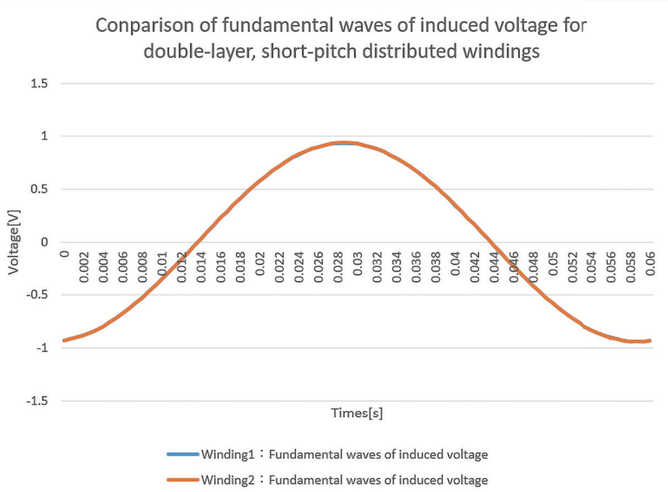

Fig. 5 U-phase induced voltage waveforms for double-layer, short-pitch distributed windings

The final coil arrangement is shown in Fig. 6. The respective arrangement of the U-phase and W-phase coils between the double-star connection has the same positional relationship as that of the V-phase coils mentioned above. This coil arrangement eliminated any phase difference between the induced voltages.

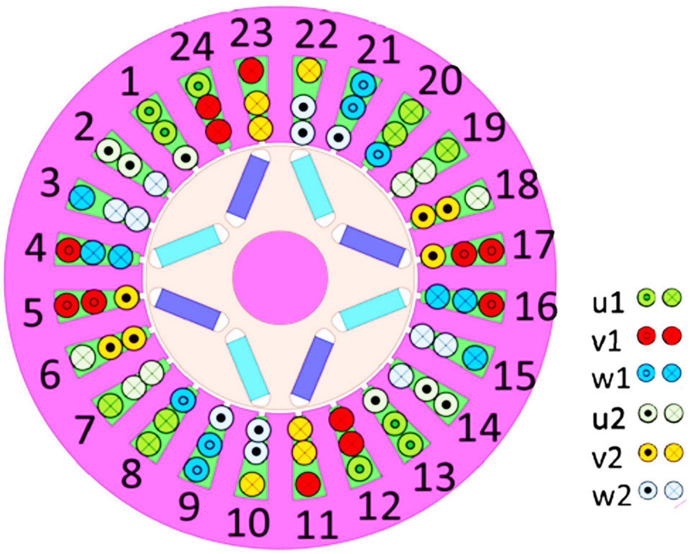

Fig. 6 Final winding arrangement

4. Results

A motor was manufactured and was confirmed performance and electric characteristic. The picture in Fig. 7 shows the appearance of the motor coil.

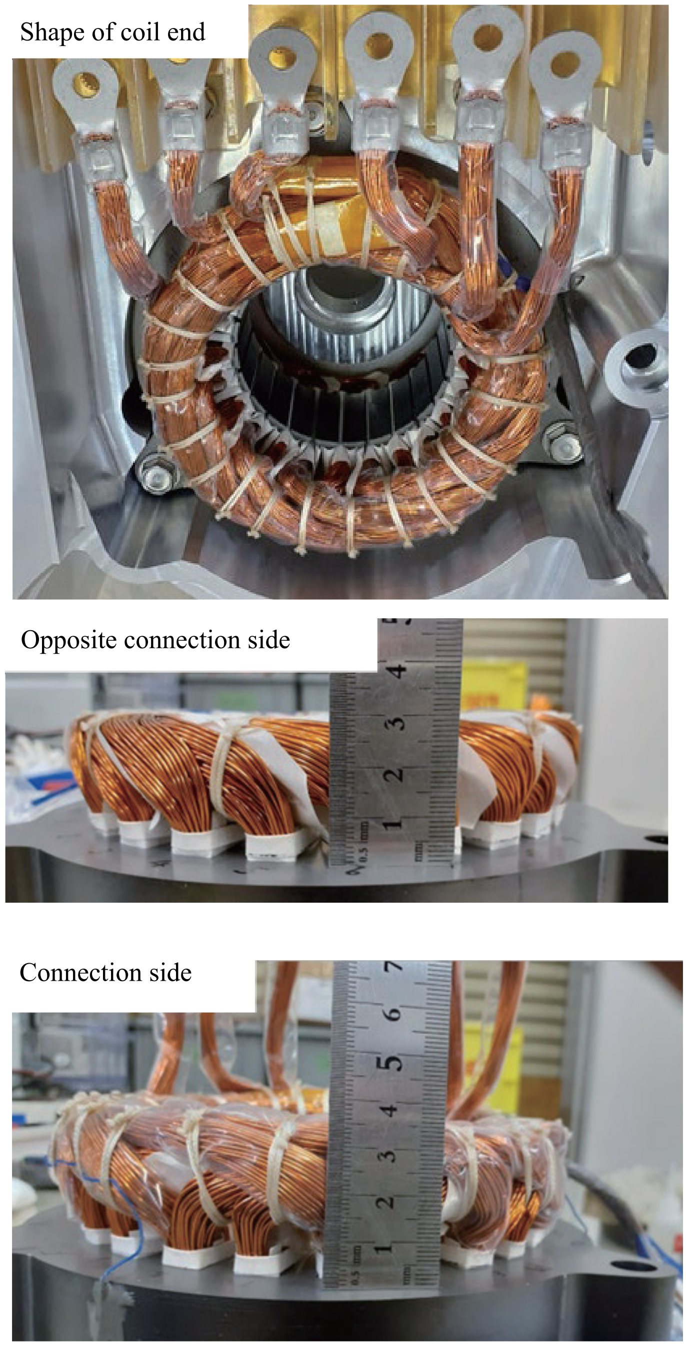

Fig. 7 Photos of windings (appearance/opposite the connection side/connection side)

The coils were manufactured according to the wiring arrangement that was examined in this study, and the coil ends were made smaller by adopting double-layer lap windings.

A current density of 17.7 Arms/mm^2 was obtained with the manufacturing specification.

Figure 8 shows the induced voltage waveforms measured for the motor. As shown in the figure, the results confirmed that there was no phase difference in the U-V line voltage between the double-star connection.

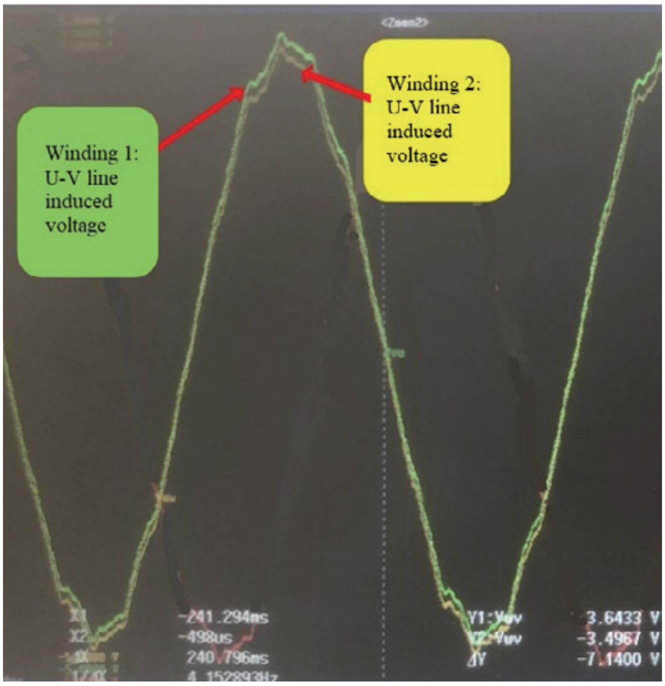

Fig. 8 Measured induced voltage waveforms

Figure 9 shows the measured output torque of the motor. The motor produced output torque almost as intended. Because the motor was not closely calibrated with the inverter, torque dropped in the vicinity of 3,000 rpm. However, the motor was in the range of its maximum torque, so if optimally calibrated, it is expected to reach the target output level as calculated.

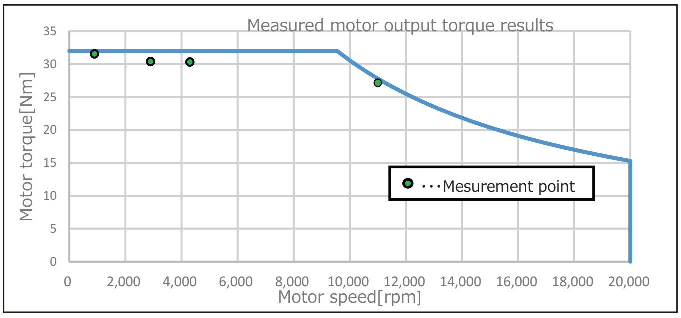

Fig. 9 Measured motor output results Measurement point

The results of a simulation revealed that there was a margin in the magnetic circuit for further motor output. With the adoption of permanent magnets having high residual magnetic flux density, it expected that the motor can produce output up to 42 kW and torque up to 41 Nm, as shown in Fig. 10.

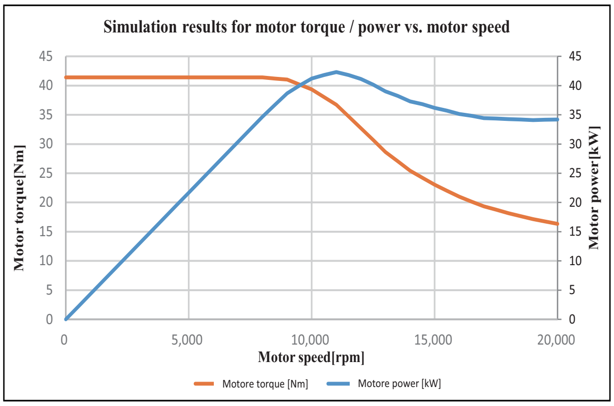

Fig.10 Simulation results for motor torque/power vs. motor speed

Simulation results for iron loss and copper loss are shown in Fig. 11. Short-pitch windings were adopted for this motor with the aim of reducing iron loss in the high-speed area. As a result, iron loss in the simulation was reduced by approximately 22% compared with full-pitch windings.

In contrast, it is projected that copper loss may worsen by around 7% in the low-speed, high-torque area owing to the reduced torque constant resulting from the adoption of short-pitch windings. The reduction of iron loss in the high-speed area also reduced the copper loss value by approximately 35%. That is attributed to the fact that a smaller current is needed to produce the required torque. It is planned to measure the precise iron loss and copper loss values in future work.

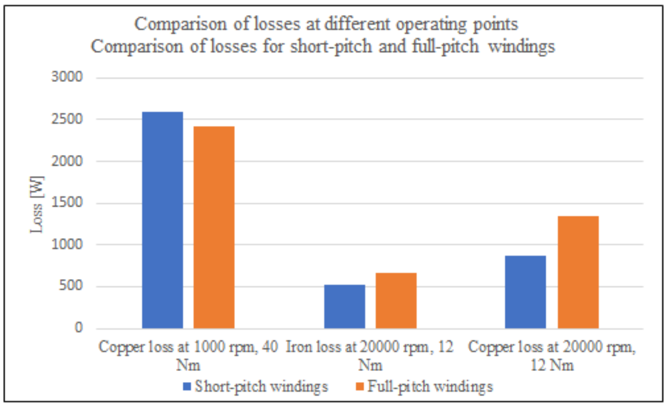

Fig.11 Comparison of losses at different operating points

Driving tests were conducted using a prototype vehicle mounted with the newly developed motor. Figure 12 shows the relationship between the driving force obtained and the vehicle speed. The results confirmed that the vehicle delivered satisfactory performance.

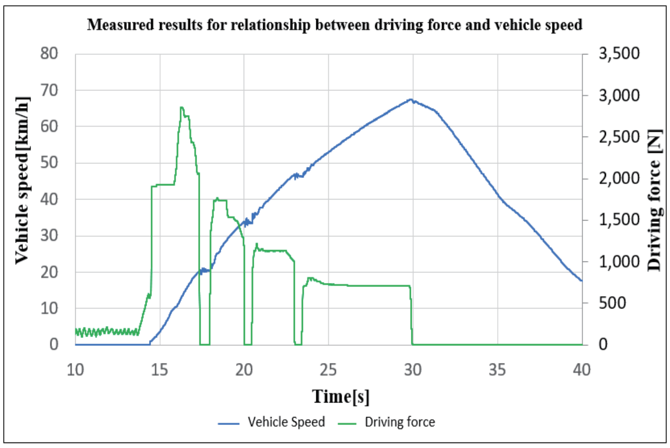

Fig. 12 Measured results for driving force vs. vehicle speed

5. Conclusion

Obtaining high motor output power with a 48V system has been regarded as being difficult. However, in this project, by adopting the parallel winding structure of the motor, the increase in the motor has been avoided, and the system has been reduced and the mounting on a small vehicle (Fig. 13). It was confirmed that the technology presented here resolved both the issue of increased iron loss due to higher operating speeds and the issue of accommodating high current levels owing to the low voltage and high motor output power.

Increased motor output can also be obtained with the same technology at other voltage levels, not limited to 48V systems. Therefore, this technology can contribute to system downsizing along with reducing costs and material usage.

Fig. 13 Photo of prototype demonstration vehicle

6. References

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■ Authors ■

Daiki TANAKA

Akira SUWABAYASHI

Junichi ASAMA

Development of steel materials and manufacturing methods for gear usable at high rotation conditions

Toshihiro ODA*　Gou KATOU*　Makoto MAEDA*

Abstract

Electrification causes a high-speed gear rotation and creates a severe (poor) lubrication environment. In this study, a new method to improve the seizure resistance and pitching resistance was developed by modifying the surface of the gear teeth. In addition, this study developed a steel material and its production method that can tolerate high-speed rotation by designing material components to retain the fatigue strength of the root of the gear teeth.

1. Introduction

From the aerodynamic performance and collision safety viewpoints, the miniaturization of the e-Axle is desired.

The motor must be miniaturized to minimize the e-axis. The torque reduction caused by miniaturization should be compensated by a high rotation to secure the power output.

Because of the high-speed rotation of the motor, the reduction gear also rotates at a high speed. This leads to a situation in which the lubrication becomes insufficient, resulting in a poor lubrication environment. In a poor lubrication environment, metal contact on the sliding surface increases, increasing the risk of seizures.

Therefore, we developed a method to prevent gear seizures that is less expensive than conventional seizure resistance methods.

2. Method to improve seizure resistance of gears

Because seizures are caused by metal bonding, they can be suppressed using dissimilar metal layers on the gear surfaces.

For components, such as washers in automatic transmissions, an inexpensive gas soft-nitriding treatment is used to form a compound layer on the sliding surfaces (Fig. 1).

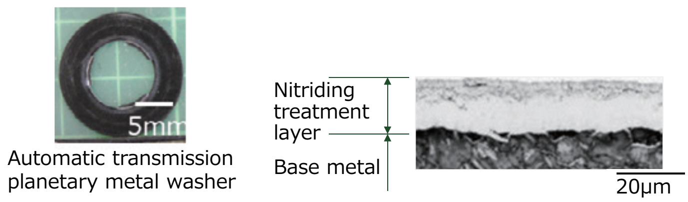

Fig. 1 Surface cross-sectional microstructure after gas nitriding treatment

However, gas soft-nitriding treatment is difficult to apply to gears because gears require high hardness below the surface, whereas gas soft-nitriding treatment can form hardened layers only on the surface.

*Innovative Technology Development Department

Therefore, an expensive molybdenum disulfide treatment is generally used for gears (Fig. 2).

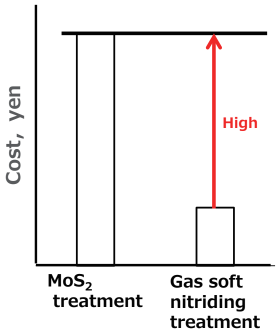

Fig. 2 Cost comparison

In this study, a steel was developed to utilize an inexpensive gas soft-nitriding treatment that can obtain internal hardness by quenching and tempering before the gas soft-nitriding treatment and maintaining the hardness after the gas soft-nitriding treatment.

3. Materials

Table 1 lists the material components of the newly developed gear.

The carbon content was increased to increase the internal hardness of the gears close to that of the existing specifications, and quenching and tempering treatments were applied. Mo and vanadium were added to suppress softening during the gas soft-nitriding treatment.

Table 1 Main material composition (wt%)

	C	Si	Mn	Cr	Mo	V
Development steel	**0.34**	0.05	0.34	1.12	**0.95**	**0.25**
JIS SCr420H	0.21	0.32	0.87	1.18	-	-

Using steel with the developed components, gears were produced during manufacturing (Table 2). Changing the manufacturing process within the range of existing manufacturing conditions is possible.

The results were compared with those of a conventional anti-seizure gear (with molybdenum disulfide treatment) and gear without countermeasures (carburized quenching and tempering treatment).

Table 2 Manufacturing methods comparison

Method			Manufacturing process				
Seizing countermeasure specifications	Develop ment	Quenching and tempering + Gas soft-nitriding treatment	Forging	Machining	Quenching and tempering	Finish processing	Gas soft nitriding treatment
	Current	Carburizing, quenching and tempering +.MoS_2 treatment	↑	↑	Carburizing, quenching and tempering	↑	MoS_2 treatment
General gear specifications		Carburizing, quenching and tempering	↑	↑	↑	↑	—

4. Metallographic structure and hardness distribution of gears

4.1 Investigation method

The study was performed at the midpoint of the tooth length on the cross section of the middle tooth width (Fig. 3).

