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CONTENTS

Foreword

A Prospective on the Future of Fluid Power Technology in Off-Road Applications

Andrea Vacca*

1. Introduction.

The market of vehicles for construction, agricultural and mining applications has been facing a revolution for the sake of sustainability and lower carbon emissions. Following the same technology progress path of on-road vehicles, electric- and hydrogen- based prime movers are now considered as an alternative to the combustion engine (CE), with implications affecting the whole vehicle actuation system. Differently from their on-road counterpart, off-road vehicles (ORVs) always require working functions (both rotary and linear functions) in addition to the propulsion. Therefore, an overwhelming topic for both academia and industry pertains to finding the right technology choice for generating and distributing power in the next generation of ORVs. Will Fluid Power (FP) remain the technology of choice for future vehicles? Or should industry focus switch to fully electro-mechanical actuation? The answer is not straightforward, and it should consider multiple factors. The following sections further elaborate the author's experience and perspective on this topic. As a warning to the reader, it should be considered that author spent his entire professional career in FP topics, and inevitably there will be some bias towards the merit of FP actuation. Nevertheless, it is the author's belief that that most of the following considerations will be of inspiring interest and will align to future development of ORV technology.

2. Prime mover technologies for future off-road vehicles.

Different scenarios for the actuation technology of current and future ORVs can be defined based on the prime mover choice: CE (either conventional diesel or based on alternative fuels such as hydrogen, biofuels, etc.), battery electric (BE) or hybrid CE/BE. Similarly to on-road applications, all these technologies have merits/demerits pertaining to the infrastructure required for supplying energy to the tank (or battery); the well to wheel energy efficiency and CO_2 impact; prime mover costs. Several sources (like [1, 2]) indicate that electric vehicles will soon dominate the low-power and short-usage applications, while the other prime mover technologies will lead the heavy-duty applications. This scenario is shown in Fig. 1, for the case of loaders.

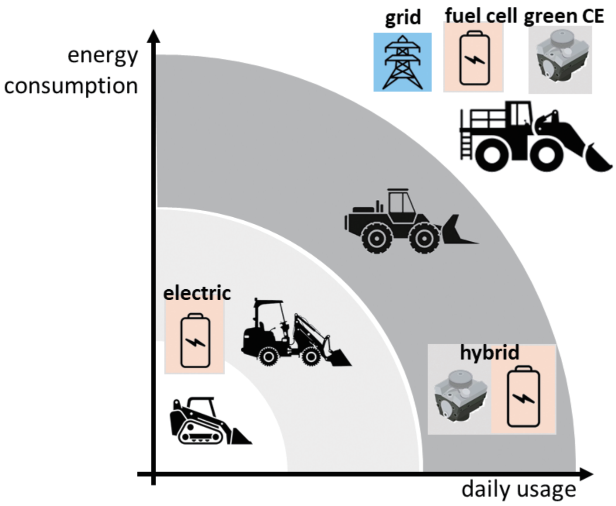

Figure 1 Most suitable prime mover technology depending on vehicle size (example of loaders)

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3. Technologies for the working functions.

Besides the propulsion that can be performed through a purely mechanical system, the working functions of an ORV require an electro-mechanical and/or a FP system. The favorable power to weight ratio, low cost, and robustness have made FP the go-to technology for conventional diesel ORVs over the last decades. However, the low energy efficiency of their FP actuation (an average of about 30 % across different ORVs was found by a US Dept. of Energy study [3]), poses severe questions on the usage of conventional FP technology for future ORVs. It is not only a matter of a more rationale usage of energy resources; in fact, future ORVs will have more stringent energy storage limitations than today's vehicles - at least for BEs and hydrogen-based vehicles - affecting their up-time between refueling or recharging events. Additionally, the unitary cost of energy is expected to be significantly higher than current diesel cost, for most of the alternative fuels. From these considerations it is clear how the *total cost of ownership* (TCO) of future ORVs will be more linked to the energy efficiency of the transmission system than in today's vehicles. Consequently, one can reach the straightforward conclusion that electromechanical actuation, often associated to much higher energy efficiency than FP, will dominate the future of ORVs. Indeed, electromechanical technology is readily available for both rotary and linear actuators, meeting the size and power requirements of many ORVs. Few fully electric ORVs also appeared (or soon to be) on the market, taking advantage of such actuators. Notwithstanding, it is still unclear which actuation technology is best among FP and electromechanical, as their potential is not yet fully exploited. This potential should be considered by looking at all the prime mover scenarios as shown in Fig. 2.

Future ORVs using green CEs (hydrogen or alternative fuels) will meet cost effectiveness by retaining FP actuation to avoid the added cost of a high-power electric actuation system. However, technology progresses to increase energy efficiency of FP system are required to achieve competitive TCO.

BEs, fuel cell, and hybrid BE/CE can instead adopt both FP and electromechanical technologies, and the choice of the best system should factor:

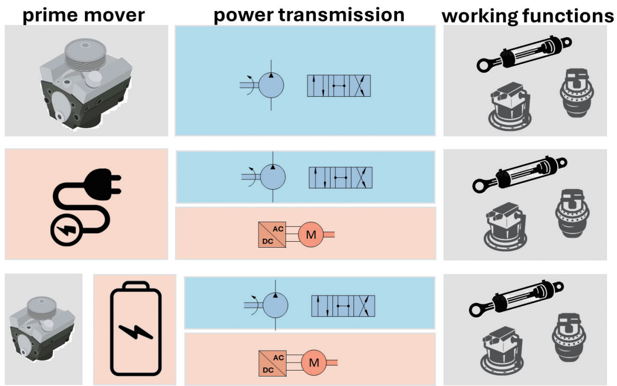

Figure 2 FP vs. electromechanical actuation in ORVs

- cost
- productivity
- energy efficiency
- space claim
- robustness
- space claim
- damping
- resistance to shock
- tolerance to contamination
- leakage potential
- cooling needs
- noise and vibration
- prime mover limitations
- installed power

With a compromise that highly depends on each specific ORV type and size. For example, ORVs with functions seldom utilized in their typical utilization cycles will prioritize installation cost over energy efficiency, while the opposite will occur for functions affecting ORV's productivity.

Some general considerations can be made while comparing electromechanical vs. FP actuation with respect to the previous bullet point list:

Cost. Electric components in the power range suitable for ORV application are currently more expensive than FP components. However, there is a price reduction tendency for electric components (batteries, electric motors, power electronics) that might soon bring their cost to a competitive level, particularly for <100 kW ORVs, where synergies with mass production capabilities developed for on-road application are possible. To remain competitive, FP must evolve in the direction of "smart components" able to perform multiple functions through electronic/software integration. For example, a smart electronic-controlled pump can reduce the current variety of hydraulic- controlled pumps, so that pump variants can be reduced along with their production cost.

Energy efficiency. For rotary functions, electric machines are simply more efficient than hydraulic motors. Consequently, for productivity functions such as propulsion, it is expected to see more and more adoption of electric technology. However, for linear functions, there is not a clear winner among the two technologies. State-of-art linear electromechanical actuators require a mechanical gearbox to convert the high-speed rotary motion of the electric machine into a linear motion, with detrimental effects in terms of efficiency, backdrive ability, and resistance to shocks. If compared to an electro-hydraulic actuator that use an electric prime mover for each linear function, the energy efficiency is only slightly favorable for electromechanical actuators in resistive mode [4], although in overrunning conditions the electro-hydraulic actuation can have advantages [5], as it will be also discussed in section 5. It is also important to note that the energy efficiency of FP system depends on the chosen layout architecture of the hydraulic system, and numerous options are available among primary-controlled, secondary-controlled and metering-controlled architectures [6]. Very often, the selected architecture for an ORV is not the one that maximizes energy efficiency. Further considerations on this point will follow.

Space claim. FP has the notorious advantage of power to weight ratio over electromechanical technology. This can be immediately deducted by comparing the mass of same-power electric vs. hydraulic, as shown in Fig. 3. The figure points out a difference in mass quantifiable in about one order of magnitude.

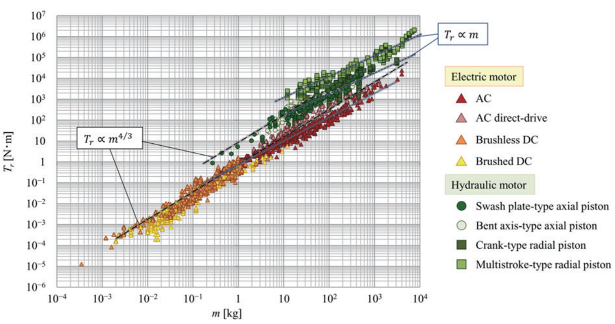

Figure 3 Mass vs. Power for commercially available electric and hydraulic machines [7]

However, the above comparison alone, does not outline all the space claim potentials given by FP technology, even when used with electric prime movers, which can be summarized with the opportunity of *grouping functions* (centralized systems) and *integrated electric-hydraulic solutions* (*ePumps*).

Grouping functions refer to the ease of combining multiple actuators to the same prime mover which is arguably one of the main prerogatives of FP systems over electric actuation technology. While each electric actuator requires a prime mover, a FP system can be equipped with proper hydraulic control valves to independently control multiple functions with a single hydraulic power source. Among other advantages, grouping functions allows reducing the number of prime movers, and therefore the overall space claims of the actuation system.

Integrated electro-hydraulic solutions refer to the design merge of electric and hydraulic components to pursue physical advantages, one of these being the reduced space claim. Examples of this ongoing effort include the ePumps developed at various institutions (in Fig. 4 the examples from the author's research center). By maximizing the usage of the inert space inside an electric machine, where a hydraulic unit can be fitter, and by leveraging better cooling strategies (such as adopting immerse cooling strategies), it is possible to achieve significant (>30%) space reduction.

Figure 4 Design integration for implementing electric and hydraulic machines capable to generate or recover hydraulic energy [8-10]

Installed power. This feature refers to the overall power of the prime movers present in the vehicle, and it can be suitable to outline a significant difference between a fully electric ORV compared to an FP-actuated ORV. With electromechanical technology, each actuator needs a dedicated prime mover matching its peak power demand. This means that a fully electric vehicle might end up having an installed power several times higher than its conventional FP technology equivalent [11], which usually benefits from the function grouping explained in the previous paragraph. This feature of electromechanical actuation is sometimes interpreted positively, as an increased potential for higher productivity. However, it also highlights the inherent design limitation of electromechanical systems, which cannot avoid increasing the installed power, compared to what is strictly necessary to perform the required ORV specific mission profiles. This negatively reflects on the usage of electric material (including rare minerals), which is against the basic sustainability concepts.

Cooling needs. Being often more energy efficient than FP systems, electromechanical actuation systems tend to have less heat dissipation, thus less cooling need. However, this consideration does not reflect the challenges associated with the implementation of cooling solutions. Ease of cooling is a key advantage of FP technology: the hydraulic fluid is not only an energy vector, but thanks to its favorable thermal properties it is also a good heat carrier. Despite being inefficient – thus with high cooling needs – today's FP systems allow a convenient placing of heat exchangers. Instead, electric technology requires cooling solutions able to locally the components where the power transformations occur. Consequently, the thermal conditioning system for a fully electric ORV is a critical, sometime challenging design aspect, particularly for heavy duty ORVs. Design integration of FP and electric components (like in Fig. 4) can be promising in EVs for leveraging both advantages of electric technology (i.e. high efficiency) and of hydraulic technology (i.e. ease of cooling), so that all the cooling requirements can be concentrated into the FP circuit.

4. Research on energy-efficient hydraulic actuation.

The recent push towards sustainable, low TCO, ORVs has brought an unprecedented interest in the development of more energy-efficient FP technology. The most energy-efficient concept is the *decentralized hydraulic*, which consists in implementing a dedicated flow supply for each working function. It is currently adopted for the propulsion of several ORVs (*hydrostatic transmissions*), but it can be implemented for the working functions as well. Two concepts are available, depending on how the flow-on-demand regulation is performed: *displacement control* (i.e. one variable displacement pump for each function) or prime mover control, or *electro-hydraulic actuator* (i.e. one variable speed electric motor for each function). Both solutions have experimentally proven capabilities of doubling the energy efficiency of the transmission systems [5, 12]. The displacement control concept is particularly attractive as it also allows reducing the installed power and the number of prime movers [11].

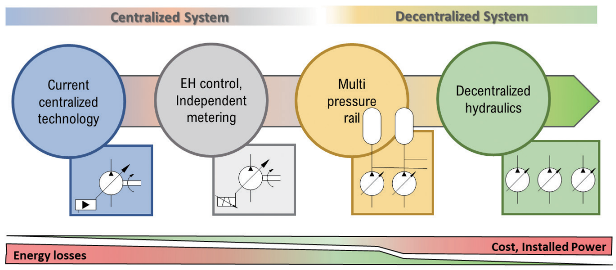

Figure 5 Portfolio of FP solutions for future ORVs

The practicality of the decentralized hydraulic concept in ORVs is however under question, as it increases component cost. Therefore, it can be justified only for reducing energy consumption of the actuators with high utilization cycles. For this reason, combinations of conventional (and inefficient) *centralized hydraulic* solutions with decentralized solutions are more likely to occur.

Several R&D institutions focused on alternatives for cost effective and practical FP solutions for the working functions of future ORVs. The most relevant effort can be summarized with the alternatives illustrated in Fig. 5. At the extreme left of the figure, there is the state-of-art centralized hydraulic technology, typically based on hydromechanical, valve-controlled systems (mainly open center and load sensing systems [6]), which has been optimized to meet the requirements of conventional diesel based ORVs. At the extreme right, there are the mentioned decentralized solutions, which bring the maximum energy efficiency benefit at the price of a higher installation cost. In the middle, there are other promising solutions that are expected to grow in commercial ORVs. First, there is the category of intelligent components based on advanced electro-hydraulic (EH) control, as opposed to conventional hydraulic pilot control. This includes smart components, such as smart pumps and smart valves, whose operation can adapt to the instantaneous requirement of the work function. These solutions, already appearing in the market, can bring to moderate /good reductions of energy consumption.

The other category of solutions is the pressure-controlled systems, either *constant pressure rail* (CPR) or *multiple pressure rail* (MPR). The CPR solution is the most elegant one: it is based on a single pressurized rail that serves all the working functions, each one with a local regulation (secondary control). Conventional hydraulic cylinders cannot be used, as they do not offer any internal regulation, and for this reason multiple chamber cylinders have been proposed [13] and have reached a level close to commercialization. Another concept for CPR is achieved by using a hydraulic transformer for each function to eliminate throttling losses [14]. Despite several efforts in developing hydraulic transformers [15], no commercial solution is yet available, although there are certainly promising solutions such as the one in [16].

MPR systems are a surrogate of the CPR concept that allow direct implementation through commercially available components. Several prototypes ORVs have shown remarkable energy efficiency gains (up to double efficiency) in both construction and agricultural fields [17, 18].

5. Energy Recovery solutions for ORVs.

The working functions of several ORVs, particularly in the construction sector, offer opportunities for energy recovery during overrunning loads. For example, in the typical use of an excavator, there is the opportunity to recover about 15% of energy associated with overrunning loads. When using electromechanical actuation, this energy amount might not be high enough to justify the added hardware complexity which is required for a successful recovery. In fact, actuators with backdrive capability are required; moreover, there are several energy transfers processes (each one associated with a component efficiency) to recover/reuse the energy from/to the actuator to/from the electric battery. Additionally, it must be considered that energy recovery process might bring to detrimental charging/discharging rates to the electric battery.

When using FP solutions, multiple options are available to handle energy recovery. The possible options are conceptually shown in Fig 6.

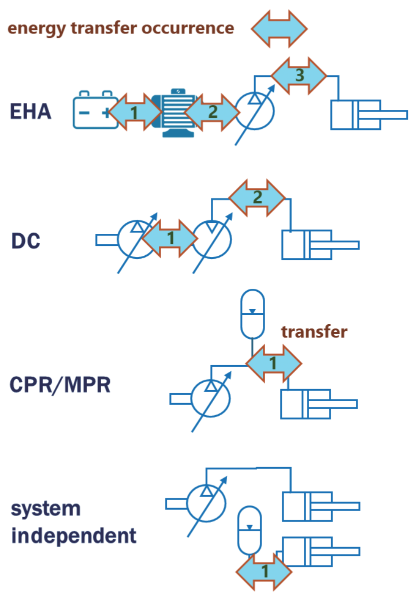

Figure 6 Solutions for energy recovery using FP

The two distributed hydraulic options (displacement control, DC and electro-hydraulic actuator, EHA) engage different mechanisms for energy recovery. Similarly to electromechanical actuators, EHA involves several energy conversion steps, and might be not appealing for ORVs. However, fewer conversion steps occur in other FP solutions: DC can engage internal energy recirculation without involving the prime mover; CPR and MPR offer a smooth energy recovery through energy accumulation in the pressure rails. There are also stand-alone solutions that have been proposed to isolate the energy recovery function from the actuator control function, which can apply for any type of hydraulic system and offer the minimum energy conversion loss. Significant is the example reported in [19].

6. Conclusion.

This paper discussed how the inherent advantages in term of power to weight ratio, layout flexibility, and ease of cooling, should collocate FP technology at least at the same level, if not superior, to electromechanical technology for the development of future ORVs, including BE, CE, or hybrid solutions. However, it is clear that conventional FP solutions do not meet TCO requirements associated with the use of novel prime mover technologies (electric and hybrid vehicles, fuel cells, combustion engines with alternative fuels) and therefore investment and research effort is required.

An adverse factor to the deployment of novel FP solutions is the complexity of hydraulic control systems that conflicts with the chronic lack of educated FP engineers, which – if no action is taken – will slowly determine the decline of the FP technology [20].

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Editorial

Mechatronics: In the Mind's Eye of an Engineer

TANAKA Yutaka*

1. Introduction

According to a dictionary, the mind's eye refers to the function of a sharp mind to see the truth of things [1]. We tend to think that the products (artifacts) created by technology are what science brings. This is true in a sense, but we should not forget that many products are born in the sensual mind's eye of engineers, which cannot be expressed in words at all. It is said that engineers rely heavily on visual, non-verbal processes for inspiration. Engineering designers are those who can assemble and operate in their minds a new device that does not even exist in the real world [2]. What is important are the images in the mind of those who have come up with a new idea or concept.

The origin of the term “mechatronics” is often misunderstood, although many readers may know that the word was created by a Japanese engineer. This paper first takes a broad look at how the word “mechatronics,” then a brand-new concept, has evolved to the present day. Next, the paper characterizes actuators, which are important components of a mechatronic system, specifically comparing electromagnetic and fluid power types. It also presents the performance of the latest electromagnetic motors for electric vehicles (EVs).

2. Origin of the Term Mechatronics

The term “mechatronics” was coined by Mr. Tetsuro Mori, an engineer at YASKAWA Electric Corporation, in 1969 [3) 4)]. Fig. 1 shows a copy of the invention registration form at that time. The form states the motivation for the invention: “Mechatronics is a composite of 'mecha' from mechanism and 'tronics' from electronics. In other words, the term was invented with the intention of adding more and more 'electronics' to the 'mechanisms' of new products and technologies in order to link the former more closely and organically to the latter.”

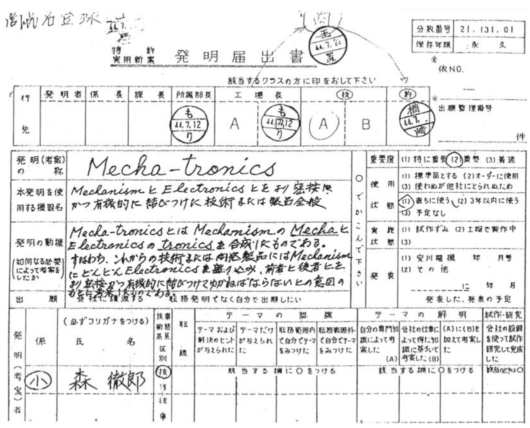

特許 実用新案 発明届出書
分類番号 21.131.01
保存年限 永久
発明(考案)の称: Mecha-tronics
本発明を使用する機器名: Mechanism と Electronics とをより密接かつ有機的に結びつけた技術または製品全般
発明の動機: Mecha-tronicsとは Mechanism の Mecha と Electronics の tronics を合成したものである。すなわち、これからの技術または開発製品には Mechanism にどんどん Electronics を盛り込み、前者と後者とをより密接かつ有機的に結びつけてゆかねばならないとの意図のもとに考案したものである。
発明(考案)者: 森 徹郎

Fig. 1 Invention registration form at that time

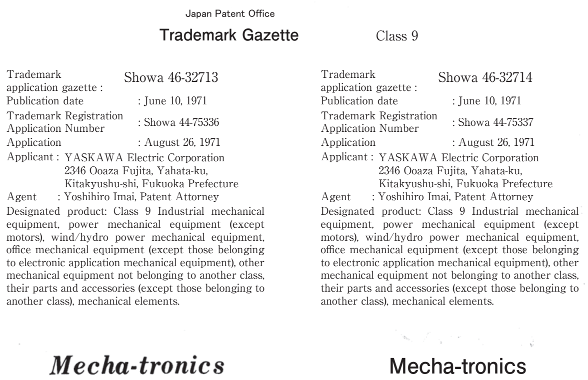
It should be noted that the “mecha” of mechatronics comes from mechanism. In fact, many popular books explain that the term “mechatronics” is a combination of mechanics and electronics [5]. I got the same answer when I asked a generative AI (ChatGPT 4o).

Although it is now widely recognized that mechatronics is an interdisciplinary academic field that encompasses mechanical, electrical and electronic, control, computer, and other engineering fields, it has its origins in the fusion of mechanisms and electronics. We should not forget the amazing inspiration and achievement of engineer Tetsuro Mori, who successfully expressed the idea of combining mechanism and electronics in one word, “mechatronics,” which did not exist at that time.

YASKAWA registered the word “mechatronics” as a trademark in 1972. Fig. 2 shows an excerpt from the trademark gazette by the Japan Patent Office [6]. Another important point in this matter is that YASKAWA later abandoned the trademark in 1978, attaching importance to the possible spread of the word in the market, thus releasing the trademark rights. As a result, the original

*Professor, Faculty of Engineering and Design, HOSEI University

Japanese word "mechatronics," a kind of Japanese English, has been recognized throughout the world since the 1980s. The concept became popular along with the word. In 1996, the Institute of Electrical and Electronics Engineers (IEEE), which is an organization for researchers in the field of U.S. information telecommunications engineering, and the American Society of Mechanical Engineers (ASME), which is an organization for researchers in the field of U.S. mechanical engineering, jointly published the IEEE/ASME Transactions on Mechatronics [7], thereby formally recognizing the Japanese English word "mechatronics" in the world. In the same year, the 1st International Conference on Mechatronics Technology (ICMT1996) was held in the U.S. Since then, the conference has been held every year mainly across Asia-Pacific. Kanazawa, Japan hosted the 27th conference in November 2024, and Hanoi, Vietnam plans to host the next one in 2025, with the participation of many engineers and researchers, including Japanese.


Japan Patent Office

Trademark Gazette   Class 9

Trademark application gazette : Showa 46-32713
Publication date : June 10, 1971
Trademark Registration Application Number : Showa 44-75336
Application : August 26, 1971
Applicant : YASKAWA Electric Corporation
2346 Ooaza Fujita, Yahata-ku,
Kitakyushu-shi, Fukuoka Prefecture
Agent : Yoshihiro Imai, Patent Attorney
Designated product: Class 9 Industrial mechanical equipment, power mechanical equipment (except motors), wind/hydro power mechanical equipment, office mechanical equipment (except those belonging to electronic application mechanical equipment), other mechanical equipment not belonging to another class, their parts and accessories (except those belonging to another class), mechanical elements.

Mecha-tronics

Trademark application gazette : Showa 46-32714
Publication date : June 10, 1971
Trademark Registration Application Number : Showa 44-75337
Application : August 26, 1971
Applicant : YASKAWA Electric Corporation
2346 Ooaza Fujita, Yahata-ku,
Kitakyushu-shi, Fukuoka Prefecture
Agent : Yoshihiro Imai, Patent Attorney
Designated product: Class 9 Industrial mechanical equipment, power mechanical equipment (except motors), wind/hydro power mechanical equipment, office mechanical equipment (except those belonging to electronic application mechanical equipment), other mechanical equipment not belonging to another class, their parts and accessories (except those belonging to another class), mechanical elements.

Mecha-tronics

Fig. 2 Trademark gazette

In the 2000s, the concept of mechatronics was widely used in engineering and industrial products. As the term became a more common concept, it became less necessary to use the word mechatronics specifically.

As described above, the word mechatronics, originally proposed by a Japanese engineer, has now spread throughout the world. I would like to pay my respects once again to the mind's eye of the Japanese engineer Tetsuro Mori.

3. Mechatronic System Configuration

In my lectures, I usually use the block diagram shown in Fig. 3 to explain the concept of mechatronics. A mechatronic system consists of five subsystems: a computer, actuators, a mechanism, sensors, and energy sources. Each subsystem can be compared to a corresponding organ or function in the human body.

This configuration can be applied to a specific servo system for positioning a degree-of-freedom load system consisting of a spring, mass, and damper with a hydraulic cylinder, as shown in Fig. 4. The actuator here consists of a hydraulic servo valve and a hydraulic cylinder. In this servo system, position and load status data is fed back from sensors to the computer, where a software-based controller sends commands to the servo amplifier according to the setpoints. The servo amplifier converts and amplifies the electrical energy supplied by the power source to drive the electromagnetic motor on the first stage of the hydraulic servo valve. It also converts and amplifies the hydraulic energy supplied by the hydraulic source to drive the spool valve on the second stage, enabling the hydraulic cylinder to perform the specified positioning according to the setpoints. The fact that actuators and a mechanism are key components of a mechatronic system to achieve the desired work is also evident from these two block diagrams.

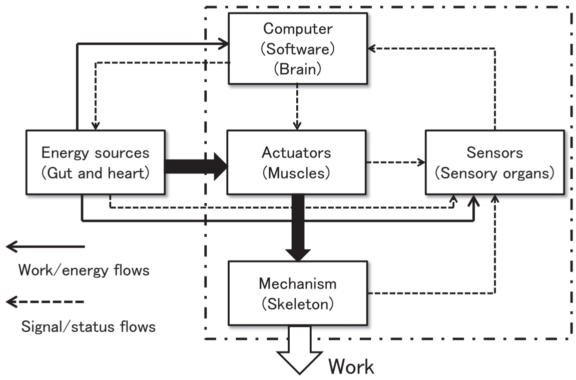


Fig. 3 Mechatronic system configuration

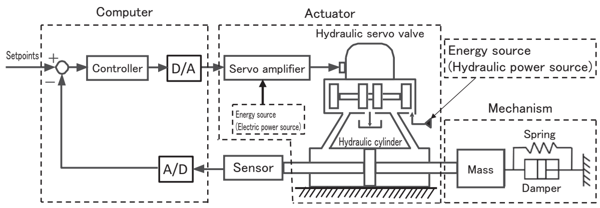


Fig. 4 Inertial load positioning servo system with hydraulic actuator

4. Actuator Performance Comparison

The actuator plays a critical role in the mechatronic system configuration shown in Fig. 3. The performance of the system is almost entirely determined by the performance of the actuator. A mechatronic system with a high-power, high-response actuator can provide high performance.

Conventional actuators can be classified by drive method into electromagnetic type, typified by AC/DC motors, and fluid power type, typified by hydraulic motors. This paper compares the performance of a commercially available electric servo, as an example of a rotary actuator, and a hydraulic piston motor.

With the mass of the actuator m [kg] and the rated power P_r [W], the power density P_d [W/kg] (power per unit mass) can be defined by the equation:

$$P_d = \frac{P_r}{m}$$

Power density is a performance measure of compactness, light weight, and high power. Engineers may set a goal to design an actuator with low mass and high power density.

Fig. 5 shows the results of a study by Sakama et al. [8] on the power density of commercially available actuators. Red triangles represent AC servo motors, orange triangles represent brushless DC motors, yellow triangles represent brushed DC motors, green circles represent swash plate-type or bent axis-type hydraulic axial piston motors, and green squares represent hydraulic radial piston motors.

In the figure, the three types of motors, namely AC servo motors, DC servo motors, and hydraulic piston motors, occupy their own area with almost no overlap, except for the red-framed area. The figure also shows that hydraulic piston motors have higher power density than AC servo motors of the same mass range. In addition, the majority of hydraulic piston motors are large, with a mass of 10 kg or more, while some of them are small, with a mass of 1 kg or less. The market for small hydraulic motors of 1 kg or less may not be large due to limited applications or structural constraints. However, the development of such hydraulic actuators of this size may have the potential to find a new market in the future.

The automotive drive system has recently shifted from internal combustion engines to electric motors. As the automotive actuator has shifted in response, an innovative movement has been seen in electromagnetic rotary actuators [9].

One example is YASA Ltd. [10] [11]. The company has developed an axial flux motor with a different operating principle from the traditional one and has used the motor in Mercedes-Benz sports EVs and Lamborghini EV supercars. According to my calculation using available data, this motor, which weighs 24 kg, has a power density of 6.67 kW/kg, which is incredible for electromagnetic motors. This motor is not a servo motor, but its performance could be plotted in Fig. 5. The motor then shows the performance indicated by the red dot, which is well within the range of hydraulic motors. This remarkable performance was probably achieved with an innovative technology

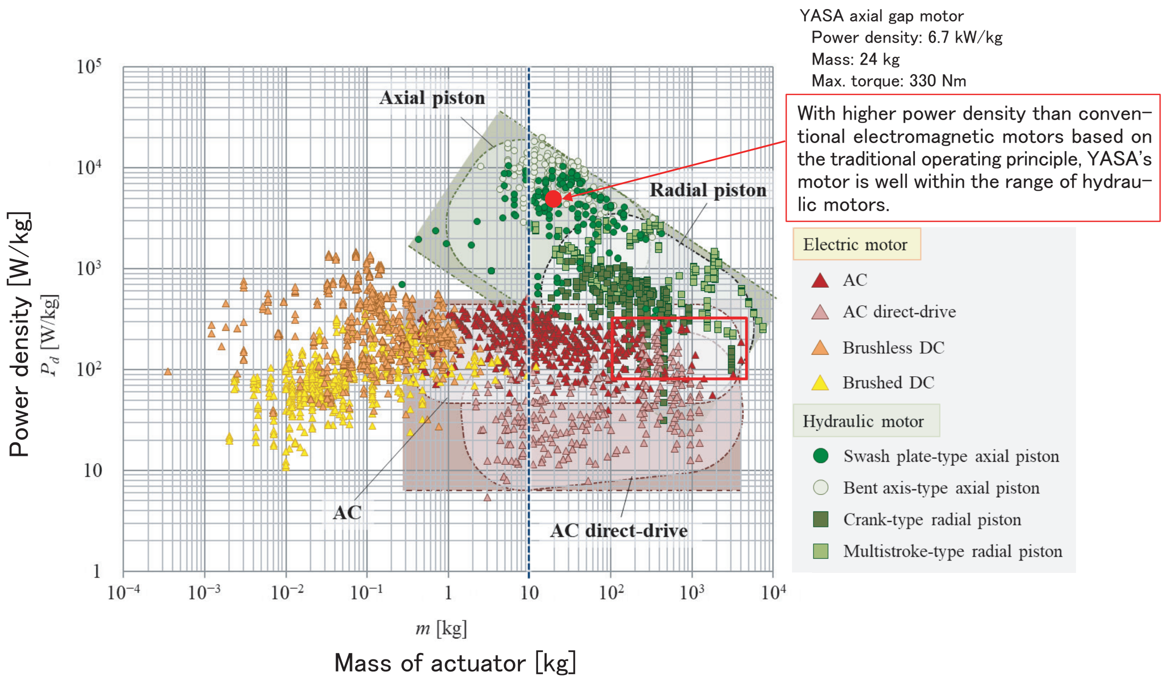


Fig. 5 Performance comparison between electromagnetic and hydraulic actuators

that was not developed by sticking to traditional principles. For your information, the person who developed and commercialized this electromagnetic motor after overcoming many difficulties was Dr. Tim Woolmer, who founded YASA after leaving the University of Oxford in the United Kingdom. He is also the kind of person with a mind's eye.