The cross-sectional metallographic structures were observed using optical microscopy after corrosion with nital, and the cross-sectional hardness was measured using a Micro Vickers (HV 0.1).

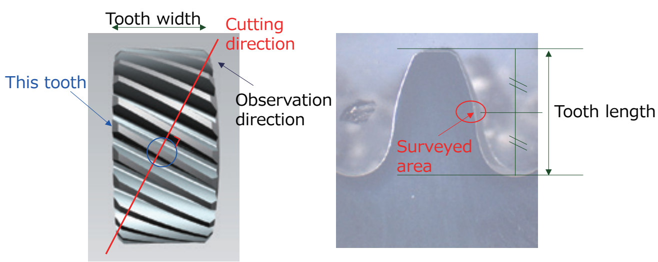

Fig. 3 Gear evaluation cross section

4.2 Results of cross-sectional structure and cross-sectional hardness

Figure 4 shows the cross-sectional structure, and Fig. 5 shows the distribution of the cross-sectional hardness.

Formation of a compound layer was observed on the surface, and a hardness higher than the target hardness was obtained.

The target hardness was estimated from the input of the gear.

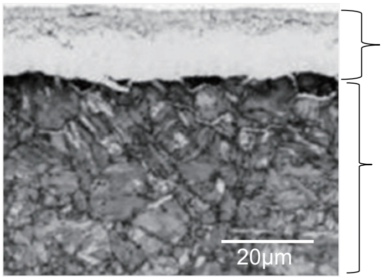

Fig. 4 Cross sectional microstructure

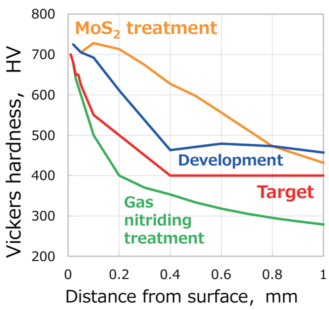

Fig. 5 Cross-sectional hardness distribution

5. Seizure evaluation

5.1 Evaluation conditions

Seizure evaluation was performed using the prototype gear.

These conditions are listed in Tables 3 and 4, respectively. In the evaluation, the rotational speed was varied using two levels of torque that simulated the high-speed running (low torque) and starting (high torque) of the EV car, and the presence of seizures was determined by visual observation.

The rotation speed in the future is expected to surpass 30,000 rpm.

In this study, an input of 30,000 rpm was not possible owing to the limitations of the test machine. Therefore, by raising the evaluation oil temperature, where oil film formation becomes difficult, a severe lubrication condition was created, and the seizure resistance was evaluated under a condition equivalent to more than 2 times the speed (30,000 rpm) of the current EV (Fig. 6).

The evaluation time under each condition was set to be 3 min.

Table 3 Low torque evaluation experimental conditions (high speed driving simulation)

Number of rotations, rpm	4,000	5,000	···	10,000
Torque, Nm	202	202	···	202

Observation Observation Observation

Table 4 High torque evaluation experimental conditions (simulating starting)

Number of rotations, rpm	1,000	2,000	···	7,000
Torque, Nm	625	625	···	625

Observation Observation Observation

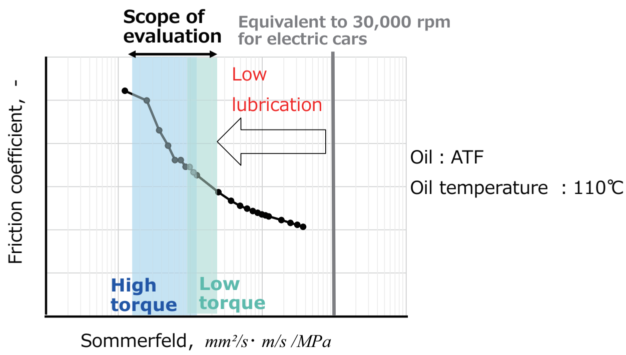

Fig. 6 Stribeck curve

5.2 Evaluation Results

(1)Low-torque condition

Seizures were evaluated at the upper-limit rotation speed of the test machine. Neither the specimen with the developed component specifications nor molybdenum disulfide treatment caused seizures. The seizure resistance of the specimen was approximately twice as high as that of the sample subjected to carburizing, quenching, and tempering treatments (Figs. 7 and 8).

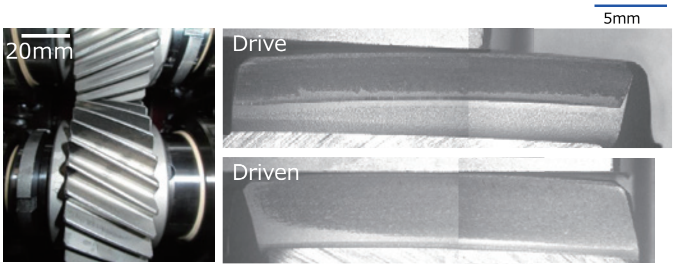

Fig. 7 Development specifications external view (after low torque evaluation test)

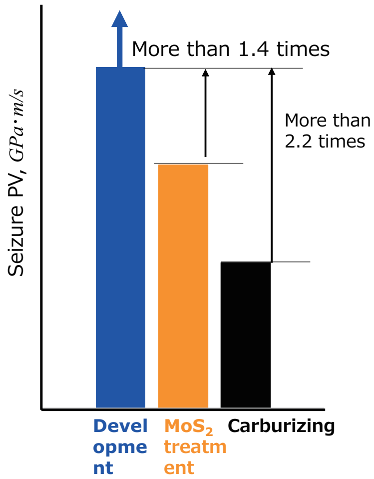

Fig. 8 Endurance test results (low torque test)

(2)High-torque condition

Gears with the developed component specifications resulted in no seizures and achieved over 2.2 times seizure resistance compared to gears with carburizing, quenching, and tempering treatment, and over 1.4 times seizure resistance compared to gears with molybdenum disulfide treatment (Figs. 9 and 10).

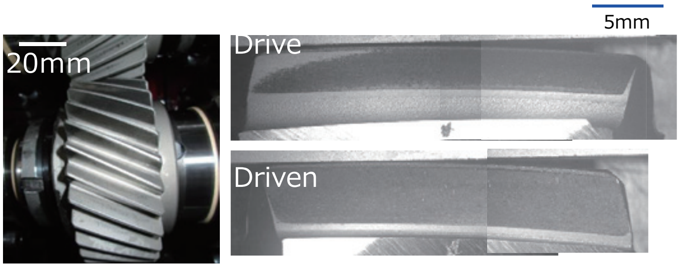

Fig. 9 Development specifications external view (after high torque evaluation test)

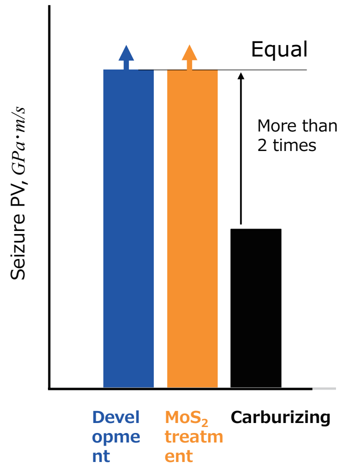

Fig. 10 Endurance test results (high torque test)

6. Discussion

In the evaluation under high-torque conditions, the developed component specifications enabled seizure resistance over 1.4 times compared to the molybdenum disulfide treatment. In the evaluation under low-torque conditions, neither patient showed seizures.

Because no significant difference was observed under the low-torque condition between the gears with the developed component specifications and the molybdenum disulfide treatment, the tooth surface after the test under the low-torque condition was studied. It was found that the friction consumption of the gear with the developed component specification, which has a hard coating layer, was approximately 4 μ m, while that of the gear with the molybdenum disulfide treatment was approximately 16 μ m, nearly 4 times larger (Figs. 11 and 12).

Compared to the molybdenum disulfide treatment, the developed component specification exhibits a higher abrasion resistance necessary for retaining the protecting layer and, thus, is superior in terms of seizure resistance even under low torque conditions.

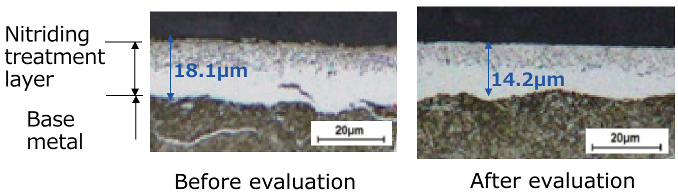

Fig. 11 Film thickness before and after evaluation tests of development specifications

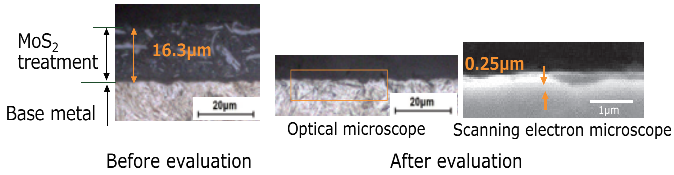

Fig. 12 Film thickness before and after evaluation tests of MoS_2 treatment

7. Summary

We developed a material and processing method that improves the seizure resistance of gears in high-speed motor rotation.

The combination of high-alloy steel components, quenching and tempering treatment, and gas soft-nitriding treatment achieved higher seizure resistance than molybdenum disulfide treatment, which is the conventional method to obtain seizure resistance.

It was possible to make the improved gears cheaper than with molybdenum disulfide treatment because the manufacturing process was changed only within the range of the existing manufacturing conditions.

8. References

Toshihiro Oda, Gou Katou, Tomoya Tamai, Ayumi Yamazaki:Development of gear materials and manufacturing methods to improve gear resistance in low-lubrication environments, Chubu Branch Research Presentation 2023, Hitotek Nagoya.

■ Authors ■


Toshihiro ODA


Gou KATOU


Makoto MAEDA

Initiatives for improving equipment reliability for Smart Factory activities

Taisuke YAMAGUCHI*   Takahiro NAONO*   Sho ITO**

Abstract

In order to further improve competitiveness in terms of cost and quality achieved through electrification, JATCO is carrying out Smart Factory activities aimed at realizing factories capable of maintaining maximum efficiency by fiscal 203X.

This paper reports on how the prevention of maintenance equipment data entry omissions and failure analysis capability improvements were achieved by adopting tablets and developing an app for the maintenance equipment management system, and how this contributed to our Smart Factory activities.

1. JATCO Smart Factory activities

The Facility&Maintenance Engineering Section of the Production Administration Department (Maintenance) is currently tackling Smart Factory activities with the following three steps.

Step 1 Maintenance equipment data collection

Step 2 Maintenance equipment data analysis

Step 3 Predictive maintenance, corrective maintenance, MP (reflected in new equipment construction)

At present, there is a failure loss of 5% between Steps 1 and 2, but JATCO is working to reduce failure loss and improve equipment reliability with the aim of reducing failure loss to 0% at Step 3 (Fig. 1).

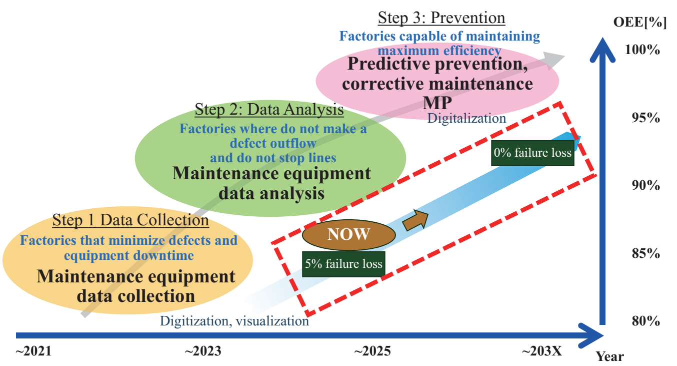

Fig. 1 Smart Factory activities

2. Understanding the current situation

2.1 Necessity of maintenance equipment data

Maintenance is currently planning measures for equipment failures which involve entering the corresponding investigation, failure analysis, and corrective action data in a management system when failures occur, and preventing failure recurrence based on this data.

At JATCO, this management system is known as SEMES, and is an acronym of Supports Efficient Maintenance of Equipment System.

Hereinafter, this system shall be referred to as SEMES (Fig. 2).

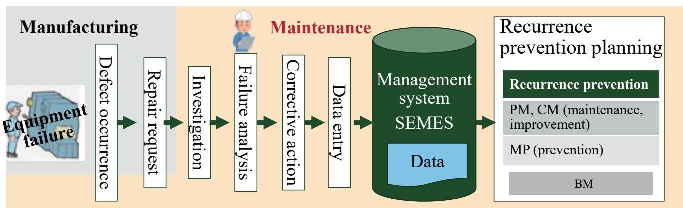

Fig. 2 Equipment failure handling process flow

*Production Administration Department   **JEPS Management Department

2.2 Understanding the current SEMES data situation and establishing issues

Analyzing the current SEMES data situation revealed the following two problems.

(1)Failure analysis, corrective action data entry omissions

Data on failure analysis and corrective action had been omitted, and this corresponded to a failure loss of 1%.

(2)Failure to analyze true cause of failure

There was a case in which the failure analysis process remained stuck at the failure location identification stage, and the true cause was not determined. This corresponded to a failure loss of 4% (Table 1).

The above two points were established as issues.

Table 1 Understanding the current SEMES data situation

	SEMES data	Failure loss
(1)	Failure analysis, corrective action data entry omissions	1.0%
(2)	Failure to analyze true cause of failure	4.0%
	Total	5.0%

2.3 SEMES data issues and causes

(1)Cause of failure analysis, corrective action data entry omissions

When dealing with failures, maintenance staff take notes at the site, and later enter data in SEMES from memory and notes at the office. Staff tend to forget details the more time passes, and are unable to understand their own notes, leading to data entry omissions (Fig. 3).

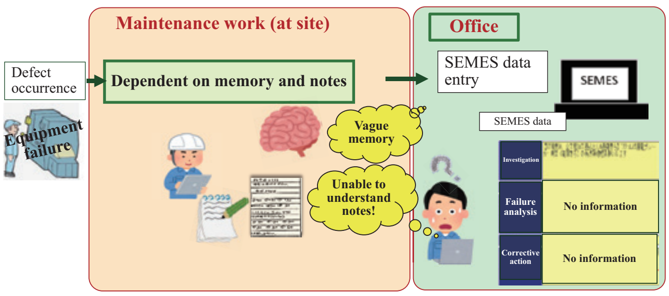

Fig. 3 Cause of failure analysis, corrective action data entry omissions

(2)Cause of failure to analyze true cause of failure

The analysis of failures by maintenance staff is dependent on individual knowledge, experience, and skill, and there is a tendency for the items that are checked to differ between staff. This variability between staff resulted in a case whether no one was able to determine the true cause of the failure, and the only measure taken was simply to restore the equipment (Fig. 4).

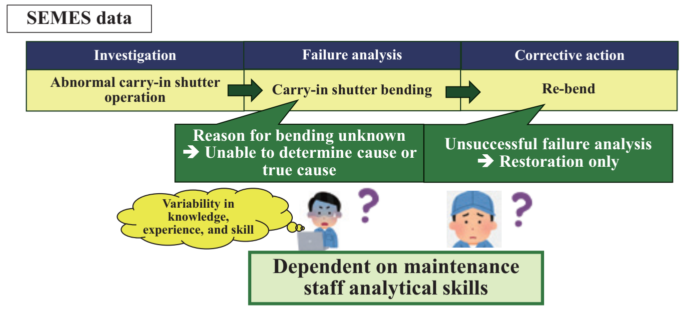

Fig. 4 Cause of failure to analyze true cause of failure

In summary, there were two issues with SEMES data.

Issue 1: "Entering data by relying on memory and notes"

Issue 2: "Failure analysis dependent on individual knowledge, experience, and skill"

3. Studying and deciding upon measures proposal

3.1 Concept

In coming up with suitable measures to address the two issues, a concept was decided.

(1)Having maintenance staff enter data at on site

(2)Being able to identify the true cause of failures without relying on skill

From these two goals, the concept of "considering the true cause on site" was decided, and measures were planned based on this (Fig. 5).

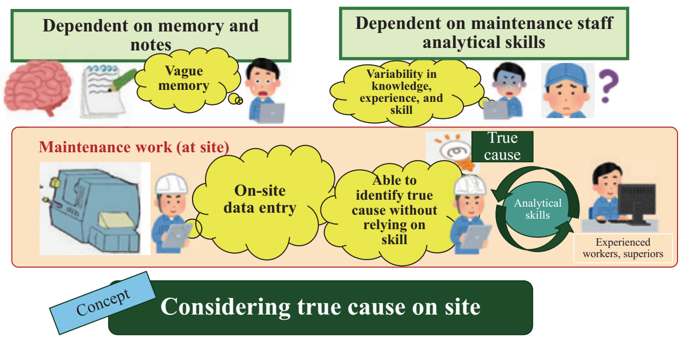

Fig. 5 Measures concept

3.2 Studying and deciding upon measures proposal

In accordance with our concept, the following three directions for measures were decided (Fig. 6).

(1)Mobile terminals should be used.

(2)Failure analysis should be navigated.

(3)Support with failure analysis should be provided.