5. In Closing

This paper has taken a broad look at how the concept of mechatronics has evolved to the present day and has pointed out that the actuator is the key component of the mechatronic system. It has also compared and evaluated the performance of hydraulic and electromagnetic actuators in terms of power density.

Ahead of the rest of the world, Japan is already experiencing the common challenges of mankind, including a declining birthrate and aging population, energy problems, environmental issues, and natural disasters. I sincerely hope that the readers of this paper will be engineers with a mind's eye who can propose and provide new solutions with advanced mechatronics technology to help tackle these challenges from Japan in the midst of the rough and tumble of globalization, just as a Japanese engineer introduced the concept and word of mechatronics, a composite of mechanism and electronics, to the world 56 years ago.

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Greetings

Greetings

KAWASE Masahiro*

KYB is pleased to celebrate the 90th anniversary of its founding and to publish this commemorative 70th issue of the KYB Technical Review. This is a testament to our ability to continually showcase our Group's technologies and the results of product development and manufacturing (monozukuri), and to demonstrate their evolution to our stakeholders, including customers and shareholders. For this, we would like to thank all those who have supported the Technical Review.

For this commemorative issue, we have invited professors distinguished in the field of fluid power to write the Foreword and Editorial. This issue also features a special program in which each division presents its own outlook for the future and shows how far the company's core technologies have expanded.

The origins of KYB technologies can be traced back to the Kayaba Research Center founded by the late Shiro Kayaba in 1919 and Kayaba Manufacturing Co., Ltd. established in 1935. In particular, the hydraulic technology applied to aircraft oil buffers was later used in automobiles, motorcycles, construction machinery, concrete mixer trucks, airplanes, auditorium and stage control systems, and vibration isolators. This technology helped the company expand its business [1)].

With these positioned as KYB's core technologies, we have continued in recent years to promote their development in step with the times to achieve electronic control and modularization of products, as well as the use of digital technology on the manufacturing floor and in the design stage (DX, AI, simulation, and other analysis technologies).

In fiscal 2025, which is the last year of the FY2023 medium-term management plan under the slogan “Mastering Quality Management - Making TQM the Basis of All Activities,” we will make company-wide efforts in the following areas:.

[1] Growth strategy
Promote technology development through a specialized department established to respond to the electrification (EV and systemization) of automobiles, automotive equipment, and concrete mixer trucks.

[2] Innovative manufacturing
Create a self-sustaining unmanned plant driven by digital technology (DX and AI) as part of the activity to advance manufacturing to the next generation under the name of “Ship'30 : Self-handling innovation plant 2030.”

[3] Cost reduction
Promote global cost reduction activities to cope with rising raw material and energy prices and production adjustments due to semiconductor shortages.

[4] Normative awareness
Strengthen compliance within the KYB Group as a corporate group and implement measures to prevent recurrence based on “quality management” to deal with inappropriate issues.

KYB is committed to improving the quality of its work, products, and services by enhancing the quality of its human resources and information in our quest to make great strides towards our 100th anniversary 10 years from now.

The KYB Group will formulate and implement growth strategies to enter new markets and new businesses for future seeding and build an innovative manufacturing system using DX and AI technologies, while making concerted efforts to grow itself and increase corporate value to earn further trust and satisfaction from stakeholders.

Finally, I hope that the KYB Technical Review will continue to be published and serve as a valuable source of technical information for engineers around the world.

Reference

1) KYB 80-year History (November 2015).

* Representative Director, President and CEO, KYB

Special Program

KYB Technical Strategy

FUJII Atsushi*

1 Introduction

Companies are constantly required to create new products and new technologies through technological innovation in order to maintain their competitiveness and achieve sustainable growth. This is also the mission of KYB, which is based on manufacturing.

In this issue No.70 of Technical Review, as a milestone and in celebration of the 90th anniversary of the company's founding, I would like to look back at the company's progress and innovation in the ten years since the 80th anniversary and outline a strategy for the next ten years.

2 Technological Advances and Innovations in Ten Years Since the 80th Anniversary

2. 1 Technological Advances

The dramatic improvement in the transmission speed of 5G network communications has accelerated the development of IoT and automated driving technology..

In addition, artificial intelligence (AI) and machine learning, in particular, have also advanced rapidly to help various industries realize automation and efficiency improvements. Generative AI is now opening up new possibilities.

2. 2 Shift to Environmentally Conscious Energy

Energy conservation efforts have shifted to sustainable, renewable energy sources such as wind and solar power generation, primarily in Western countries. In other words, they have become carbon neutral in one fell swoop.

In the automotive industry, battery electric vehicles (BEVs) are rapidly gaining popularity, with manufacturers such as Tesla and BYD having a major impact on the market. This trend is currently experiencing uncertainty, but the direction of the technology innovation will continue.

2. 3 Changes in Society

The COVID-19 pandemic has changed the way we work and live. Digital technology has advanced rapidly with the proliferation of remote work, and communication tools such as Teams® have improved work efficiency and enabled flexible work arrangements. Advances in the virtual world have made it easier for people to communicate and collaborate remotely. In addition, the need for vaccine development has advanced biotechnology, including gene-editing technology. In the Asian region, cashless payments are becoming more popular and QR code payments are now very common. Related technologies are also spreading rapidly.

The changes in the external environment described above have naturally had an impact on the internal environment.

Of course, the proliferation of remote working has improved the efficiency of our meetings. The product and technology development function has gradually optimized CAE analysis and product design based on 3D models. The BEV-related technology function has promoted the development of eAxle [Note 1)], suspension, and steering systems. Improvements in communication speed have led to advanced remote control of construction machinery, requiring the development of hydraulic equipment that can be controlled by electronics.

On the manufacturing floor, it is now common to identify items with QR codes, and production lines have been automated with AGVs and robots.

Note 1) An integrated unit consisting of a drive motor, inverter, and transaxle (reducer).

3 Strategies for the Next Ten Years

KYB's issues for the next ten years are to maintain and expand existing businesses and to create new value by addressing new businesses. To achieve this, we need to have multi-faceted technical strategies as follows:

3. 1 Product and Production System Process Innovation

In response to the demand for faster technological development as the years go by, we will improve the efficiency of the production system from development to manufacturing. By building a digital twin environment as the axis, we

* Deputy Managing Executive Officer, General Manager of Engineering Div., General Manager of Basic Technology R&D Center, and Curator of KYB Museum

will promote process innovation based on 3D models. 3D data will be used in all processes, such as prototyping in virtual space, production simulation, automatic generation of molds and machining programs, and concentrated management of inspection programs and measurement data, thereby shortening development time.

3. 2 Technology and Product Development Based on Technology Roadmaps

The critical challenges for KYB in product development are to improve the electrification and automation of mobility, which are advancing along with improvements in AI/communication technology and battery technology. Activities are underway to integrate these challenges into company-wide roadmaps. Currently, it is expected to commercialize the CASE-compatible products under development, as well as to launch Smart Road Monitoring and the oil condition monitoring system, which are potential new business models. Meanwhile, we will need to shift to the development of products and systems supported by sophisticated software. In the future, it will be difficult to carry out technology development using only accumulated knowledge and insights as in the past. We will even have to venture into the possibility of replacing hydraulic power with electric motor power in our technology/product development. In addition, it will be essential to respond to increasingly stringent environmental regulations, especially those being promoted in Europe.

3. 3 Human Resources Development and External Appeal

In order to expand our technological domain as described above, we would like to discuss the expansion of the Open Innovation Program, including joint studies with research institutions such as universities and technology exchanges with other companies in a wide range. In particular, for power control and vibration control, which are KYB's core technologies, the Basic Technology R&D Center will resume technology exchanges with major universities in Europe and the U.S., which have been suspended since the COVID-19 pandemic, so that we can follow the global situation of the hydraulic industry even more closely. KYB will also promote its presence not only to Japanese organizations, but also to overseas research institutes. We may need to consider a mechanism to use not only the Development Center, but also the Basic Technology R&D Center and the Production Technology R&D Center as places for information exchange.

We have activities to establish strategies from a long-term perspective by backcasting and creating future timelines for young engineers, who will play a key role in the future of KYB. In a collaborative activity (DLab) with the Future Invention Center of the Institute of Science Tokyo (formerly Tokyo Institute of Technology), our young employees who are possible candidates for future management presented what they envisioned for a future society. I am convinced that their paradigm shift can generate further technological innovation.

4 In Closing

I am reminded that the basis of KYB's technical strategy is to improve itself, to develop products and services demanded by customers and society, and to provide engineers with work that gives them pleasure and a sense of fulfillment.

Special Program

KYB Approach to Production Engineering

HABA Keiichi

1 Introduction

In 2025, KYB celebrated its 90th anniversary. In this milestone year, we also celebrated 35 years of publishing KYB Technical Review since its first issue in 1990, with the publication of the 70th issue. Looking back at the first issue, I found articles on design engineering, including hydraulic pumps and hydraulic active suspensions, as well as articles on production engineering, including plastic processing of tubes and automatic transfer of parts. The order of the articles shows that KYB, a manufacturing company, was already emphasizing production engineering. This report describes how KYB is and will be involved in production engineering.

2 About Production Engineering

The design engineering and production engineering of a product significantly affect its quality, cost, and production efficiency. While design engineering determines the specifications and functions of the product, production engineering determines an effective production method to implement the design. Even if the design is excellent, that is not enough by itself to deliver good products to customers. This is because there are always variations in manufacturing due to people, equipment, materials, and manufacturing methods. This means that not all parts can be processed and assembled in an ideal state. Production engineering is therefore an elemental technology that is indispensable to manufacturing and necessary to keep such variations within acceptable limits and to deliver products with the target quality by design in an efficient, stable manner. You cannot compete with others by analyzing and mimicking the shape and materials of a product and then purchasing and installing off-the-shelf production equipment prior to manufacturing. That level of engineering is out of the question. The only way to gain the manufacturing expertise that will keep your company competitive is to master a manufacturing technology that other companies cannot imitate and produce it on a large scale.

3 Future Production Engineering

It has been said that the strength of the Japanese manufacturing industry lies in “on-site skills.” This is partly because factory workers have accumulated expertise, know-how, and their own methods over many years, which have worked well as tacit knowledge. While it is important to pass on this expertise of veteran workers, the problem has arisen that young workers are not easily recruited as the labor force shrinks due to a declining birthrate and an aging population.

On this other hand, KYB is working on an activity called Ship'30 (Self handling innovation plant 2030) to advance manufacturing for the next generation. We will create a self-sustaining unmanned factory driven by digital technology with minimal transportation, inventory, and operational tasks.

In order to respond to these societal and internal problems and to realize our aspirations, we need to further deepen the traditional role of production technology: providing good products quickly at reasonable prices. Specifically, we will promote automation technology that uses robots and AI to improve production efficiency, use real-time monitoring and data analysis that monitors the status of production equipment and processes and implements self-sustaining processes through abnormality detection and error prevention, and establish a flexible production system that can quickly adapt to changes in product specifications or production volume according to customer demands and achieve efficient utilization of labor.

In addition, to maintain and improve our global competitiveness, we need to use digital twins that combine these technologies with digital data to realize optimization and efficiency improvement in a virtual space. The essence of digital twins is to reproduce a mechanism and its operating state in physical space in a virtual space, thereby enabling simulation, analysis, and optimization. To achieve this, it is necessary to transform the flows of people and things on the production line into data and build a digital twin of the line. Currently, KYB has not fully prepared a database of production line knowledge, which is a future challenge. One of the possible benefits of digital twins is the transformation of value chain operations processes from product development, design, production, and shipping. When people, things, and information are connected throughout the value chain, it is possible to "front-load" work. By simultaneously designing products and processes in a data-driven way, efficient manufacturing can be discussed from the upstream. For example, manufacturing engineers can use digital twins to look at the chain from materials to finished goods to shipping, and suggest highly efficient, low-cost manufacturing to design engineers. By bringing the upstream process into our field of vision, we can help avoid getting caught up in the concentrated volume work just before mass production begins. In this way, we hope to shorten development time, maximize impact, and focus on our core mission of production engineering. I believe that as automation and efficient production progress, we will come closer to achieving the goal of "human-independent production" as a countermeasure to the shrinking labor force, which is one of the societal issues.

On the other hand, we must also promote sustainability initiatives to reduce environmental impact and achieve sustainable production. Our corporate spirit is "by providing technologies and products that make people's lives safe and comfortable, the KYB group dedicates to the society." To achieve this, production engineering must respond to societal challenges by improving energy efficiency in the manufacturing phase, changing existing processes to those that do not use environmentally harmful materials, and reducing waste.

4 In Closing

Production engineering involves researching and developing new technologies and processes to solve manufacturing problems, establishing specifications, and building and installing mass-production equipment. However, installing new technologies is not always easy. In fact, many times we have to use brute force to get the job done. In these days of louder calls for work style reform, circumstances need to change. This is one of the reasons why the number of people willing to work in production engineering has decreased in recent years. In order to overcome this situation, digital twins of production lines should be realized as mentioned above. We aim to realize attractive production engineering that enables front-loading of production technology development, sufficient offline preliminary verification, and smooth deployment of new technologies in mass production lines.

At the end of the day, manufacturing, or monozukuri, is about developing people. I want young engineers to feel that production engineering is interesting and rewarding. I want to develop the next generation of production engineers through their work, where they face and overcome difficult challenges.

Author

HABA Keiichi

Joined the company in 1994. General Manager, Production Technology R&D Center, Engineering Div.
Taken present post after engaging in welding R&D in R&D Sect. No.1 of the Center and working as the section manager.

Special Program

Technical Prospects for Automotive Components Business

BABA Tomohiko

1 Introduction

The word "automotive" is an adjective widely used to refer to "things related to automobiles" or simply "related to automobiles." As the driving of automobiles has become increasingly automated in recent years, there has been a growing demand to provide value related to general transportation rather than just driving. This is precisely the proposition of "mobility," which means "easy to move." For Automotive Components Operations, which mainly produces equipment and components for automobiles, motorcycles, and railways, the challenge for the future is how to adapt these products to the possible borderless mobility society of the future.

In order to realize the corporate spirit of "By serving technologies and products that make people's lives safe and comfortable, KYB group dedicates to the society," it is essential for Automotive Components Operations to collaborate in co-creation not only with Hydraulic Components Operations and the Special Purpose Vehicles Div., but also with external organizations, including those in other industries. In doing so, we should leverage our vibration control and power control expertise accumulated over many years to create new value. In an age where everything is connected to create value, we will provide technologies that connect things to things, things to people, and people to people, and work to solve societal issues related to mobility.

2 Eliminating Vulnerable road users

Many developed countries, including Japan, are facing declining birth rates and an aging population with fewer people able to own and drive cars. In the rural areas of these countries, the elimination or reduction of public transportation services hinders the free movement of people. Therefore, there is an urgent need to expand mobility with an automated driving function that can safely be used by everyone. By highly coordinating full-active suspensions for more aggressive vertical damping and steering-by-wire systems for more precise steering control with brake control, it will be possible to move comfortably to destinations without accidents. We will promote the development of actuators that enable such movement and devices/systems for interconnection.

3 Eliminating Environmental Degradation

Emerging countries and developing countries, also known as the Global South, are increasingly using more conventional means of transportation, such as cars and motorcycles. While we expect our hydraulic equipment to be more widely used in these countries, we need to consider environmental measures for the equipment throughout the product life cycle.

We are working on a development program to replace petroleum-derived hydraulic fluids used in shock absorbers, a core product of Automotive Components Operations, with those derived from natural materials. The aim of this replacement is to use raw materials derived from natural materials that absorb CO2 when they are being produced (for carbon neutrality), to ensure the biodegradability of the fluids in case of leakage, and to improve the recyclability of the products after disposal (Fig. 1). With this development program as an opportunity, we will apply life cycle environmental measures to all products and services handled not only by Automotive Components Operations but also by the company.

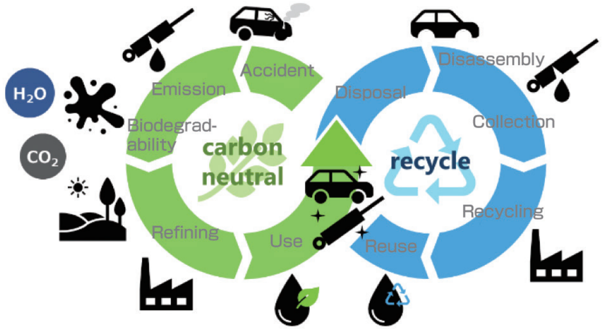

Fig. 1 Environmental measures for hydraulic fluids

In addition, KYB's Development Center (Kawabe-cho, Kamo-gun, Gifu Prefecture), the company's development headquarters, is working to coexist with wildlife in a lush green environment and to preserve Lespedeza tomentosa, a rare plant listed as an endangered species (Class II), as a contribution to local communities (Photo 1).

Photo 1 Environment around the Development Center

4 In Closing

As automobiles transform into mobility, we are beginning to provide value not only by making things (Monozukuri) but also by creating experiences (Kotozukuri). With the idea of shifting from competition to co-creation, we are developing human resources that can contribute to society, with an emphasis on connecting with people inside and outside the company.

Author

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Special Program

Technical Prospects for Hydraulic Components Business

NAKAMURA Masayuki

1 Introduction

Hydraulic Components Operations (hereinafter, HC) designs and manufactures its own hydraulic products for global markets. These core products include pumps, valves, motors, and cylinders for mobile equipment such as construction, agricultural, and industrial vehicles. Today's automotive market is undergoing dramatic environmental changes due to disruptive technological innovation based on digitalization and emerging competitive players. Such environmental changes are also occurring in other industries. The business environment in which HC operates is no exception.

This report outlines the technologies and products that HC is developing. In particular, it describes some research and development programs that engineers are working on with an eye to the future, contributing to increased competitiveness and the implementation of the growth strategy.

2 Overview of Technologies and Products Under Development

2. 1 Direction of Development

In response to the market's increasing demand for digitalization and carbon neutrality, we are developing electronically controlled hydraulic equipment and its sensors, as well as condition diagnosis systems using their combined technologies. In this way, we are working to create new value in addition to the traditional development of new models or lower-cost products.

2. 2 Research and Development System (Fig. 1)

HC manufactures its product groups (pumps, motors, valves, cylinders, and equipment) at various production plants in and outside Japan. HC's development teams stationed at these plants work to develop products in parallel with their production sites in a cost-conscious manner. The Engineering Div. includes the Basic Technology R&D Center, which conducts a wide range of advanced research on basic technologies such as materials, control, information, and electronics; the Production Technology R&D Center, which conducts advanced research on production techniques such as machining, assembly, and heat treatment; and the CAE Promotion Department., which supports the promotion of analysis technology. These departments constantly work with HC's development teams to support their development.

2. 3 New Departments for Electronification and Electrification

In addition, new functions have been created to speed up the development of products with integrated electrical/electronic elements, which are difficult to handle by engineering departments specializing in mechanical engineering alone.

These new functions are the System Engineering Department and the Advanced Electrification Unit Development Office. The System Engineering Dept. supports HC's engineering departments with electrical/electronic elements and devices such as sensors and electronic controllers, control system software development, and analysis technology including model-based development. The Advanced Electrification Unit Development Office conducts unit development specializing in electrification.

2. 4 Testing and Evaluation

Prototypes developed by the engineering departments are tested and evaluated by dedicated departments whose functions are different from those of the development departments. The evaluation of prototypes is carried out on testing equipment specific to the production site.

We are also developing and expanding actual machine test sites where developed products can be installed on the parent machine and evaluated and even demonstrated to validate the entire machine system. Through these sites, we are helping engineers improve their ability to develop systems and present them to customers.

The development teams of HC, the R&D teams of the Engineering Div., and the new functions work together on a daily basis to achieve synergy effects, improve the quality of technology and product development, and accelerate development.

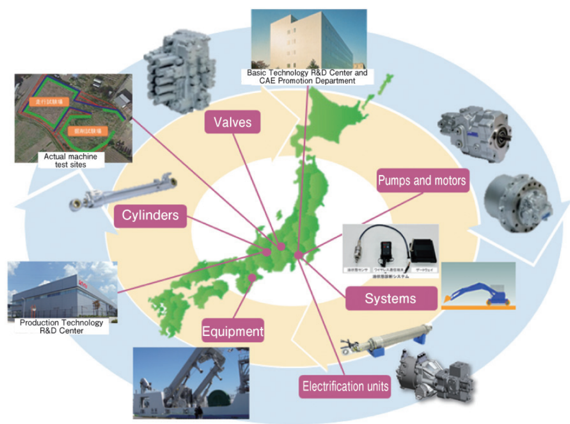

Fig. 1 Research and development system

3 Development for the Future

3. 1 Oil Condition Diagnostic System (Fig. 2)

We have developed a system for real-time diagnosis of the condition of the hydraulic fluid of hydraulic equipment used in plant equipment, construction machinery, or other equipment. Currently, it is common practice to periodically replace the fluid of hydraulic equipment to prevent the equipment from shutting down due to the occurrence of problems, even if the fluid is in good condition for use. The system we developed connects the target hydraulic equipment with sensors and communication devices to the customer via the cloud and analyzes and diagnoses the oil data using an algorithm based on the knowledge and expertise accumulated at KYB. The system uses the Internet of Things (IoT) to estimate whether the oil or equipment is deteriorating or abnormal, and suggests maintenance or replacement at the right time, contributing to less waste of hydraulic fluid or higher efficiency in maintenance operations.

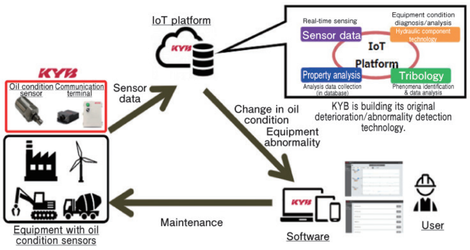

Fig. 2 Oil condition diagnostic system

3. 2 Energy Saving System for Excavators (Fig. 3)

We are currently developing an integrated electronically-controlled hydraulic system with a pump, valves, and ECU (software) for power excavators and other hydraulic equipment to improve productivity and reduce CO2 emissions. With the original system with electronic control, we aim to minimize energy consumption and improve operability, contributing to energy savings and higher productivity.

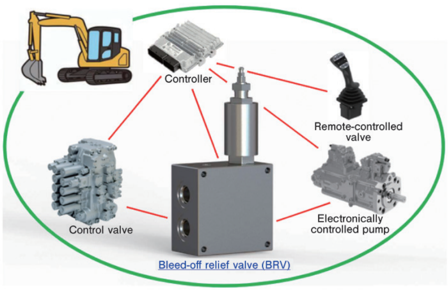

Fig. 3 Energy saving system for excavators

3. 3 Motor-driven Pump Unit for Construction Machinery (Fig. 4)

In the context of the global movement toward carbon neutrality, the construction machinery and industrial vehicle industries, including power excavators, are accelerating efforts to replace their diesel engines with motors. In line with these efforts, we are now developing a motor-driven hydraulic unit that integrates the variable displacement hydraulic pump for load sensing, which has proven its performance in mini excavators, with an inverter, motor, reduction gear, and motor oil pump for cooling. By combining the low-noise, high-efficiency variable displacement pump with the high-speed motor including the reduction gear, we will realize a highly efficient compact unit that will contribute to the achievement of carbon neutrality.

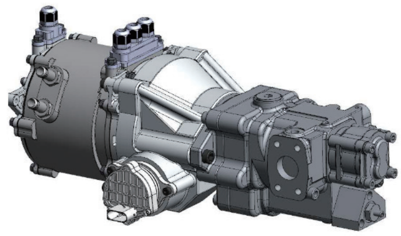

Fig. 4 Motor-driven pump unit

4 In Closing

Under the corporate spirit of “vitality, love and creativity” established by founder Shiro Kayaba, KYB has created its original products based on the “hydraulic DNA” relentlessly refined and inherited from the founder, thus contributing to the development of society. Traditionally, with the goal of contributing to energy savings and higher operability of parent machines, the company has continuously improved hydraulic equipment, especially by improving its circuits and increasing the pressure and efficiency of the equipment. By making full use of various analysis technologies for materials, fluids, mechanisms, and structures, it has mainly advanced its internally established proprietary technologies. But these are not enough. In addition to electric/electronic/motor technologies, we need to further combine digital technologies such as ICT/IoT with our existing technologies. In this way, promoting open innovation while introducing external management resources in a timely manner will be necessary conditions for us to accelerate commercialization and continue to grow.

KYB will continue to introduce external resources and combine them with its existing experience, track record, and technical capabilities to create value beyond customers' expectations. By improving the safety and productivity of construction machinery and agricultural equipment, we will help make people's lives more prosperous.

Author

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Special Program

Technical Prospects for the Special Purpose Vehicles Business

KAMIJYO Takashi

1 Introduction

The Special Purpose Vehicles Div. manufactures and sells concrete mixer trucks as its core product, as well as environmental products including pruned tree shredder trucks. The special purpose vehicles business will be exposed to significant changes in the external environment. We need to respond to the demand for electrification of trucks and create a second pillar product after concrete mixer trucks.

This report provides technical prospects for the special purpose vehicles business.

2 Responding to Changes in the External Environment

One of the changes in the external environment affecting the entire special purpose vehicles industry is the electrification of trucks to reduce CO_2 emissions during transportation. Truck manufacturers generally plan to electrify small vehicles first and then move on to larger vehicles. We believe it is our social responsibility to develop and launch concrete mixer trucks that are comparable to such electrified trucks. While working with truck manufacturers, we will propose drive systems for the mixer section to develop concrete mixer trucks with even higher energy efficiency.

3 Growth and Development of New Products

The Special Purpose Vehicles Div. has begun taking orders for a new motorhome (Fig. 1). Based on the concept of "a motorhome that stimulates the spirit of adventure and allows you to enjoy driving," the vehicle can be driven on highways, mountain roads, and even city streets thanks to the suspension and vehicle attachment technologies. The living space inside the vehicle has been designed to be luxurious and elegant, as if traveling to destinations in a cottage. It is important to get this product on the right track, although we have only just begun to work on motorhomes. To achieve this, we need to integrate technologies owned by other divisions, such as vibration control and hydraulic technologies, with the suspension and vehicle attachment technologies of the Special Purpose Vehicles Div. and thereby continue to develop new types of motorhomes. In this way, we need to expand our product range.

Fig. 1 Motorhome "VILLATOR"

4 In Closing

The Special Purpose Vehicles Div. has complete products that can show you what KYB is all about. As mentioned in the technical prospects above, we as members of the Special Purpose Vehicles Div. would like to develop and launch products using these technologies to give customers pleasure and fun and to enhance the KYB brand.

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Technical Article

Application of Ultrafine Bubbles to Grinding Processes

HATAYAMA Yousuke・MIZUTANI Masayoshi

Abstract

Ultrafine bubbles (UFBs) are microbubbles with diameters below 1 μm. Recent studies have shown that using a coolant containing UFBs (UFB coolant) in grinding processes can improve grinding performance and machining accuracy. However, the mechanism behind this effect remains unclear. While some studies attribute the improved performance to the superior wettability of UFB coolant compared to conventional coolant, this alone cannot fully explain the effects, as there are instances where UFB coolant does not provide significant benefits.

One notable property of UFBs is their ability to generate hydroxyl radicals (OH) upon collapse, which may promote oxidation on workpiece surfaces. This study explores the role of surface oxidation in the grinding performance of UFB coolant. Experiments revealed that the degree of surface oxidation and the composition of oxides vary depending on the type of gas used in UFB water. Friction and wear tests further demonstrated that the gas type in UFB coolant affects the coefficient of friction, which aligns with differences in grinding performance. These findings suggest that the oxidation induced by UFBs influences the friction and wear characteristics of workpieces, leading to changes in grinding performance.

1 Introduction

The term "fine bubbles" is a general term for microbubbles having a diameter of 100 μm or below. Bubbles with diameters above 1 μm are called microbubbles, and those having a diameter of 1 μm or below are called ultrafine bubbles (UFBs). This terminology is defined by the International Organization for Standardization (ISO)[1].

One characteristic of UFBs is that they are colorless and transparent. They also remain in water for a long time. Due to these characteristics, UFBs are used in various fields such as cleaning, disinfection, and water purification[2]. In recent years, many studies[3-8] have reported that the use of coolant containing UFBs (UFB coolant) in grinding processes can improve grinding performance and machining accuracy. In these studies, the reasons for this effect have been investigated and discussed mainly from the point of view of wettability. Kobayashi et. al. reported that UFB coolant contributes to lower contact angle than conventional coolant[6], while Watanabe et. al. reported that UFB coolant contributes to lower slip angle and lower surface tension than conventional coolant[7,8].

On the other hand, we have indicated that there is no significant difference in wettability between conventional coolant and UFB coolant depending on the presence or absence of UFBs and have confirmed that the grinding performance varies even in this situation[9]. This result suggests that the effect of UFBs in grinding processes may involve a factor other than wettability. We think that this factor is due to the collapse of UFBs.

It is known that when UFBs collapse, their interiors reach high temperatures and high pressures due to adiabatic compression and that collapsing UFBs break the surrounding water particles to generate hydroxyl (HO) radicals[Note 1], which are strong oxidants[10,11], and release high-pressure energy to the surrounding substances. Focusing on these phenomena, we have also confirmed that, when a piece of carbon steel is immersed in refined water or UFB water, stronger oxidation of the workpiece surface occurs in the UFB water. Additionally, we have confirmed that there is a difference in the friction characteristics of the oxidants generated on the workpiece surface depending on the presence or absence of UFBs [9].

In light of the above findings, this paper investigates and discusses how UFBs may affect grinding processes from the point of view of workpiece surface oxidation. Specifically, we hypothesized that the degree of workpiece surface oxidation can vary with the type of UFB gas, as long as the probability of UFB collapse depends on the type of UFB gas and the UFB collapse affects the workpiece. Based on this hypothesis, we immersed test pieces in several UFB waters with different types of gas and UFB coolant and left them as they were to observe changes in surface properties. We then examined changes in the composition of the oxidants produced and the effect of these changes on the friction and wear characteristics of the materials. In addition, assuming actual machining, we immersed untreated test pieces (not previously immersed or left in UFB water or UFB coolant) in UFB coolant and subjected them to friction and wear tests to determine their changes. Finally, we performed a surface grinding test using a common grinder to validate the hypothesis.

Note 1) Highly reactive chemical species composed of oxygen and hydrogen atoms. Have strong power to cause oxidation reaction.