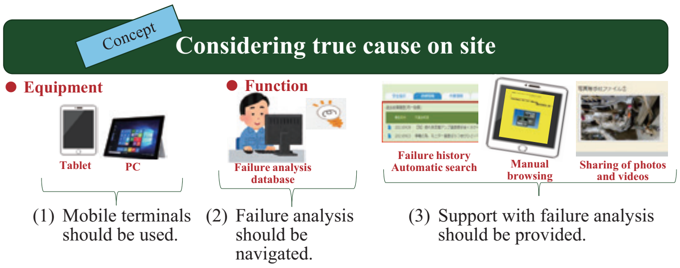

Fig. 6 Measures proposal study

In terms of direction, we proposed measures, conducted an evaluation, and then came to a decision.

(1)For our mobile terminals, we compared laptop PCs with tablets, and decided to adopt tablets due to their outstanding cost performance.

(2)For navigating failure analysis and (3) supporting failure analysis, we began developing an in-house app that allows new functions to be added, and modifications to be made quickly and efficiently (Fig. 7).

Concept Considering true cause on site	Measures (proposal)	Tool	Benefit	Cost	Management	Adoption
On-site entry	(1) Use of mobile terminals	Tablet	O	O	O	Yes
		Laptop	○	△	○	No
Able to identify true cause without relying on skill	(2) Failure analysis navigation (3) Failure analysis support * Automatic failure history search Manual browsing Sharing of photos and videos	SEMES modification	○	△	△	No
		App	O	O	O	Yes

Fig. 7 Deciding measure

4. Implementing measures

4.1 On-site data entry using tablets

In order to link SEMES and tablet data, we opted to use QR Codes (Fig. 8).

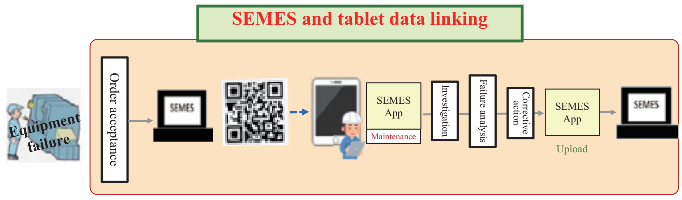

Fig. 8 On-site data entry using tablets

4.2 Failure analysis navigation app

(1)Creation of failure analysis database

We created a database based on FTA to address failure locations by using past data accumulated by multiple experienced maintenance staff.

(2)Failure analysis navigation app development

- Navigation function

This function allows users to navigate failure analysis data by calling lists of investigation items for failure locations from the database, and entering indicated items. The function has also been equipped with an interlock that prevents users exiting the app if they fail to enter data in the investigation item list.

- Additional navigation function

We also added a function that allows maintenance staff to add new function locations and investigation items to the database using the app.

By doing so, we were able to consolidate the knowledge, experience, and skills of maintenance staff.

JATCO developed a proprietary failure analysis database and navigation app in house (Fig. 9).

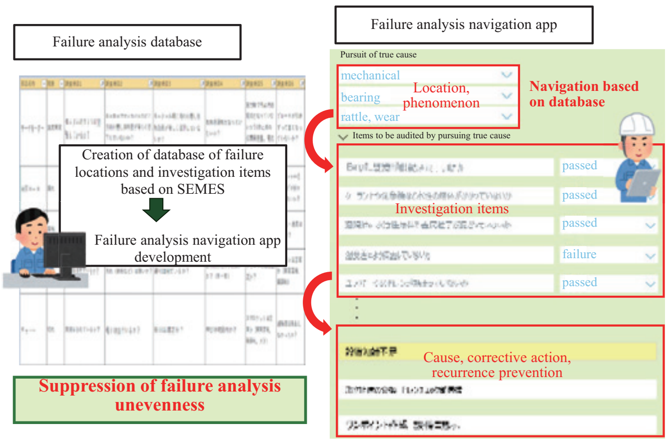

Fig. 9 Failure analysis navigation app

4.3 Failure analysis support app

The fault analysis support app consists of automatic failure history search, instruction manual browsing, and photo and video viewing functions.

(1)Automatic failure history search

By entering the equipment number or name of the equipment manufacturer at the tablet, failure history is automatically collected and displayed.

(2)Instruction manual browsing

By entering the model number of an NC unit or robot, etc. at the tablet, an instruction manual is displayed, allowing it to be browsed on site.

(3)Viewing photos and videos

By searching failure history, photo and video data can be viewed on site (Fig. 10).

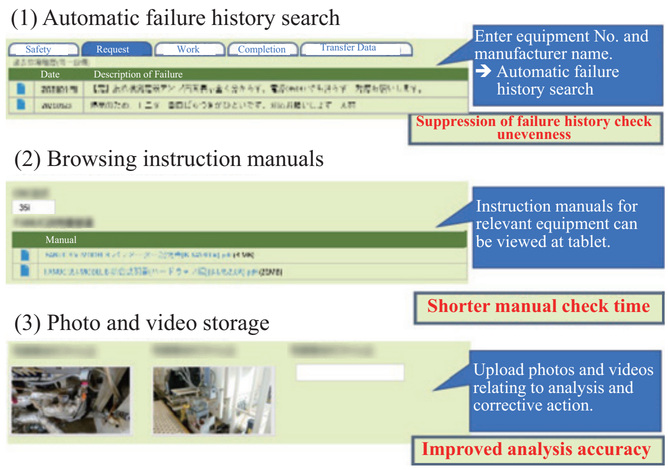

Fig. 10 Failure analysis support app

5. Verifying the benefits

By implementing the above measures, we achieved the following benefits.

(1)Failure analysis, corrective action data entry omissions

Failure to enter failure analysis and corrective action data became a thing of the past, and failure loss improved by 1%.

(2)Failure to analyze true cause of failure

Maintenance staff were able to identify the true cause of all failures, and failure loss improved by 1% (Table 2).

Table 2 SEMES data situation

	SEMES data	Failure loss
(1)	Failure analysis, corrective action data entry omissions	0.0%
(2)	Failure to analyze true cause of failure	3.0%
	Total	3.0%

(1): 1% → 0% 1% improvement
(2): 4% → 3% 1% improvement

6. Future Issues

The ability of maintenance staff to analysis failures has improved, but we still have a failure loss of 3%. We intend to address this by seeking to further improve failure analysis accuracy.

7. References

(1)Makoto HIROSAKI: Construction of a platform for supporting promotion of manufacturing workplace data digitization and improvement of overall equipment effectiveness, JATCO Technical Review No.22, pp.111 - 115.

(2)Taisuke Yamaguchi (plant engineer), Initiatives for Realizing Equipment Reliability Improvement Cycle, Vol.55, No.9, pp.34 - 44, Japan Institute of Plant Maintenance, 2023.

■ Authors ■

Taisuke YAMAGUCHI

Takahiro NAONO

Sho ITO

Smart Factory initiatives aimed at achieving highly efficient production sites

Masayuki MIYAZONO*　Naoki TSUBAKI*

Abstract

As electrification advances, improvement of overall equipment efficiency at manufacturing sites is required for further improvement of cost and quality competitiveness. To do so, further analysis of the primary causes of declining operating rates and shortening of the improvement cycle are necessary. We have therefore promoted the digitization of information. This report describes the development and development of an in-house system designed to respond promptly to changes in the business environment and the needs of each manufacturing site.

1. The Smart Factory JATCO is aiming to achieve

At JATCO, activities to digitize information inside factories to improve overall equipment efficiency (OEE), referred to as Smart Factory activities, are promoted based on the roadmap shown in Fig. 1 and the following three steps.

Step1:Factory that minimizes defects and equipment stoppage time

Step2:Factory that does not pass on defects and does not stop production lines

Step3:Factory that maintains maximum efficiency

Progress as of 2023 is between Step 1 and Step 2. The actual OEE at JATCO is around 80%, and we are aiming to achieve 90% in Step 2 and 100% in Step 3[(1)].

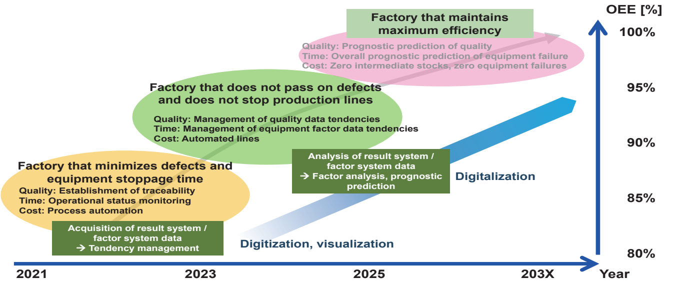

Fig. 1 Roadmap to JATCO's Smart Factory

2. How to promote digitization and visualization

2.1 Necessity of digitizing information at production sites

To improve OEE, it is necessary to share the operational status and changes of production lines, as well as to identify the causes of the declining operating rates and implement countermeasures. For prompt information sharing, a system in which information is digitized and stored so that necessary information can be collected and analyzed without human intervention is absolutely essential.

As an information storage system, JATCO has built EQ_Connect, which is an unified information platform for the entire company[(1)].

EQ_Connect is a platform that supports the visualization of data at sites by consistently carrying out data collection, transfer, storage, and visualization.

This report describes the in-house development of a subsystem to be connected to EQ_Connect.

2.2 Necessity of in-house development of the subsystem

The subsystem was developed for the purpose of flexibly responding to various requirements at each manufacturing site.

*JEPS Management Department

JATCO has manufacturing sites that range from casting and processing to assembly. The information to be managed and analyzed differs depending on each manufacturing site, as each site has different manufacturing methods and unique equipment. Therefore, the optimal input devices differ.

For example, on processing automation lines, tablets or PCs with large screens are required at the end of the lines.

On the other hand, on assembly lines, small portable devices that can be used to input the reasons for the stoppage of individual pieces of equipment without leaving the line are required.

Like this, in order to respond to the needs that vary depending on individual equipment, in-house development is necessary, as person-hours, costs, and lead times would become enormous if they were outsourced.

In addition, as a flexible response, we have carried out in-house development to enable us to respond quickly and precisely through analysis and utilization. This includes changes to collect information that meets the issues in the ever-changing production lines, integration with newer devices, and data collection using new technologies such as AI.

In addition, as a side effect, by gathering software assets and know-how, we were able to shorten lead times for system improvements and make in-house development a possibility.

3. Development methods to maximize merits

In the in-house development of the system, the development was carried out under the following policy in order to maximize the merits.

1)Adopting an agile development process

Agile development is a system and software development method that involves repeating the plan, design, implement, and test development process in smaller functional unit cycles. Detailed specifications were clarified and additional requests were reflected through multiple trials at the manufacturing site from the test stage. In addition, by improving proficiency through tests, we could smoothly transition to the start of operation.

2)Utilization of off-the-shelf software

While utilizing free and opensource software and paid package software (outsourced systems), we have carried out agile in-house development of interfaces between devices and systems without hindering customizability. Our aim is to minimize development person-hours and lead times.

3)Supporting various input devices and sensors

The devices for acquiring signals from equipment were developed in-house from control circuit boards. They have been developed to have degrees of freedom in the quantities and types of signals that can be connected.

4)We developed them using a web-based system at the core, and input has been made possible not only from computers but also tablets, smartphones, and IoT devices. In addition, Wi-Fi and private LoRa communications were adopted. LoRa communication allows for a longer transmission range than Wi-Fi, enabling stable communication while covering the entire factory building. The positional relationship of the devices is shown in Fig. 2.

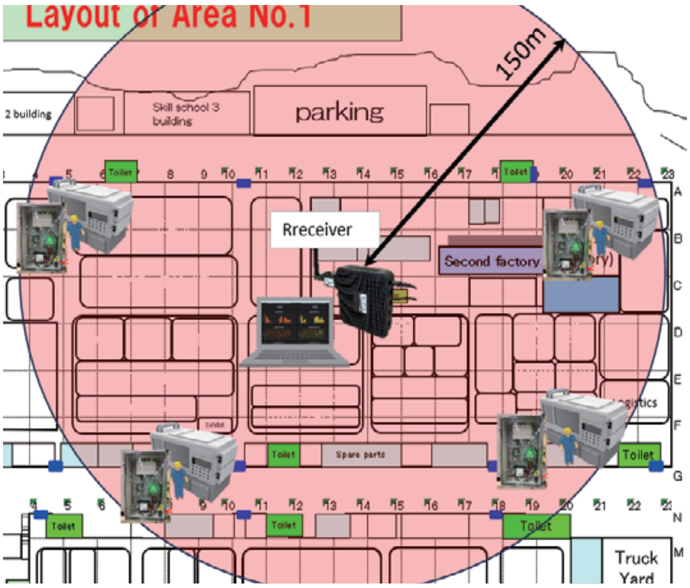

Fig. 2 Visualization of device locations

4. In-house development cases

Cases involving the development policies are shown below.

4.1 Development of JPH Monitor System, a simplified operation monitor

The JPH Monitor System is a system developed in-house that acquires production volumes hourly. It is installed on existing equipment for which it is difficult to automatically acquire operational information.

This time, we designed and created the hardware (base) and developed the software, achieving in-house development of the JPH Monitor System.

An outline of this system is shown in Fig. 3. This system is able to transmit, record, and display equipment production quantities and production times to a database server over a wireless network. It also has the following features.

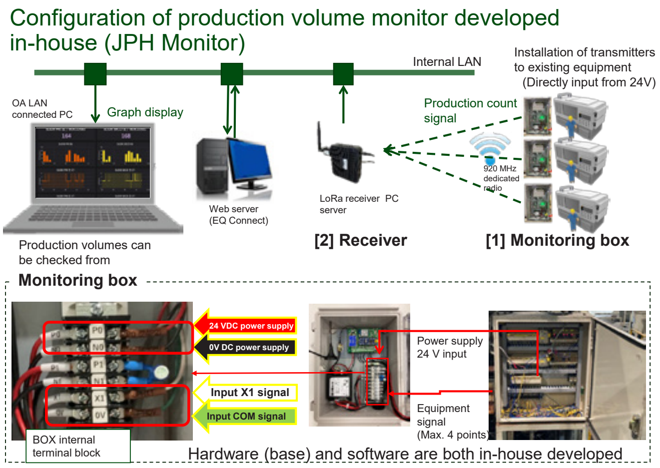

Fig. 3 JPH Monitor System

- It is a hardware that is easy to install as it does not require additional fabrication of wiring, etc. in accordance with the standard specifications of the factory.
- Using private LoRa communication, long range communication is possible even inside the factory, and no additional infrastructures is necessary.
- Using dedicated reception software, data can be acquired simply by connecting a receiver to the server.
- EQ_Connect data can be used.

Since hardware and software are all developed in-house, they can be customized in accordance with the requirements from the production lines. And through additional customization of the software, it was also possible to easily respond to acquisition of equipment error occurrence times, numbers of error occurrences, high cycle equipment data, and analog sensor data.

4.2 Digitization of handwritten daily reports

For information that must be input by production line operators, a system to directly input information via tablets was developed, and the accuracy of input data was improved while reducing the amount of paper used and eliminating losses resulting from copying.

In developing this system, we utilized Grafana as an open-source BI tool. This is a tool that visualizes stored data. Meanwhile, Pleasanter Community Edition was utilized as a low-code application development platform.

5. Measures to encourage establish at production sites and operational management

The quality and quantity of DX personnel were improved and increased to expand and establish digitization at production sites.

- An ICT team with intermediate level digital skill operators was launched in the Company-Wide Management Department to carry out in-house development and provide support.
- DX teams that promote digitization were placed in each factory.
- Skill improvement was carried out by solving problems jointly by each DX team and the ICT team.
- A DX Lab was established in the Production Division, and an environment in which trial and error is possible was constructed. And personnel development was implemented by holding consultation meetings for help solve problems and accepting personnel who wish to improve their skills.

The DX promotion system of the Production Division is shown in Fig. 4.

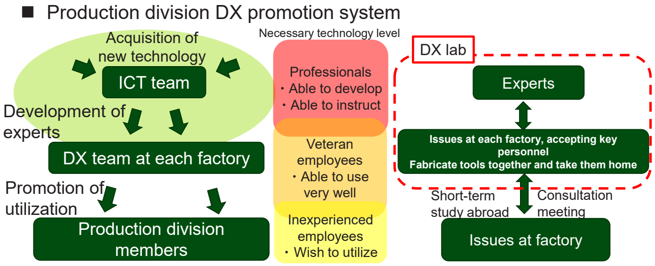

Fig. 4 DX promotion system in the production division

6. Conclusion and future initiatives

Through these activity, we were able to see the prospect of achieving Step 2 of our OEE goal.

And, by increasing the number of DX promotion members and clarifying authority, we were able to expand our system to promote independent digitization.

We want to advance improvements in technologies for collected data analysis in order to achieve Step 2: Factory that does not pass on defects and does not stop production lines.

7. References

(1)Makoto HIROSAKI: Construction of a platform for supporting promotion of manufacturing workplace data digitization and improvement of overall equipment effectiveness, JATCO Technical Review No. 22, pp.111 - 115.

■ Authors ■

Masayuki MIYAZONO

Naoki TSUBAKI

Prediction and visualization of the medium to long-term supply chain

Honoka UEDA*

Abstract

Procurement Division considers various matters with an eye to possible future changes for the shift to electric vehicles. The main work of Project Procurement Department, to which the author belongs, is the coordination of supplier selection activities for new units and purchased parts cost lowering activities for current units, the compilation of information on medium to long-term unit quantities and its deployment within the department. This paper considers whether new valuable information (data) that can be used in consideration of the future of JATCO can be generated using a DX tool to combine currently-held information (data) handled in this work. This paper introduces the details of specific initiatives.

1. Introduction

It is said that the automobile industry is currently undergoing a “once-in-a-100-years” transformation, and the shift to electric vehicles is accelerating.

Since JATCO’s main products will also change from automatic transmissions (ATs) and continuously variable transmissions (CVTs) to electric units, the parts used, suppliers and transaction amount will also change greatly.

In Procurement Division, looking ahead to this kind of future, moves to suppress the productivity inefficiencies expected due to a significant decrease in suppliers and the numbers of ATs and CVTs, and efforts to secure stable supply and maintain price competitiveness have started together with suppliers.

This activity is referred to as the “ICE transformation.” Consequently, to contribute to this activity, it was decided to take on the challenge of finding out whether the future supply chain can be predicted by combining “currently-held information (data)” using DX, and whether we can provide visualized information to enable the early discovery of opportunities in the reconstruction of the future supply chain.

2. Aims of the initiative

The three following aims were set on this initiative.

(1)Generation of “valuable information (data)” by combining “currently-held information (data)”
(2)Visualization of data so that information can be grasped visually and easily
(3)Ensuring of security to protect confidential information such as supplier transaction amounts and unit quantity information

Taking these three aims as the pillars of the activity, this paper considers the data to be used, how to combine it and how to incorporate DX.

*Purchasing Project Department

3. Tools used

Based on the three aims of the activity above, the following functions and features were considered suited to the content of this activity for the DX tool, and kintone [1] was used.

(1)It is possible to read Excel [2] data and set access authority in detail using standard functions.

(2)Data combination and calculation can be carried out automatically by using an additional program with expanded functions known as a plug-in.

(3)Graphs and dashboards [3] can be prepared simply.

The plug-in functions used were the expanded functions krewData [4] for data combination, calculation and output, and krewDashboard [5] for dashboarding. With krewData, aggregated data flow across apps can be prepared by intuitive operation, and with krewDashboard, the data of each app can be made into various kinds of graphs in accordance with the purpose by simple drag and drop operation, and they can be displayed in a dashboard on one screen.

4. Prediction of trends in medium to long-term parts purchasing amounts

Predictions of medium to long-term annual parts purchasing amounts were calculated by "purchase price for each part number × future numbers of parts used in a unit."

Specifically, the purchased parts list (part number, part name, number of parts used per unit, supplier, price, etc.) for each unit, and the medium to long-term number of parts classified by unit were used. Both types of data are "currently-held information (data)" used in the normal business of cost management and project management in Project Procurement Department.

These two types of Excel data were read into kintone, and a flow was prepared to combine the data and perform automatic calculations with krewData (Fig. 1).

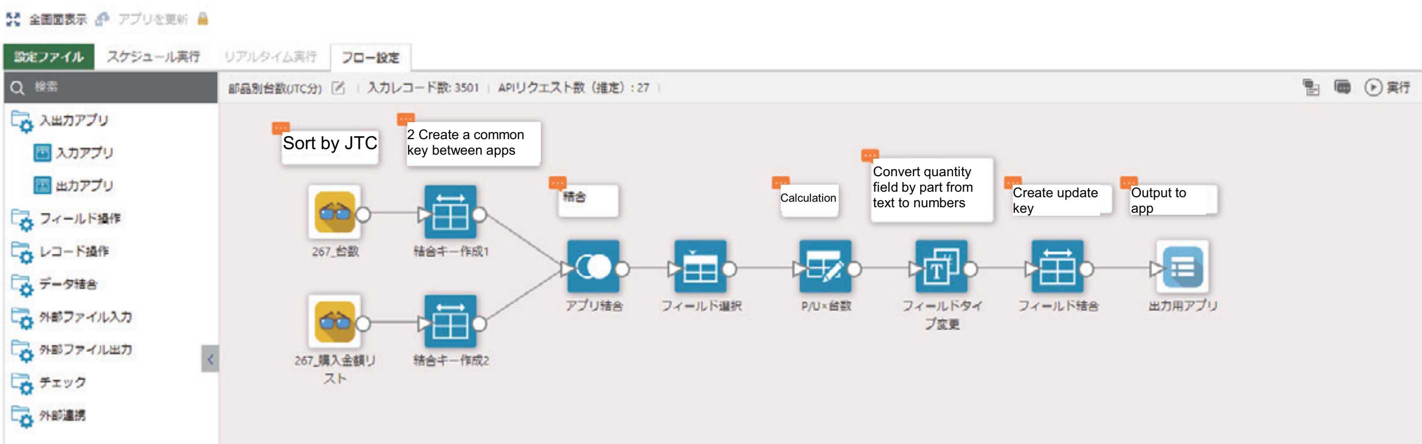

Fig. 1 krewData setting screen

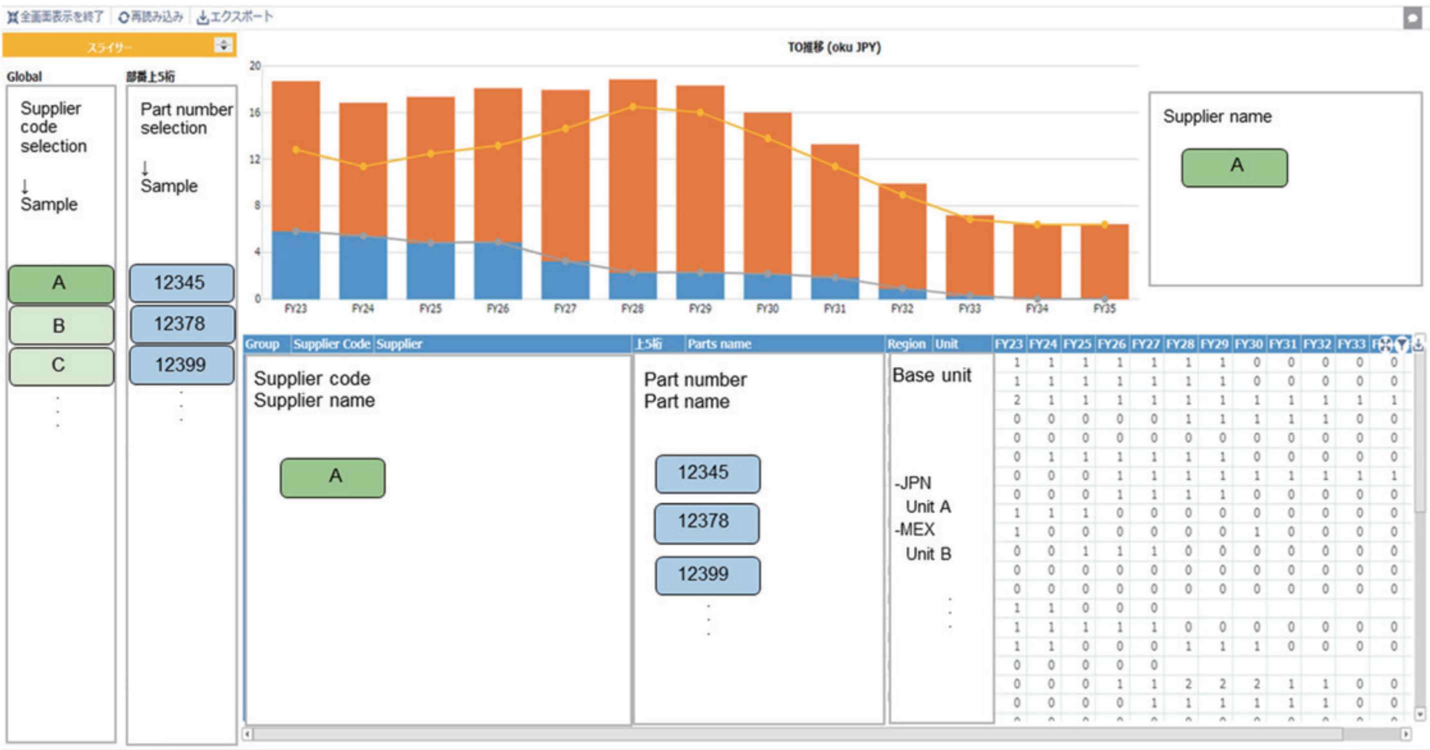

Fig. 2 App dashboard screen (prepared using krewDashboard)

In addition, about 70,000 pieces of data calculated by this method were graphed and a dashboard prepared using krewDashboard (Fig. 2).

If a slicer is installed on the left side of the screen and a supplier or part number is selected, the graph and pivot table in the center are linked.

The trend in the purchase price can be confirmed at a glance on the graph by supplier or part number, and more specifically, detailed, broken-down information such as the purchase price by unit, production base and year can be confirmed on the pivot table.

In addition, it is also possible to output these data to PDF and Excel and use them.

The point we struggled over was that a data format easy for humans to understand and a data format easy for computers to understand are different. We often summarize data in a so-called tabular format with vertical and horizontal axes, but it is necessary to have data in a table format with one row and one set of data as a preliminary step to combine and aggregate data using a computer. The number of parts data used in this initiative was in a tabular format with the vertical axis for units and the horizontal axis for fiscal year, but when the data was combined in krewData still in that format, it did not align well with the table format purchased parts list and the flow became extremely complex. When the data was combined after using the query function to correct the table format, it was possible to prepare a simple flow like that in Fig.1. This data cleansing [6] work is a very important point in DX, and felt like a point that anybody would struggle over as a preliminary step.

5. Result

The three aims mentioned above were achieved as follows.

(1)Generation of "valuable information (data)" by combining "currently-held information (data)"

By using the data we handle in ordinary business such as cost aggregation and project management, and combining it using DX, it was possible to generate data with utility value in "ICE transformation" activities.

(2)Visualization of data so that information can be grasped visually and easily

It was possible to realize data aggregation from various starting points, such as by supplier or part number, and visualization using the dashboard function.

(3)Ensuring of security to protect confidential information such as supplier transaction amounts and unit quantity information

Using kintone functions, it was possible to ensure security by setting access rights in accordance with each individual's role such as browsing rights, app editing rights, data deletion, data output, etc., and removing the browsing rights of anybody other than related parties.

This app started operation in March 2022, and when Parts Procurement Department communicates with each supplier about "ICE transformation" activities, it actually outputs and uses data from the app.

Until now, individual buyers in Parts Procurement Department had to identify all of the parts used in each unit for each supplier, obtain the future parts quantity data for that unit, and calculate and graph the purchasing prices, and it took a considerable amount of work time. However, by using the newly created app as master data and performing maintenance regularly on the project side, it is possible to provide the latest information at all times, and people on the user side can obtain their desired data right away by intuitive operation from the dashboard screen.

6. Future outlook

We will not only retain the various types of data that we own, but will also generate significant new utility value when we combine it with other data and knowledge for a particular purpose.

More valuable methods of use should also be possible with the output produced in Project Procurement Department this time by combining it with other data and knowledge possessed by other departments.

For example, by extracting similar parts from each unit and multiplying data arranging each respective supplier, parts prices and specification compatibility by the medium to long-term purchasing amounts by supplier and part that were the output data this time, it will be possible to create material to consider the consolidation of part numbers and the integration and downsizing of suppliers' production lines.

If we can connect to things like the improvement of productivity, the stability of supply and cost reductions by doing this, we will be able to aim for the establishment of a more appropriate, more robust supply chain.

To realize this using DX, it will be necessary to unify the organization of the data to be combined so that the system can be understood easily. As mentioned above, this data cleansing work was one of the points we struggled over in this initiative, and required a great deal of manual work. From now on, we also want to work on creating a system so that people can combine data freely and quickly to create the data they want.

We want to continue working on DX while using digital technology appropriately so that we can provide future-oriented data that is valuable not only for JATCO, but also for suppliers during this great era of transformation.

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(1)(4)(5)kintone, krewData and krewDashboard are registered trademarks of Cybozu Inc.

(2)Excel is a registered trademark or trademark of Microsoft Corporation in the United States and other countries.

(3)A data visualization tool that organizes various data graphically so that it can be understood at-a-glance (Reference https://liskul.com/dashboard-28575).

(6)Improving the accuracy of data by correcting data errors, non-entry, duplication and other errors (Reference https://business.ntt-ast.co.jp/content/cloudsolution/column-357.html).

■ Author ■

Honoka UEDA

Development of the world's first CVT sailing stop for the European market

Satoshi NAKANO* Itaru SHINOHARA** Fumito SHINOHARA*** Sunho LEE****

Abstract

For the first time, a sailing-stop technology was adopted by Jatco CVT-X, in combination with CVT, for the European market.

In recent years, European manufacturers and suppliers have actively adopted it for the purpose of CO_2 reduction and improved fuel efficiency. However, although the technology can serve the intended purpose, it is necessary to make compatible with drivability performance during re-acceleration.

This paper explains in detail how the world's first sailing-stop technology that utilizes the features of the Jatco CVT-X has achieved drivability performance during re-acceleration.

1. Introduction

Recently, although carbon neutrality has been realized through the electrification of vehicles, continuous CO_2 reduction has also been aimed at for ICE. From 2020 to 2024, the CO_2 reduction target in Europe is 95 g CO_2/km based on the emission test method, and there is a high penalty of 95 € per 1 g/km of excess emissions. However, there is a preferential treatment called an eco-innovation system that grants the right to vehicles equipped with innovative technologies for controlling CO_2 emissions, for which CO_2 reduction cannot be completely verified. Particularly, among European manufacturers, car models that adopt the sailing-idle function in combination with DTC and AT have become commercially available; thus, sailing-stop technologies are increasingly needed.

Because the CVT can carry out a highly flexible stepless shift even at a sailing stop, it has a technical value in that it can control the precise driving force intended by the driver and realize stable re-acceleration performance.

This study introduces the sailing-stop technology developed by Jatco CVT-X (CVT-X) for the European market.

2. Outline

The sailing stop is a control in which the engine is stopped while coasting a vehicle, and the clutch between the engine and transmission (T/M) is separated (Fig. 1).

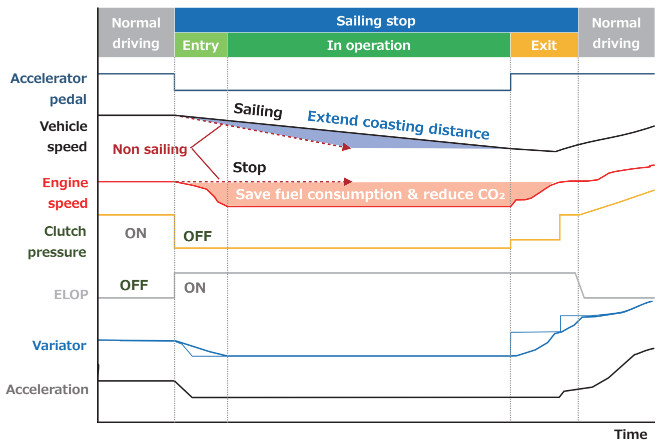

Fig. 1 Sailing stop control outline

*JATCO France SAS **Experiment Department, JATCO Engineering Ltd ***Unit System Development Department
**** System Performance & Control System Development Office, JATCO Korea Engineering Corporation

Sailing extends inertial running distance. therefore, the gradually decelerating speed reduces the driver's unnecessary accelerator pedal operation, and the engine operation time can be reduced.

The activate range of the vehicle speed is wide from high to low, as in the case of highways and urban driving, and the sailing stop is activated when the accelerator pedal is released.

The engine is stopped during the activation of the sailing stop, but a clutch release and variator shift are required for T/M.

The oil flow rate must adapt to rapid shifting of variator, such as sudden heavy braking, road surface input, and re-acceleration. The CVT-X adopts a twin oil pump system, and at the sailing stop, electric oil pumps (ELOP) are used instead of mechanical oil pumps (MOP) because MOP cannot obtain adequate flow rates during engine shutdown and restart. The twin oil pump system aims to reduce mechanical loss using MOP and ELOP, which are smaller than conventional CVT. The MOP is used to reduce mechanical loss in low-flow situations where the vehicle speed is kept constant. The MOP and ELOP are used in conjunction during heavy braking and rapid acceleration conditions, which require a significant flow rate. In the case of an idle stop or a coast stop, where the engine stops during low-speed driving, the ELOP is operated in place of the MOP [1].

To cancel the sailing stop, the accelerator pedal, brake pedal, or shift lever is operated to return to the normal running mode. Here, the reacceleration is of particular importance. The key is approaching the sense of acceleration close to the normal driving mode during accelerator pedal operation when the acceleration demand is high, such as in an overtaking scene on a highway.

The following chapter explains the requirements for the operation's performance.

3. Requirements for operation performance

Drivability performance indicates the smoothness and stability of the drive when the driver accelerates/decelerates the vehicle. During re-acceleration, linear and smooth accelerations are required to respond closely to the accelerator operation. In the case of normal re-acceleration without a sailing stop, a rapid downshift is achieved by the CVT in a coordinated manner with engine control. The lag and response (Fig. 2) were used as performance indicators. The same indicators were used for re-acceleration from the sailing stop. The lag indicates the period between the accelerator pedal depression and the initial response. A long lag leads to response delay and the driver feeling idle. The response indicated the time required to reach an acceleration that matched the accelerator operation. These indicators were defined based on the benchmark results of DCT vehicles while considering marketability.