2 Experimental Methods

2. 1 UFB Generation Conditions

In this paper, a UFB generator originally developed by KYB [9] [12] was used. Of the various UFB generation principles [13], the rotary shear method with a static mixer was chosen for the generator to achieve high density and high flow rate. Four evaluation fluids were used: [1] purified water, [2] UFB water, [3] coolant diluted with purified or tap water, and [4] UFB coolant. The coolant used was a water-soluble synthetic solution type with a concentration of 2.5%. Fluid [2] was purified water exposed to the UFB generator. Fluid [3] was the coolant that had been diluted to a specified concentration with purified water for immersion or friction/wear testing, or with tap water for grinding testing, and then circulated (mixed) in the UFB generator without gas injection. Fluid [4] was the same coolant as [3] that was introduced into the UFB generator and subjected to gas injection to generate UFBs. Table 1 shows the UFB generation conditions, where the gas concentration is the ratio of the gas flow rate to the fluid flow rate (volumetric flow rate at standard conditions), and the number of passes is the number of times the fluid was circulated. The number of passes for UFB generation was set as shown in Table 1 for the following reasons. The number of passes for water was set at 360 to achieve a UFB number concentration of approximately 1.0 billion/mL. The number of passes for coolant was set at 40, which has been shown to improve the grinding ratio [9]. Three gases were selected for the following reasons. Air was chosen because of its widespread use and high practicality. O_2 was chosen because we believed that an O_2-rich environment was suitable for aggressive oxidation of the workpiece. CO_2 was chosen because existing studies had shown that the CO_2-UFB density decreased by 90% 30 minutes after UFB generation, causing CO_2-UFBs to collapse easily [14]. When UFBs collapse, OH radicals are generated [10] [11] to facilitate oxidation of the workpiece.

The initial UFB number concentration of UFB water was 1.14 billion/mL for Air-UFB, 0.96 billion/mL for O_2-UFB, and 0.11 billion/mL for CO_2-UFB. CO_2-UFB generation was only about one-tenth that of the other gases, even under the same generation conditions. This is probably because CO_2-UFBs collapse easily in the stage immediately following UFB generation and are unable to remain stable bubbles for long.

Several methods exist for measuring UFB number concentration [15]. In this paper, particle tracking analysis (NanoSight NS300 NTA3.4, Malvern) was employed. In this method, particles suspended in a liquid are illuminated with a laser to emit scattered light, which is captured by an objective lens and filmed. This allows all particles to be tracked on the screen, allowing particle size and number to be measured from their Brownian motion velocity [16]. However, it should be noted that this method could not quantify the number of UFBs in the UFB coolant, because the method cannot distinguish UFBs from particles in the coolant itself, due to the measurement principle.

Table 1 UFB generation conditions

Liquid	Type	Water	Coolant
Gas	Type	Air, O_2, CO_2	
	Concentration	2.5%	
Disk speed		2400rpm	
Number of passes		360	40

2. 2 Test pieces

The test pieces used in this paper were made of S50C (or S45C according to a component analysis from the corrosion rate and XPS mentioned later), which had been quenched and tempered to have a hardness of 504.1 to 591.3 HV (N = 10 measurements). Their dimensions were 50 mm (length) x 50 mm (width) x 10 mm (thickness). One test piece was cut into 15 mm x 15 mm pieces for use in the immersion or friction/wear test. The surface of the test piece to be evaluated in the immersion or friction/wear test had been ground prior to use to remove any cutting marks or oxidation scale. The surface roughness after grinding was R_a 0.36 to 0.48 μm (N = 10 measurements).

2.3 Immersion Test

To determine the effects of the UFB collapse and gas type on the oxidation of the test piece surface, the test piece was immersed in the evaluation fluids. Changes in the test piece were visually observed. Fig. 1 shows a sketch of the immersion test. 400 mL of evaluation fluid was poured into a glass bottle, and the test piece was immersed with the surface to be evaluated facing up and left standing. The test piece surface was visually inspected for five days. If the surface was oxidized, the oxides were evaluated for composition and corrosion rate.

The composition of the oxides was analyzed by X-ray spectroscopy (XPS) [Note 2) 17)]. An XPS analyzer (Thete Probe, Thermo Scientific) was used for the composition analysis.

Corrosion rate is a measure of how much a metal corrodes over a given period of time. We evaluated the corrosion rate to determine how deep the oxidation was progressing. In general, the corrosion rate is determined based on the decrease in mass of the test piece because some types of corrosion can progress locally, making it difficult to determine the decrease in thickness of the test piece. The corrosion rate can be calculated using the following equation [18]:

$$W = \frac{M_1 - M_2}{S \times T} \tag{1}$$

where W is the corrosion rate [mdd], M_1 is the mass of the test piece before the test [mg], M_2 is the mass of the test piece after the test [mg], S is the surface area of the test piece [dm^2], and T is the number of days of the test. A higher corrosion rate indicates a higher degree of corrosion. In this paper, the corrosion rate was evaluated three days after the immersion.

Note 2) A method of qualitatively analyzing elements on the surface of a material, or analyzing the chemical composition and chemical bonding state of the surface, by detecting and measuring the spectrum of light electrons emitted by samples of the material when irradiated with X-rays.

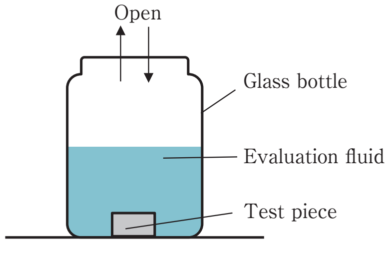


Fig. 1 Sketch of immersion test

2. 4 Evaluation of Friction and Wear Characteristics

Assuming the use of UFBs in grinding processes, friction and wear tests were conducted to clarify the phenomena of friction and wear between the workpiece and the abrasive grains. A ball-on-disk type testing machine was used for these tests. Fig. 2 shows the experimental system. A friction and wear testing machine (FPR-2000, RHESCA) was used in the experiments. As shown in the figure, the test piece is mounted on a tray fixed on a table. The table is moved linearly from side to side to slide the test piece against the ball. The ball is then pulled in the sliding direction due to the friction force between the ball and the test piece. This friction force is measured by a load cell inside the tester and divided by the weight of the load (applied load) to obtain the coefficient of friction. The ball is made of aluminum oxide, which corresponds to the abrasive grains used in the grinding experiments described later.

The test conditions are given in Table 2. Firstly, to investigate the characteristics of the oxides formed, the tests were carried out in a dry environment using the test pieces obtained in the immersion test described in section 2.3. Secondly, to determine the relationship between the test piece oxidation induced by UFBs and the machining of the material and to study its effect on the friction and wear phenomena in actual machining, untreated test pieces were immersed in the evaluation fluids and subjected to the friction and wear tests. After the tests, the wear marks were observed using a digital microscope (VHX-5000, KEYENCE). The area of the wear marks was calculated from the recorded images.

2. 5 Grinding Experiments

In order to verify the validity of the hypothesis about the mechanism behind the UFB effect on the grinding processes studied in the immersion and friction and wear tests, the grinding performance was evaluated in actual machining. The grinding conditions are shown in Table 3. A precision surface grinding machine (EPG-63S, NAGASE INTEGREX) and a WA resinoid grinding wheel (WA100M8B, MITSUI GRINDING WHEEL) were used. The depth of cut and grinding velocity were set at two levels. The combination of a depth of cut of 0.004 mm and a grinding velocity of 83.3 mm/sec. is called the low machining load condition, while the combination of a depth of cut of 0.010 mm and a grinding velocity of 104.2 mm/sec. is called the high machining load condition. These different conditions were set to determine whether the UFB effect varies with the balance between the oxidation rate and the machining speed, based on the estimation that the oxide layer caused by UFBs is considerably thinner than the depth of cut.

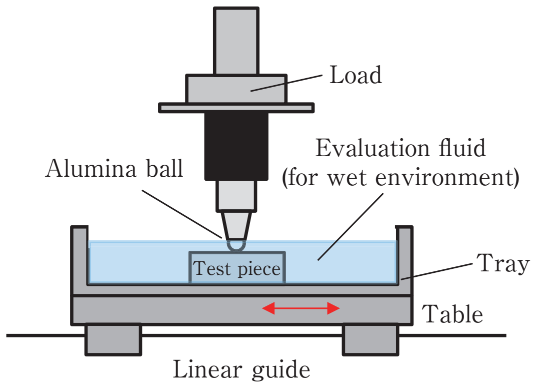


Fig. 2 Experimental system for friction and wear tests

Table 2 Test conditions for friction and wear tests

Test environment	Dry	Wet
Travel	5 mm	
Linear velocity	5 mm/s	
Weight of load	100g	
Test duration	1800s	5400s

Table 3 Grinding conditions

Item		Unit	Low machining load	High machining load
Grinding wheel	Dimensions	[mm]	$\phi 300 \times 30$	
	Peripheral speed	[m/s]	28	
Depth of cut		[mm]	0.004	0.010
Grinding velocity		[mm/s]	83.3	104.2
Removal amount		[mm]	0.8	
Number of grindings		[time]	200	80

Fig. 3 shows an illustration of the measurement of grinding force. A multicomponent dynamometer (9257B, Kistler) was used to measure grinding force. Normal force Fn and tangential force Ft are expressed in Equations (2) and (3) [19]:

$$F_n = C_p \left(\frac{\pi V_W tb}{2V_G}\right) \tan\alpha \quad (2)$$

$$F_t = C_p \left(\frac{V_W tb}{V_G}\right) \tan\alpha + \mu F_n \quad (3)$$

where V_w is the grinding velocity, t is the depth of cut, b is the grinding width, V_G is the peripheral speed of the grinder, μ is the coefficient of friction between the grinder and the workpiece, α is the half-apex angle of the grain, and C_p is the specific grinding energy. The value obtained by dividing F_n by F_t is the ratio of the two force components. A lower ratio of the components indicates higher cutting performance and better grip, while a higher ratio of the components indicates a lower coefficient of friction.

Fig. 4 shows an illustration of grinding ratio measurement. The grinding ratio is calculated by dividing the volume of workpiece removed by the volume of abrasive wear. A higher grinding ratio indicates less abrasive wear. As shown in Fig. 4, when a workpiece narrower than the Grinding wheel is ground, the grinding surface of the Grinding wheel has a step. This step was transferred to a carbon block. The profile of the transferred surface was used to measure the step and determine the volume of Grinding wheel wear.

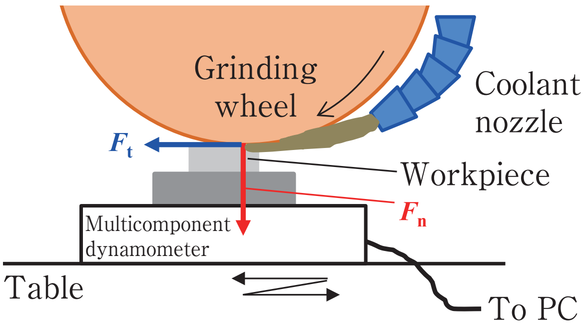


Fig. 3 Grinding force measurement system

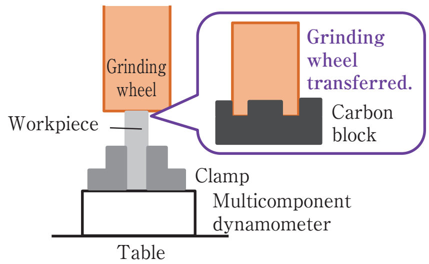


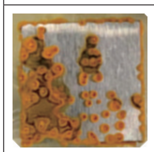
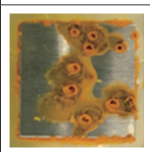
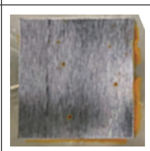
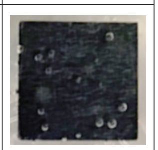
Fig. 4 Grinding ratio measurement system

3 Results and Discussion

3. 1 Behavior of Test piece Surface Oxidation Induced by UFBs

Table 4 shows pictures of the appearance of the test pieces immersed in the water group (purified water, UFB water) for one day. All of these test pieces have rust on the surface and can be visually identified as oxidized. Focusing on the difference in appearance between the different gases, the test pieces in the purified water and the Air-UFB water show similar changes, but the latter has a slightly larger oxidized area. The test piece in the O_2-UFB water has almost no rust, although slight rust can be seen near the edges. This is probably because O_2-UFBs exist stably in water and are unlikely to collapse [20]. Without a collapse of bubbles, which is the trigger for oxidation, the test piece in O_2-UFB was therefore probably not easily oxidized. The unlikelihood of the test piece being oxidized is also due to the high amount of dissolved oxygen in the O_2-UFB water. In an environment with high levels of dissolved oxygen, steel undergoes passivation, resulting in a significantly lower corrosion rate [21]. A measurement of the amount of dissolved oxygen in the O_2-UFB water during preparation showed a maximum of about 38 mg/L. This is about 4.5 times the saturation dissolved oxygen. This means that the high concentration of dissolved oxygen facilitated the passivation of the test piece surface to suppress the corrosion (oxidation) of the material surface.

Table 4 Appearance of test pieces (per water group, after 1-day immersion)

Purified water	Air-UFB water	O_2-UFB water	CO_2-UFB water
			

In contrast, the test piece in the CO_2-UFB water showed completely different changes than the other gases. While the test piece immersed in the O_2-UFB water partially rusted in red, the test piece immersed in the CO_2-UFB water was completely black. This is due to the likelihood of CO_2-UFBs collapsing [14] to facilitate oxidation of the workpiece, and the acidic solution containing carbonic acid produced when CO_2 was dissolved in water. These changes probably facilitated the oxidation of the test piece surface to produce oxides with a characteristic composition.

Table 5 shows the appearance of the test pieces immersed in the coolant group (coolant diluted with purified water, UFB coolant) for five days. All of these specimens show no visible oxidation. This is probably due to the anticorrosive effect of the coolant itself. Thus, simply immersing the test piece in any coolant and leaving it there will not cause oxidation.

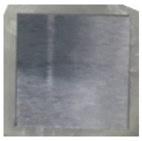
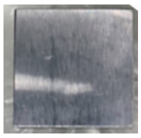
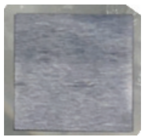
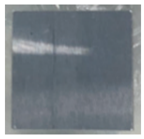
3. 2 Corrosion Rate of test pieces

Fig. 5 shows the results of measuring the corrosion rate of the test pieces oxidized in UFB water. The error bars indicate the maximum and minimum limits of the measurement with N = 3. With respect to the corrosion rate of the test piece in purified water, the test piece in Air-UFB shows 2.4 times, the one in O_2-UFB shows 1.0 times, and the one in CO_2-UFB shows 8.9 times. These results indicate that the presence of UFBs facilitates the oxidation of the test pieces (S50C) used for this study. It should be noted that the test piece in the O_2-UFB water has a corrosion rate almost equal to that of the test piece in purified water, although the former has a smaller oxidized area (Table 4). This is probably because the test piece in the O_2-UFB water is appreciably oxidized in the depth direction, despite the small surface area where oxidation can be visually identified.

3. 3 XPS Analysis of Oxides

Fig. 6 shows the XPS spectrum related to the oxides of the test pieces oxidized in UFB water, and Fig. 7 shows the ratio of the components of the spectrum related to the oxides. In Fig. 6, where the horizontal axis indicates the chemical bonding energy, the graph shows specific values depending on the elements and their chemical bonding state. The "measured" curve is drawn by plotting the raw data obtained by measuring the intensity of the light electrons emitted by the test piece as a function of the bonding energy. The "background" curve represents unnecessary signals due to secondary or scattered electrons. This background data has been subtracted from the measured data and the resulting peaks have been factorized into several model functions and then synthesized. The result is plotted as the "synthesized" curve. In this way, the contribution of each element and its chemical state can be analyzed while reproducing the peak of the measured data [22) 23)].

Table 5 Appearance of test pieces (per coolant group, after 5-day immersion)

Coolant diluted with purified water	Air-UFB coolant	O_2-UFB coolant	CO_2-UFB coolant
			

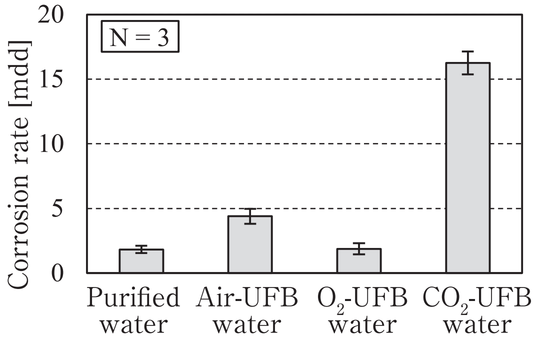


Fig. 5 Corrosion rate of test pieces

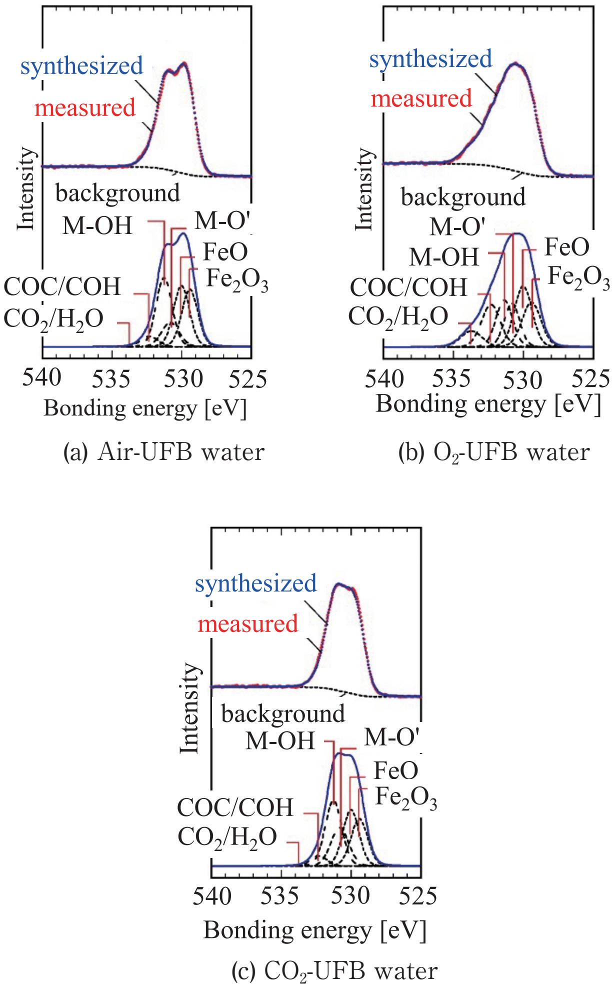


Fig. 6 Spectrum related to oxides of oxidized test pieces

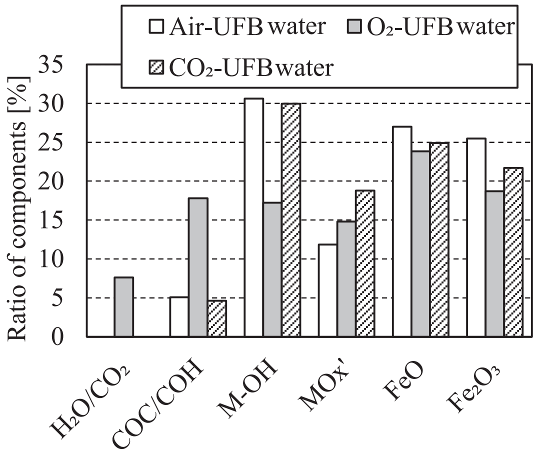


Fig. 7 Ratio of components of the spectrum related to oxides

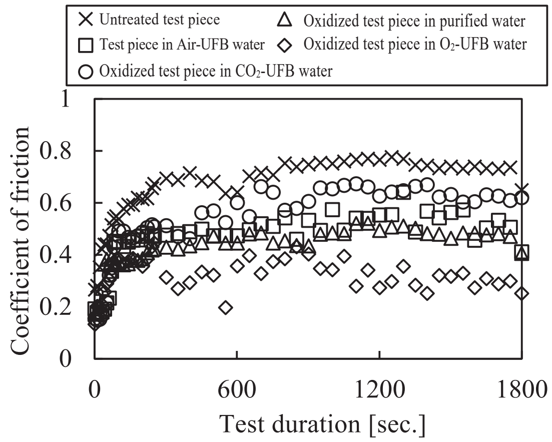


Fig. 8 Coefficient of friction of oxidized test pieces

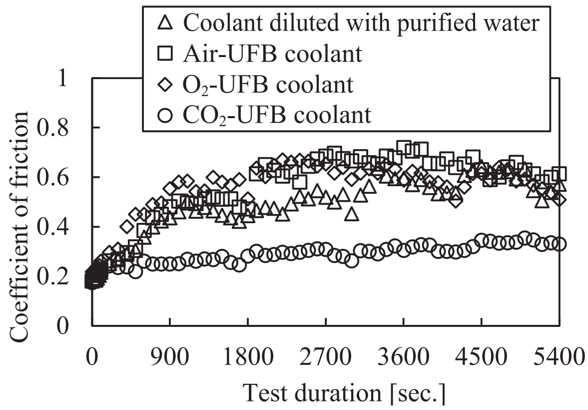


Fig. 9 Coefficient of friction of untreated test pieces

Fig. 7 shows that the peak shapes and the composition after separation differ from gas to gas. Specifically, the spectrum for the Air-UFB water increases in the upper right direction with higher proportions of FeO and Fe_2O_3, while the spectrum for the CO_2-UFB water increases in the upper left direction with higher proportions of M-OH' and MOx', which involve high bonding energy. We also examined the Fe 2p spectrum associated with black rust, but did not observe any difference in the spectral profile between different UFB gases. It was verified that the test pieces were oxidized in different visually detectable ways to produce oxides of different compositions depending on the type of UFB gas.

3. 4 Friction Characteristics of Oxides Produced by Various UFBs

The oxides produced in section 3.1 were subjected to the friction and wear tests. The results are shown in Fig. 8. The tests were conducted with N = 3 to 5 for each condition, from which typical data have been plotted in the figure after confirming that the data have little variation. According to the figure, the test pieces oxidized by different UFBs show lower coefficients of friction than the untreated test pieces. The coefficient of friction was highest in the specimen in CO_2-UFB water, almost same level in the test pieces in purified water and Air-UFB water, and lowest in the test pieces in O_2-UFB water. The lowest coefficient of friction in the O_2-UFB water is due to the deep oxidation in the depth direction over a tiny oxidized area which is almost impossible to identify visually (Table 4). Thus, the dry friction and wear tests have shown that the oxides generated in the O_2-UFB water have the lowest coefficient of friction.

3. 5 Friction Characteristics That Simulate Actual Machining

To simulate actual machining, untreated specimens were immersed in the coolant diluted with purified water and various UFB coolants and subjected to the friction and wear tests as they were. The resulting changes in the coefficient of friction are shown in Fig. 9. Similar to section 3.4, these tests were conducted with N = 3 to 5 for each condition, from which typical data have been plotted in the figure. Although these test pieces were not found to have any visually detectable oxidation when simply immersed and left standing (Table 5), Fig. 9 shows a significant difference in the coefficient of friction between the gas types. In the friction and wear tests on the immersed test pieces, the lowest coefficient of friction was found in the test pieces in CO_2-UFB. The test pieces in O_2-UFB, which had the lowest coefficient of friction in the evaluation of the oxides themselves (Fig. 8), showed a coefficient of friction equivalent to those in Air-UFB in the immersion tests.

Fig. 10 shows an example of wear marks and Fig. 11 shows the results of the wear mark area measurement. The error bars in Fig. 11 indicate the maximum and minimum limits of the measurement with N = 3. A statistical test with a significance level of 5% was performed to find a significant difference in the wear mark area. Thus, in this experimental system, it was confirmed that the wear mark area for the UFB coolant was equal to or slightly larger than that for the coolant diluted with purified water. This is probably because the oxidation induced by UFBs facilitates the removal of material.

Based on the results of section 3.1 and this section, the mechanism behind the UFB effect in

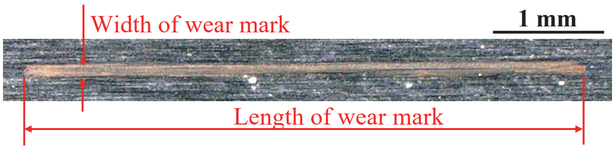


Fig. 10 Example of wear marks (Air-UFB coolant)

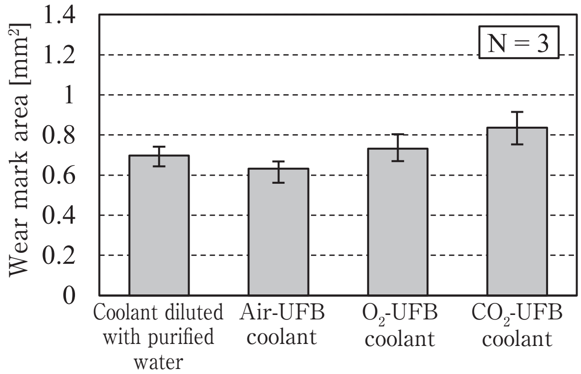
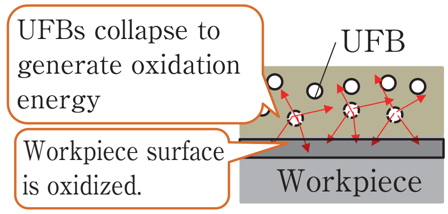
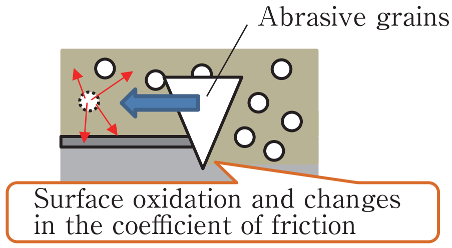


Fig. 11 Results of wear mark area measurement



(a) Collapse of UFBs and oxidation of workpiece surface



(b) Changes in the coefficient of friction due to oxidized workpiece surface

Fig. 12 Conceptual diagram of the mechanism behind the UFB effect on grinding processes

the coolant is discussed below. As mentioned above, the test pieces that were simply immersed and left in the evaluation fluids of the coolant group did not show any visually detectable changes in appearance, but they did show a significant difference depending on the gas type in the friction and wear tests. This suggests that the UFB effect in the coolant cannot be obtained without some movement, such as mixing, near the machining point. The dynamic stimulus may contribute to the collapse of the UFBs to cause continuous oxidation of the test piece surface, resulting in the changes in friction and wear characteristics.

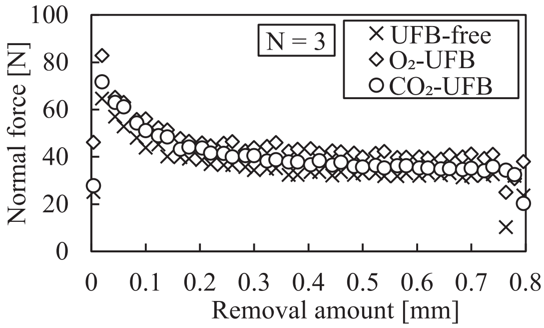
The above discussion is summarized in Fig. 12. In the vicinity of the machining point, UFBs collapse due to the high-speed rotation of the grinding wheel and other factors. The collapse of UFBs produces OH radicals, which oxidize the workpiece surface to change the surface properties (Fig. 12(a)). In particular, the surface being ground has a high surface energy due to material removal [24] which makes it easily oxidized. Grinding is a phenomenon of friction and wear between the workpiece surface and the abrasive grains. With the collapse of UFBs, the workpiece surface is oxidized to change its friction and wear characteristics, resulting in changes in the grinding performance (Fig. 12(b)).

3. 6 Grinding Performance Using UFB Coolant

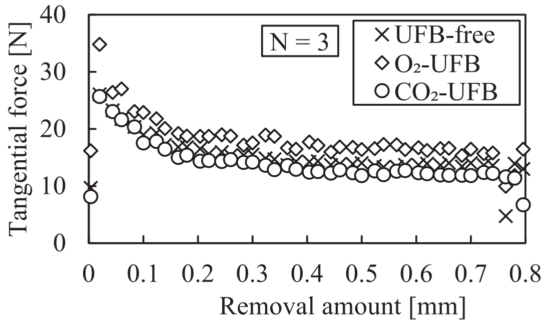
This section describes a surface grinding experiment we conducted using O_2-UFB and CO_2-UFB coolants that exhibited the distinctive friction and wear characteristics described in sections 3.4 and 3.5.

Figs. 13 and 14 show the grinding force measurement results and Fig. 15 shows the component ratio calculation results. Machining was carried out with N = 3 for each condition, the average of which is shown in the figures. Under the low machining load condition, the normal force was O_2-UFB > CO_2-UFB > UFB-free and the tangential force was O_2-UFB > UFB-free > CO_2-UFB (Fig. 13). Under the high machining load condition, following the removal of 0.1 mm or larger, the normal force was UFB-free > O_2-UFB > CO_2-UFB and the tangential force was UFB-free > O_2-UFB > CO_2-UFB (Fig. 14). The ratio of the two force components was CO_2-UFB > O_2-UFB ≃ UFB-free for both grinding conditions (Fig. 15), suggesting a decrease in the coefficient of friction between the grinder and the workpiece. These results are consistent with those of the wet friction and wear tests (Fig. 9).

Fig. 16 shows the grinding ratio measurement results. The error bars indicate the maximum and minimum limits of the measurement with N = 3. The grinding ratio under both conditions was improved compared with UFB-free, although the grinding force decreased or increased depending on the gas type. Under the low machining load condition, the grinding ratio for both O_2-UFB and CO_2-UFB was 1.3 times that of UFB-free, with no difference between gas types. However, under the high machining load condition, the grinding ratio for O_2-UFB was 1.2 times and that of CO_2-UFB was 1.7 times, showing the high effect of CO_2-UFB. This is probably due to the difference in the oxides produced. Iron oxide, which is rust formed on the surface of metallic materials, is very hard [25], brittle, and prone to peeling. This means that the workpiece surface oxidized by UFBs is likely to be removed. Oxides produced by O_2-UFBs have a high coefficient of friction, allowing the abrasive grains to grip the workpiece well. The grinder appears to have a very sharp tool, as if it had been dressed for high cutting performance. On the other hand, the oxides produced by CO_2-UFBs have a low coefficient of friction. This suppresses grain wear to improve the grinding ratio.