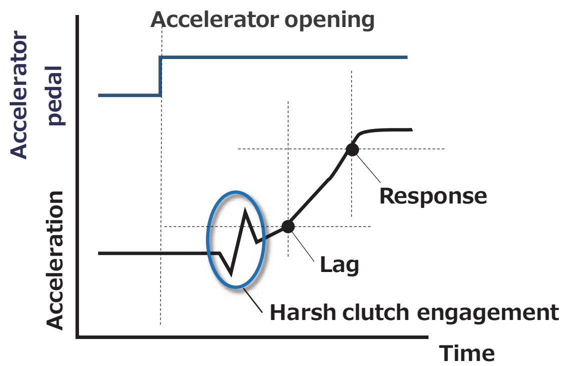

Fig. 2 Acceleration feeling index

Sailing-stop re-acceleration (Fig. 3) requires the operation of phase A before phase B, which usually corresponds to the re-acceleration conditions. In phase A, the clutch is put into the engagement-standby state from the release state and into the engaged state after synchronizing the clutch rotation speed. The sense of linear acceleration can be realized by shortening this synchronization time. For this purpose, it is important to control the following three factors:

- Engine speed
- Rotation synchronization by variator shift
- Timing of clutch engagement

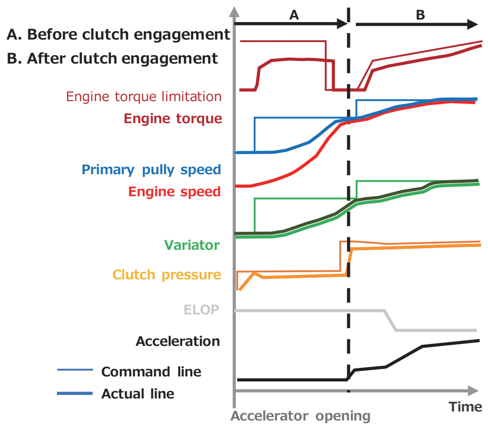

Fig. 3 Re-acceleration control concept

The CVT has the advantage that the flexibility to set the gear ratio is higher than that of the stepped transmission DCT; hence, it is easy to realize stable lag and response by providing accurate amounts of downshift according to the required driving force. However, to obtain smooth acceleration without harsh clutch engagement (Fig. 2), it is necessary to obtain a condition in which the three factors mentioned above are accurately controlled to achieve highly precise coordination (control balance).

4. Measures for smooth re-acceleration

4.1 Strategy for lag and response

While re-accelerating, during which the accelerator pedal is deeply depressed, the demand for lag and response increases. In particular, in the medium to high-speed range where the variator transmission ratio becomes high, the downshift function before clutch engagement shown in Fig. 4 (hereafter referred to as "Pre-low down shift") becomes important. For example, when the clutch is engaged, as described above, the acceleration response worsens with the clutch engagement time compared with normal re-acceleration. To address this problem, a pre-low downshift function is added to guarantee the required driving force after clutch engagement. There is a tradeoff between lag, response, and harsh clutch engagement. When the amount of downshift is too large, the gear ratio becomes low, and the sensitivity to harsh clutch engagement increases, likely to cause rough acceleration. In addition, the shift time is prolonged, and the time to complete the clutch engagement (phase A) is delayed, thereby worsening the lag. However, when the amount of downshift is too small, the worsening of lag can be avoided, but the downshift occurs only after the completion of clutch engagement (phase B), which delays the generation of the driving force up to the target response time. Therefore, the amount of pre-low downshift must be optimized to balance the desired lag and response times and sensitivity to harsh clutch engagement.

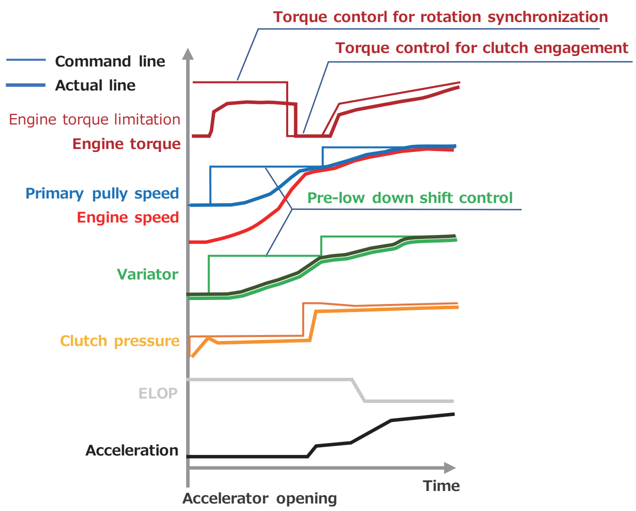

Fig. 4 Method of re-acceleration improvement

4.2 Strategy for harsh clutch engagement

To realize a smooth acceleration performance with suppressed harsh clutch engagement, it is necessary to engage the clutch by controlling the clutch differential rotation below the target differential rotation (Fig. 5). The clutch input speed becomes the turbine shaft speed, which is synchronized with the engine speed by the lockup. The clutch output speed was the primary pulley speed of the variator.

Clutch differential rotation = clutch output speed - clutch input speed (1)

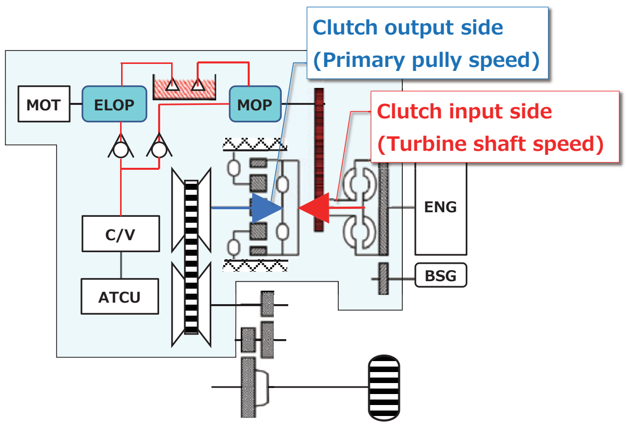

Fig. 5 CVT-X block diagram

The clutch engagement steps until completion are as follows (Fig. 4).

1)Clutch input speed control

After restarting, the rotation-synchronizing torque control increased the engine speed to the target speed.

2)Clutch output speed control

It is increased to the target speed by pre-low downshift.

3)Pre-clutch-engagement input/output shaft control

The input/output shaft is controlled within the target rotation by clutch-engagement torque control.

4)Start of clutch engagement

Clutch engagement is completed within the target differential rotation.

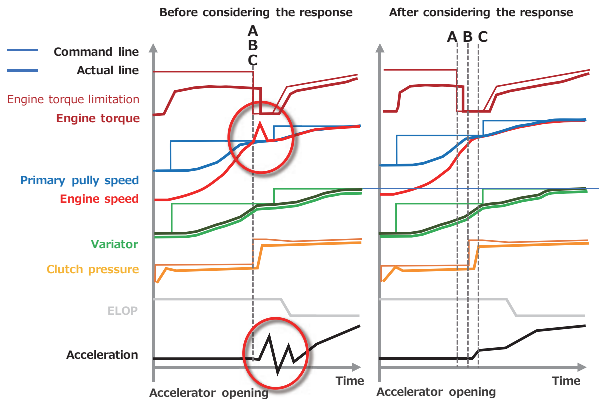

Fig. 6 Clutch engagement harsh optimization

The time required to commence steps 3) and 4) (Fig. 6A, B) was determined using Equations (1) and (2), respectively.

Differential rotation to judge the completion of shift change = target clutch input speed - target variator ratio × secondary pulley speed (2)

The timings of steps 3), torque control, and 4), the start of clutch engagement, must be adapted considering the response delay, which is the time from the command of the control to the actual response. For example, if it is simply set to the target differential rotation without considering the above, harsh clutch engagement push up occurs (Fig. 6, left). After the clutch engagement command is given, the actual engagement is not completed in time; thus, the engine speed through the target, which causes a sudden torque increase owing to the inertial torque upon clutch engagement. Therefore, as shown in Fig. 6 (right), smooth acceleration is realized by adapting the start timing considering the response delay.

4.3 Engine Control Coordination

Furthermore, to suppress harsh clutch engagement, it is necessary to adopt suitable engine characteristics and CVT characteristics. The following two characteristics were particularly influential:

1)Engine re-startability

When the sailing stop is activated, the engine slows down owing to inertia and finally stops completely (hereafter referred to as the engine stops). Depending on the timing of the driver cancel operation, the engine is restarted during the engine stops, and the restarting method is switched between the Belt-driven Starter Generator (BSG) method and the injection method, depending on the number of revolutions at that time. Smooth acceleration was achieved by stabilizing the difference in the rate of increase in the engine speed between the two methods through rotation-synchronizing torque control.

2)Timing of engine restart, variation in the rate of increasing engine speed

Some causes of the variation in the increasing engine speed rate are the piston cycle state at the engine stops and the intake air temperature. For example, when the piston of the engine stops in the compression stroke, restarting is delayed. Because the engine restart control prioritizes avoiding the stalling engine, clutch-synchronizing torque control from the CVT is not accepted, the engine speed increases largely, and harsh clutch engagement occurs (Fig. 7).

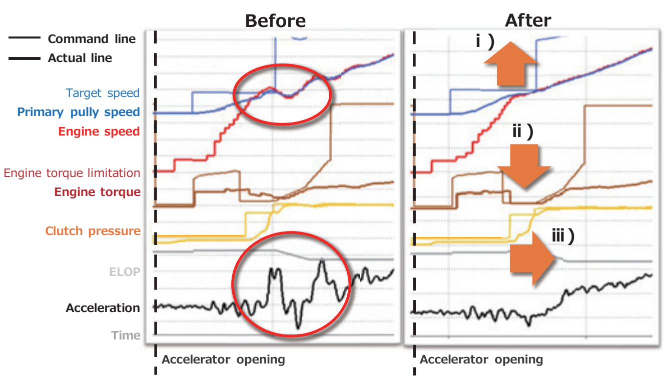

Fig. 7 Engine control interference and the measure

This problem can be avoided by adopting the following measures (Fig. 7):

i)Increasing the amount of pre-low downshift, delaying the start timing of clutch-engagement torque control, and avoiding interference from the restart control.

ii)Limiting the amount of clutch-engagement torque control in proportion to the downshift to the lower side and adjusting the driving force after clutch engagement to balance the harsh clutch engagement.

iii)When the torque limit is tightened, the rotation rate increases slowly. By delaying the time required to start clutch engagement in accordance with the increase in the rotation rate, it is possible to realize smooth acceleration performance while controlling the engine restart timing and rate variation.

As described above, a linear and smooth acceleration, corresponding to the operation of the accelerator by the driver, was realized by adapting the CVT considering the engine characteristics and control (Fig. 8).

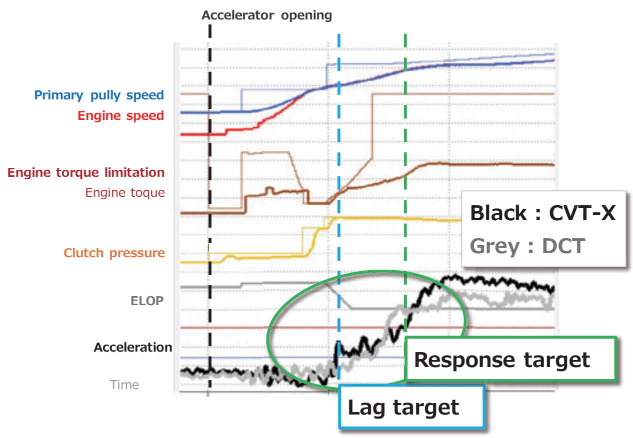

Fig. 8 Comparison CVT-X and DCT

5. Summary

In this development, it was possible to prove the technical value position where stable lag and response performances can be easily realized by step-less transmission, which is an advantage of CVT over the DCT (Fig. 9).

It was possible to suppress the harsh clutch engagement, which the DCT managed by clutch-slip control, to realize a highly competitive linear and smooth acceleration performance by precisely coordinating the control that considers three factors (engine speed, variator shift ratio, and clutch engagement). In this development, the tradeoff between lag, response, and harsh clutch engagement was satisfied by preemptively clarifying the target performance values of each function and the key considerations in rate variation, whereby it was possible to narrow down the key points to be considered. By realizing this function, the attractive quality of the CVT-X was improved.

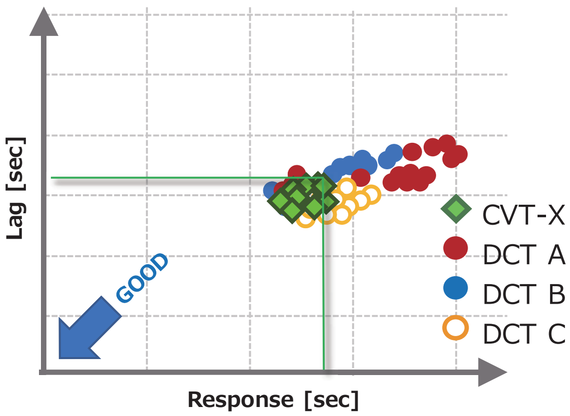

Fig. 9 Re-acceleration performance comparison with competitive DCT cars

6. References

(1)Shingo SUZUKI, Kohei TOYOHARA, Makoto OGURI, Masaya MATSUMURA:Development of a new CVT featuring high efficiency and wide ratio coverage, JATCO Technical Review No.22, p.74 - 79.

■ Authors ■


Satoshi NAKANO


Itaru SHINOHARA


Fumito SHINOHARA


Sunho LEE

Improvement in development efficiency through time reduction of model-in-the-loop simulation

Ayumu OSHIMA* Kentaro MATSUNAGA* Jaeho KIM*

Abstract

Model-based development has been widely used for the efficient development of control software. In the model design phase, verification of the virtual environment is important. However, model-in-the-loop simulation (MILS), which is used to verify transmission-control software, requires extremely long simulation times. Therefore, we introduced methods and tools that reduce simulation time to increase development efficiency. This paper introduces the details of these approaches.

1. Introduction

Model-based development has been widely used in the development of control software, with blocks representing each control function. In model-based development, control specifications are described by a model directly used for the simulation. This process allows designing and verification to be performed in a short cycle (Fig. 1). These verification methods and environments using models are known as model-in-the-loop simulations (MILS). For example, if a design error is discovered during the actual vehicle verification phase, which is set in the latter half of the development process, the process must return to the design phase for redesign. However, if the MILS is used for verification in the design phase, the control software can be modified with a small amount of rework, even if errors are discovered. Thus, efficient development can be achieved[(1)].

One approach is to perform verification using a model created before implementing the control software in the transmission control unit (ATCU). We prepared a transmission-controlled MILS (TM-control MILS). However, the simulation time for the TM-control MILS was extremely long. Therefore, we attempted to reduce the MILS simulation time. This paper presents the details of these efforts.

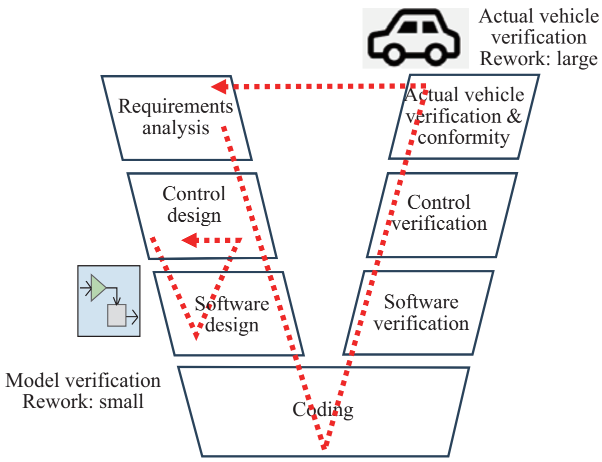

Fig. 1 V process of control development

2. Current state and challenges of TM-control MILS

The configuration of the TM-control MILS is as follows. The TM-control MILS comprised three models: a driver model simulating actual vehicle operation, a plant model representing the actual vehicle and transmission equipment through physical equations, and a controller model that includes the transmission control. The models were connected to form a single model for simulation (Fig. 2).

Among these models, the driver and plant models were limited to minimum necessary functions. However, the controller model had more blocks and a larger volume than the other models because it incorporated all the control

*Control System Development Department

software implemented in the ATCU. This configuration resulted in a long simulation time for the entire TM-control MILS. Specifically, a simulation using a 30s test case took approximately 600s, which was 20 times longer, to complete the calculation.

Therefore, we started to consider whether the simulation time could be reduced. We aimed to reduce the simulation time within twice of the real-time period.

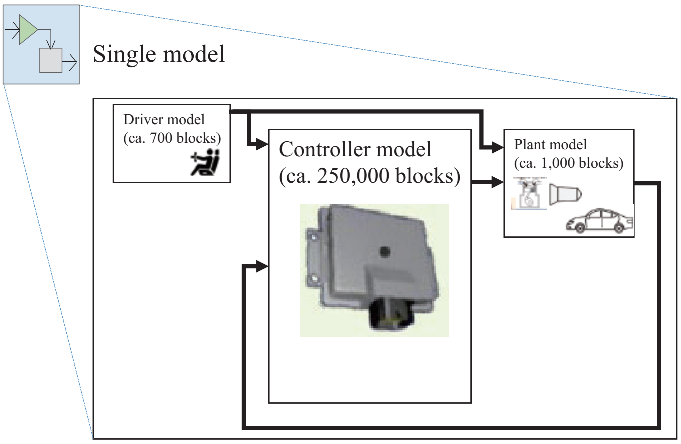

Fig. 2 Overview of the TM-control MILS

3. Methods to solve the problem

We employed the following two methods to reduce the simulation time for the TM-control MILS.