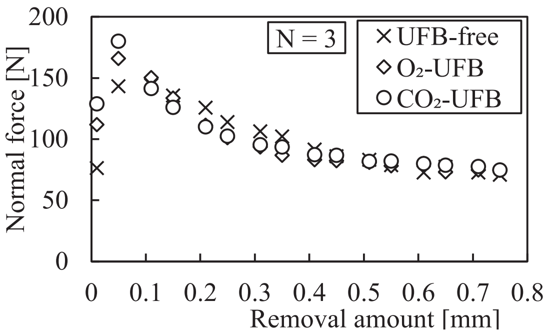


(a) Normal force

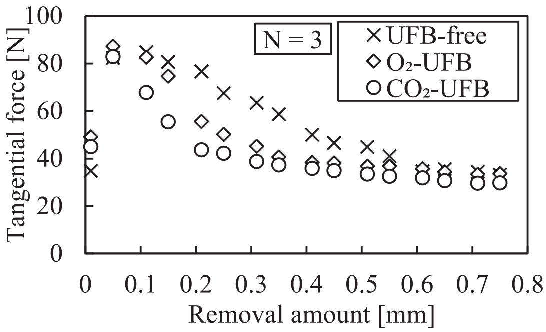


(b) Tangential force

Fig. 13 Results of grinding force measurement (low machining load)



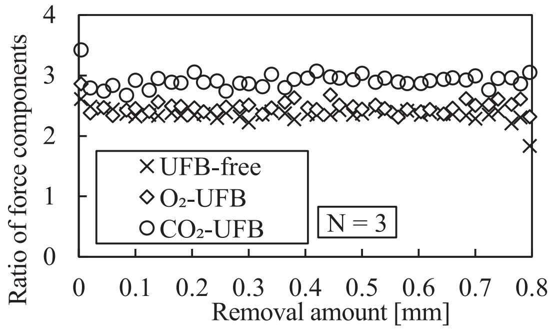
(a) Normal force



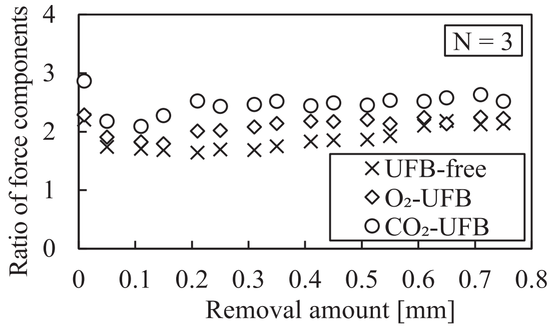
(b) Tangential force

Fig. 14 Results of grinding force measurement (high machining load)

It is discussed below why the test pieces in dry or wet conditions show a high or low coefficient of friction depending on the gas type, resulting in different degrees of improvement in the grinding ratio. This is probably due to the susceptibility of



(a) Low machining load



(b) High machining load

Fig. 15 Results of calculation of the ratio of force components

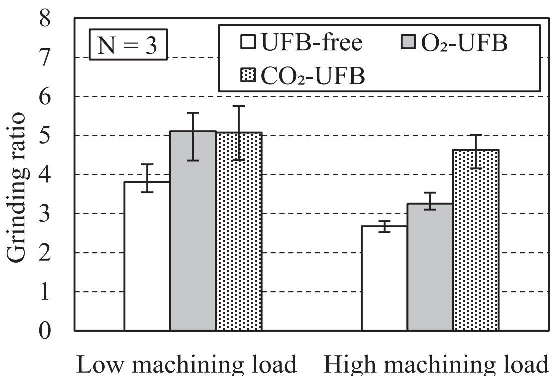


Fig. 16 Results of grinding ratio measurement

UFBs to collapse depending on the gas type. While O_2-UFBs are suitable for test pieces that are oxidized on the surface over a long period of time, such as in immersion testing, CO_2-UFBs are suitable for continuous oxidation of the workpiece surface over a short period of time, such as during grinding. In particular, when the workpiece has a lower coefficient of friction to reduce the tangential grinding force, its material is susceptible to removal, resulting in an improved grinding ratio.

4 Conclusions

In this paper, the mechanism behind the UFB effect on grinding processes using UFB coolant was investigated and discussed by conducting immersion and wear/friction tests, focusing on the oxidation of the workpiece surface induced by the collapse of UFBs. In addition, grinding experiments were conducted for verification to obtain the following:

(1) In water, the degree of oxidation of the test piece surface and the composition of the produced oxides depends on the type of UFB gas.
(2) In coolant, test pieces will not oxidize on the surface simply by being immersed in coolant and left standing. However, adding a dynamic stimulus, such as mixing, changes their friction and wear characteristics.
(3) The type of gas used in the UFB coolant affects the grinding performance. This change is consistent with the results of the friction and wear tests.
(4) These tests have shown that the oxidation of the workpiece surface induced by UFBs affects the friction and wear characteristics, leading to changes in grinding performance. This is the mechanism of the UFB effect in grinding processes.

5 Acknowledgement

This paper has been reprinted with permission from the following papers, with some modifications:

1. HATAYAMA Yousuke, OKOSHI Hiromu, MORI Terumi, YOSHIDA Futoshi, KURIYAGAWA Tsunemoto, MIZUTANI Masayoshi: “Development of high-concentration ultrafine bubble generator system for grinding process”, Journal of the Japan Society for Abrasive Technology, Vol.67, No.12, pp.657-663 (2023).
2. HATAYAMA Yousuke, OKOSHI Hiromu, TERADA Yuichiro, MORI Terumi, YOSHIDA Futoshi, KURIYAGAWA Tsunemoto, MIZUTANI Masayoshi: “Surface Oxidation and Friction/Wear Characteristics of Carbon Steel by Ultrafine Bubble Coolant”, Journal of the Japan Society for Precision Engineering, Vol.90, No.2, pp.253-258 (2024).

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Technology Explanation

Construction of CFD Analysis Technology for Internal Gear Pumps

SHIMIZU Tomoka・SUZUKI Kazunari

Abstract

The electrification of vehicles has accelerated the development of eAxle drive units from the viewpoints of energy saving, compactness, and low cost. The use of hydraulic pumps in these eAxle units is diversifying, and demand for cooling and lubrication applications is increasing. On the other hand, hydraulic pumps used in automobiles are required to be more efficient and quieter from the viewpoints of energy conservation and low noise. To meet these performance requirements, design strategies based on theory and phenomenology are necessary, and CFD (Computational Fluid Dynamics) analysis technology has been used to predict pump flow characteristics and optimize pump design.

In this paper, we focus on the flow characteristics of an internal gear pump and confirm the prediction accuracy of CFD analysis technology. The causes of flow reduction are mentioned, and a highly accurate prediction technique is obtained by considering crevice leakage, bubbles, and cavitation. In addition, a case study of the application of this technology to a development project of engineering department and its improvement is reported.

1 Introduction

The automotive industry has promoted the electrification of vehicles as an environmental measure and has accelerated the development of eAxle drive units from the viewpoints of energy saving, compactness, and low cost. The eAxle unit is a package product consisting mainly of gears, motors and inverters, in which oil is often used to lubricate the gears and cool the motors. The oil is supplied by hydraulic pumps for lubrication or cooling. KYB is currently developing an internal gear pump for these lubrication and cooling applications. Similar to the drive units, these internal gear pumps are required to be energy saving (higher efficiency of pumps). In addition, the pumps themselves need to be even quieter, in line with the trend towards low-noise vehicles due to electrification. In response to these requirements, various measures are taken, including reducing pressure loss due to fluid resistance, reducing crevice leakage, adjusting the timing of port operation, and stabilizing internal pressure. To meet even higher performance requirements, design strategies based on theory and phenomenology are necessary. KYB uses Computational Fluid Dynamics (CFD) analysis technology. Focusing on the flow characteristics of internal gear pumps, this paper explains the analysis technology for internal gear pumps based on the flow characteristics of hydraulic pumps, along with a case study of applying the technology to an internal gear pump development project.

2 Analysis

2. 1 Flow Characteristics

Fig. 1 is a graphical representation of the speed-flow characteristics of common hydraulic pumps. The dashed line shows the theoretical discharge flow, and the solid line shows the actual discharge flow. The theoretical flow of a hydraulic pump is calculated from the displacement and speed of the pump and is therefore proportional to speed. In reality, higher speed results in higher flow loss. This flow loss is dominated by the loss due to internal leakage up to a certain speed level: the theoretical flow is reduced by the same amount as the leakage loss ([1]). As the speed continues to increase, the internal flow rate increases, causing local pressure drops in the suction line and pump chamber. These contribute to larger bubbles in the oil and the occurrence of cavitation to reduce the ratio of oil volume to suction volume, resulting in a significant reduction in flow ([2], [3]) [1].

The ratio of theoretical flow to actual flow is called volume efficiency, which is used as a measure to evaluate the efficiency of hydraulic pumps. Therefore, one of the approaches to increase pump efficiency is to increase the volume efficiency, in other words, reduce the flow loss.

KYB designs and analyzes hydraulic pumps considering [1] through [3] in Fig. 1, which are the major causes of flow loss.

[1] Crevice leakage inside the pump

A hydraulic pump, which has rotating and oscillating motions, has clearances between its parts to prevent seizure. These clearances can be passages for the fluids, including the flow of oil from the suction port to the discharge port caused by pumping and the flow of oil circulating inside the pump through the clearances. Therefore, the suction flow is reduced by the same amount as the internal circulation flow to become the discharge flow, resulting in lower volume efficiency.

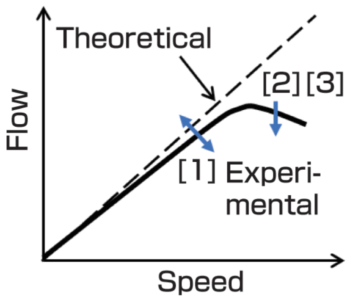

Fig. 1 Speed-flow characteristics

In addition, when high-pressure oil enters the low-pressure zone due to internal leakage, the pressure pulsation is exacerbated, causing a noise problem. Therefore, the clearances, which are essential to prevent seizure and can cause lower volume efficiency and noise problems, must be properly designed to prevent seizure and reduce leakage.

[2] Bubbles in the oil

Fig. 2 shows a visualized section of the suction oil passage of a vane pump. The white dots in the oil passage represent bubbles contained in the hydraulic oil. These bubbles are created when the hydraulic oil is mixed with air during oil mixing or tank oscillation in the hydraulic circuit and have flown into the pump. For example, in the continuously variable transmission (CVT) system, which is used to continuously change the gear ratio of an automobile, it is said that 10% to 30% or more bubbles are contained in the hydraulic fluid in the hydraulic circuit.

These bubbles in the oil swell as the pump speed increases to produce a higher flow, resulting in a lower fluid pressure. The pump is now unable to deliver as much flow as the volume of the swollen portions of the bubbles, resulting in a lower discharge flow rate. These larger bubbles can also cause vibration, noise, and equipment damage, and reduce the apparent stiffness of the oil. They can reduce system responsiveness [2].

[3] Cavitation occurring in the pump

Fig. 3 shows a visualized section of the pump chamber of a vane pump. The white areas in the pump chamber represent bubbles due to cavitation. This cavitation occurs, when the fluid pressure is below the saturated vapor pressure due to higher flow velocity inside the pump or other reasons the fluid vaporizes and bubbles form. As in case [2], the pump can no longer deliver as much flow as the volume of the bubbles formed, resulting in a lower discharge flow rate. This can cause equipment damage due to erosion. It is therefore important to suppress cavitation [2].

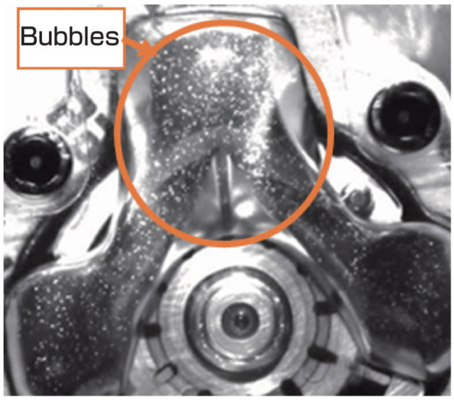

Fig. 2 Bubbles in the hydraulic fluid

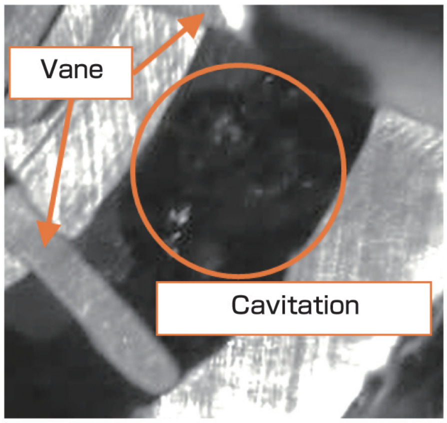

Fig. 3 Cavitation caused by pumping

Therefore, to accurately predict the flow characteristics of an internal gear pump, which is a positive displacement pump like the vane pump, it is necessary to reflect the clearances in the analysis model, consider the mixed flow, and formulate the cavitation phenomenon.

2. 2 Target Internal Gear Pump

Fig. 4 shows an overview of the parts of the internal gear pump used in this paper. The rotor assembly, consisting of an inner rotor, an outer rotor, and a shaft, is sandwiched between the body and cover. The inner rotor has six teeth, and the outer rotor has seven teeth. In the internal gear pump, as the inner rotor rotates, the outer rotor rotates to create a gear mesh that forms the pump chamber. The increase or decrease in volume of the pump chamber provides the pumping action. The volume of the pump chamber is minimum just before the suction port and increases in the area of the suction port, allowing oil to enter the chamber. The pump discharges the oil as the volume of the pump chamber decreases in the discharge port area (Fig. 5).

2. 3 Analysis Conditions

The analysis was performed using commercially available Simerics MP+® software (Simerics Inc., USA). Fig. 6 shows an example of a computational grid for the fluid part of the internal gear pump. Since the shape of the pump chamber changes from moment to moment with rotation, the size of the computational grid also changes accordingly. The shape of the pump chamber for the maximum and minimum mesh size is shown in Fig. 7.

Table 1 summarizes the analysis conditions. The calculation was performed considering the mixed flow of oil and gas. The total computational grid consists of about 400,000 cells. The pump chamber uses a fine mesh to accommodate dramatic changes in its volume and occupies about 50% of the total number of cells.

To consider internal leakage in the internal gear pump as well, the clearance between the inner and outer rotors (hereinafter, "tip clearance", in Fig. 8), the clearance between the cover or body and each rotor, and the clearance between the outer rotor and the circumference of the body (hereinafter, "side clearance" and "body clearance", in Fig. 9) were added to the analysis model.

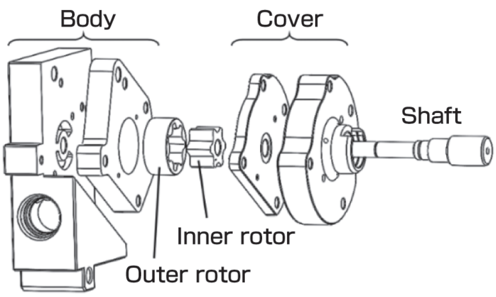

Fig. 4 Components of internal gear pump

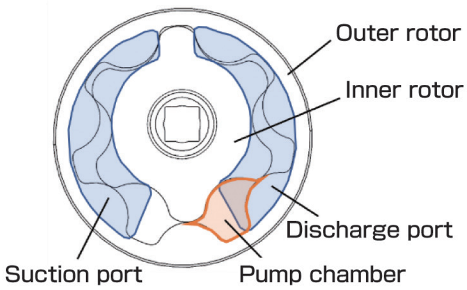

Fig. 5 Rotor parts names

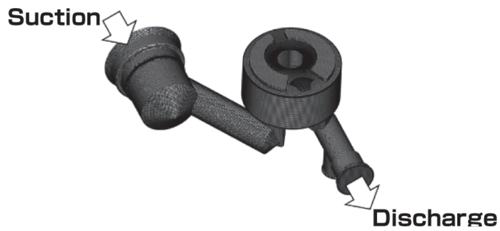

Fig. 6 Computational grid

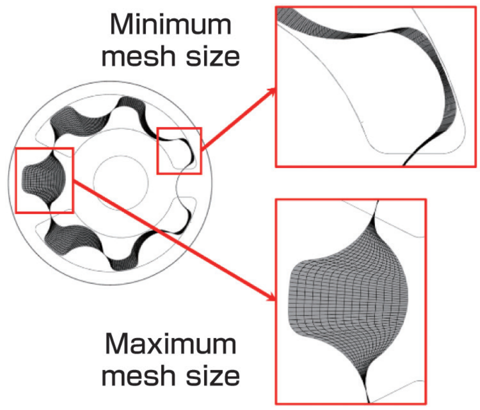

Fig. 7 Moving boundary of pump chamber model

2. 4 What to Adjust for Internal Gear Pumps

In order to perform the CFD analysis of internal gear pumps considering the flow losses mentioned above, the analysis model settings and analysis conditions were adjusted. The adjustment items are described below:

Table 1 Analysis conditions list

Fluid parameter			
Oil	Temperature	100	℃
	Density	786	kg/m³
	Viscosity	0.0048	Pa・s
	Bulk modulus	1.52	GPa
	Vapor pressure	400	Pa (Abs.)
Gas	Density	0.94	kg/m³
	Viscosity	2.194×10^{-5}	Pa・s
Boundary conditions			
Suction pressure		0	MPa (Gage)
Discharge pressure		0.2, 0.5	MPa (Gage)
Rotation speed		1000, 3000, 5000	—

Fluid model		
Two-phase flow	Homogeneous medium model	
Viscosity	Laminar flow model	
Grid		
Moving boundary	Sliding mesh	
Pump chamber	Hexagonal lattice	
Other	Tetrahedral lattice	
Minimum cell size	1×10^{-5}	m
Total number of cells	Approx. 400,000 cells	
Computation		
Time	1.5 to 2 days	

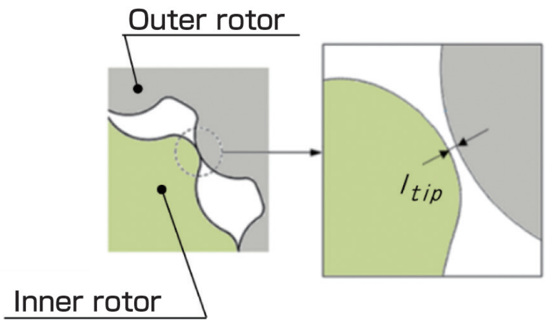

Fig. 8 Tip clearance

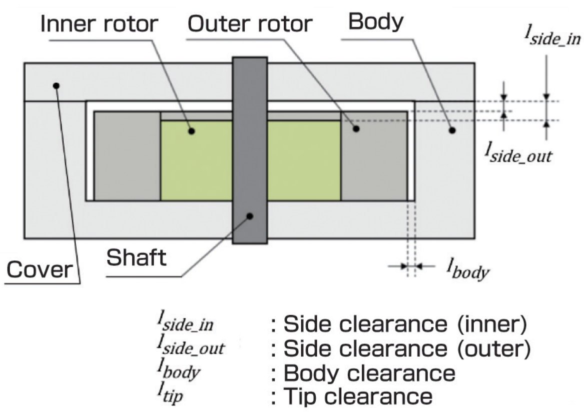

Fig. 9 Side and body clearances

[1] Cavitation model

A numerical model called the Singhal model was used in the analysis to represent cavitation phenomena. This model takes into account the liquid-vapor phase change and the effect of non-condensable gases, which allows for the representation of vapor generation and disappearance and gas transport [3]. R_e and R_c in equation (1) are coefficients related to vapor generation (evaporation) and disappearance (condensation). KYB has set these coefficients to appropriate values for hydraulic fluid to improve accuracy. However, we performed the calculation with a constant mass fraction of gas bubbles contained in the oil, without considering the precipitation of dissolved air and the expansion and contraction of the bubbles. We then adopted the Singhal model, which had been improved to account for these factors, to further improve accuracy.

(Equation for liquid-vapor phase changes; partial extraction)

$$\frac{\partial(\rho f_v)}{\partial t}+\nabla\cdot(\rho \vec{V} f_v)=\nabla\cdot(\Gamma\nabla f_v)+R_e-R_c \tag{1}$$

ρ : Liquid mixture density
f_v : Vapor mass fraction
$\vec{V}$: Computational grid volume
Γ : Equation of diffusion phenomenon
R_e : Vapor generation rate
R_c : Vapor disappearance rate

[2] Clearance setting

Clearance settings, which are often set using design dimensions as a reference, are such small values that they can be significantly affected by the dimensional accuracy of the analysis model. An example of this for internal gear pumps is the interaxis distance between the inner and outer rotors. The internal gear pump discharges oil as the outer rotor rotates while the inner rotor rotates as described above. If the axis-to-axis distance is out of specification, this misalignment is a tip clearance error. If this error exceeds the minimum tip clearance, the inner rotor will contact the outer rotor. In the analysis context, part of the computational domain will be lost, making the calculation impossible. Therefore, for accurate analysis, it is important to check all dimensions that affect the clearances as finely as the clearances themselves, such as whether the interaxis distance is accurately reflected in the model.

[3] Resolution of analysis model

The analysis model consists of connected triangular faces. The more complex the model, the more triangles are needed to represent the shape. Without taking this into account, for example, a smooth curved part of the model cannot be reproduced with these triangles, resulting in many angular parts. The model will not represent the clearances between the parts correctly, and in the worst case it may have problems such as disabled computation due to the inner and outer rotors touching each other.

Therefore, we refined the mesh to accurately reproduce the shape of the analysis model of the internal gear pump. Fig. 10 compares different mesh sizes of the curved part of the analysis model. In the finer mesh model, the curved part consists of more coordinate points to improve the resolution of the analysis model, which enables the accurate reproduction of the model.

2. 5 Results of CFD Analysis

In the following, the results of CFD analysis with/without consideration of the adjustment items mentioned in the previous section are compared with the experimental results (Fig. 11). Red dots indicate the analysis results without consideration and blue dots indicate the analysis results with consideration, while the black line shows the experimental results. According to the figure, the analysis before consideration shows a poor prediction accuracy, especially at one point (low speed) with a maximum of 22.5%, while the analysis after consideration shows a high prediction accuracy in all speed ranges, marking a maximum of 3.0%.

3 Design Proposal Case

3. 1 Internal Gear Pump Prototype

Assuming the cooling applications for eAxle drive units, the internal gear pump should use a low-viscosity hydraulic fluid from the viewpoint of cooling efficiency. The hydraulic fluids currently used in eAxle cooling pumps generally have a lower viscosity than the hydraulic fluid for the power steering and CVT, which are the development targets of KYB. Low viscosity hydraulic fluids are prone to turbulence at the same flow rate as thicker fluid. Turbulence can cause localized pressure drops, resulting in cavitation. Therefore, compared to conventional hydraulic pumps, eAxle cooling pumps raise concerns about lower volume efficiency due to the occurrence of cavitation. We then verified this issue with test results and found lower volume efficiency at high-speed ranges. Against this problem, we used CFD analysis and considered improvement suggestions to try to increase the efficiency. Fig. 12 shows the flow lines of the suction oil passage of the internal gear pump as viewed from the rotational axis, and Fig. 13 shows the amount of cavitation occurring in the pump chamber. These results showed that the oil could not be introduced up to the black circle point of the suction oil passage, resulting in many cavitation points inside the pump chamber. These could have reduced the volume efficiency. Therefore, we improved the shape of the suction oil passage to smoothly introduce the oil to the black circle point and suppress cavitation to improve volume efficiency.

3. 2 Improvement Strategies

Fig. 14 compares the shape of the suction oil passage as seen from a direction perpendicular to the axis of rotation before and after the improvement. The suction oil passage before the improvement had a sharp bend with a step just

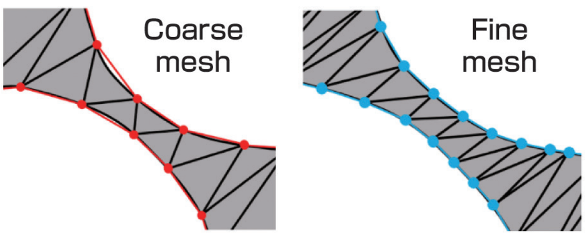

Fig. 10 Mesh comparison

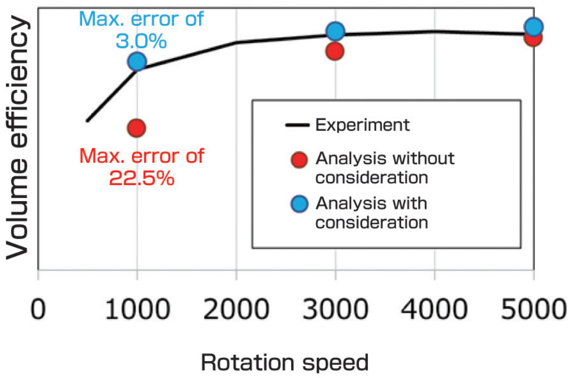

Fig. 11 Speed-volume efficiency

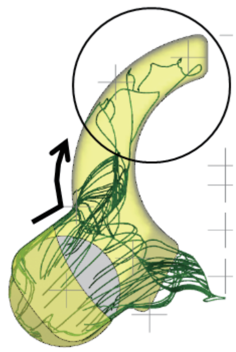

Fig. 12 Flow lines of suction oil passage before improvement

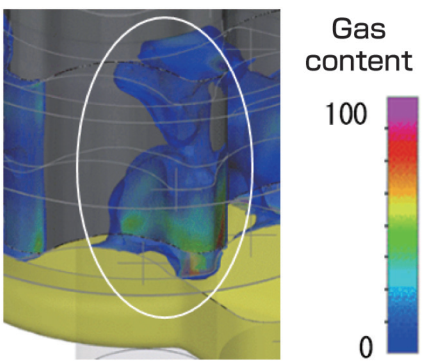

Fig. 13 Cavitation spots in the pump chamber

before entering the suction port. This step caused poor flow and prevented the oil from reaching the end of the suction port. After the improvement, the shape of the bend was modified to have a curvature and eliminate the step. In addition, the suction port was widened in the depth direction to allow the oil to flow to the end of the suction port.

Fig. 15 shows the shape of the suction oil passage as viewed from the direction of the rotational axis before and after the improvement. Compared with the bend before the improvement, the improved passage had no bend, so the oil can flow straight into the suction port.

3. 3 Results of Improvement

Figs. 16 and 17 show the results of the analysis of the flow lines of the suction oil passage after the improvement strategies were implemented, and the amount of cavitation occurring in the pump chamber, respectively. These results confirmed that the improved suction oil passage allowed the oil to flow smoothly into the end of the suction port and reduced the amount of cavitation in the pump chamber. The volume efficiency increased by a maximum of 2.6% at high speed.

After this analytical verification of the effect of the improved shape of the suction oil passage, we built and evaluated an actual prototype machine. Fig. 18 shows the results of a speed-volume efficiency test on the prototype pump under specified pressure and oil temperature conditions. The test showed that the volume efficiency at high speed increased by a maximum of 4.3% from the level before the improvement.

4 Concluding Remarks

This paper has generally explained the flow characteristic analysis technology for internal gear pumps, along with the analysis settings, the volume efficiency prediction accuracy, and a case study of the application of the analysis technology.

The flow characteristics of hydraulic pumps, especially their flow rate, can be reduced by three possible causes. Crevice leakage could be addressed by considering the clearances between parts in the analysis model. The other two phenomena (bubbles and cavitation) could be reduced by considering mixed flow and using a numerical model of cavitation to achieve high prediction accuracy for speed-volume efficiency.

This analysis technology was applied to an internal gear pump development project. We modified the shape of the oil passage of a prototype pump through an improvement activity to be able to suggest a design for higher volume efficiency.

From now on, we will work to construct a discharge pressure pulsation prediction technology that will contribute to the development of a high-efficiency, low-noise internal gear pump.

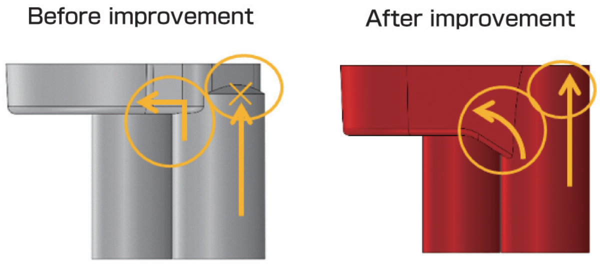

Fig. 14 Changing the shape of the suction oil passage

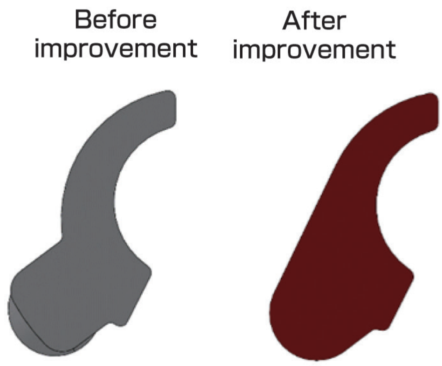

Fig. 15 Enlarging the suction oil passage

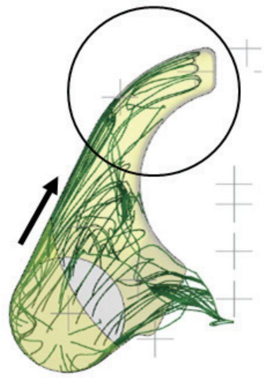

Fig. 16 Flow lines of suction oil passage after improvement

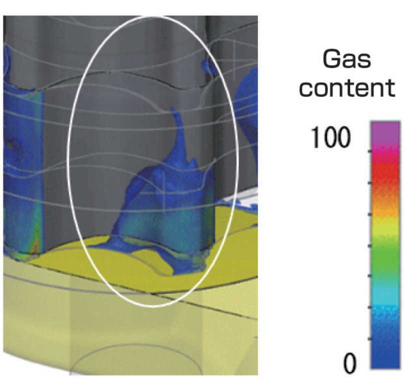

Fig. 17 Cavitation spots after improvement

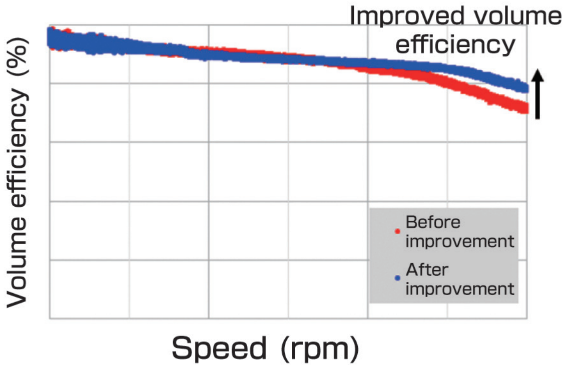

Fig. 18 Volume efficiency comparison result

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Technology Introduction

Construction of Self-Assembly Line Using Multi-purpose Assembly Robots

UGAJIN Yuuta, YAMAGUCHI Toshihisa

1 Introduction

At the KYB Sagami Plant, workers must perform heavy lifting and learn many tasks, which makes them feel burdened (futan), dissatisfied (fuman), and anxious (fuan). (These three feelings may be referred to as the "3Fs" in Japanese workplaces). Additionally, the plant faces the risk of production stoppage due to the difficulty of retaining personnel because of the declining birthrate and aging population. The plant also faces an increasing risk of production line stoppage due to equipment failure, as the amount of complex, highly productive equipment has increased. One effective countermeasure is to develop anomaly prediction technology based on automation and digital technology, which is the focus of the company's internal innovation plant project. This paper reports on the construction of a line through technology development.

2 Background

The Sagami Plant manufactures travel motors for hydraulic excavators with a machine mass of up to 5.0 tons (Fig. 1). The speed reducers (Fig. 2) for these motors are purchased from a partner company. The purchased speed reducers are placed on the travel motor assembly line at the Sagami Plant and then assembled with the motors to form the finished product.

Fig. 1 Travel motor with speed reducer

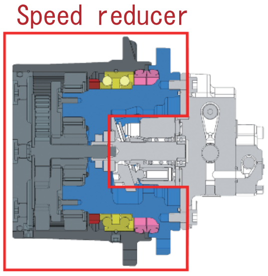

Fig. 2 Cross section of travel motor

As there is a plan to increase the production volume of travel motors, the supply of speed reducers was expected to be insufficient.