(1)Simulation method using executable forms produced by converting models

A method for converting a model into an executable form is as follows. Conventionally, a model is simulated by interpreting the described operations and translating them individually into a machine language. Therefore, for a model in which the operation results are switched by conditional branches, the results are not produced until all the operations are completed. The time required for a one-by-one translation into a machine language is considered. These factors result in longer simulation times.

By contrast, a simulation method that converts a model into an executable form converts first the entire operation into a machine language. In this case, only the minimum number of necessary operations are performed. The parts, including the conditional branches, are extracted from the entire operation and optimized. This process eliminates unnecessary operations, thereby reducing the simulation time (Fig. 3).

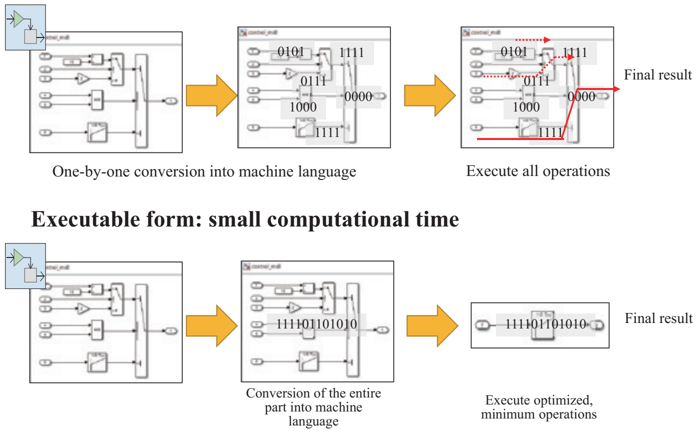

Fig. 3 Difference between a model and an executable form

The software tool VEOS from dSPACE was used to apply the method to the TM-control MILS (Fig. 4). VEOS has the following functions: model import, conversion of models into executable forms, and simulation with executable files.

When building a model with a large volume in VEOS, an error can occur. To avoid this error, a single large model must be preliminarily divided into multiple models with smaller volumes before being imported into the VEOS. Because the TM-control MILS models are large, they can be split into multiple smaller models.

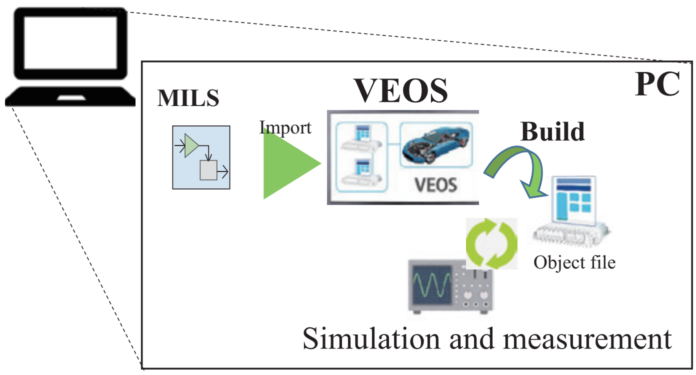

Fig. 4 Simulation environment using VEOS

(2)Model simulation performed on a dedicated computer

The method for performing model simulations on a dedicated computer is described as follows. The hardware dedicated to model simulation was used independent from the PCs. The model was downloaded to the processor core of the dedicated computer for the simulation. A SCALEXIO processor unit (hereinafter referred to as SCALEXIO) from dSPACE was used as the dedicated computer (Fig. 5). It is a hardware tool equipped with a processor core with high computing power and a real-time OS.

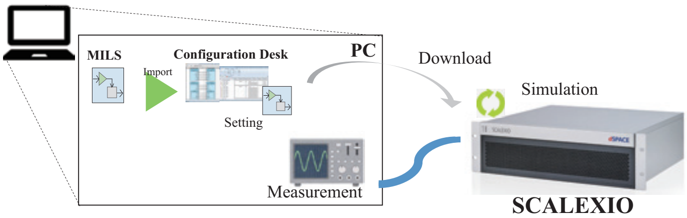

Fig. 5 Simulation environment using SCALEXIO

4. Results of simulation time reduction

The results of simulation time reduction obtained using the tools is described below.

(1)Results obtained by converting models into executable forms

The models were converted into executable forms in VEOS for TM-control MILS simulations. The simulation time was reduced to approximately four times that in real time.

As described in Section 3, the large number of model blocks in the original model for TM-control MILS caused errors in the VEOS. Therefore, the original model was divided into several smaller models with equal number of blocks. The smaller models imported into the VEOS were successfully converted into an executable form without generating any errors (Fig. 6).

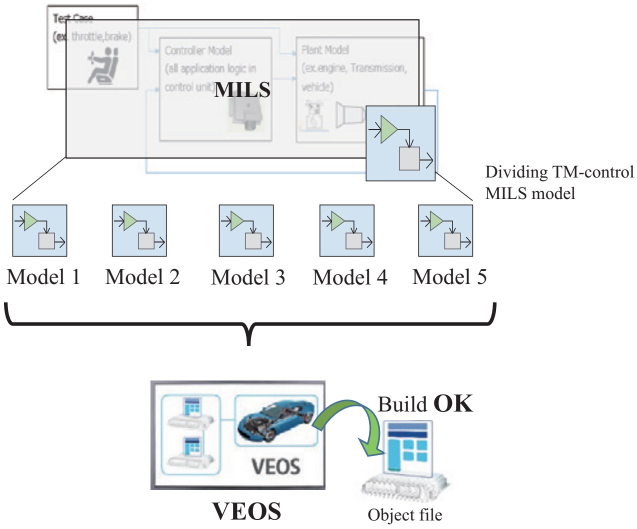

Fig. 6 Model division for MILS

Using the VEOS, we found a correlation between the number of model divisions and simulation time. The relationship between them is shown in Fig. 7. The results were obtained using 30s test cases. The numbers of divisions were up to 10. The results showed that the simulation time increased from 120s to 300s (4 to 10 times the real time) as the number of divisions increased.

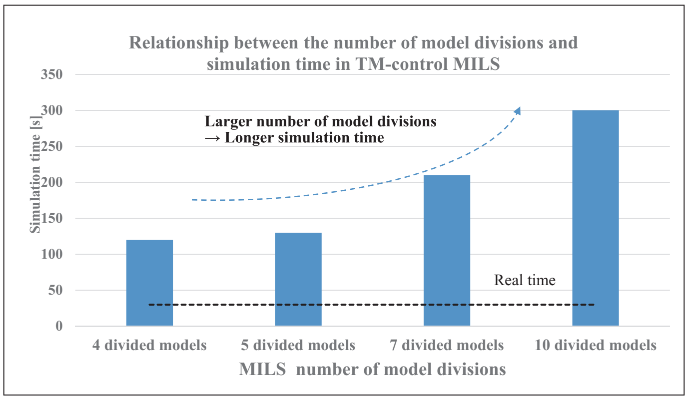

Fig. 7 Relationship between the number of model divisions and simulation time

The correlation between the number of model divisions and the simulation time was affected by sequence in which the model operations are completed and the subsequent operations are performed (Fig. 8). The larger the number of divisions, the more processes are required to specify the order of operations, resulting in an increase in the operation and simulation times. The order of operations must be specified and defined. If not defined, the order of operations might be different from that of the original model, and the expected result would not be obtained. However, specifying the order of operations among the models can produce the desired results similar with those of the original model.

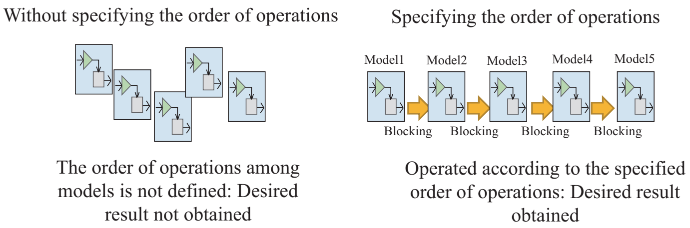

Fig. 8 Specification of the order of operations

Verification using MILS can target not only the entire TM control but also a single function with a small volume. This approach is called single-function MILS. The MILS is limited to the control functions of the controller and plant models, and is suitable for verifying only a certain control function. For example, for a single-function MILS limited to the shift control function, the simulation time was reduced to approximately half of the real time (Fig. 9). In actual development, the single-function MILS can be satisfactorily used for verification in a shorter simulation time when only a certain control function is verified.

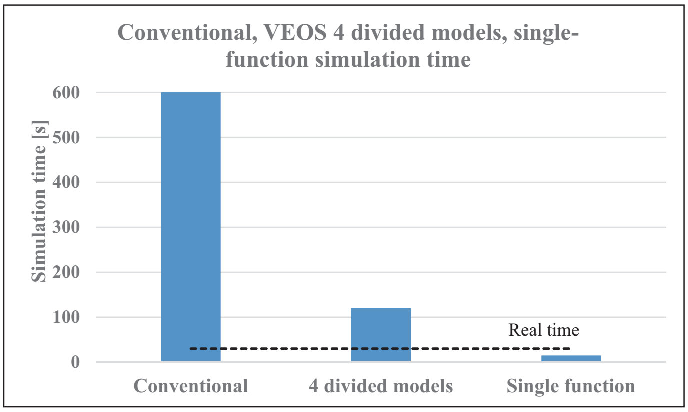

Fig. 9 Comparison of simulation time between conventional MILS and VEOS

⑵ **Results of the simulation using a dedicated computer**

Using SCALEXIO, TM-control MILS simulations without model division in VEOS could be performed for a period of time comparable to real time (Fig. 10). This is because SCALEXIO executed the MILS simulations on a dedicated high-performance computer. In addition, SCALEXIO has a real-time OS that differs from OSs used in common PCs.

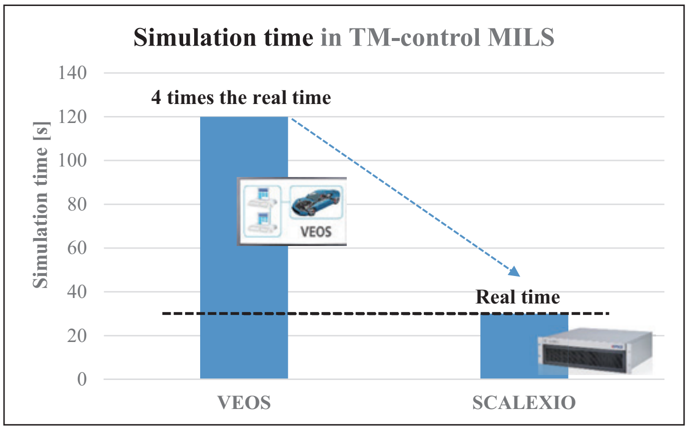

Fig. 10 Simulation time of TM-control MILS

Simulations using SCALEXIO require not only a PC but also dedicated hardware, which requires a large capital investment if the system is allocated to each designer. Therefore, we assume that it is ideal to operate one system as a shared resource used by several people. The ability to run high-volume TM-control MILS simulations in real time without dividing the models would be beneficial, even if the system is not used frequently.

5. Conclusions

We have achieved our goal to reduce the TM-control simulation time within twice of the real-time period.

A previous simulation took approximately 20 times longer than the actual time. When the models were converted to executable forms, the simulation times were reduced by a factor of 4–10. For a single-function MILS, the simulation time was reduced to less than the real time. For simulations using a dedicated computer, the time was reduced to the level of the real time.

6. Discussion

The two approaches described above were effective in improving the usability of MILS because they both reduced the simulation time. We believed that the control software development can be achieved more efficiently by utilizing these MILSs.

In actual verifications using the MILS, two approaches can be used depending on the application. When partial verification is sufficient, the approach of converting a single-function MILS model to an executable form is effective for simulation in a time shorter than real time. When the entire control software is to be verified, the approach of using a dedicated computer is effective because it can perform TM-control MILS simulations without dividing the model.

7. Future issues

Both approaches require tools. Therefore, to apply these tools within a company, it is necessary to examine the number of tools required and develop a capital investment plan that considers them. In addition, to use MILS and tools in the actual development process, the following are future issues: deciding a specific design phase, determining management and operation rules for MILS shared among developers.

For technological development, we are considering expanding the virtual verification area to enable control verification without an actual ATCU. In the current TM-control MILS, the OS is modeled in a simplified manner. We are considering building a virtual ECU simulation environment to simulate the entire ATCU in combination with the actual software. This will enable verifications during the design phase, even when actual ATCU equipment or actual vehicles are required.

We will continue to pursue further development efficiency by effectively utilizing the merits of model-based development.

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■ Authors ■


Ayumu OSHIMA


Kentaro MATSUNAGA


Jaeho KIM

The mechanism causing hydrogen embrittlement flaking of transmission bearings

Hiroyuki MARUYAMA* Kazuhiro HAYAKAWA* Kouhei TOYOHARA*
Hiromu SOYA* Yoshiteru KANAYAMA* Katsuaki SASAKI**

Abstract

There have been many research reports on hydrogen embrittlement flaking generated on bearing samples. However, there have been few reports of studies performed in actual operating environments. This paper clarifies the mechanism and influencing factors causing the hydrogen embrittlement flaking on pulley support bearings, taking into consideration the assembly and operating conditions of a continuously variable transmission unit.

1. Introduction

In recent years, the performance requirements for transmissions have been increasing year by year in order to reduce CO_2 emissions, which requires even lower friction and further reduction in size and weight of transmissions. For transmissions (e-Axles) used in electrified vehicles, motors are expected to become smaller to obtain higher rotational speeds in the future. For conventional continuously variable transmissions (CVTs), further expansion of ratio coverage and reduction of internal friction will be required. For bearings used in such transmissions, it is necessary to guarantee reliability considering how they are used in harsh environments.

Hydrogen embrittlement flaking is one of the various failure modes of bearings. There have been considerable researches[(2)] reporting on the mechanism causing hydrogen embrittlement flaking on bearing samples. However, there are few research reports on the actual transmission operating environment.

In a belt CVT, multiple bearings are used to support the pulley (Fig. 1). In tests using a bearing sample and a CVT unit under normal test conditions, the service life of the bearing is as designed. However, the bearings get damaged earlier than the service life calculated under the relevant conditions when a combined acceleration endurance test is conducted with combined operations such as start, stop, and high-speed driving (hereinafter referred to as the combined acceleration endurance test) at high oil temperatures.

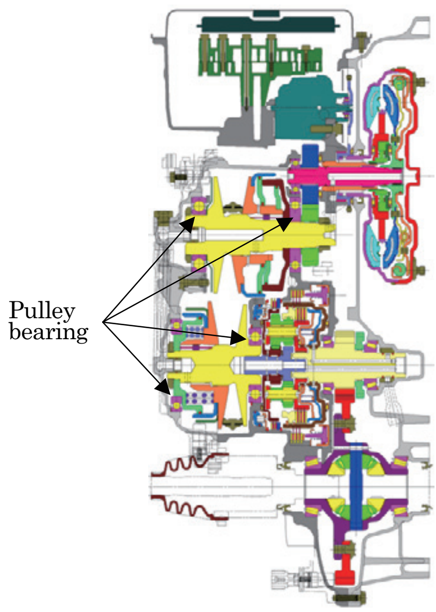

Fig. 1 Schematic structure of Jatco CVT 7

*Hardware System Development Department **Application Engineering Depratment, NTN Corporation

As shown in Fig. 2, flaking occurs on the load area of the bearing outer ring's inner surface, whose inside contains a white layer. Further detailed analysis shows a larger than normal amount of hydrogen penetration, indicating the occurrence of hydrogen embrittlement flaking.

This paper clarifies the mechanism of hydrogen embrittlement flaking occurring on the pulley support bearings, taking into consideration the assembly and operating conditions of a CVT unit.

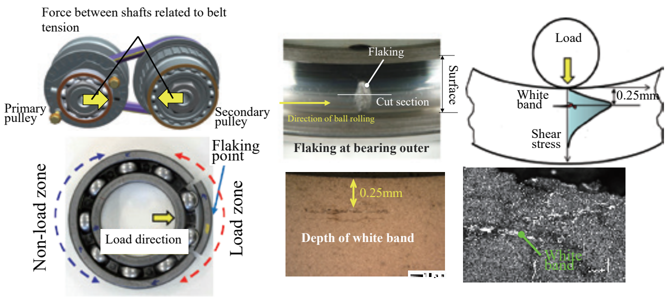

Fig. 2 Hydrogen embrittlement flaking

2. Mechanism causing the hydrogen embrittlement flaking

In general, hydrogen embrittlement flaking on a metal sliding part is considered to occur through the following mechanism (Fig. 3).

(1)The surface pressure, sliding velocity, and lubricant temperature of metal sliding surfaces are factors that influence the activation energy for decomposing hydrogen and other substances from hydrocarbons. They are also factors that influence the breakage of the oil film existing between metals. Thus, repeated sliding at high surface pressure, high sliding velocity, and high oil temperatures can easily generate hydrogen, causing oil film breakage to expose bare metal surfaces.

(2)The bare metal surface acts as a catalyst reducing the activation energy for decomposition into hydrogen atoms. Therefore, the bare metal surface becomes a factor accelerating the generation of hydrogen atoms, whose number increases.

(3)The hydrogen atoms are adsorbed on the bare metal surface where the oil film breakage occurred.

(4)The adsorbed hydrogen atoms diffuse into the metal via their own kinetic energy.

(5)Hydrogen atoms diffused into the interior concentrate at the shear stress generation site just below the sliding surface.

(6)The continuous repetition of the phenomenon causes a white layer to form.