We then planned to manufacture speed reducers in-house (Table 1) to meet the demand for higher production. However, the Sagami Plant has limited space for an additional assembly line. Under the difficult space conditions, we had to construct a compact self-assembly line.

Table 1 Matrix of internal and external assembly/production

Hydraulic excavator	Speed reducer	Motor
～5.0ton	Partner company +KYB	KYB
5.0～8.0ton	KYB	KYB
12.0～35.0ton	KYB	KYB

3 Purpose

To construct an assembly line to meet the demand for higher production of travel motors for hydraulic excavators with a machine mass of up to 5.0 tons, and to allow workers to feel less burdened, less dissatisfied, and less anxious.

4 Targets

Table 2 shows the target values:

Table 2 Target values

Item	Target (compared to conventional level)
Space	20% lower
Output productivity	30% higher

5 Requirements

[1] Develop a new technology for assembly automation.
[2] Develop a predictive maintenance (anomaly prediction) function for lines where production (monozukuri) never stops.

6 Line Overview

The speed reducer assembly line consists of parts cleaning, assembly, and inspection processes. To improve output productivity, the first half of the line among these processes has been fully automated (Fig. 3).

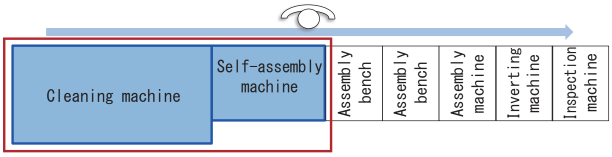

Fig. 3 Block diagram of assembly line

The self-assembly machine installed in the first half of the line is shown in Fig. 4. It is designed to efficiently perform various assembly tasks on workpieces carried on the conveyor using a 6-axis robot, hands, and fixtures arranged around it.

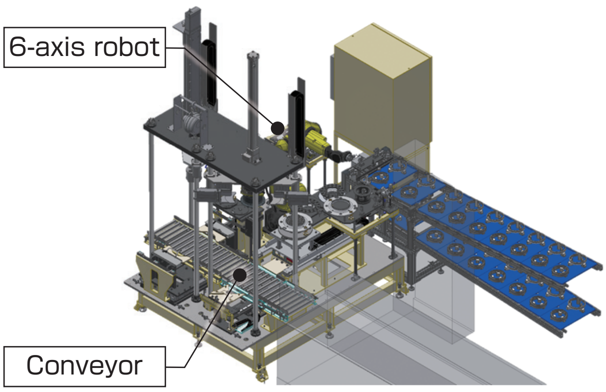

Fig. 4 Self-assembly machine

7 Implementation

7.1 Establishing Self-assembly Technology for Heavy Parts

Until 2021, assembly work at Sagami Plant mainly depended on manual labor. Workers performed heavy lifting, such as lifting a 13 kg workpiece with their hands (Photo 1).

Photo 1 Heavy lifting work[1)]

In 2022, the plant semi-automated assembly operations as Step 1 of an improvement program. Specifically, a semi-automatic machine was introduced to assemble heavy work with a cylinder (Photo 2) and assemble light work using manual means. The cylinder was chosen instead of a robot because the heavy work could only be lifted by a large robot, which took up a lot of space.

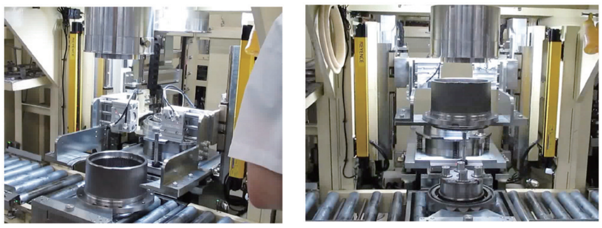

Photo 2 Semi-automation[1)]

In 2023, Step 2 of the improvement program involved fully automating the semi-automated equipment established in Step 1. Specifically, the cylinder is used to assemble heavy work, while a robot assembles light work (Fig. 5). The equipment is designed so that the robot is only used for light assembly, including fixtures and small workpieces, thereby reducing the robot's payload. This makes it possible to use a small robot (Fig. 6).

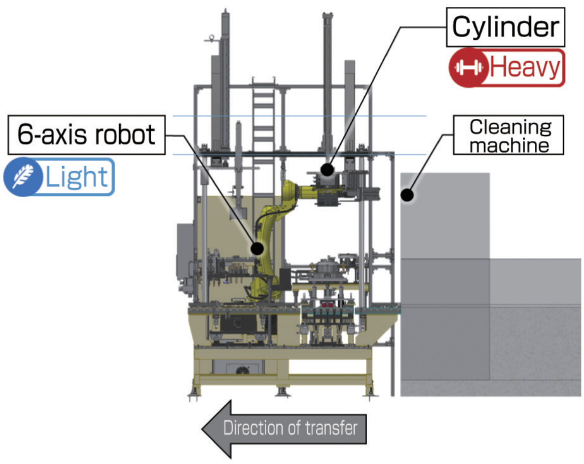

Fig. 5 Self-assembly machine (front view)

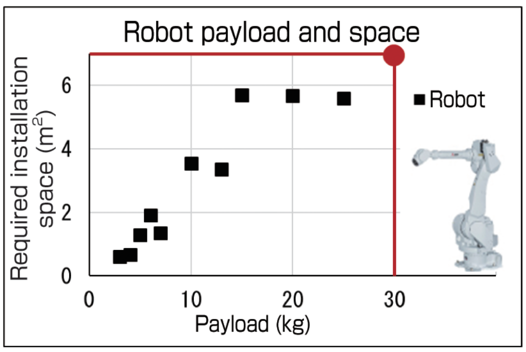

Fig. 6 Robot payload and space

7.2 Development of Technology to Create Lightweight, Multi-Purpose Robots Compatible with a Variety of Fixt

There were 27 processes that needed to be automated. Using 27 units for these processes would result in complex equipment that requires a high cost and large installation space.

We then decided to use multi-purpose robots. Of the 27 processes, 17 were selected to be handled by a single robot to minimize the number of units. The multi-purpose robot has four types of hands and seven types of fixtures (Figs. 7 and 8), which can be changed many times in a cycle to achieve lower equipment costs and smaller installation space.

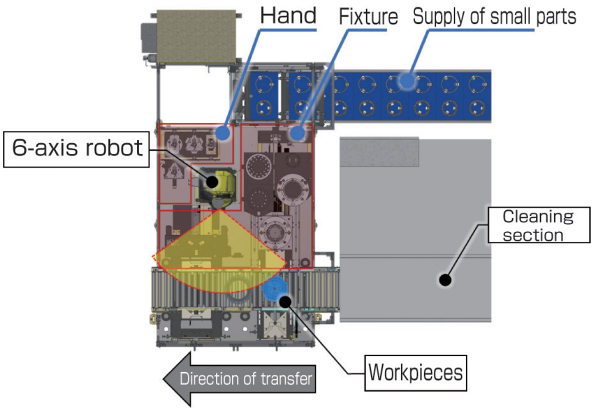

Fig. 7 Self-assembly machine (top view)

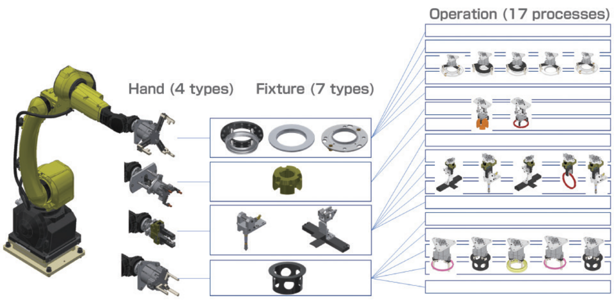

Fig. 8 Robot with a set of hands and fixtures

In addition, it was very difficult to verify beforehand that operations relying on the experience and intuition of skilled workers could be performed properly by the robot. In particular, in the operation of tightening the ring nuts[Note 1)], which are very thin, the nuts were tightened at an angle in some cases, resulting in galling (Fig. 9).

In the existing process, workers temporarily tighten the nuts by hand before finally tightening them with a tightening tool to prevent galling. This temporary tightening is a very difficult job that requires some experience.

Note 1) Large nuts of about M130.

We then iterated on a prototype fixture for horizontally inserting ring nuts (Photo 3) to successfully develop a final fixture. By using rapid prototyping with a 3D printer, we were able to explore effective solutions quickly and inexpensively.

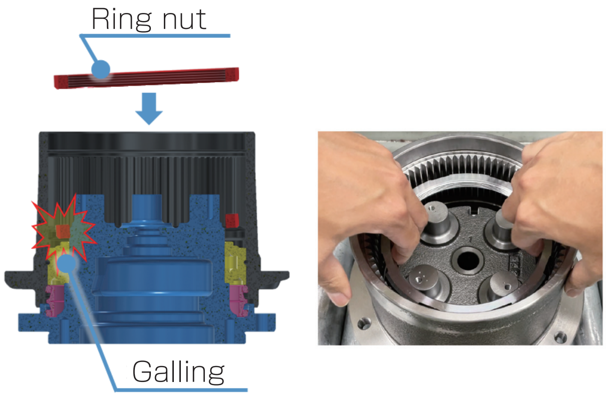

Fig. 9 Galling due to ring nut tightening

This fixture acts as a guide for the ring nuts, allowing a ring nut to be set exactly level. Now the ring nuts can be fully tightened with a tightening tool without manual temporary tightening. In this way, we have successfully replaced skilled labor with robot operation.

Photo 3 Horizontal insertion fixture (prototype)

In addition to the angled setting, we had another challenge. When a ring nut was inserted into the fixture, it was necessary to align the rotation phase. To solve this problem, we designed a special hand (Fig. 10). This special hand allowed the phase alignment to be performed without the need for advanced robot controls such as force sensors.

Fig. 10 Special hand

7.3 Reducing the Risk of Production Stoppage by Developing a Predictive Maintenance Capability

As production equipment becomes more automated, the number of sensors must increase, raising the risk of a sporadic failure. The majority of components are subject to corrective maintenance, although some are covered by preventive maintenance (Table 3).

Table 3 Current maintenance scheme

Equipment units	Equipment maintenance
Robots	Preventive maintenance * Annual maintenance by manufacturer
Parts that break frequently	Preventive maintenance * Periodic parts replacement
Other parts	Corrective maintenance

As a countermeasure, we embedded a function that monitors the operating time of the actuators and issues an alarm if it deviates from the control value (Fig. 11). We connected the equipment to PCs in the office via the internal LAN so that we could graphically view the changes in operating time. This allowed us to monitor trends in equipment movement, implement predictive maintenance, and reduce sporadic breakdown time.

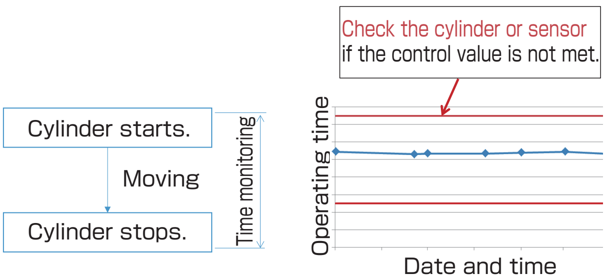

Fig. 11 Predictive maintenance

8 Results

The results of the implementation are shown in Table 4.

Table 4 Results of implementation

Item	Target	Result	Evaluation
Space	20% reduction	27% reduction	○
Output productivity	30% improvement	30% improvement	○

9 Conclusions

We have prepared technology to increase the production volume of travel motors for hydraulic excavators with a machine mass of up to 5.0 tons. We have also constructed a more worker-friendly assembly line that makes workers feel less burdened, less dissatisfied, and less anxious.

During the construction of the line, the Production Engineering Dept. and Machine Tools Center[Note 2)] held weekly specification review meetings from the stage of discussing the specifications. In addition, personnel from the Production Engineering Dept. were internally transferred to the Machine Tools Center to jointly prepare equipment drawings, manufacture the equipment, and conduct commissioning. This close coordination between the two departments for the start-up of the equipment led to the successful construction of the line. The internal transfer allowed us to learn robot technology, which is essential for promoting automation in future capital investments.

From now on, we will work with internal research departments and the Machine Tools Center to address elemental technologies for highly difficult operations.

Note 2) A department for KYB's in-house equipment manufacturing.

10 In Closing

We would like to take this opportunity to express our sincere gratitude to all the departments that cooperated in the construction of this line and to all those who provided guidance and support.

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Product Introduction

Development of EPS with In-house Manufactured PP for Yamaha Motor

AOYAMA Masashi, KIKUCHI Teruyuki

1 Introduction

KYB's electric power steering (EPS) for off-road vehicles has a long history, dating back to 2005 when the EPS was first used in the world on all-terrain vehicles (ATVs) of Yamaha Motor Co., Ltd . (“Yamaha Motor”). Specifically, the EPS is a column EPS whose electronic control unit (ECU) is separate from the EPS body (the “conventional EPS”). This conventional EPS has been used in ATVs and recreational off-highway vehicles (ROVs) by many manufacturers. It is still being mass-produced 20 years after it was first introduced.

Meanwhile, the percentage of off-road vehicles equipped with EPS has been increasing. Especially with the recent trend of larger vehicles, EPS has been required to deliver higher power to provide the driver with comfortable steering, such as the need for less steering force and suppressed kickback. KYB also set the goal of achieving higher EPS power and developed a pinion EPS for off-road vehicles equipped with an in-house manufactured power pack (an ECU-integrated brushless motor; “PP”) . This EPS is hereinafter referred to as the “Pinion EPS” . Since 2019, we have been mass-producing the Pinion EPS for other vehicle manufacturers.

However, the majority of existing off-road vehicles used the column EPS. Vehicle manufacturers were expected to undertake large-scale development if they installed a different type of EPS in their off-road vehicles. In reality, we had to develop a higher-power column EPS and expand the EPS product line.

In this project, we developed a column EPS equipped with an in-house manufactured PP (the “Product”) in order to increase the performance of the conventional EPS. We started mass production in 2024 for Yamaha Motor’s Wolverine RMAX 1000 (Fig. 1) and Grizzly 700 (Fig. 2). The following sections describe the mechanical specifications and control functions of the Product.

Fig. 1 Wolverine RMAX1000 (ROV)

Fig. 2 Grizzly700 (ATV)

2 Mechanical Specifications

2. 1 Adoption of Standard Module and Conventional EPS Parts

The EPS market for off-road vehicles is smaller than that for passenger cars. Therefore, it was important to develop the Product with a limited number of new parts in consideration of cost.

For the Product, we then decided to use the standard module that we had developed for the Pinion EPS. The standard module is a compact package of the in-house manufactured PP, a torque angle sensor, and a worm reduction gear (Fig. 3). The use of this module resulted in a higher reduction ratio, a larger motor assist torque, and about 2.8 times the EPS output torque of the conventional EPS. A comparison of key specifications between the conventional EPS and the Product is shown in Table 1.

In general, when EPS is installed in a vehicle, the engagement specifications must be customized to match the vehicle layout. This means that 100% standardization of EPS is impossible unless the customer chooses off-the-shelf products. The Product, which uses the standard module and parts of the conventional EPS, has a minimum of new parts to achieve a standardization rate of as high as 80%.

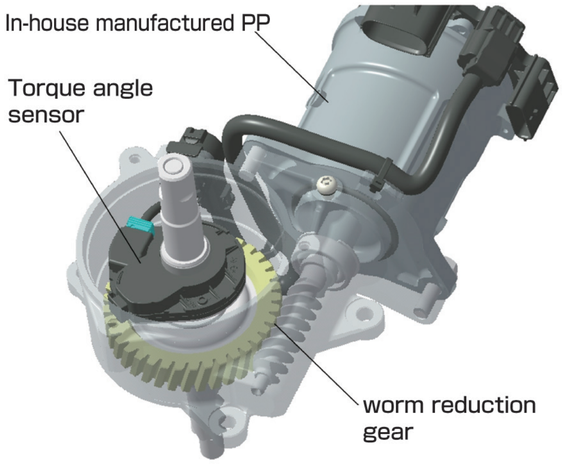

Fig. 3 Components of standard modules

Table 1 Comparison of key specifications

Item	Conventional EPS	The Product
Reduction ratio	17 : 1	18.5 : 1
Motor assist torque	1.5Nm	4.2Nm
EPS output torque	22.9Nm	65Nm

2. 2 Gear Case Main Mold Standardization

The column EPS consists of two housings, except the motor/PP. The gear case houses the worm gear reducer.

The column EPS for ROVs and ATVs comes in different specifications depending on the vehicle requirements. Here are two examples. The first is the difference in the way the torque is transmitted from the column EPS to the tires. For ROVs, the output shaft of the column EPS is connected to an intermediate shaft. The torque is typically transferred from the shaft to the tires via a rack and pinion.

For ATVs in turn, the output shaft of the column EPS is screwed to a pitman arm. In most cases, the torque is transmitted from the pitman arm to the tires via a tie rod. The connection point between the pitman arm and the tie rod is not on the same axis as the output shaft (Fig. 4). The output shaft is subjected to a bending moment during torque transmission. This is a characteristic of the column EPS for ATVs.

The output shaft of the Product for ROVs, where bending moments are small, is supported at a single point to reduce cost, while that for ATVs is supported at two points as a measure against bending moments. The first support of the output shaft has been designed to be at the same axial height for both models, making it possible to standardize the internal structure of the gear case, except for part of the structure on the side of the output shaft.

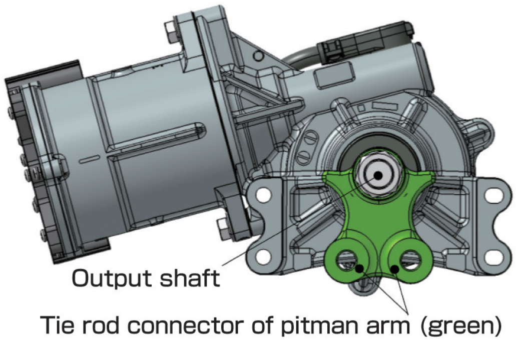

Fig. 4 Output shaft structure for ATVs (with pitman arm assembled)

The second example of different specifications depending on the vehicle requirements is the difference in the way the housing is attached to Yamaha Motor's vehicles. The column EPS for ROVs is attached to the vehicle with the female threaded housing on the input shaft side, while the column EPS for ATVs is attached to the vehicle with the housing on the output shaft side using nuts and bolts.

The conventional EPS is designed so that the vehicle attachment function and the worm reduction gear installation function are implemented in two different housings. This means that the die casting mold of the gear case is not standardized (Fig. 5)

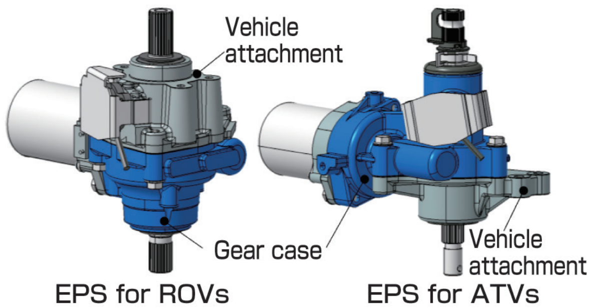

Fig. 5 Gear case of conventional EPS

In the Product, the EPS for ROVs also uses the vehicle attachment of the EPS for ATVs (Fig. 6). This addition allows the vehicle attachment for ATVs to be used as the fixture attachment point for the EPS assembly process, eliminating the dedicated assembly attachment point prepared in the conventional EPS. Now, the EPS for ROVs and ATVs have the same appearance and the main die casting mold of the gear case is shared. In addition, we have set a dedicated inner ring for this model in part of the structure on the output shaft side. It is now possible to produce the gear case with fewer set-ups.

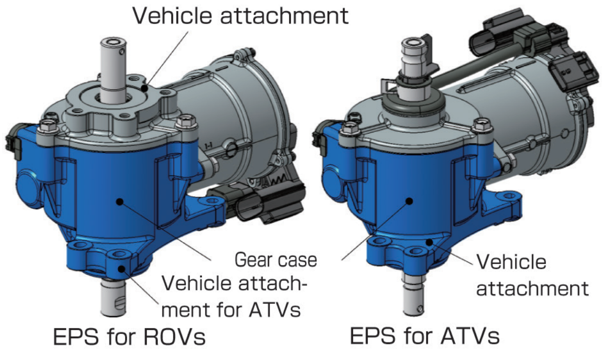

Fig. 6 Gear case of the Product

3 Control Function Development

Among the steering functions required in off-road vehicles, steering responsiveness and disturbance inhibition are particularly important. In order to meet the steering performance requirements, the Product was installed with base current control, stabilizing control, and derivative current control.

Fig. 7 shows a general block diagram of the Product's control system.

The next sections describes the implementation of each control.

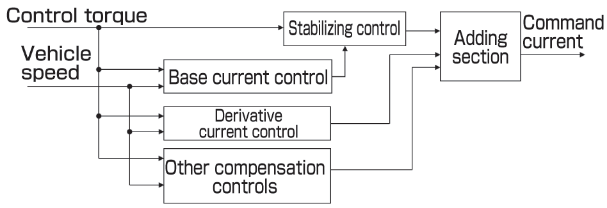

Fig. 7 General block diagram of the Product's control system

3. 1 Base Current Control

This is a control function that determines the current value for controlling the base current (the "base current value") from the control torque generated when the driver operates the steering. Compared to the conventional EPS, the Product uses a high-output motor based on which the base current value has been set. Table 2 compares the electrical equipment of the old and new products.

Table 2 Comparison of electrical equipment of old and new products

Item	Conventional EPS	The Product
Configuration	ECU-separate motor	ECU-integrated motor
Motor	Brush type	Brushless
Motor assist torque	1.5Nm	4.2Nm
Weight	1.60kg + 0.87kg	2.0kg

To enable the driver to clearly perceive the onset of steering, we tuned the steering feel range as shown in Fig. 8 (within the area enclosed by the green dashed line). As a result, the steering feels smoother than the conventional EPS.

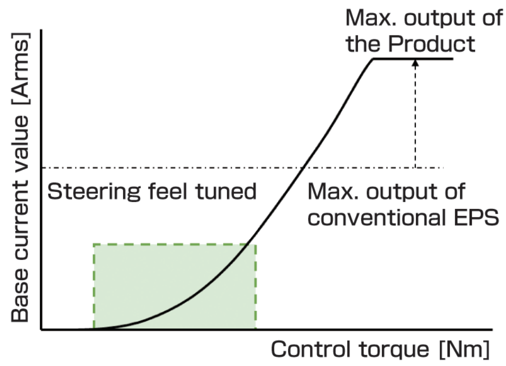

Fig. 8 Conceptual drawing of base current control

3. 2 Stabilizing Control

The Product's control system mainly consists of a torque feedback control that feeds back the EPS output torque. The input and feedback torques are used to calculate the control torque. This torque is then used to determine the motor current command via the stabilizing, base current, and compensation controls. The motor current command generates the motor torque necessary to operate the Product. Fig. 9 shows the basic configuration of the torque feedback control system.

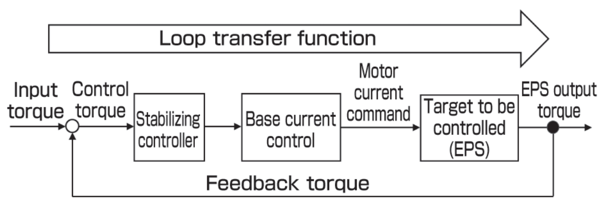

Fig. 9 Basic configuration of torque feedback control system

In the base current control described in the previous section, increasing only the current value results in an increase in the gain of the loop transfer function of the torque control system over all frequency ranges. This results in an unstable condition (causing self-excited vibration).

To ensure stability of the torque control system, the phase of the loop transfer function must be advanced in the high frequency range. The Pinion EPS uses phase compensation control to advance the loop transfer function of the torque control system. Fig. 10 shows a block diagram of the phase compensation control.

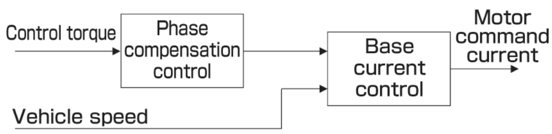

Fig. 10 Block diagram of phase compensation control

However, we found it difficult to achieve both high responsiveness and stability at the same time by increasing the base current value through vehicle tuning. This was because tuning was done in terms of frequency response (gain, phase) or based on evaluation using an actual EPS unit.

Then, in order to achieve high responsiveness and stability by increasing the base current value, we added a stabilizing control. A block diagram of the stabilizing control is shown in Fig. 11.

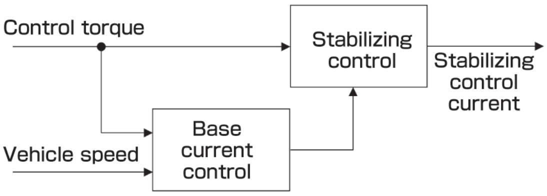

Fig. 11 Block diagram of stabilizing control

This stabilizing control provides the gain or phase margin of the torque control system regardless of the magnitude of the current slope of the base current value. Table 3 compares the specifications of the phase compensation and stabilizing controls.

Table 3 Comparison of control specifications

Comparison	Phase compensation controller	Stabilizing controller
Controller configuration	Phase advance x 2 Phase delay x 1	Feedback of status and disturbance estimation based on general stabilizing controllers
Tuning method	Based on frequency response Based on behavior evaluated using an actual EPS unit	Model-based tuning using a control target model
Tuning parameter	Gain cut-off frequency of phase compensator	Specific frequency, attenuation factor

In this project, we used a model-based development approach with a control target model to investigate parameters. We specified the natural frequency and attenuation factor to perform desktop tuning, which dramatically improved the operating efficiency.

3. 3 Differential Current Control

This differential current control processes the control torque with a high-pass filter (HPF) and a low-pass filter (LPF) to obtain a torque differential value and adds it to the base current value.

Using this control in the low control torque range allows the steering torque to increase gradually, improving the responsiveness. Fig. 12 shows a block diagram of the differential current control.

HPF is used to perform differential calculations, while LPF is used to reduce the high-frequency noise associated with differential calculations.

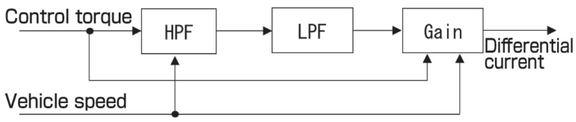

Fig. 12 Block diagram of differential current control

4 In Closing

With the adoption of the Product by Yamaha Motor as a springboard, we will also encourage other manufacturers to use the Product in vehicles that currently use the conventional EPS. In addition, we have expanded our product line of high-output EPS for off-road vehicles. From now on, we will propose appropriate specifications to meet market demands, using the Product and the Pinion EPS.

Finally, we would like to take this opportunity to express our gratitude to Yamaha Motor and those involved in KYB for their cooperation in this development project.

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1) MIYAKE, TOMITA: “Development of EPS for Non-Passenger Vehicles”, KYB Technical Review No.60 (April 2020).
2) MATSUMOTO, ENOMOTO, KENJO, FUKUSHI: “Control Technologies for In-Vehicle Electric Actuators”, KYB Technical Review No.65 (October 2022).

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Product Introduction

Development of Cartridge Type Vane Pump for Electric Pumps

KUBO Kohei

1 Introduction

KYB began producing vane pumps for hydraulic power steering in 1955. Today, it develops and supplies vane pump products as hydraulic sources of CVT or AT to meet market needs.

This paper introduces a cartridge type[Note 2)] vane pump for electric pumps[Note 1)] to be used as the hydraulic source of a new AT[Note 3)] or CVT[Note 4)] that contributes to higher fuel efficiency of the vehicle.

Production of this product was started in October 2022.

Note 1) An oil pump driven by an electric motor.

Note 2) A mounting system in which the pump housing is provided on the main machine to form an assembly when mounted.

Note 3) An acronym for Automatic Transmission.

Note 4) An acronym for Continuously Variable Transmission.

2 About Electric Pumps

First of all, let me explain what an electric pump is.

An electric pump is a pump driven by a motor that can be controlled by itself by receiving a signal from the vehicle (main machine) (Fig. 1). Its main feature is the ability to deliver any required flow rate at any required time, drastically reducing waste.

With the recent electrification of vehicles, electric pumps are being used in various applications with higher demands. Examples of these applications include cooling/lubricating electric drive motors or batteries, and hydraulic sources of AT or CVT for hybrid cars.

Note that vane pumps for CVT/AT traditionally mass-produced by KYB are driven by engines and are called mechanical pumps.

Mechanical pumps have been improved many times to achieve very good performance, but the following challenges remain.

[1] They must have a large displacement volume to provide the required flow rate even at low speeds, requiring a high theoretical pump torque.

[2] They inevitably discharge a larger flow than necessary at high speeds, resulting in a lot of waste.

[3] They require an electric pump for pressure retention to be able to discharge when idling.

These challenges of mechanical pumps can be solved by electric pumps if their speed is controlled in a manner appropriate to the application. This can lead to an improved mileage of the vehicle.

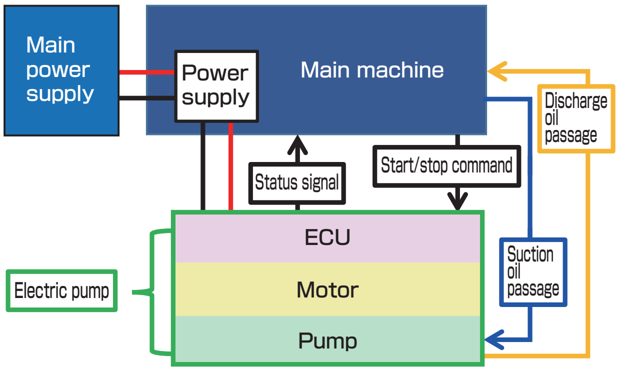


Fig. 1 Electric pump

3 Development Details

Figs. 2 and 3 and Table 1 show the appearance, a diagrammatic development view, and detailed specifications of the cartridge type vane pump developed in this project, respectively.

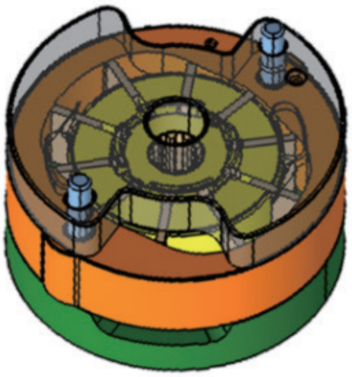


Fig. 2　Appearance of the electric vane pump

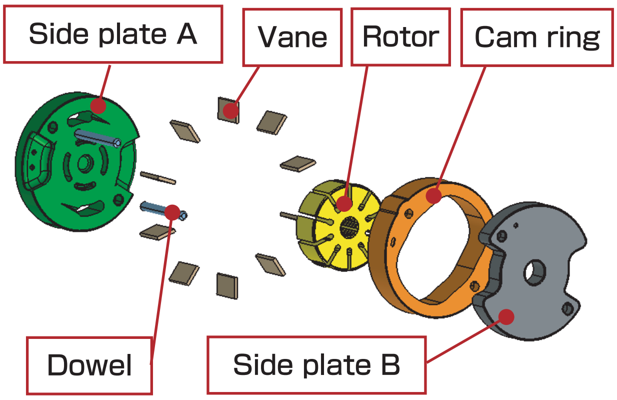


Fig. 3　Diagrammatic development view

Table 1　Specifications of the developed pump

Type	Balanced vane pump
Displacement volume	～4 cm³/rev
Maximum rotation speed	3,300rpm
Maximum pressure	4.0MPa
Operating temperature	−40～165℃

3. 1　Development Concept

For an electric pump to be adopted in a vehicle equipped with a traditional mechanical pump system, it must provide superior cost performance in terms of space saving, energy saving, low noise, and low cost.