(7)The white layer is a hard and brittle structure. When internal stress is repeatedly applied, internal fracture progresses from the layer to generate cracks. These cracks eventually propagate to the sliding surface, leading to flaking.

(8)Hydrogen that penetrated into the metal, on the other hand, has the tendency to be released. Therefore, hydrogen embrittlement flaking is unlikely to occur because hydrogen is released in the stopped state and during intermittent operation, whereas hydrogen continues to penetrate in continuous operating environments.

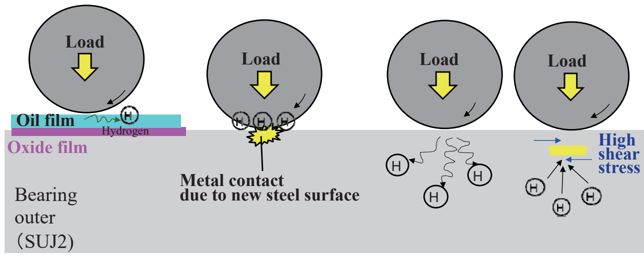

Fig. 3 Mechanism causing hydrogen embrittlement flaking

According to this mechanism, the following validation tests were performed:

- Sensitivity test for the amount of hydrogen penetration
- Measurement of bearing oil film thickness test using a CVT unit
- Test to confirm amount of hydrogen released while the vehicle is stopped

3. Methods used in validation tests

3.1 Sensitivity test for the amount of hydrogen penetration

Considering the mechanisms described in Chapter 2, the sensitivity of the factors influencing the amount of hydrogen penetration into bearings in a CVT unit was compared with the sensitivity obtained from tests using bearing samples.

The test machine for a bearing sample is shown in Fig. 4. Sensitivity tests were performed for influencing factors such as radial load, oil temperature, and rotational speed. The amount of hydrogen penetration into the bearing interior was examined after the tests were completed.

We also investigated the amount of hydrogen penetration depending on inputs such as torque and rotational speed of the bearings in a CVT unit. In the tests, the start and stop pattern and the constant input of loading were adopted (start–stop or constant load).

The test conditions are listed in Table 1.

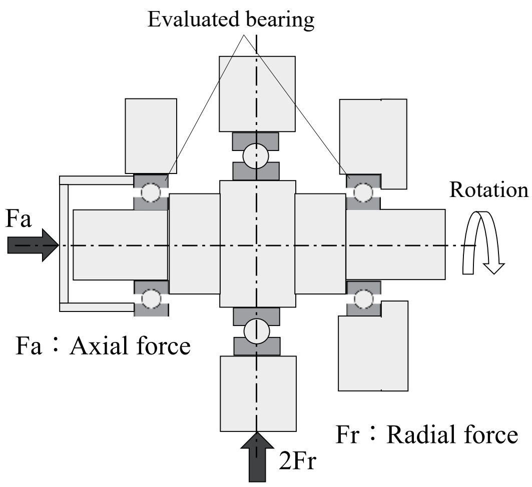

Fig. 4 Schematic of bearing unit test equipment

Table 1 Test conditions

	Influential factor	Radial load	Oil temperature	Input speed	Start-stop or constant loading
1	Radial load	2 conditions (medium and large)	High	High	Constant
2	Temperature	Large	2 conditions (medium and high)	High	Constant
3	Temperature	Large	High	3 conditions (small, medium, high)	Constant
4	Start-stop or constant loading	Medium	High	-	2 conditions (start-stop test pattern of triangular wave form)

Lubricant: CVTF (NS-3)

3.2 Bearing oil film thickness test using a CVT unit

There are various methods for measuring oil film thickness: optical, electrical, and ultrasonic methods, and methods using the properties of X-rays and neutron beams that penetrate the material. To measure oil film thickness in a CVT unit, these are necessary: minimizing changes to peripheral components, and installing the measurement instrument in a test facility that is capable of conducting endurance tests. Therefore, we used the electrical resistivity method with a bridge circuit. Figure 5 shows the measurement system of the electrical resistivity method. The inner and outer rings of the bearing are insulated by coating the surfaces other than their raceways with ceramic. While balls are rolling, contacting the oil film on the ring surface, the resistance in the circuit is infinite, meaning no electric current flows. Conversely, when balls are in direct contact with the metallic ring surface, current flows in the circuit. Thus we have developed a measurement system built in a CVT unit to determine the contact state between balls and the ring surface through changes in voltage.

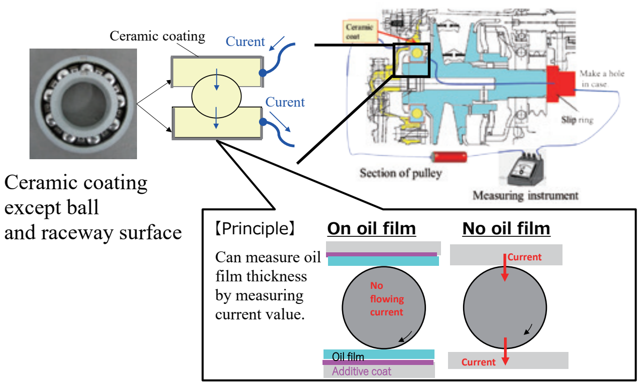

Fig. 5 Test method for measuring oil film

The bridge circuit diagram for obtaining voltage is shown in Fig. 6. The combined resistance R of the circuit is:

$$R = R1 + (R2 \times Rx / (R2 + Rx)) \quad (1)$$

where Rx is resistance between balls and the outer ring raceway. When the oil film between balls and the outer ring breaks, allowing the balls to come into metal-metal contact, $Rx = 0\ \Omega$. Then, the voltage of the circuit is $V = I \times 0$ from Eq. (1), and the value read on the voltmeter is 0 V.

When an oil film is formed between balls and the outer ring to eliminate the direct metal-to-metal contact, they are insulated from each other. Then, the combined resistance is $R = \infty\ \Omega$ from Eq. (1). Then, the voltage is $V = I \times \infty$, which equals ∞ given the equation, but the voltmeter value indicates 1 V because the voltage of power supply applied to the circuit is 1 V.

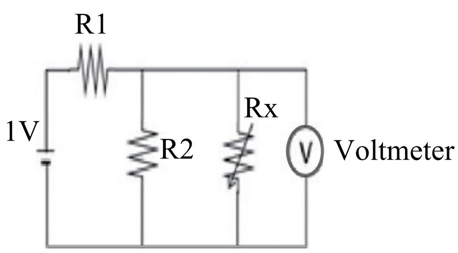

Fig. 6 Circuit for measuring oil film

The maximum acceleration start condition was extracted from the combined accelerated endurance test to measure with two oil temperature levels. The test conditions are listed in Table 2.

Table 2 Test condition for measuring oil film thickness

	Oil temperature	Input torque	Input speed	Primary pressure	Secondary pressure
Combined durability test conditions (Full acceleration start)	2 conditions (medium and high)	High	~medium	~medium	~high

3.3 Test to confirm amount of hydrogen released while the vehicle is stopped

Hydrogen was charged at 25 mA/cm^2 for 120 minutes in the electrolytic cathodic hydrogen charging test. Gas chromatography analysis was then used to measure the rate and amount of hydrogen released under high oil temperature isothermal condition simulating the stopped state of a vehicle (Fig. 7).

Conditions

Solvent: 3%NaCl, 0.3%NH_4SCN

Time: 120min,

Input: 25mA/cm^2

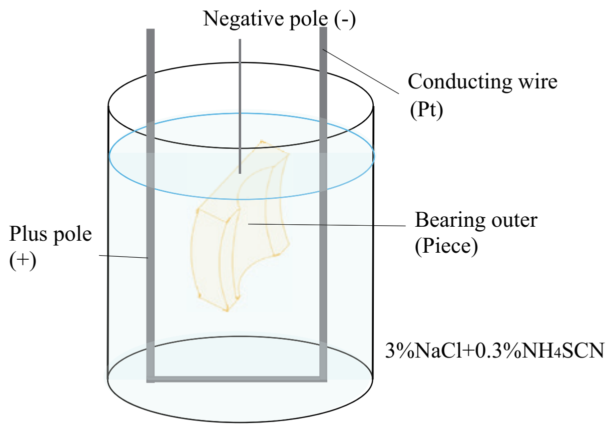

Fig. 7 Test for charging hydrogen

4. Test results

4.1 Results of the test of sensitivity to the amount of hydrogen penetration

Figure 8 shows the test results.

- A positive correlation was obtained for hydrogen penetration, load, and oil temperature, whereas a negative correlation was obtained for rotational speed.
- The test with repeated start–stop inputs in the CVT unit shows more hydrogen penetration than the case with a constant input.

The magnitude of sensitivity to the factors affecting hydrogen penetration is in the order of load, oil temperature, and start–stop pattern.

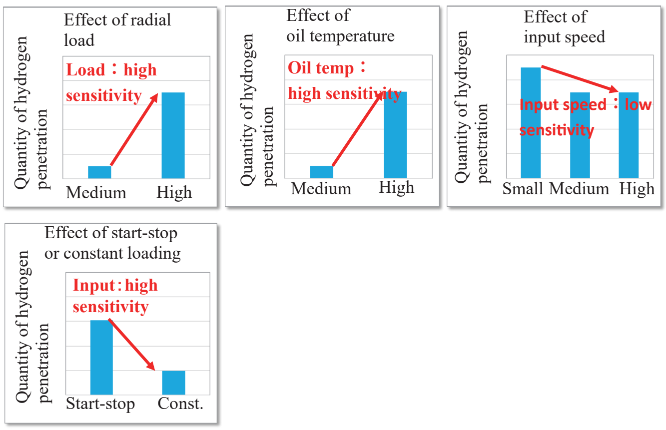

Fig. 8 Sensibility of hydrogen penetration for bearing

4.2 Results of oil film thickness measurement using a CVT unit

Figures 9 and 10 show the measurement results of the bearing's oil film thickness using a CVT unit. The stages in the profile are classified by the input conditions into three: section (a) is the stage before the rise of primary oil pressure, primary torque and primary rotational speed, section (b) is the stage during the rise, and section (c) is the stable stage after the rise.

- In section (a), representing the stop state, the voltage is 0 V regardless of the oil temperature. The result indicates that no oil film is formed between the balls and the ring raceways.
- At normal oil temperature, the voltage is 0 to 0.6 V in the former half of section (b), indicating an oil film is formed intermittently. In section (c), the voltage is about 1 V, which indicates that an oil film is formed.
- At high oil temperatures, the voltage is 0 V in the former half of section (b), indicating that no oil film is formed. In the following section (c), the voltage is about 1 V, which indicates that an oil film is formed, as in the case of normal oil temperature.

These results indicate that no oil film is formed in section (a), corresponding to the pre-start state regardless of the oil temperature. In section (b), no oil film is formed when the oil temperature is high. On the other hand, under normal conditions with low oil temperatures, an oil film forms intermittently. In section (c), an oil film is formed regardless of the oil temperature. Thus, in the former half of section (b), when the input of the influencing factor is rising, a significant difference is observed in the formation of the oil film depending on oil temperatures.

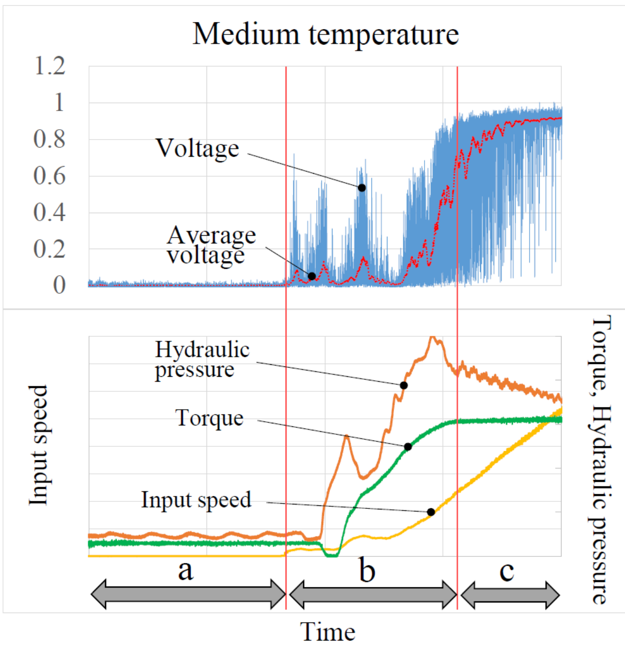

Fig. 9 Measured oil film thickness (medium temperature)

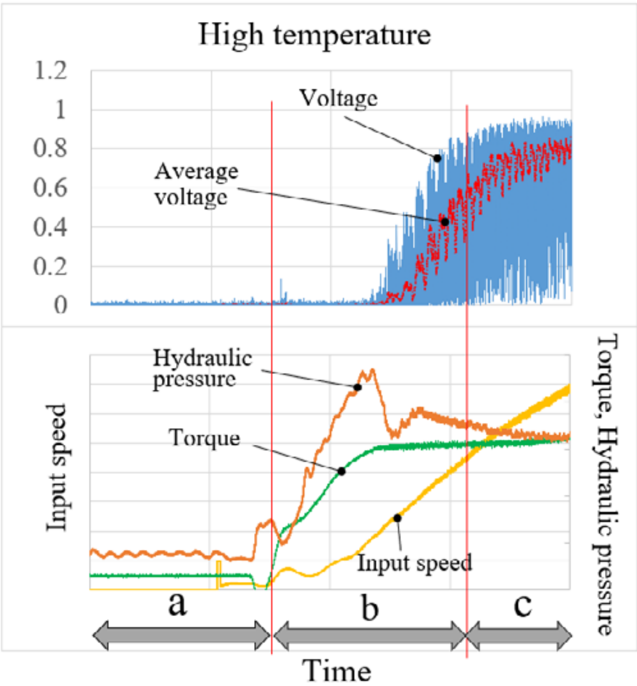

Fig. 10 Measured oil film thickness (high temperature)

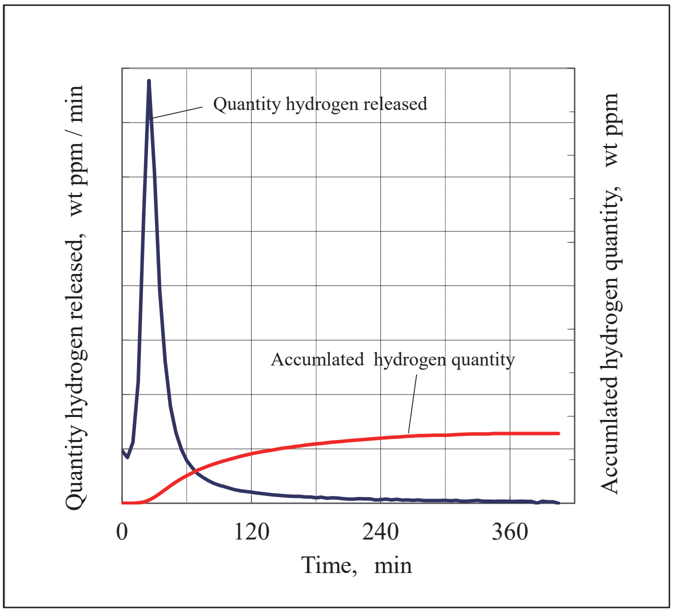

Fig. 11 Measured quantity of hydrogen released (high temperature)

4.3 Results of test to confirm amount of hydrogen released while the vehicle is stopped

In the electrolytic, cathodic charge test, hydrogen was charged, and then the amount of hydrogen release was measured after a period of time to simulate a vehicle's stopped state. Figure 11 shows the measurement result of the amount of hydrogen released. The effect of the stop time is significant. In particular, hydrogen is rapidly released in the initial 60 minutes.

5. Discussion on the hydrogen embrittlement flaking mechanism in the CVT unit

In the former half of section (b), where a significant difference in oil film thickness was observed in the measurement using a CVT unit, oil film breakage occurred at temperatures higher than the normal temperature. We suppose that the high oil temperature lowered the viscosity of the oil, causing the oil film to break at start, and that this condition was maintained until the rotational speed became high. The results are consistent with those obtained from the sensitivity tests performed with bearing samples to measure the amount of hydrogen penetration depending on oil temperature.

In the test using a CVT unit, the belt is tensioned at all times from the stopped state. Therefore, a high load is also applied to the bearing. Considering the results of the sensitivity to influencing factors in the tests using bearing samples, bearings in CVT units are susceptible to hydrogen penetration.

In the combined accelerated endurance test using a CVT unit, the hydrogen embrittlement flaking occurred only with high oil temperatures. The fact suggests that the hydrogen embrittlement flaking occurs with the following mechanisms: 1) A high oil temperature produces a low oil viscosity; 2)

With the low viscosity, the oil film is easily broken when a high load is continuously applied from the start state to the state with a high rotational speed; and 3) The sustained oil film breakage lets hydrogen penetrate into bearings easily. Furthermore, in the combined accelerated endurance test, no interval was set in order to shorten the test time. Therefore, hydrogen was unlikely to be released. In that test, the conditions were more likely to cause hydrogen embrittlement flaking than the actual operating environment.

6. Summary

Sensitivity tests and oil film measurements were performed for factors influencing hydrogen penetration considering the operating conditions of the CVT unit. We clarified the mechanism causing the occurrence of hydrogen embrittlement flaking in the CVT unit environment. Hydrogen embrittlement flaking is a phenomenon that occurs only in continuous operation at high oil temperatures in combined accelerated endurance tests.

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■ Authors ■

Hiroyuki MARUYAMA

Kazuhiro HAYAKAWA

Kouhei TOYOHARA

Hiromu SOYA

Yoshiteru KANAYAMA

Katsuaki SASAKI

Laser welding of dissimilar materials with cast iron and carbon steel in differential gears

Daichi NISHIMOTO* Shota TSUDA* Takayuki TABUCHI* Shuichi SHIMADA** Takefumi SUZUKI*

Abstract

The electrification and downsizing of automobiles require welding of cast iron and carbon steel in power train components. However, delayed cracking is a problem in welding dissimilar materials including cast iron. As a countermeasure against delayed cracking, adding nickel (Ni) while welding is a technique used to reduce stress and ensure toughness, yet it is still difficult to eliminate the cracking. This paper investigated the results of welds composed of dissimilar materials, cast iron and carbon steel, and finds that stirring Ni is important. In addition, the following were observed in the welds: 1) The heat-affected part is harder than the molten part, creating a higher risk of cracking; 2) During welding, cooling rates sufficient to generate martensite are produced.

1. Introduction

In recent years, with the adoption of electric vehicles, space for mounting batteries must be ensured. Therefore, compact and lightweight power train components are required. Weight reduction is also required for gasoline-powered vehicles to achieve lower fuel consumption.

In differential gears, bolts have been used to join the case part (made of cast iron) that houses the differential mechanism and the final gears (made of carbon steel). As shown in Fig. 1, bolted joints are large to ensure the joint surface, and the weight also increases with the number of bolts. Laser welding has the potential to realize more compact and lightweight power train components, replacing this method of joining cast iron and carbon steel. However, the delayed cracking that occurs within a few days after welding is a problem in welding dissimilar materials including cast iron, making it difficult to apply laser welding to production.

In this paper, the following are investigated to reduce delayed cracking: 1) the state of the material microstructure changing depending on the laser irradiation conditions; and 2) the Ni distribution affecting the formation of the material microstructure.

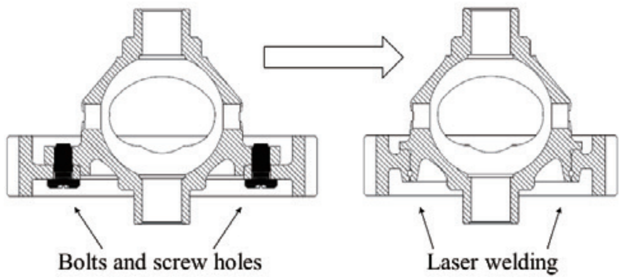

Fig. 1 Downsizing and weight reduction by laser welding

*Parts Process Engineering Department **Engineering Management Department

2. Causes and countermeasures for delayed cracking

Delayed cracking is considered to occur within 48 hours after welding the heat-affected or molten parts. The detailed mechanism causing delayed cracking has not yet been elucidated. As shown in Fig. 2, delayed cracking is considered to be caused by three factors: metal microstructure of the weld, diffusible hydrogen, and internal stress. Although the full picture of delayed cracking is still being studied, research has been conducted separately on each of the three factors. The following shows what have generally been observed.

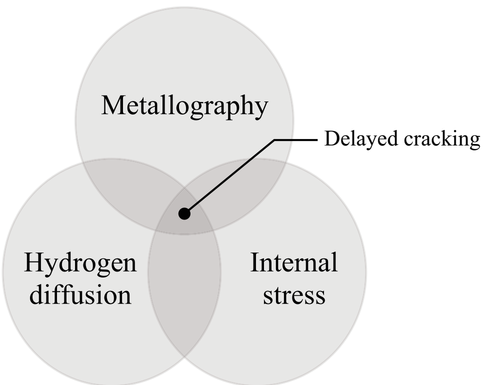

Fig. 2 Three elements of delayed cracking

2.1 Metal microstructure

From the viewpoint of metal microstructure, the formation of martensite in the heat-affected part exposed to rapid cooling is a cause of cracking. In welding, the temperature history applied to the material includes rapid heating and cooling. Therefore, hard microstructures such as martensite are easily formed. Martensite is formed by increasing the cooling rate in the temperature range from the melt temperature to around 500°C. Therefore, preheating and slow cooling processes are sometimes used to control the metal microstructure.

2.2 Diffusible hydrogen

Inside metal materials, there are hydrogen atoms that can move in the crystal lattice at room temperature. This hydrogen is called diffusible hydrogen. Diffusible hydrogen atoms tend to accumulate in highly stressed parts inside the material. Hydrogen embrittlement occurs when diffusible hydrogen atoms accumulate in parts with a high internal stress produced by welding. The hydrogen embrittlement is known to be a cause of delayed cracking. Diffusible hydrogen can be either contained in the material before welding or entrained from the surroundings during welding. Reducing the amount of hydrogen remaining after welding is important as a countermeasure against delayed cracking.

2.3 Internal stress

In general, Ni is added in welding materials that includes cast iron. In production processes, a Ni alloy wire is fed during welding. The purpose of the Ni addition is to lower the residual internal stress. The thermal expansion coefficient is minimized when about 36% of Ni is added to iron (Fe)(1). This alloy is known as Invar. Its characteristic is used to reduce the amount of shrinkage of the molten part during cooling. In addition, Ni does not bond with carbon (C). Therefore, adding Ni is also effective from the viewpoint of ensuring toughness, as it prevents the hardening of the molten part in which C dissolves gathering from the surroundings.

This paper is the first step toward a full understanding of delayed cracking. We measured the Ni concentration distribution in the molten part and investigated the relationship between the occurrence of delayed cracking and the Ni concentration distribution as well as the laser irradiation conditions. From the viewpoint of metal microstructure, we also observed the microstructure of welds and measured the hardness distribution in order to investigate the relationship between the crack-generated and high-hardness sites. The temperature history was measured to confirm whether rapid cooling actually occurred to form the high-hardness microstructure.

3. Experimental methods and results

Figure 3 shows the overview of the laser welding experiment. The base metals are cast iron and carbon steel. Both were welded with the addition of 70%-Ni alloy wire having a diameter of 1.0 mm. The wire was fed into the molten bath from an angular direction of 45° viewed from the front side of the laser beam. For the shielding gas, N_2 was used. The laser used was a Yb:YAG infrared laser whose emitted beam had a focal diameter of 0.4 mm. The welding was conducted with six levels of conditions as shown in Table 1. Three levels—2,510 W, 2,650 W, and 2,710 W—were set for the laser power, and two levels, -2.5 mm and -3.0 mm, were set for the focal height measured from the weld surface. The welding state was photographed from above with a high-speed infrared camera. After welding, samples were cut in the direction shown in Fig. 4 to measure the Ni concentration distribution and hardness distribution.

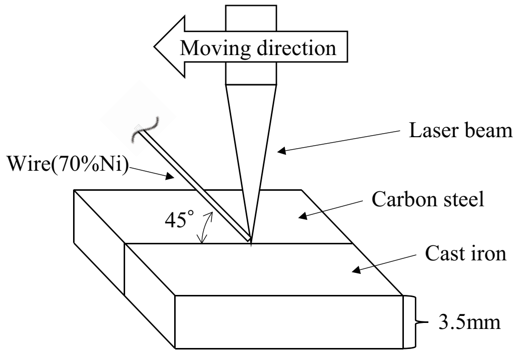

Fig. 3 Laser welding setup image

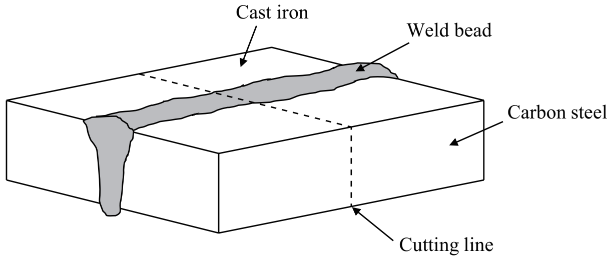

Fig. 4 Cutting

Table 1 Experimental settings

No.	Laser power (W)	Focus position (mm) (from surface)
1	2,510	-2.5
2	2,650	-2.5
3	2,710	-2.5
4	2,510	-3.0
5	2,650	-3.0
6	2,710	-3.0

3.1 Ni concentration distribution

3.1.1 Measurement method

An electron probe micro analyzer (EPMA) was used to measure the Ni concentration distribution. The EPMA is an elemental analysis instrument that lets electrons impinge on a sample to measure the characteristic X-rays emitted. The maximum acceleration voltage of the instrument used was 30 kV. The weld cross sections were measured and the color maps showing concentration distribution were created. The Ni alloy wire for welding was used as the reference for the concentration so that it could be visually compared based on the same level.

3.1.2 Results and discussion

Figure 5 shows the results of the color mapping of the Ni concentration distribution and the cracking occurrence level for each laser irradiation condition. The cracking occurrence level is evaluated and shown as a scale classified into three levels such as low, middle, and high. With a focal length of -2.5 mm, Ni stagnates at the top, whereas it reaches the bottom half part with a focal length of -3.0 mm. The Ni concentration distribution has a greater effect on cracking than the laser power, which can also vary the cracking rate.

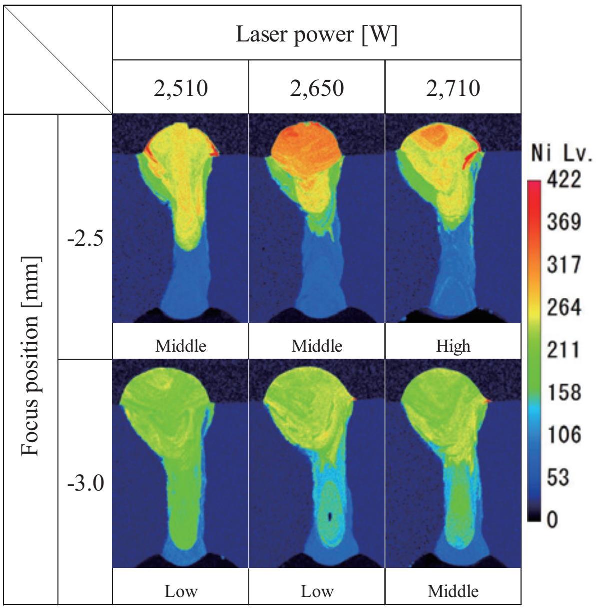

Fig. 5 Distribution of Ni and crack rate

3.2 Measurement of hardness distribution

3.2.1 Measurement method

A micro-Vickers hardness tester was used to measure the hardness distribution, with a load of 300 g and a pitch of 0.2 mm. The hardness distribution was mapped on an isometric photograph of the sample. The measurement area was 5 mm long (24 points) and 3.5 mm wide (17 points), including the molten and heat-affected parts on both sides of the sample.

3.2.2 Results and discussion

Figure 6 shows the results of the hardness distribution color mapping. The heat-affected part, especially on its cast iron side, shows a maximum hardness of over 600 HV. Microstructural observation in that part indicates the formation of martensite. The hardness of the molten part, on the other hand, is suppressed to 300 - 350 HV, indicating that the Ni addition is effective in ensuring the toughness of the molten part.

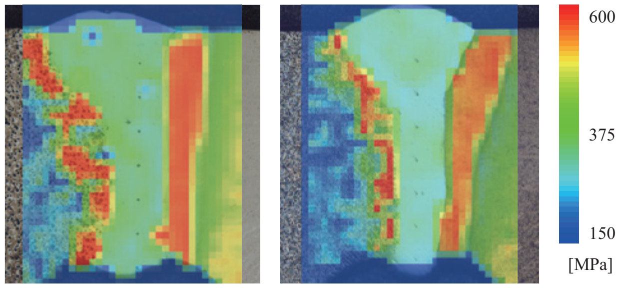

Fig. 6 Hardness distribution of welded area

3.3 Measurement of temperature history

3.3.1 Measurement method

The temperature history was measured using sample's image data taken by a high-speed infrared camera. It was capable of capturing images with a maximum pixel size of 640 ☓ 512 and a frame rate of 1,000 fps. The wavelength sensitivity was set to 3,000 - 5,000 nm to exclude the influences of laser light and fumes. The captured image data were converted to temperature using the emissivity inherent to the materials. The elapsed time was calculated using positional information to create a temperature history graph.

3.3.2 Results and discussion

The process of creating the temperature history and the graph are shown in Fig. 7. The temperatures were calculated using the emissivity 0.35, which is the average of the emissivity values of 0.29 and 0.42 for cast iron and iron, respectively. On the surface of the molten part, rapid cooling at a rate of over 800˚C/sec is observed even after solidification. Cooling rates sufficient for the formation of martensite are supposed to occur even in the heat-affected part.

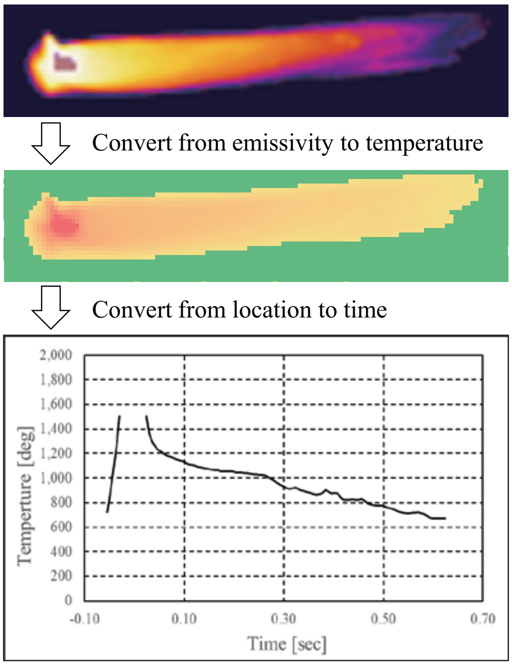

Fig. 7 Creating a temperature history graph

4. Summary

The microstructure was investigated as one of the three factors influencing delayed cracking occurring in welds composed of cast iron and carbon steel. The results obtained from this investigation are:

1. We established measurement methods for the Ni distribution, hardness distribution, and temperature history, which were visualized successfully.
2. The Ni distribution was found to have a significant effect on the cracking.

5. Challenges left for future

Using the measurement methods established in this study for the Ni distribution, hardness distribution, and temperature history, we will continue to investigate the mechanism causing delayed cracking from the viewpoint of metal materials. The investigation considering the other two factors, stress and hydrogen, will also be performed in order to elucidate the whole mechanism causing delayed cracking.

6. References

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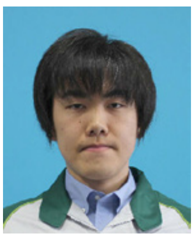
■ Authors ■


Daichi NISHIMOTO


Shota TSUDA


Takayuki TABUCHI


Shuichi SHIMADA


Takefumi SUZUKI

Introducing the Jatco CVT-XS (JF023E) for the Nissan Sentra

The Jatco CVT-XS (JF023E) is installed on the Nissan Sentra that Nissan Motor Co., Ltd. rereased in North America in October 2023.

The newly developed JF023E has a completely redesigned hydraulic system and uses a twin oil pump to downsize the mechanical oil pump and reduce mechanical loss. In addition, by using a multi-plate lock-up, three-way linear solenoid, the engine speed is suppressed during launch and re-acceleration, achieving the feeling of acceleration that the driver intended.

By placing the control valve vertically instead of horizontally, and lowering the overall height of the unit, we have achieved the crash requirements for small cars. Moreover, by reducing the belt winding diameter, we were able to shorten the distance between the pulley shafts and increase the gear ratio (from 7.0 to 7.9), achieving both an increase in the gear ratio and a smaller unit.

These technologies contribute to fuel efficiency, power/driving performance, and vehicle safety performance, and have earned high praise from customers.

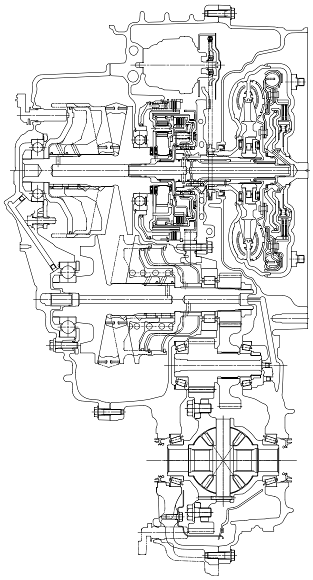


Fig. 1 Main cross-sectional view

Table 1 Specifications of JF023E

Torque capacity	280 Nm
Torque converter size	230 mm
Pulley ratios	2.805 - 0.357
Ratio coverage	7.9
Reverse gear ratio	0.745
Final gear ratio	5.034
Selector positions	P, R, N, D, B
Overall length	379.9 mm
Weight (wet)	94.6 kg

Nissan Sentra

発行人（Issuer）

大 曽 根 竜 也 Tatsuya OSONE — CTO Chief Technology Officer

編集委員会（Editorial Committee）

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　　　　　　イノベーション技術開発部
　　　　　　〒417-8585
　　　　　　静岡県富士市今泉 700-1
　　　　　　TEL: 0545-51-0047（代）
　　　　　　FAX: 0545-51-5976
編　　　集　Eーグラフィックス コミュニケーションズ株式会社
　　　　　　東京都三鷹市牟礼 6 丁目 25 番 28 号

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JATCO Ltd
700-1 Imaizumi, Fuji City, Shizuoka
417-8585, Japan

JATCO Ltd

700-1, Imaizumi, Fuji City, Shizuoka 417-8585, Japan
TEL: +81-545-51-0047 FAX: +81-545-51-5976

www.jatco.co.jp/english