We then reviewed the design of the traditional mechanical pump for the following issues in order to develop an optimized motor-driven pump.

3. 1. 1　Downsizing and Torque Loss Reduction

In order to have a higher degree of freedom in vehicle mounting, the electric pump must be compact.

In addition, the drive torque of the pump is directly related to the power consumption because the motor has the sole function of driving the pump. Therefore, we worked to develop a downsized pump with lower torque as a top priority.

The drive torque of a vane pump is the sum of the theoretical torque and the torque loss (friction). To improve mechanical efficiency, it is necessary to reduce both theoretical torque and friction.

We then decided to downsize the vane pump to the limit, taking productivity into account, to reduce the sliding area of the parts, as shown below, thereby reducing friction:

[1] Thinner cam ring
[2] Smaller rotor
[3] Use of thinner vanes (1 mm thick)

Finally, we downsized the pump to the manufacturing limit that would allow durability and mass production, resulting in a cam ring 46% narrower (Fig. 4) and a rotor 32% smaller in outer diameter (Fig. 5) than the traditional mechanical pump.

We used thin-walled vanes, the second case at KYB, to reduce the pressure-receiving area and the sliding area (Fig. 6).

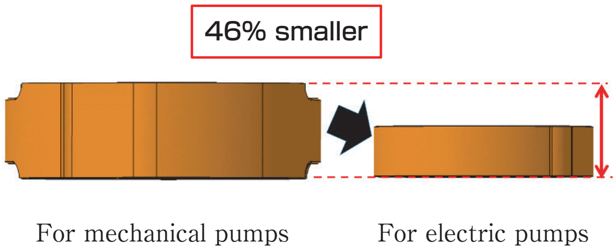


Fig. 4　Conceptual drawing of cam ring thinning

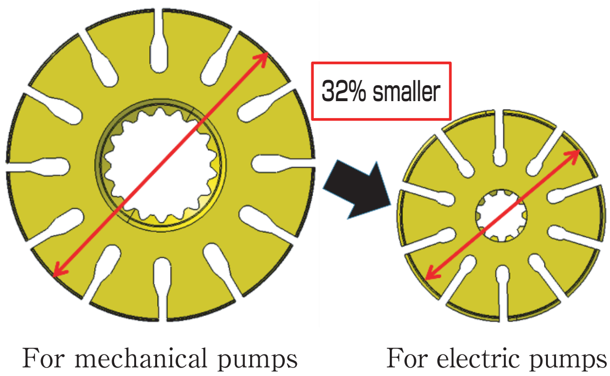


Fig. 5　Conceptual drawing of rotor outer diameter reduction

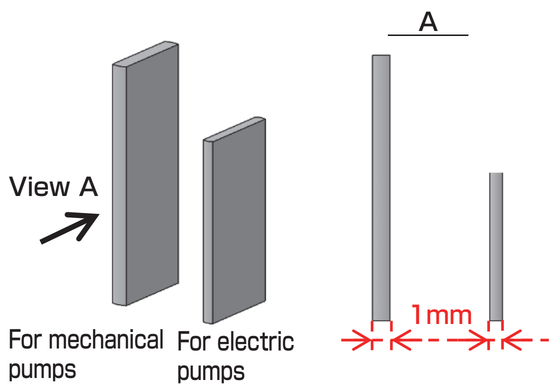
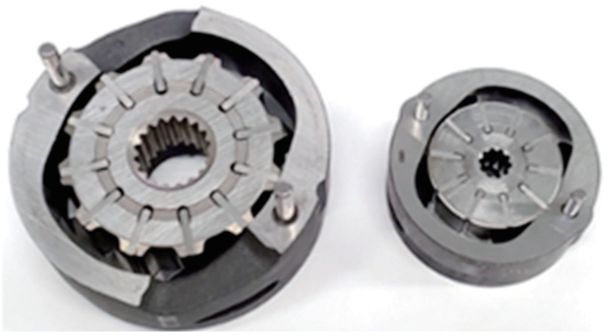


Fig. 6　Vane pump thinning

The resulting pump had excellent mountability, high efficiency, and low cost, achieving a torque loss reduction of approximately 52% over the existing product performing the same work.

Photo 1 compares the size of the vane pump for electric pumps to the size of the vane pump for mechanical pumps that KYB has traditionally mass-produced.



For mechanical pumps　For electric pumps

Photo 1 Cartridge size comparison

3. 1. 2 Improving Volume Efficiency

In the vane pump developed in this project, we optimized the clearance of each sliding part according to the operating conditions. Reducing the clearance will reduce the internal leakage of the pump, that is, the flow loss, which will improve the volume efficiency. On the other hand, the durability of the pump will be worsened, with potential issues such as seizure in the sliding parts. Nevertheless, the pump was subjected to analysis and durability testing to find the optimal clearances while improving the volumetric efficiency. As an example, Fig. 7 shows the results of FEM analysis of the side plate.

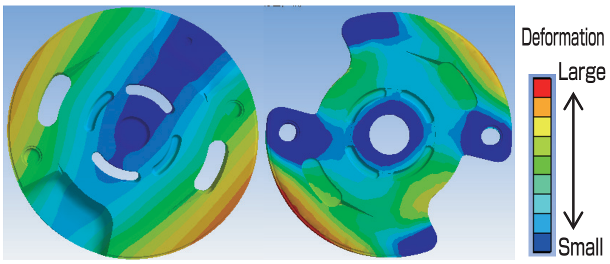


Fig. 7 FEM analysis results

3. 1. 3 Use of Ten Vanes

The quietness of automobiles has been improving year by year. With the electrification of vehicles, the demand for quietness is increasing. Electric pumps are no exception, so it is essential to develop a low-noise pump. We then focused on reducing the vibration of electric pumps. The frequency of vane pump noise is greatly affected by the number of vanes. Unlike the traditional mechanical pump for CVT/AT, which is designed to be quiet by using 12 vanes, we decided to redesign the vane pump developed in this project to have ten vanes so as to avoid resonance with the motor, which has a number of poles (multiples of two) and a number of slots (multiples of three).

We optimized the timing position of the pump suction and discharge ports for ten vanes to prevent resonance with the motor, successfully achieving the quietness required for electric pumps.

Reducing the number of vanes by two also contributed to cost reduction.

3. 1. 4 Use of the Cartridge Design

The mechanical pump currently manufactured by KYB is assembled into a housing (the "pump assembly") prior to delivery to the customer (Fig. 8).

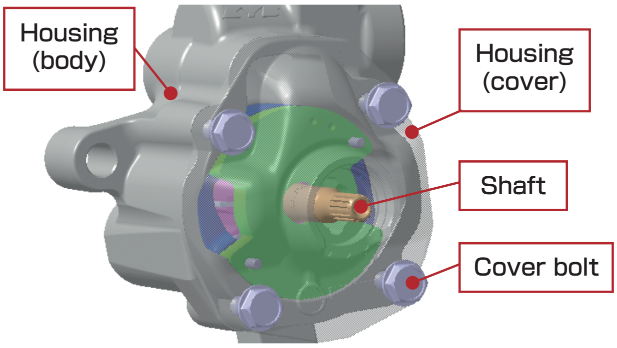


Fig. 8 Appearance of the pump assembly

In this project as well, we initially designed the pump assuming that it would be delivered to the customer as a pump assembly. However, we decided to supply the pump only as a cartridge design, which was a first for KYB pumps, because supplying only functional parts of the pump would reduce the number of parts to reduce costs.

Then we had to face the following new challenges:

[1] Ensure handling in mass production
[2] Avoid dents during transportation
[3] Clarify the scope of functional warranty

For [1], side plates A and B were incorporated into the cartridge to allow easy carrying during manual handling and to prevent the ingress of contaminants. This addition of parts achieved the minimum configuration of the pump that could ensure the required pump performance.

Regarding [2], the pump developed in this project was designed so that the motor shaft, which transmits the power to the pump, is installed on the motor side. This means that the pump cartridge alone cannot fix the position of its components using the shaft, allowing the rotor to move freely. As a result, the rotor can be moved by vibration during transportation or other occasions and come into contact with other parts, causing dents (Fig. 9).

We then developed and patented an easily removable tray specifically designed for the cartridge, which positions the rotor and prevents the cartridge from rotating (Fig. 10).

For [3], we decided to have the cartridge pump performance tested at KYB, so that we could deliver the cartridge pump to the customer as a functional component under warranty, in addition to the dimensional warranty.

As a result, we were able to guarantee the performance of the cartridge pump with a minimum number of components. The reduced weight and size improved transportation efficiency to achieve both product marketability and cost effectiveness. This led to the implementation of need-based product development.

3. 1. 5 Use of New Materials

The operating conditions of the electric pump that we aimed to develop in this project involve lower pressures and speeds than those of the conventional mass-produced mechanical pump.

Therefore, we wanted to use materials that were commercially available and which considered the productivity of downsized pumps. By evaluating durability many times from the early stage of development, we were able to select materials that contribute to durability.

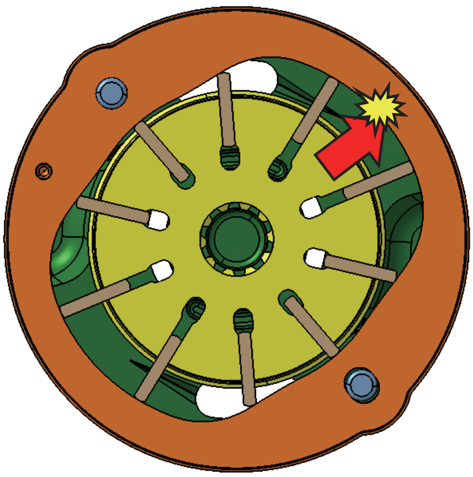


Fig. 9 Contact by moving rotor

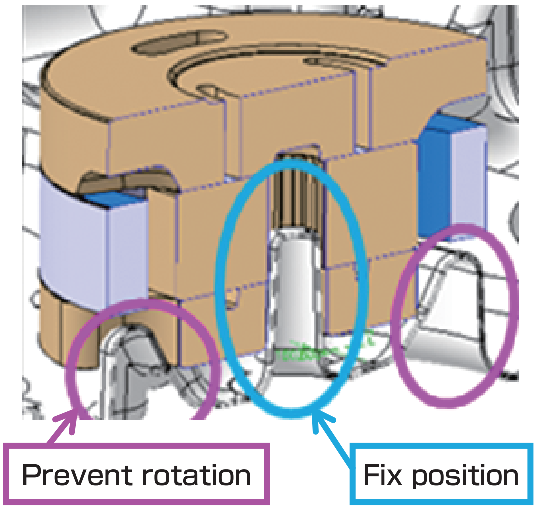


Fig. 10 Shape of tray

4 Conclusions

In this project, we developed a vane pump for electric pumps for the first time in KYB to achieve the following:

[1] Developed KYB's smallest vane pump optimized for use as an electric pump.
[2] Developed KYB's first cartridge-type vane pump.
[3] Adopted new materials.
[4] Established optimal pump specifications for motor characteristics.

5 In Closing

Thanks to the great cooperation of those involved in this development project, we have been able to develop and mass-produce the vane pump for electric pumps in spite of specifications that have never been seen in products previously developed by KYB. We would like to take this opportunity to express our deep gratitude to the partner companies and all those in the internal related departments for their cooperation in this development project.

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Product Introduction

Development of Piston Pump PSVL-50 for 3 to 4-ton Mini Excavators

TAKEI Gen

1 Introduction

KYB's first mass-produced piston pump product for the Load Sensing (LS) system of mini excavators was the PSVL-54 for 5 to 6-ton excavators in 1996. In 2001, the company launched PSVL-42 for 3 to 4-ton excavators. In its history of more than 20 years, this product has remained almost as originally designed.

In recent years, more and more LS systems have been introduced into the mini excavator market. KYB has a range of LS system pumps for excavators of 3 tons or more, many of which have a long history as mentioned above. In anticipation of further growth in demand for LS systems in the future, we have developed the PSVL-50.

2 Overview of the Developed Product

2. 1 Product for LS System

KYB's LS system products consist of PSVL series pumps and KVSX series control valves. These products are available as a hydraulic system for excavators from the 3-ton to 8-ton series (Table 1). The newly developed PSVL-50 is designed for 3 to 4-ton excavators and is the successor of the current PSVL-42.

Table 1 LS system product lineup

3 ton	5 ton	7 ton	Piston pump	Control valve
			PSVL-42	KVSX-12
			PSVL-50	(KVSX-12or14)
			PSVL-64	KVSX-14
			PSVL-84	KVSX-18

2. 2 Current PSVL Series

The specifications of the current PSVL series are summarized in Table 2. The appearance is shown in Fig. 1. KYB's PSVL series features LS gain change control using a pilot pump and its discharge flow (LS control differential pressure changes according to input speed) as a standard function. As the engine speed is reduced, the maximum flow of the pump decreases accordingly. If the LS gain change control function is not available, the pump would reach the maximum operating speed in the middle of the input operation with the lever. With this function, the engine speed can be lowered along with the LS control flow, providing a wider range of cooperative operation of lever input and operating speed.

Please note that these specifications or standard features may be modified to meet customer requirements. Functions not listed in the specification table are subject to review for addition. KYB believes that its flexibility is one of its strengths.

Table 2 PSVL series specifications

	Model	PSVL-42	PSVL-64	PSVL-84
	Displacement (cm^3/rev)	Max 42.0	Max 64.0	Max 84.6
	Maximum pressure (MPa)	24.5	28.0	32.0
	Input speed (rpm)	2500	2400	2200
	Pilot pump	Standard		
	Displacement of pilot pump (cm^3/rev)	4.0 or 7.0		
	Maximum pressure of pilot pump (MPa)	4.9		
Control system	LS control	Standard		
	LS gain change control	Standard		
	Horsepower control	Standard		
	Hydraulic pilot horsepower control shift	○	○	○
	Electromagnetic proportional horsepower control shift	○	○	○
	Pilot operated directional control valve	×	×	×
Installation	Spigot joint diameter (mm)	101.6	101.6	152.4
	Bolt pitch (mm)	180.0	200.0	228.6
	Bolt hole size (mm)	14.0	17.5	17.0
	Suction port (mm)	SAE 1 1/2 (port size ϕ38)	SAE 2 (port size ϕ45)	SAE 2 1/2 (port size ϕ63)
	Discharge port	G3/4	G3/4	G1

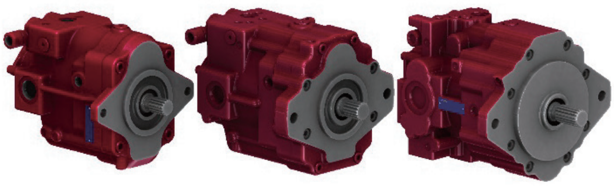

Fig. 1 Product appearance
(from left to right: PSVL-42, PSVL-64, PSVL-84)

2. 3 PSVL-50 Product Specifications

Table 3 shows the product specifications of the current PSVL-42 and the newly developed PSVL-50. Fig. 2 shows the appearance of these products.

Table 3 Product specifications

Item		Current product	Developed product
Model		PSVL-42	PSVL-50
Displacement (cm^3/rev)		Max 42.0	Max 50.0
Maximum pressure (MPa)		24.5	28.0
Input speed (rpm)		2500	2500
Maximum input torque (horsepower control) (N・m)		165 (114)	223 (150)
Maximum flow rate (L/min)		106.0	125.0
Pilot pump		Standard	Standard
Control system	LS control	Standard	Standard
	LS gain change control	Standard	Standard
	Horsepower control	Standard	Standard
	Hydraulic pilot horsepower control shift	○	○
	Electromagnetic proportional horsepower control shift	○	○
	Pilot operated directional control valve	×	○
Overall length (mm) *Including GP, except options		265.5	259.2
Overall height (mm)		218.0	171.0
Overall width (mm)		210.0	170.0
Weight (kg)		30	23
Installation	Spigot joint diameter (mm)	101.6	101.6
	Bolt pitch (mm)	180.0	146.0
	Bolt hole size (mm)	14.0	14.0
	Suction port (mm)	SAE 1 1/2 (port size φ38)	SAE 1 1/2 (port size φ38)
	Discharge port	G3/4	G3/4

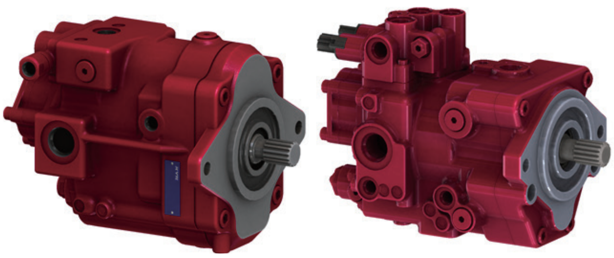

Fig. 2 Product appearance (Left: PSVL-42, Right: PSVL-50)
*The current product appears with standard features provided, while the developed product appears with full options provided. The same applies to the appearance in all figures on the following pages.

The basic product specifications include a maximum displacement of 50 cm^3/rev, which is the highest level in the 3 to 4-ton class market, a maximum pressure of 28 MPa, and a maximum input torque of 150 N・m during horsepower control. The developed product uses a mounting flange of standard SAE-B specifications, which is a non-standard feature in the current product.

2. 4 Features of the Developed Product

2. 4. 1 Weight Reduction

The developed product has been substantially modified in its internal configuration for downsizing and weight reduction. Mainly by modifying the pump displacement control mechanism, we have significantly reduced the overall height and reduced the weight of the pump body by about 23% from the current product as shown in Fig. 3, contributing to improved mountability on the actual machine and cost reduction.

2. 4. 2 Design for LS System

The developed product, designed to be used for an LS system, incorporates the valve essential for LS control into the pump body to reduce cost and weight (Fig. 4).

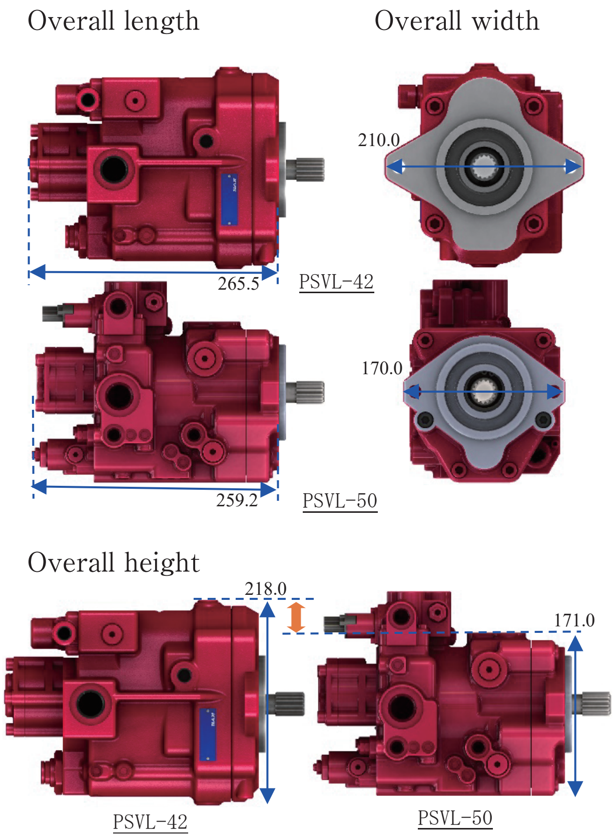

Fig. 3 Size comparison

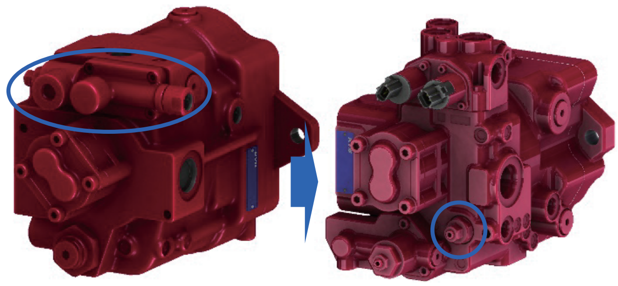

Fig. 4 LS valve appearance (Left: current product, Right: developed product)

2. 4. 3 Optional Functions

The developed product offers two optional functions.

One is the horsepower control shift. As shown in Fig. 5, the horsepower control characteristics can be shifted in parallel with electrical signals or external pilot pressures. This function can be freely

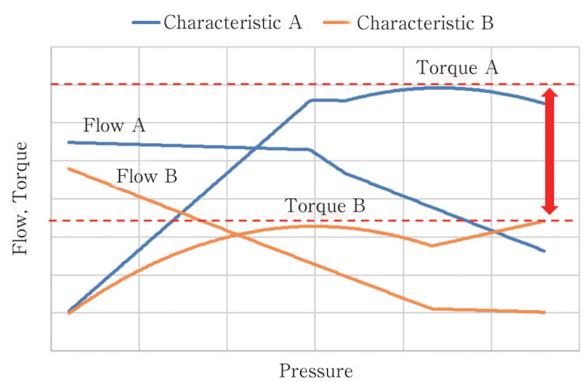

Fig. 5 Example of horsepower control shift characteristics

customized according to the customer's needs, allowing a variety of control.

In order to achieve both the various control characteristics of the horsepower control shift and productivity, we replaced the conventional internal horsepower control valve with an external type. This replacement made it possible to enable/disable the horsepower control shift only by attaching/detaching the valve. While the conventional product required a change on the body housing side, the developed product has a standardized body housing regardless of whether it has this option or not. The developed product saved space by designing the proportional solenoid used for the electromagnetic proportional horsepower control shift to face the pump body.

The other optional function is the pilot operated directional control valve. This is a valve used to switch the pilot pressure supply to lever operation, second gear drive, or other operation. As shown in the schematic diagram in Fig. 7, it includes a pilot relief valve and an accumulator check valve. This directional control valve is often installed in the machine body separate from the pump. With this option, excavator manufacturers can choose to concentrate components by integrating the valve into the machine layout or can reduce piping by mounting the valve on the pump.

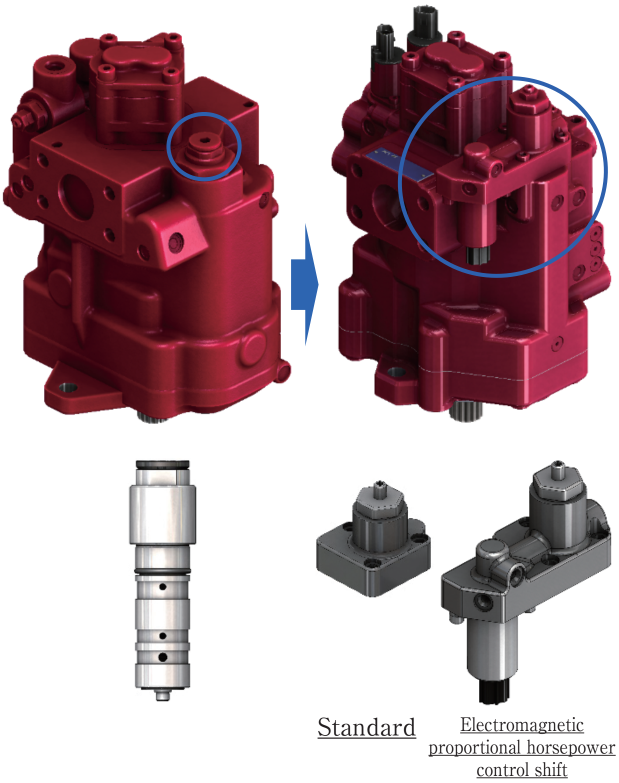

Fig. 6 Horsepower control valve (Left: conventional product, Right: developed product)

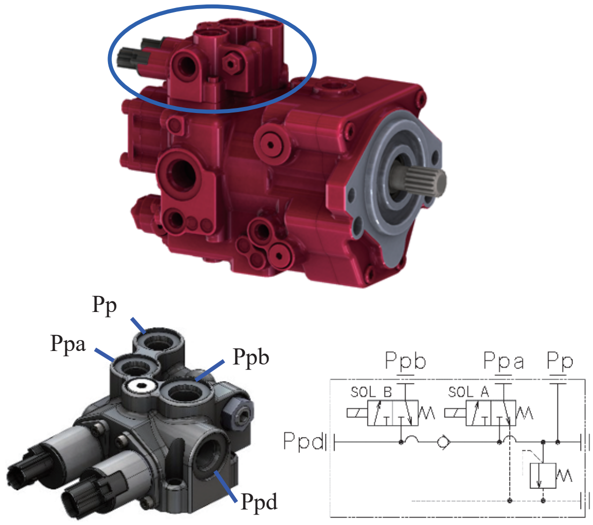

Fig. 7 Pilot operated directional control valve

3 Future Prospects

Based on the product model developed in this project, other classes of next-generation PSVL series are planned to be developed sequentially. The new product configurations are expected to significantly reduce the weight of the products compared to the conventional counterparts. Developing series products will contribute to social goals such as achieving carbon neutrality. To release the products earlier, we are committed to working harder on development.

4 In Closing

We are very pleased that, with the help of those around us, we were able to successfully launch the product, despite the challenges we faced during development due to the significant changes made to the current pump.

Finally, we would like to express our deep gratitude to everyone involved for their tremendous cooperation during the development.

Author

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Product Introduction

Development of Swing Valves on Motorcycles

SAKAWAKI Toshihiko

1 Introduction

Motorcycles in the Supersport (SS) category are positioned as flagship vehicles prioritizing driving performance. They are also used as the basis for racing vehicles.

These motorcycles are manufactured using cutting-edge technologies to provide the high performance expected of a flagship model.

To enhance riding performance, these motorcycles' suspension systems are designed with top-of-the-range structures from suspension manufacturers. Some vehicles have electronically controlled suspensions.

KYB provides a lineup of high-performance front forks for SS motorcycles, including an air-oil-separate system (AOS II)[1] and a large cylinder structure. Conversely, rear cushion units (RCUs) use a general aluminum gas piggyback structure in many models.

2 Aim of Development

In this project, we focused on "road feel", which is a critical sensory evaluation factor for motorcycle performance. Road feel must be improved due to its close relationship with handling and stability.

Improving road feel requires stabilizing the load that the tires press against the road (ground contact force), i.e., minimizing fluctuations in this load. Adjusting the suspension spring reaction and damping forces according to the vehicle and road conditions provides riders with a high level of road feel (Fig. 1).

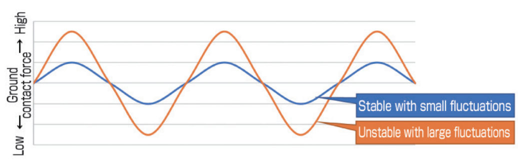

Fig. 1 Ground contact force during driving (conceptual drawing)

In general, the damping force is adjusted using leaf valve and orifices. While it is possible to adjust the damping force from low to high speeds, fine adjustments are impossible in the very low speed range (Figs. 2 and 3).

This makes it difficult to control the initial movement of the suspension, which sometimes results in riders not having the desired road feel.

Thus, achieving the damping force characteristics in the very low speed range for the high-level road feel required in SS motorcycles is difficult with conventional suspension structures alone. A new suspension structure was then needed to enable control in the very low speed range (Fig. 4).

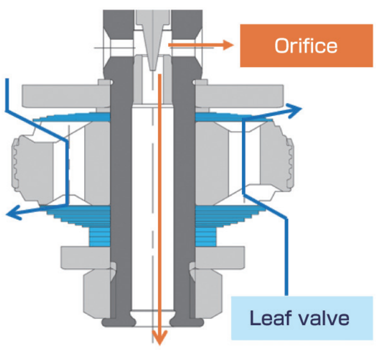

Fig. 2 Conventional structure

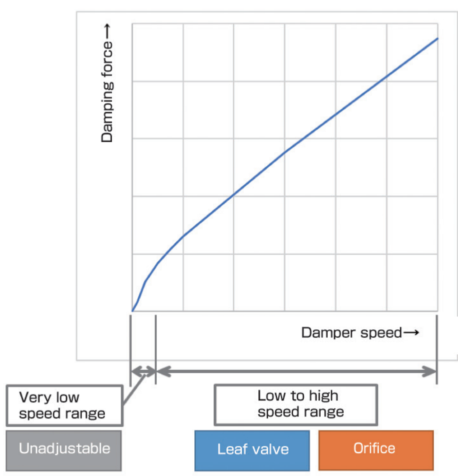

Fig. 3 Damping force characteristics

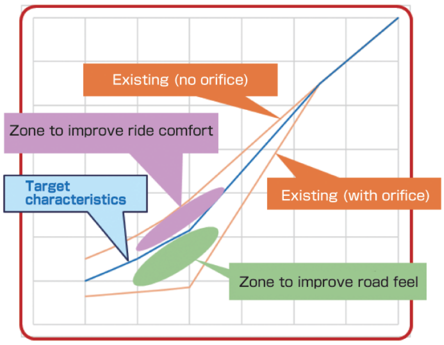

Fig. 4 Damping force characteristics (very low speed)

3 Overview of Development

The following describes the comparison and evaluation of the swing valve structure for four-wheel cars and the swing valve structures developed for motorcycles.

3. 1 Structure Study

3. 1. 1 Swing Valve for Four-wheel Cars

Fig. 5 shows the structure of the swing valve that controls the damping force at very low speeds. This valve is mass-produced for four-wheel cars.

A non-seating leaf valve is installed in series with the main valve to control the damping force at very low speeds, ensuring a high-quality comfortable ride.

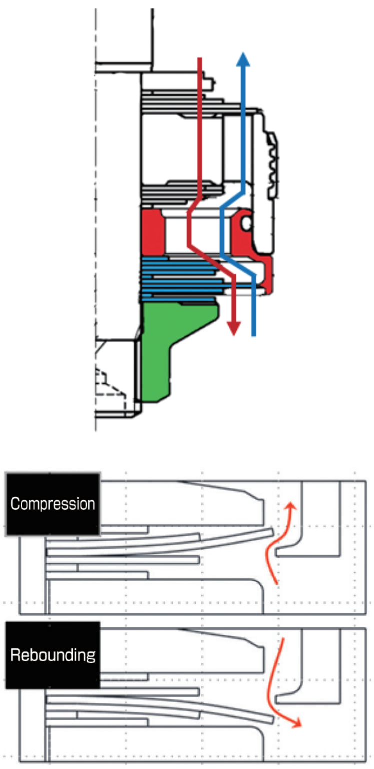

Fig. 5 Swing valve structure for four-wheel cars [2]

3. 1. 2 Swing Valve for Motorcycles

We studied the use of swing valves in motorcycle applications to control the damping force at very low speeds.

If a swing valve is installed in series with the main valve, it may deform and crack when the damper speed increases to raise the flow. To address this, we installed a swing valve in parallel with the main valve, dividing the flow of operating fluid into two lines. This reduced the load and alleviated the stress occurring in the valve. The goal was to control the damping force at very low speeds, which can be achieved with a low flow rate. Thus, both durability and damping control were achieved.

As shown in Fig. 6, installing a non-seating leaf valve in parallel with the main valve enabled control of the damping force in the very low speed range while suppressing the effect on the damping force characteristics of the main valve.

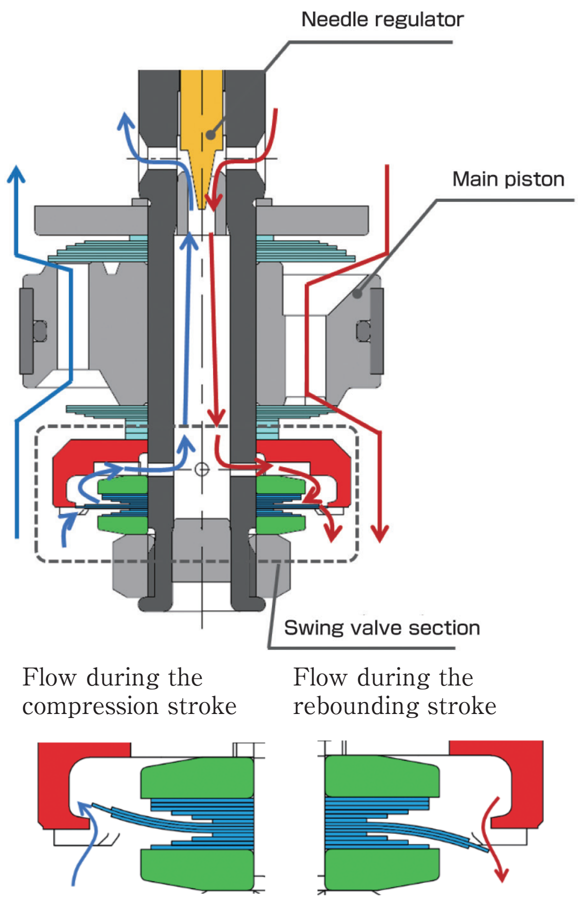

Fig. 6 Swing valve structure for motorcycles

In this project, we also studied the oil passage design to enable parallel installation of the swing valve. To support the various damping force characteristics required by each model, we designed the oil passage so that the main and swing valve specifications can easily be changed.

3. 2 Characteristics

Figs. 7 and 8 show the damping force characteristics of the different structures in the very low speed range.

The red lines represent the damping force characteristics of the conventional structure with the narrowed orifice at very low speeds, while the blue lines indicate the characteristics of the swing valve. The swing valve shows a linear rise in damping force, whereas the conventional structure shows an increase that is not linear. Narrowing the orifice in the conventional structure shown in red increases the damping force at very low speeds, resulting in a steep rise in damping force that is not linear.

The swing valve for motorcycles has achieved the linear damping force characteristics in the very low speed range. In response to input from the road surface, the swing valve generates an appropriate amount of damping force, giving the rider a high level of road feel.

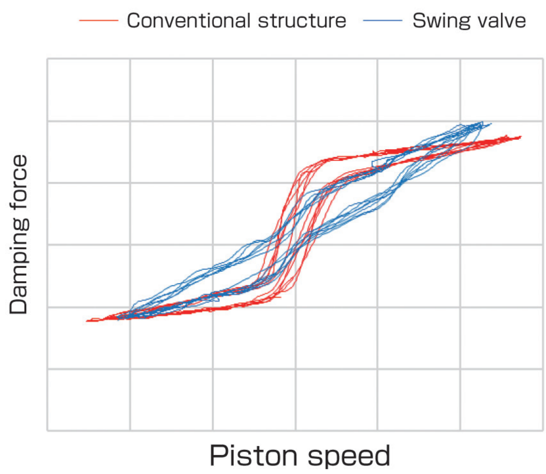

Fig. 7 Damping force-speed waveform

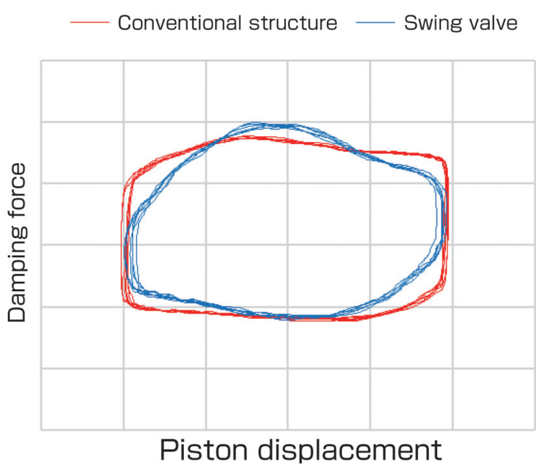

Fig. 8 Damping force-displacement waveform

3. 3 Riding Evaluation

The riding evaluation focused on road feel and handling, which were the primary goals of the development.

The results showed that the swing valve improved the absorption of small gaps and swells during cornering with the appropriate damping force in the very low speed range, resulting in higher road feel compared to the conventional counterpart.

According to measurements of RCU movement on the actual vehicle, the conventional product exhibited unstable structure with significant movement in response to road surface input during cornering. In contrast, the swing valve exhibited limited movement. Thus, the measurement data taken on the actual vehicle confirmed that road feel was improved by minimizing fluctuations in ground contact force (Fig. 9).

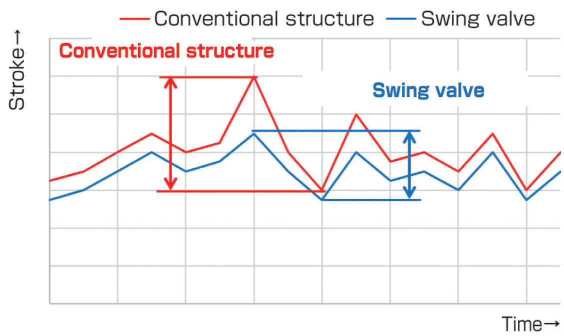

Fig. 9 Measurement data on actual vehicle (during cornering)

Additionally, the swing valve enabled control of the suspension movement from the beginning, offering a high-quality feel and improved ride comfort.

However, concerns arose that the higher damping force in the very low speed range would restrict suspension movement and inevitably make handling heavier, worsening maneuverability. Fortunately, the swing valve's linear increase in damping force in the very low speed range did not excessively suppress suspension movement. Instead, it enhanced ground contact feel while maintaining handling feel.

Measurement data from the actual vehicle proves that the swing valve delivers movement equivalent to that of the conventional counterpart when changing direction. Handling performance, including the light feel when changing direction, remains the same (Fig. 10).

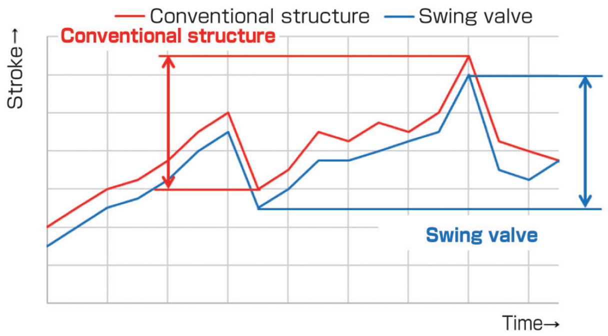

Fig. 10 Measurement data from actual vehicle (when changing direction)

During the riding evaluation, the damping force was intentionally increased in the very low speed range. While road feel improved, the motorcycle felt heavier when changing direction, resulting in worse maneuverability.

These findings showed that controlling the damping force at very low speeds with the swing valve enables adjustment of the balance between road feel and handling according to vehicle characteristics.

4 Conclusions

We successfully developed a swing valve as a new suspension structure for SS motorcycles. Riding evaluations showed that the swing valve improved road feel during cornering without compromising maneuverability.

Although the swing valve was developed for SS motorcycles, road feel during cornering is an important feature for all motorcycle categories. Therefore, the swing valve can also be applied to vehicle categories other than SS.

5 Prospects

The swing valve, which was developed for motorcycles, can be added to the standard motorcycle valve structure. It can be used with any structure, including steel single-tube gas and aluminum piggyback structures. We plan to offer the swing valve to SS motorcycle manufacturers and other Japanese and overseas vehicle manufacturers as a performance improvement.

6 In Closing

Finally, we would like to take this opportunity to express our sincere gratitude to the related departments for their support and cooperation in developing this product.

References

1) TOMIUGA: “Development of the Front Fork (AOS II) for Super Sport Motorcycles”, KYB Technical Review No.50 (April 2015).
2) YASUI: “Development of Valve for Ultra-Low Speed with High Damping Force”, KYB Technical Review No.57 (October 2018).

Author

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Engineering Dept., KYB Motorcycle Suspension Co., Ltd.
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Product Introduction

Eco-0.4cc Pump

TSUJII Yoshikatsu

1 Introduction

Takako Industries, Inc. mass-produces and sells the TFH Series small axial piston pumps (the “small pumps”) shown in Photo 1. We sell the small pumps to a variety of industries and have received high evaluations for the hydraulic pumps' efficiency and compactness. However, some customers have earnestly requested that we provide small pumps with minimum specifications at more reasonable prices. These customers do not necessarily require the maximum specifications or performance of the current mass-produced counterpart, but they want to maintain the features of the piston pump. In order to promote further sales expansion, we must respond to these customers' desires.

Recognizing the need for economical (or inexpensive) small pumps, Takako Industries began developing a 0.4 cc/rev pump. It was the smallest pump in the series and the most in-demand by customers, who wanted it to be sold at a reasonable price. This report introduces our efforts to develop an affordable 0.4 cc/rev small pump (the “Eco-0.4”).

Photo 1　Small axial piston pump series

2 Specification of the Product under Development

Table 1 compares the specifications of the currently mass-produced TFH-040, the Eco-0.4 under development, and the desired product of customers (with specifications selected from the results of interviews with customers).

The Eco-0.4 has a maximum discharge pressure of 14 MPa, which remains unchanged, and a maximum rotation speed of 3,500 min^{-1}, lower than the 5,000 min^{-1} specified for the THF-040. We discussed reducing the overall length, outside dimensions, and weight of the currently mass-produced product as much as possible. However, we prioritized reducing the overall length because more customers wanted this than reducing the outside dimensions.

3 Approach to Achieve Target Costs

3. 1　Allocating Target Costs

We discussed with our Sales department to set a target selling price for the Eco-0.4 and decided on the target cost for that price. We used the VE approach [Note 1)] to allocate costs to each part against the target cost. The following shows our general flow of discussion:

Note 1) An acronym for Value Engineering. It is an approach to maintaining or reducing costs while

Table 1　Comparison of specifications of TFH-040, Eco-0.4, and customer-desired product

Item		TFH-040 (mass-produced product)	Eco-0.4 (product under development)	Customer's desire
Displacement volume	[cc/rev]	0.401	0.403	Around 0.4
Discharge pressure	[MPa]	14	14	11
Rotation speed	[min^{-1}]	5000	3500	3300
Rotation direction	[−]	Bi-rotational	Bi-rotational	Bi-rotaional
Operating temperature	[℃]	＋5～＋60	＋5～＋60	Under discussion
Outside dimensions	[mm]	□30×61.4	□34×53	Smaller
Weight	[g]	270	225	Lighter

enhancing or preserving the quality and functions of the product or service.

[1] First, divide the TFH-040 components into four groups based on their functions. Then, calculate the cost of each group to determine the cost ratio among them.
[2] Prioritize the four functions to be subjected to VE.
[3] Allocate a target cost to each function.
[4] Based on the results of steps [1] to [3], allocate a target cost to each Eco-0.4 functional component group.
[5] Allocate a more detailed cost to each part of the component groups.

In fact, we could not achieve the target without fundamentally reducing costs. Therefore, we considered reducing the number of parts in step [5] above. As a result, the Eco-0.4 had 20% fewer parts than the TFH-040, which contributed to both cost reduction and resource conservation.

3. 2 Part Cost Reduction Measures

Photo 2 shows an Eco-0.4 sample product in the development stage. Its housing and other casing parts were machined from solid blocks. In the mass production stage, however, as shown in Fig. 1, the casing parts use an aluminum die-cast housing to reduce processing man-hours and product weight. The internal parts of the pump use sintered materials and stamped parts to reduce costs. In addition, we aim to improve productivity and reduce costs by diverting parts currently produced in volume.

We are also working on this cost reduction activity by producing parts at Takako Industries' global production sites and by developing new suppliers in cooperation with the Purchasing and Procurement departments.

Photo 2 Eco-0.4 sample product

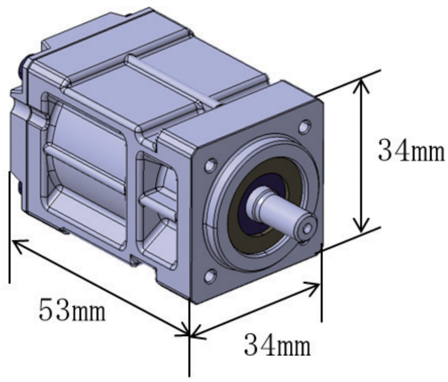

Fig. 1 Eco-0.4 mass-production model

4 Performance

4. 1 Efficiency Characteristics

Our customers typically use electric motors to power small pumps. They adjust the pump flow by changing the motor speed. Therefore, the TFH series or the Eco-0.4 is required to deliver stable performance (volumetric efficiency Note 2)) across the low to high speed range.

Fig. 2 shows the volumetric efficiency characteristics of the Eco-0.4 when the discharge pressure is held at 14 MPa and only the pump speed is varied. The volumetric efficiency of the Eco-0.4 is approximately 1 to 2 percent lower than that of the mass-produced TFH-040 across the entire speed range. Thus, we have confirmed that the Eco-0.4 successfully maintains the features of a piston pump.

Note 2) The ratio of the actual measured displacement volume to the theoretical displacement volume (JIS B 0142: 2011).

The actual displacement volume is affected by the tolerances of each component as well as by volume loss due to pump leakage.

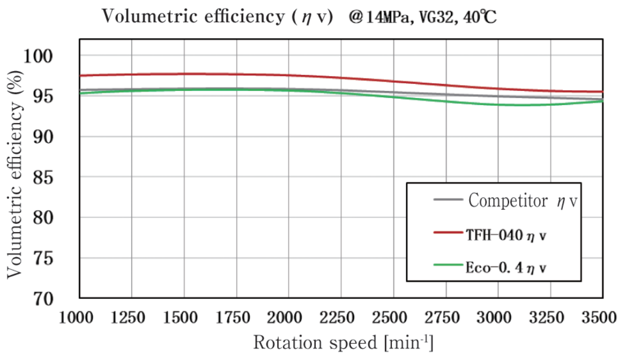

Fig. 2 Comparison of volumetric efficiency characteristics

4. 2　Durability

To verify its durability at the development stage, we subjected the Eco-0.4 to the same tests as the TFH-040, including continuous and repeated durability tests. The Eco-0.4 showed no performance decrease or component malfunction in any of the tests, proving its durability. Fig. 3, for example, compares the volumetric efficiency characteristics before and after the continuous durability test. The results shown in Fig. 3 are from testing in which the pump speed was held at 3500 min^{-1} and only the discharge pressure was varied.

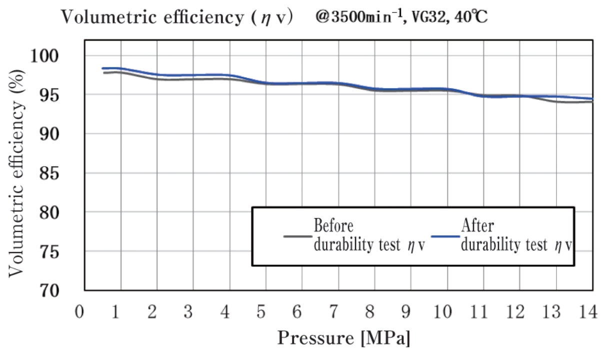

Fig. 3　Comparison of volumetric efficiency characteristics before and after continuous durability test

5　Exhibition at IFPEX 2024

Takako Industries participated in the IFPEX 2024 exhibition held in September 2024. Photo 3 shows our booth at the exhibition, where we showcased a sample of the Eco-0.4 (Photo 4). Many visitors were interested in the compactness of the mass-produced TFH series, the world's smallest class of small pumps. Along with introducing the TFH series, we also presented the Eco-0.4. Some visitors expressed more interest in the Eco-0.4, making us recognize a demand for an economical (or inexpensive) type of the product.

Photo 3　Takako booth at IFPEX 2024 exhibition

Photo 4　Eco-0.4 presentation board

6 Expected Applications

Through the exhibition (at IFPEX 2024) and sales activities, we received numerous inquiries regarding brake- and steering-related applications, as shown in Photo 5 and Fig. 4, respectively. All of these applications require small pumps that can instantly deliver flow and control flow according to steering.

Customers can choose between the mass-produced TFH-040 and the Eco-0.4 based on their desired cost and performance. In either case, we will make optimal proposals to satisfy our customers.

Photo 5 Trailer brake

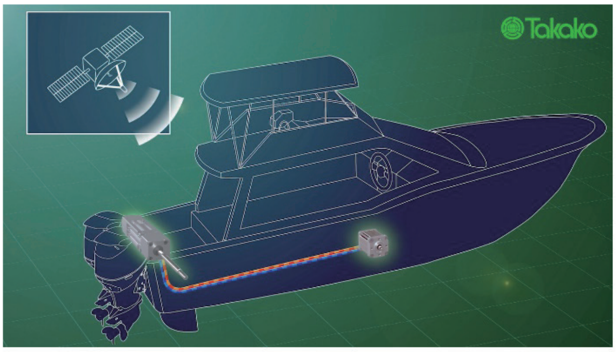

Fig. 4 Ship steering

7 Results of Development

Table 2 summarizes the results of developing the Eco-0.4. Compared to the existing mass-produced TFH-040, the Eco-0.4 features reduced resource usage, a lighter weight, and a shorter overall length while maintaining performance. Additionally, cost estimation results showed that the fundamental cost reduction target set forth in section 3.1 was achieved, though details are omitted here. Therefore, the Eco-0.4 satisfies the requirements for an economical (or inexpensive) small pump.

Table 2 Eco-0.4 development results

Volumetric efficiency @14 MPa, VG32, 40℃	: Equivalent to our existing model
Cost reduction	: Target achieved
Resource reduction	: 20% fewer parts than our existing model
Weight reduction	: 17% lighter than our existing model
Overall length reduction	: 14% shorter than our existing model

Note: "Our existing model" refers to TFH-040.

8 Prospects

As of the time of writing this report (December 2024), the development for product commercialization has been completed. We will now transition to development tailored to customer inquiries. We have already received several inquiries from Japanese and overseas customers, but some of their detailed requirements are unclear. Therefore, we will promote development while collecting and organizing accurate information, updating it as needed.

9 In Closing

We would like to express our sincere gratitude to the external and internal project members, including those from the Sagami Hydraulics Engineering Dept. of the HC Operations and Materials Engineering Sect. of the Basic Technology R&D Center of Engineering Div. of KYB Corporation.

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IFPEX Postscript [1)]

FUJIE Tomoya

1 Introduction

The 27th International Fluid Power Exhibition (IFPEX) 2024 was held from Wednesday, September 18 through Friday, September 20, 2024, at Tokyo Big Sight's East Exhibition Hall 3. KYB was one of the participants.

The theme of this IFPEX was “Connect the Future with Fluid Power!” The event aimed to engage a diverse audience, including students and future generations, by showcasing the strengths of physical fluid power and the industry's potential.

The previous event, held in 2021, took place when the impact of the COVID-19 pandemic was still being felt, resulting in a total number of visitors that was nearly half of the usual amount. The 2024 event was expected to have many visitors, with almost no pandemic-related impact. Fig. 1 shows the venue layout.

2 KYB's Exhibition

In response to the IFPEX theme, KYB developed the exhibition concept, “Bring new 'joy' to the future with the 'DNA' of hydraulics” to raise awareness of the company.

[1] Exhibits

KYB grouped and selected its exhibits with the keywords “DNA” and “Joy” included in the concept and related to the ideas below, which are roughly categorized.

◆“DNA”: Time frame: Past to present; Topic: Supporting society

⇒Traditional technology

- Construction machinery hydraulic products

Fig. 1 IFPEX 2024 venue layout [2)]

◆“Joy”: Time frame: Future; Topics: Environmental conservation, labor shortage measures, safety, etc.
⇒Future technology
- Electrification
- Sensing (<experience-based sales> service)

KYB presented a larger number of demonstration products and hands-on exhibits than before to help visitors easily understand and enjoy its products and services, as well as to raise awareness of the company.

[2] Booth preparation

KYB usually exhibits its products at IFPEX by presenting internal parts and fittings mounted in an actual machine or vehicle. Due to its product features, the company's exhibition tends to appear quite serious at first glance, seeming to be nothing more than “a line of metal blocks put a table”. We were concerned that this image would hinder visitors' interest in the company. To address this concern, we incorporated the following ideas into the design of our booth:

◆Incorporate a bright, eye-catching image.
⇒Use colors carefully based on the company’s color scheme. Incorporate intermediate colors and gradations to express the concept.

◆Design a booth that feels open and makes exhibits easy to see. Arrange the exhibits in a layout where people can enter from any direction.

◆Display a mock-up model of a mini excavator at the center to allow visitors to easily identify its major components.
⇒Positioned as a landmark of the booth, the mock-up model was designed to be visually appealing. We also prepared and distributed a limited number of promotional items related to the event to ensure that visitors would remember us even after leaving the booth.

Photo 1 shows an overview of the KYB booth. Photo 2 shows the mock-up of the mini excavator. Photo 3 shows the presentation board for the oil condition diagnosis system.

Photo 1　Overview of KYB booth

Photo 2　Mini excavator mock-up model
(including hydraulic equipment for construction machinery)

Photo 3　Oil condition diagnosis system
(sensing, <experience-based sales> service)

3 During the Exhibition

Our booth had many visitors, exceeding the number in 2017 before the pandemic. Hopefully, this was due to our thorough preparation. We were able to conclude the exhibition without any particular problems. We were very pleased to see our attendees here and there, explaining the exhibits and communicating well with visitors who had many questions, throughout the exhibition.

However, one thing that needs to be evaluated and reflected on is our collaboration with Mynavi for the first time. The collaborative exhibit focusing on students and recruitment might not have been operated effectively.

4 Competitors' Exhibition and Trends

While participating companies generally exhibited a wide product lineup at previous events, I had the impression at this event that they shifted to showcasing their products and services, focusing on what they really wanted to promote.

Some competitors designed their booths to create an illusion, while others used a single phrase to make a strong impression. Many companies made an effort to showcase their products in unique and appealing ways, which was impressive.

I noticed a particular trend that some companies emphasized not only their products, but also services or experience-based sales, such as condition monitoring. This implies that the industry is moving in a certain direction.

5 In Closing

I would like to express my gratitude to the organizers and everyone involved in this event, as well as all those who visited the exhibition. I hope that our exhibition, presentations, and participation in workshops will help the whole industry further develop.

Thank you very much.

References

1) "Fluid Power", Vol. 38, No.4 (November 2024)
2) IFPEX 2024 material.

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Introduction

20 Years of KYB Museum

KOMUTA Kumi, FUJISAWA Kyoko, SATO Tomonori

1 Introduction

In March 2025, KYB will celebrate its 90th anniversary, and in October 2025, the KYB Museum will mark its 20th anniversary. To commemorate these milestones, we are honored to have been granted this valuable space in this issue of the KYB Technical Review.

This article briefly explains the “Background of the Establishment” and “Evolution of Exhibit Renewal” of the KYB Museum. These topics are covered in more detail in issues No.40 (April 2010) and No.69 (October 2024), respectively. Instead, we will focus on what has happened in the last 20 years and the museum's membership in the Kanagawa Company Museum Liaison Committee.

2 Background of the Establishment

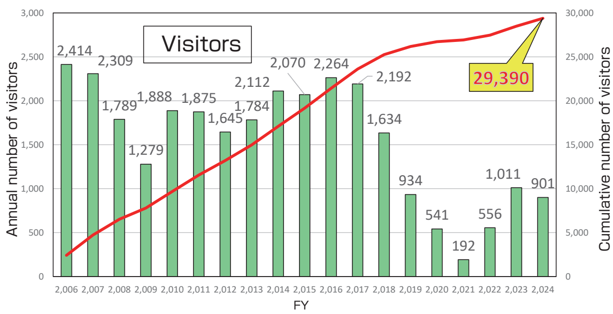
The KYB Museum first opened in October 2005 as part of KYB's 70th anniversary celebrations, initially for internal use by employees. It opened to the public in April of the following year, showcasing the company's technical history. The museum is located on the 1st and 2nd floors of the first R&D center (approximately 750 m^2) of the KYB Sagami Plant (Photos 1 and 2).

Photo 1 1st floor at the time of museum’s opening in 2005

Photo 2 1st floor as of 2024

3 Number of Visitors and Number of Exhibits

As of the end of November 2024, the cumulative number of visitors is 29,390 (Fig. 1). In addition, a visit to the KYB Museum is part of the new employee training curriculum, through which 1,901 new employees have visited the museum for training. Due to the COVID-19 pandemic and other reasons, some of the training programs have been held online, and an additional number of new employees have participated in the online training, bringing the total number of participants to 2,044. We hope that these training programs continue to contribute to the key training objectives of “Conveying the history, depth, and breadth of KYB technology”, “Inheriting KYB's DNA and management philosophy”, and “Cultivating awareness of norms”.



Note) The annual number of visitors in fiscal 2024 reflects the total number of visitors by the end of November 2024.

Fig. 1 Number of visitors

When the museum was established, the number of exhibits was approximately 120. We now have about 630 exhibits and are working to gradually expand the lineup.

The Chronology of Major Products and the Historical Timeline were updated in 2011, 2016, and 2023. The SA, HC, Sealing, and other exhibits were updated as needed (Photo 3).

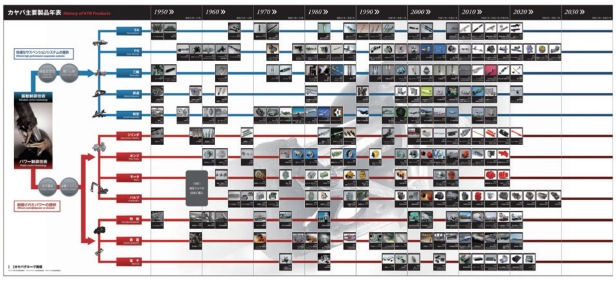


Photo 3 Chronology of Major Products as of 2024

4 Major Events Over the Past 20 Years

Since opening in October 2005 for internal use by employees, the KYB Museum has seen many events. The following chronology lists the major events:

October 2005 - Opened for internal use by employees as part of the 70th anniversary commemorative project of KYB

April 2006 - Opened to the public for external visitors

June 2006 - Article on the opening of the KYB Museum published in the June issue of "Auto Mechanic"

August 2006 - Joined the Kanagawa Company Museum Liaison Committee (* For more information, see Section 5)

February 2010 - Updated the exhibit of semi-active control systems for railway vehicles

October 2011 - Updated the Chronology of Major Products
- Updated the Historical Timeline

July 2012 - Exhibited the Oleo lubricating pump kit (Photo 4)

February 2014 - Exhibited the steer-by-wire system (Photo 5)

Photo 4 Oleo lubricating pump kit

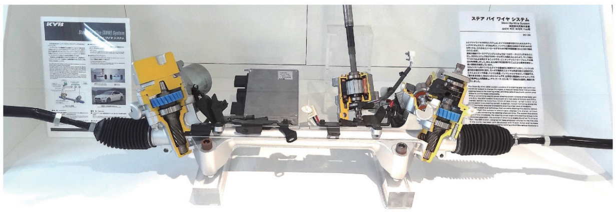


Photo 5 Steer-by-wire system

March 2014 - Exhibited the drive recorder

June 2014 - Significantly changed the layout of the hydraulic engineering area

January 2015 - Reinforced the eight Major Product Information Panels (the "Signature Towers") (Photo 6)

Photo 6 Major Product Information Panel

May 2016 - Installed the Patent Timeline
- Updated the Chronology of Major Products

December 2016 - Updated the Historical Timeline

February 2017 - Exhibited valve casting cores

July 2017 - Sponsored and participated in the Kanagawa Science Summer (July-August)

February 2018 - Relocated the EPS experience machine from the 45th Tokyo Motor Show (Photo 7)

Photo 7 EPS experience machine

July 2018	- Sponsored and participated in the special outreach lecture “Kintaro papa school 2018” hosted by the Minamiashigara City Board of Education (July-August)
October 2018	- Exhibited the active suspension system (ASTRIC) on the Odakyu Romancecar 70000 series GSE - Exhibited the external proportional solenoid damping force adjustable shock absorber - Suspended public access to the KYB Museum (from October 18, 2018, to March 31, 2022, for three and a half years)
July 2019	- Held a Parent-Child Workshop Event at Kumagaya Plant
August 2019	- Held a Parent-Child Workshop Event at Sagami, Gifu North, Gifu East, and Gifu South Plants
November 2019	- Held the Casual Reading-Only Histrical Archaive Exibition at Sagami, Aikawa, and Gifu North Plants (Photo 8)

Photo 8　Stand-and-Read Museum

February 2020	- Installed the smart security camera (Photo 9)

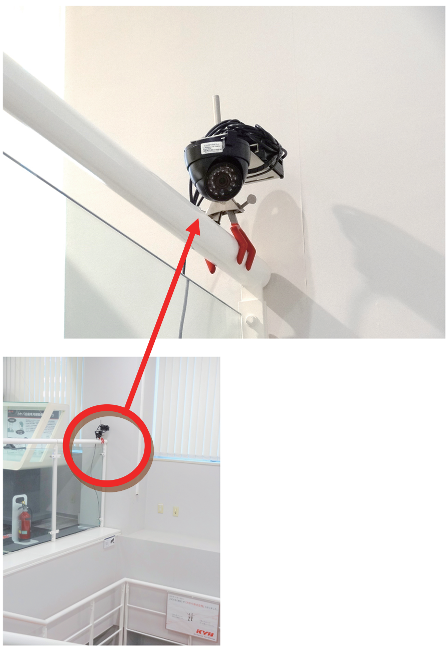


Photo 9　Smart security camera

April 2020	- Renovated the SA exhibition area (completed by March 2023)
October 2020	- Installed a presentation board to ensure that the lessons learned from the issue of seismic isolation/mitigation equipment for buildings would not be forgotten
June 2021	- Reassigned Oleo to the aircraft business
August 2021	- Exhibited the electronic control suspension system (KADS) for motorcycles
December 2021	- Exhibited the shock absorber SwingValve - Exhibited the shock absorber Prosmoth®
March 2022	- Held the Student Virtual Company Tour hosted by the Japan Automobile Parts Industry Association (JAPIA) at the KYB Museum - Changed the Japanese name of the KYB Museum
April 2022	- Installed a special large poster at the main entrance in conjunction with the change of the Japanese common name of the company
July 2022	- Initiated HC exhibition review activities (ongoing)
August 2022	- Began reviewing the DNA Panel, Chronology of Major Products, Historical Timeline, and Eight Signature Towers
February 2023	- Updated the DNA Panel - Updated the Chronology of Major Products - Updated the Historical Timeline - Updated the Eight Signature Towers
July 2023	- Exhibited developed components of the travel motor (MAG-33) - Sponsored and participated in the Kanagawa Science Summer 2023 (July-August)
September 2023	-Exhibited the boom cylinder mock-up for mining machinery
October 2023	-Exhibited components of the load sensing (LS) system for excavators (pumps, valves, travel motors, swing motors, and cylinders) -Established a corner for developed products (oil condition monitoring and cylinder oil leakage detection systems) (Photo 10)

Photo 10 New corner for developed products

October 2023 -Updated the sit ski exhibit (Photo 11)

Photo 11 Sit ski

October 2023 -Exhibited the butted cylinder
-Received a visit by Ms. Kei Takeoka, a motor journalist, filmed and broadcast on YouTube ("Kei Takeoka Visits the KYB Museum")

November 2023 -Exhibited the rally suit used by Mr. Ukyo Katayama during his participation in the Paris-Dakar Rally

December 2023 -Exhibited the 1 pinion type EPS for off-road vehicles

May 2024 -Established a corner for the KYB rally project (Photo 12).

Photo 12 Newly established KYB rally project corner

July 2024 -Article about a visit to the KYB Museum published in the September issue of "Car Goods Magazine"
-Sponsored and participated in the Kanagawa Science Summer 2024 (July-August)
-Exhibited the electronically controlled shock absorber
-Exhibited the improved damping force adjustable shock absorber (low friction)

August 2024 -Held a Parent-Child Workshop Event at Sagami Plant

November 2024 -Sponsored and participated in a Parent-Child Workshop Event at Heavy machinery fan appreciation festival presented by the Hitachi Construction Machinery official fan club
(held at AEON TOWN Fujimino, Saitama Prefecture)
-Article about a visit to the KYB Museum published in the November issue of Journal of Plating & Surface Finishing

November 2024 -Exhibited the smart road monitoring system (Photo 13)

Photo 13 Smart road monitoring system

5 Membership in the Kanagawa Company Museum Liaison Committee

Established in 1985 by five companies, the Kanagawa Company Museum Liaison Committee (the "Committee") is a place for corporate museums in Kanagawa Prefecture to exchange information.

The KYB Museum joined the Committee in August 2006, when it opened to the public, and it has remained a member ever since.

Currently, the Committee has 16 member companies that take turns hosting regular meetings. The KYB Museum has hosted seven of these meetings. Through information exchange among members on various issues related to the nature and operation of corporate museums, we have made improvements to enhance customer satisfaction (Photo 14).

Photo 14 Regular meeting at KYB Museum

We have carried out various activities through the Committee. The main activities are described below.

5. 1 Participation in Attendant Staff Training Seminar

Training seminars have been held to promote mutual learning and networking among attendants. Since September 2008, the KYB Museum has participated in ten training seminars to improve the capabilities of its attendants (Photo 15).

Photo 15 Attendant staff training seminar

5. 2 Participation in the Kanagawa Science Summer

The Kanagawa Science Summer program, implemented by Kanagawa Prefecture, aims to spark children's and youth's interest in science and technology, as well as enhance their desire to learn. From the summer vacation period through fall, science museums and companies within the prefecture that support this initiative hold events.

The KYB Museum first participated in the program in July 2017 and has held a total of 12 events, including the most recent one in August 2024. Each day-long event is attended by ten parent-child pairs, who are selected by lottery from applicants, and has been well-received every year. (The program was interrupted for a while due to the need for infection control related to the COVID-19 pandemic).

These events have been held under various themes, including “Learn About Hydraulics (Pascal's Principle) and Friction (What Is Tribology?)!”, “Zoom in on the Microscopic World with a Microscope!”, “Craft Your Own Excavator Front Part!”, and “Operate a Mini Excavator!” (Photos 16, 17, 18, and 19).

Photo 16 Learn About Hydraulics (Pascal’s Principle) and Friction (Tribology)

Photo 17 Craft Your Own Excavator Front Part

Photo 18 Operate a Mini Excavator

Photo 19 Leaflet distributed to all elementary schools in Kanagawa Prefecture

The Science Summer program had a ripple effect. The "Craft Your Own Excavator Front Part!" event received external offers and was held at a special outreach lecture hosted by the Minamiashigara City Board of Education in July 2018 and at the Official Fan Club Presents Heavy Equipment Fan Appreciation Festival in November 2024.

It was also held as a Parent-Child Workshop Event for the children of KYB employees at the Kumagaya, Sagami, Gifu North, Gifu East, and Gifu South Plants in the summer of 2019, as well as at the Sagami Plant in 2024 (Photos 20 and 21).

Photo 20 Parent-Child Workshop Event (at Kumagaya Plant)

Photo 21 Parent-Child Workshop Event (at Gifu North Plant)

Due to the great popularity of KYB's events in the Science Summer program, we plan to continue holding them with even more exciting content.

6 Conclusions (Toward the Future)

As mentioned in KYB Technical Review No.69, we are renewing the exhibits of diverse product families using a unified "form" and "board" design. This design allows a wide variety of visitors to understand the exhibits' contents, even if they are visiting alone.

Specifically, we will systematically renew the exhibits based on the museum's existing concept: "Our Precision, Your Advantage."

「Our Precision, Your Advantage」

☞Convey KYB's history and its technological prowess in design, production, and manufacturing to customers.

☞Given the diverse nature of KYB's business areas, inform employees about the high level of the company's products and technologies across all divisions to enhance their motivation.

Additionally, for visitors from other countries, we plan to create guided narration videos in two languages using translation applications: English and Chinese.

We kindly request that all Operations and Divisions continue to provide support and cooperation.

7 In Closing

Customers and suppliers who would like to visit the KYB Museum should contact their KYB representative and apply via the KYB bulletin board.

The museum is also open to the public on certain days. You are welcome to visit the museum if you are interested in the exhibits (More information is available on the KYB Museum page of the KYB website).

Finally, the KYB Museum is a place where you can see how KYB's DNA is connected to your daily life.

We are all looking forward to your visit.

KYB Museum page of KYB website (Japanese only)

KYB on YouTube (Japanese only)

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Essay

Essay from Expatriate in Germany and Spain

IIDA Ryo

1. Introduction

As a sales representative, I was expatriated to Munich, Germany from April 2018, and then to Pamplona, Spain from April 2019 to August 2024.

While in Germany, I participated in the project to establish the Munich Branch (as it was then called) of KYB Europe GmbH (KEU). In Pamplona, I worked at the Navarra Branch of KEU alongside local sales personnel.

The six and a half years of my expatriation coincided with the height of the COVID-19 pandemic. The outbreak of this novel infectious disease significantly impacted my expatriation activities.

Since the pandemic greatly changed my professional and personal life, either positively or negatively, I would like to share my experience as an expatriate by comparing life before and after the pandemic, conveying the unprecedented experience as well.

2. Expatriation in Germany

2.1 Introduction to the City

Munich is a city located in southern Germany.

During my time there, I did not experience any inconvenience. More than 4,000 Japanese people lived there, and many foreign companies, including Japanese companies such as MUJI (Ryohin Keikaku Co., Ltd.), had established a presence, along with various Japanese grocery stores.

While overall security is good, you should be careful in places with many tourists, late at night, on streets with few people, and around large railway stations like the Hauptbahnhof (Central Station). This is something to keep in mind when visiting any European country.

The city has an extensive public transportation system with buses, trams, subways, and trains. You can easily get around the city without a car. Children six and under can ride public transportation for free, which their parents will appreciate.

Munich is famous for its beer festival called Oktoberfest, which attracts more than five million visitors who enjoy drinking beer in large mugs (Photo 1).

Like Japan, Munich has four distinct seasons. Due to its high latitude, the city is generally considered cool in summer and cold in winter. However, due to the effects of recent global warming, summers have become very hot. Conversely, during the winter of 2018 when I was living there, the city experienced one of its coldest winters in years.

Photo 1 Oktoberfest venue and my son wearing traditional clothing

2.2 Work

My work in Germany began with the establishment of the Munich Branch (as it was then called). At that time, the headquarters of KEU was located in Düsseldorf. Accordingly, my expatriate life began in Düsseldorf.

My top priority was travelling to Munich every week to lay the groundwork for my life there. I was unfamiliar with the area and had no acquaintances in Munich. I remember having difficulty finding my house.

The initial office was a rented space. I quickly found the office space, received the keys, and moved in by the end of April, right after arriving in Germany. Despite being small enough for only four people, the office was a comfortable space with good sunlight (Photo 2).

My next task in Munich was to hire employees. First, I needed Germans who spoke Japanese.

Despite the high penetration of English, German was essential in applying for a visa, opening a bank account, and doing other procedures in Munich. I interviewed several Germans for recruitment at the Düsseldorf headquarters and successfully hired the desired employee. This was followed by hiring another German designer. Finally, KEU's Munich Branch began operating with a four-person team consisting of two Germans and two expatriates.

Photo 2 Inside the initial Munich Branch

As a sales representative, my role was sales planning.

I took periodic business trips to Spain to meet with the local sales personnel at the Navarra Branch of KEU. KEU's manufacturing sites were located at KYB Suspensions Europe, S.A.U. (KYBSE), where the Navarra Branch was located; at KYB Advanced Manufacturing Spain S.A.U. (KAMS), also in Spain; and at KYB Manufacturing Czech, s.r.o. (KMCZ), in the Czech Republic. Consequently, I spent much less time in Munich and was primarily in Spain or the Czech Republic.

Munich Airport was in a very convenient location for traveling around Europe. To get to Pamplona Airport in Spain, I had to take two flights, either via Frankfurt Airport in Germany or Madrid Airport in Spain.

Bilbao Airport, located nearly two hours north of Pamplona, is accessible from Munich with a direct flight. Therefore, there were two options for reaching Pamplona from Munich: taking two flights or taking a flight and a nearly two-hour ride.

During the initial stage of my expatriation, I flew to Pamplona Airport via Frankfurt Airport because I enjoyed flying.

On the other hand, it was somewhat difficult to reach KMCZ in the Czech Republic. While it was easy to reach Prague Airport from Munich Airport with a flight of nearly one hour, getting to Pardubice, where KMCZ was located, required a one-and-a-half-hour ride from Prague Airport.

After noticing that it was easier for me to travel directly from Munich to Pardubice, taking into account the time spent waiting for flights and the hassle of security checks, I took the five-hour, 500-kilometer ride.

Another thing to keep in mind when traveling in Europe is that flights often run behind schedule. First flights in the morning are usually on time, but afternoon flights rarely are.

In fact, I often missed connecting flights and failed to reach my destinations. On other occasions, my flight arrived at a different airport because the destination airport had bad weather.

When this happened, the airline gave me a boarding pass for the next day and a hotel voucher. Sometimes I ended up staying in a city or country I had never expected.

Whether you view this situation as a crisis or an opportunity to gain experience is up to you. I believe that being able to enjoy yourself in these situations is an important mindset for a low-stress expatriate life.

2. 3 Life

2. 3. 1 Daily Life

When I first moved overseas with my family (my son was three years old at the time), I looked for a house there by considering the educational environment for my son and the convenience of transportation for my family.

The city had two IKEA stores, which made it easy for German residents to buy kitchen parts and assemble them themselves. The do-it-yourself (DIY) spirit of the Germans moved me somewhat.

Because of this mentality, I had to do a lot of DIY work when setting up the house. I had quite a bit of difficulty with the electrical connections for the room lighting. Luckily, there was no electric shock or fire.

German houses generally have no air conditioners. In the summer, it was very hot, partly due to the effect of global warming.

Conversely, German houses are well insulated in the winter. We spent the winter very comfortably with the central heating system.

Although it was warm inside the house, the heavy snowfall allowed us to build large snowmen on the balcony. We also bought a sled to go sledding. Sometimes my son went to kindergarten in a sled.

I found supermarkets and drugstores full of goods. Most commercial facilities were closed on Sundays, which are designated rest days. However, bakeries, gas stations, and small shops were open. We could buy basic necessities in small supermarkets attached to gas stations even on Sundays.

There were also hospitals run by Japanese physicians that provided medical treatment in Japanese. However, prescriptions must be taken to Apotheken (pharmacies in Germany), where only German is spoken. In Munich, German is basically the only language spoken, although English may be understood at tourist sites and by young staff in shops due to the city's size.

Gas stations are self-service. The way cars are cleaned at German gas stations is interesting: Customers can walk alongside their car through a corridor on a conveyor belt that carries the car through the washing machine. Families with young children should definitely try this style of car wash.

In Munich, you can enjoy not only German cuisine but also dishes from other countries in their authentic flavors. The kebabs, in particular, are superb thanks to the large Turkish immigrant population. There was a kebab restaurant near the Oktoberfest grounds that was so good I went there every week.

German cuisine is typified by the tastes of German bread, potato salad, sausages, dairy products, and smoked fish. Even after repatriation, my family remembers these flavors fondly.

During the winter, when the sun sets earlier and the city takes on a gloomy atmosphere, the streets come alive with activity as Christmas approaches. The highlight of winter is definitely Weihnachtsmarkt (Christmas markets).

Munich alone has at least 20 Christmas markets of various sizes (Photo 3).

A popular way to enjoy Christmas markets is to drink gluhwein (hot wine) to warm up in the cold winter weather. Each Christmas market provides a different design of gluhwein cups. Collecting the cups was one of my favorite things to do there.

Christmas markets are also held in cities other than Munich. Visiting other cities to enjoy Christmas markets was so much fun.

2. 3. 2 Traveling

Due to its location in southern Germany, Munich was an ideal place from which to easily travel by land to Austria, Switzerland, Liechtenstein, and the Czech Republic. I really enjoyed the traveling to these countries.

I visited several beautiful places that could not be seen in Japan, including Garmisch-Partenkirchen at the foot of Zugspitze Mountain in the summer and Český Krumlov in the Czech Republic in the winter. I will always remember these places.

Additionally, northern Germany has a different atmosphere than southern Germany. Berlin, in particular, was an interesting city with a slightly gloomy ambiance and traces of communism.

Instead of traveling to faraway places, it was fun to go on picnics to nearby farms and parks (Photo 4).

The Autobahn (highway) was very convenient for traveling between cities and accessing suburbs. There were a relatively high number of service areas along the Autobahn, all of which were very clean. However, be aware that they only had paid restrooms, most of which required coins.

When crossing a border, you may be required to show your ID at a checkpoint or passport control. Be sure to carry your ID with you.

Also, note that the Autobahn is free in Germany, but may be charged once you cross a border. In Switzerland, you need to purchase a pass sticker similar to Japan's vehicle inspection certificate and attach it to your front windshield. According to

Photo 3 Munich during Christmas market season

Photo 4 Neuschwanstein Castle

my research, the sticker must be purchased in Switzerland. In fact, I crossed the border into Switzerland with no specific check. I was nervous about whether I could buy the sticker at the next service area after crossing the border.

In hindsight, it might have been possible to purchase the sticker in Germany beforehand. As of 2024, the sticker is available online.

3. Expatriation in Spain

3.1 Introduction to the City

Pamplona is a city located in northern Spain.

This charming city has a long history, but it is a small city with a population of 200,000. I think there are fewer than 20 Japanese residents.

Pamplona hosts the San Fermín Festival. This grand and spectacular event is commonly known as the “running of the bulls” and is one of Spain's three major festivals.

As depicted in Hemingway's novel, the festival transforms the entire city into a festive atmosphere (Photos 5 and 6).

During the initial period of my expatriation in Pamplona, I found it slightly more difficult to live in this small city than in Munich. However, being able to live a compact life was good because necessities were conveniently available.

Stores are also closed on Sundays in Spain. Additionally, many small businesses close for siesta from around 2 p.m. to 5 p.m.

In the city center, you can walk or take the bus to manage daily life. However, you need a car to get to shops like McDonald's, shopping malls, and large stores, as they are located in suburban areas. Autopistas are toll roads, and many sections have no service areas. The city has a moderate climate throughout the year, similar to that in Aichi Prefecture in Japan, where I live. However, I experienced very hot summers with increased temperatures due to heat waves from the Sahara Desert, which were probably affected by global warming. There were casualties in some places. In the winter, it snows about once per season. Before leaving for work each morning, I often checked the thermometer on the street in front of my house through the window. I noticed significant temperature differences between morning and evening, which sometimes made it difficult to choose what to wear. Because of the city's high latitude, it was light outside until after 10 p.m. in the summer, while the sun set very early in the winter. The running of the bulls' festival lasts about one week, and the fireworks start at 11 p.m., right after sunset, which is very late by Japanese standards. Although I could see the fireworks very well from my house, which was next to the display site, the loud noise for successive nights after 11 p.m. was quite hard to endure. Spain celebrates Christmas on December 25, though not as extravagantly as Germany, and Epiphany on January 6, the day the three wise men visited Jesus.

Children are happy to receive presents twice a year. During the Christmas season, a bread-like cake called Roscón de Reyes is available at every bakery and supermarket (Photo 7). This cake contains small porcelain dolls or beans. Whoever

Photo 5 Formal dressing at the San Fermín Festival

Photo 6 Pamplona during the San Fermín Festival

Photo 7 Roscón de Reyes

finds a doll or a bean when the cake is cut is considered to have good luck for the year, much like with a fortune cookie.

I found one in the Roscón de Reyes served at the office. I heard that whoever gets the fortune is supposed to buy the Roscón de Reyes the following year. I wonder if someone else would have bought one for me since I was not in Spain the following year.

3. 2 Work

In April 2019, I was transferred to KEU Navarra Branch, where I worked in the office alongside local sales personnel. Although I had already been able to communicate with them while stationed in Munich, it became clear that working together in the same office would be easier.

While the transfer eliminated the need for business trips to Spain from Germany, I now needed to have long business trips to the Czech Republic where KMCZ was located. It took almost a whole day to travel from Navarra to KMCZ.

I always flew to reach any destination for business or personal reasons, so I was a frequent flyer.

Working hours in Spain differ significantly from those in other countries. Spanish people typically take a one-hour lunch break between about 1 p.m. to 3 p.m. Since there was no company cafeteria, some employees went home for lunch. Expatriates usually ate lunch at the nearby affiliated restaurant, Don Javier. Ororbia, where KYBSE was located, was a small village with a few restaurants (Photo 8).

The restaurant served a quite large lunch, including an appetizer, main course, dessert, and coffee. However, the menu lacked variety. The appetizer was a large plate of vegetable salad, and the main course was grilled beef, pork, chicken, or fish. For dessert, we often had Cuajada, a yogurt made from goat milk that originated in northern Spain. I learned most of the Spanish words used in restaurants at Don Javier.

The way of working changed greatly before and after the COVID-19 pandemic. At the height of the outbreak, the plant and office were closed, forcing us to work from home.

Even after the pandemic calmed down, the work-from-home system remained. Many local employees came to the office in the morning and worked from home in the afternoon.

Although we had fewer opportunities to meet each other at the company, a work environment in which people could work anywhere became available thanks to the dramatic development of online meeting tools, such as Teams.

Many discussions about minor issues were held during Teams meetings, instead of taking the trouble to take business trips by air to foreign countries. In this sense, we have become able to work more easily with more flexibility.

Photo 8 Church at Ororbia Village, where KYBSE was located

3. 3 Life

3. 3. 1 Daily Life Before COVID-19 Pandemic (with my family)

Since there was no Japanese school in Pamplona, my son attended a local kindergarten where only Spanish was spoken.

Of course, he could not speak Spanish at first, but he watched Spanish children's programs persistently to learn Spanish words before enrolling in the kindergarten. After about one month of eight hours a day of exposure to Spanish in kindergarten, my son had made amigos (friends). I was impressed by his ability to adapt to new environments.

Due to the nature of my work, I frequently traveled for business purposes to different places in Europe. My wife and son spent many nights alone together.

Pamplona was so convenient that any place in the city center was accessible by bus or on foot. We interacted with other expatriates who had been transferred there at the same time and had children around the same age. My wife and son seemed to enjoy spending time with them. I am very grateful to my family for having to move twice across borders and live in unfamiliar lands.

Pamplona has big supermarkets in the suburbs. We went there every Saturday to buy food. Spanish large supermarkets typically have raw ham and wine sections. In the cured ham section, lines of pig legs were hung up. We could buy delicious cured ham and wine at the supermarket. Unfortunately, Spanish dairy products were not as good as those in Germany, despite the presence of DANONE, a familiar yogurt brand in Japan.

Because Pamplona is the birthplace of ZARA, it has many fast fashion brands that sell clothing suitable for the Japanese body type.

When I was sent there, I found vacant land with an IKEA sign. However, IKEA ultimately did not open. It was like the Sagrada Familia of Pamplona.

The nearest IKEA stores were located in Bilbao and Zaragoza, both of which were about a two-hour ride from Pamplona. Visiting these large cities for shopping and sightseeing was enjoyable.

Another “Sagrada Familia” or unfinished project of Pamplona was the Starbucks. I heard that a Starbucks finally opened in the fall of 2024.

The Spanish love coffee. Even bars and bakeries can serve good coffee at reasonable prices. I wonder if this fact had prevented Starbucks from opening shops earlier.

A variety of international cuisines, including Chinese, Thai, Japanese, and Indian, were available. These dishes were not spicy, which made them easily accepted by Spanish people. Sometimes, I felt slightly unsatisfied with the Spanish taste, which is neither spicy nor hot.

Local restaurants operate according to the typical Spanish schedule: opening at 2 p.m. for lunch and at 8 p.m. for dinner. This may be difficult for families with children, but bars open around 5 p.m. However, be aware that they only serve a few types of pinchos right after opening because their ovens are not yet lit (Photo 9).

The most difficult thing about living in Pamplona may be the language barrier. Basically, I was required to speak Spanish no matter what I wanted to do. Fortunately, I love language. I'm glad I was able to understand Spanish before I left.

Photo 9 Pamplona's famous foie gras

3. 3. 2 Traveling

About an hour's drive north of Pamplona will take you to a city called San Sebastián.

The city is famous in Japan as the “city of gourmets”. While there are several Michelin-starred restaurants, I think the best way to enjoy San Sebastián is to hop around to the bars (Photo 10).

The narrow streets are full of bars of all kinds. Why not try bar hopping, tasting a dish and having a drink at one bar before moving on to the next? Another famous thing in San Sebastián is Basque cheesecake. You can try the authentic “Baschee” in the city.

A bar-hopping tip is to strike up a conversation with the staff instead of waiting in line for your turn.

The San Sebastián region is known as French Basque. Although the land belongs to Spain, the atmosphere is French. The region has a unique cuisine that differs from Spanish cuisine.

I also frequently went to Bilbao, which was a nearly two-hour ride from Pamplona. Due to its airport, Bilbao was convenient to access anywhere inside and outside Spain.

The city of Bilbao is home to the Guggenheim Museum, which has an extraordinary appearance, as well as the Vizcaya Bridge, which is registered as a World Heritage Site and was the first bridge in the world to carry people and traffic. The Vizcaya Bridge is sometimes featured on the Japanese children's TV program Pythagora Switch, produced by the Japan Broadcasting Corporation (NHK). My son gets excited every time he sees it because he has been there (Photo 11).

The foreign destinations we travelled to were Ireland and Portugal.

I went to Ireland in August. Unlike Spain in midsummer, it was already very cold in Ireland, as if it were fall. The famous Irish stew was tasty and warmed my cold body.

It was also a great experience to visit Galway, which appeared in an English singer Ed Sheeran's music video. While living in Germany, I also visited the filming location of another music video in the Hintertux mountains (Photo 12).

I went to Portugal in early January, just as the COVID-19 pandemic was approaching. Compared to Spain, Portugal was warmer and more comfortable. I went as far as Cape Roca, the westernmost point of continental Europe, and visited many shops to try different kinds of pastel de nata, a famous Portuguese egg tart (Photo 13).

Photo 10 Bar street in San Sebastián

Photo 11 Vizcaya Bridge in Bilbao

Photo 12 Port city of Galway

Photo 13 Cape Roca in Portugal

3. 3. 3 Emergency Return to Japan During the Height of COVID-19 Pandemic

At the end of 2019, there was an outbreak of bronchitis among children in Pamplona. Hospitals in the city were full. Some children had to be hospitalized in other cities.

We traveled to Portugal during the 2020 New Year's holiday. I remember many passengers coughing heavily on my flight back to Pamplona.

News outlets began reporting that a mysterious infectious disease was spreading throughout the world. On January 30, 2020, the World Health Organization (WHO) declared a Public Health Emergency of International Concern (PHEIC).

On February 1, Japan identified passengers with positive results for the novel coronavirus on the Diamond Princess cruise ship. In Spain, according to reports, some of the participants in the International Women's Day demonstration had become patients. Meanwhile, Italy suffered a pandemic. The news reported that Spain had many casualties in nursing homes and was already experiencing a pandemic. Panic buying at supermarkets began, resulting in empty shelves of toilet paper, rice, pasta, and other goods (Photo 14).

Photo 14 Panic buying at a supermarket

On Friday after kindergarten, my son said "See you next week" to his friends as usual. However, as rumored, the kindergarten was closed starting next week, and suddenly lockdown began. During the lockdown, we were basically prohibited from going out, and only one family member was allowed to go for shopping at supermarkets. The restrictions were so strict that we could only go to supermarkets in different time zones according to our age (Photo 15).

At the end of March, the company had finally decided to temporarily send the expatriates back to Japan.

By that time, most land and air routes had been closed. The EU borders were closed. Madrid Airport, one of Spain's hub airports, was only open to flights from the U.K., which was outside the EU. Fortunately, the only way to come back from

Photo 15 Even your smartphone tells you to stay at home

Europe to Japan was to fly from the U.K., so we traveled to Madrid by land and then flew back to Japan from the U.K.

The photo below shows the arrival information signboard at Haneda Airport on the day I returned to Japan. The service from Heathrow Airport was operating, but all the other flights had been canceled (Photo 16).

Photo 16 Flight information with most services canceled

We managed to return to Japan with only the bare necessities. We then had to take PCR tests, undergo two weeks of health monitoring and isolation, and do things we had never done before.

In the situation, I began working remotely from a place ten thousand kilometers away from Spain. Due to the time difference, some meetings were held at midnight in Japan. Nevertheless, I was able to handle the remote meetings thanks to the scheduling of meetings that required my attendance to be held at times as early as possible in Spain. The most difficult thing was the amount of time computers were connected to the server at the Spain site due to the long distance. We had to wait several minutes just to open a single file.

3. 3. 4 Daily Life During the Convergence of COVID-19 Pandemic (Expatriation Alone)

As the COVID-19 pandemic settled down, we were supposed to return to Spain. However, considering that the future situation was still uncertain, I decided to become an expatriate alone.

The single expatriates in Spain started their expatriate lifestyle in an atmosphere somewhat like a male student camp.

We lived work-centered lives, only coming home to sleep. Fortunately, Don Javier, the affiliated restaurant mentioned above, helped us a lot with nutrition. However, when the pandemic started to settle down, Don Javier was acquired by a Chinese owner who requested a raise in price. Ultimately, we stopped using Don Javier around 2024 and started using another restaurant under a new contract.

Since many restaurants and bars welcomed groups of men, we were not stressed about eating in Pamplona.

Unlike Munich, northern Spain was rich in fresh seafood due to its proximity to the sea. The locals had a habit of eating octopus and squid, which were particularly delicious. Pamplona was also rich in meat dishes because it is surrounded by mountains. Chuletón, a steak of aged meat, was especially tasty (Photo 17).

Photo 17 Chuletón

I didn't always eat out. Sometimes, I tried cooking at home, making Nagoya-style chicken wings and twice-cooked pork.

However, I did not stick with cooking for very long. During the final stage of my time abroad, I often relied on delivery services. I highly recommend online ordering services that allow you to easily enjoy food from various restaurants. Note that this system may be difficult to use because delivery personnel may call you in Spanish if they cannot locate your address.

I talked with my family in Japan every weekend via FaceTime and played online games with my son. I am grateful for technological advancements.

After the 2023 fiscal year, when the COVID-19 pandemic had passed, I enjoyed a fulfilling expatriate life. The lifting of the ban on overseas travel allowed Japanese businesspeople to visit foreign countries, including Spain. It was always a pleasure to meet other Japanese people, as well as expatriates. With more opportunities to eat out with my Japanese colleagues on business trips, I started trying new restaurants as well.

The Japanese restaurants in Pamplona only served so-called “fake Japanese food”. Personally, I didn't miss Japanese food because I liked Spanish food and could eat whatever was served. Nevertheless, there were some occasions when I actually wanted to eat Japanese food.

In early 2024, when my colleagues were staying in Pamplona for long-term business trips, we tried two new Japanese food restaurants that had just opened.

The first was a ramen shop called Buga Ramen. Inside, the shop had Japanese signs on the walls and many anime figurines on display, creating a somewhat suspicious atmosphere. We first tried the gyoza, which was pretty good. However, I could not tell if the gyoza was worth the price because Spanish supermarkets sell frozen gyoza that tastes pretty good. Then, we finally tried the ramen. It looked good, but only the appearance was good. The other dishes were nice, though, so if you visit Pamplona, it's worth trying Muga Ramen.

The second one was a hot pot restaurant. The staff were Chinese, who explained how to eat the hot pot to us in fluent Chinese when we first visited the restaurant. They probably did not expect to find Japanese residents in Pamplona. In response to their fluency, I replied “Vale”, which means “okay” in Spanish.

This hot pot restaurant turned out to be excellent. I loved it so much that I went almost every week. The great thing about this restaurant was that they served thinly sliced meat, which is very difficult to find overseas. In general, overseas supermarkets do not sell thinly sliced meat.

Customers are supposed to make their own dips. There was sesame paste on the tables, and you could thin the paste with the hot pot soup to make a sesame dip. Customers were also allowed to bring their favorite ingredients. We brought ponzu sauce and seasonings with us every time we visited. Right before I returned to Japan, I brought sukiyaki sauce to the restaurant and asked the staff to let us set up a sukiyaki pot. The hot pot restaurant had become a place that could be called a Japanese restaurant. From now on, it would be more accurate to say that Pamplona has good Japanese restaurants (Photo 18).

Photo 18 Hot pot

3. 3. 5 Preparing for Repatriation

My long life as an expatriate had almost come to an end when my successor was selected. During that time, I was a single expatriate who no longer went out traveling or sightseeing. However, I decided to do the things I had wanted to do.

First, I decided to watch the running of the bulls' festival. I had experienced the festive atmosphere during festival season before, but I had never watched the running of the bulls itself. The world-famous bullring in Pamplona has the capacity to hold a large audience, making it one of the five biggest bullrings in the world (Photo 19).

Photo 19 Bullring in Pamplona

Although fewer cities practice bullfighting in the traditional way - actually killing the bulls with swords - Pamplona is one of the few that still does. However, traditional bullfighting may eventually fade away with time.

Next, I traveled around the cities I had wanted to visit with my wife, including Guernica, which appears in Picasso's painting, and Altamira, famous for its cave paintings.

Finally, on my last trip, I decided to visit Santiago de Compostela, located in western Spain.

Spain has a pilgrimage route called the Camino, similar to Ohenro, Japan's pilgrimage routes. The final destination of the Camino is the Cathedral of Santiago de Compostela.

Pamplona is also one of the stops along the pilgrimage route. I sometimes saw pilgrims walking the long route. The distance from Pamplona to Santiago de Compostela is about 800 kilometers. It typically takes pilgrims one month or longer to reach the final destination on foot. That was beyond my ability, so I opted for an easier pilgrimage by car.

The Cathedral of Santiago de Compostela is one of the most majestic churches I have ever visited. Simply visiting it made me feel sacred (Photo 20).

Photo 20 Cathedral of Santiago de Compostela

By the way, one of my favorite Spanish dishes is Pimientos de Padrón. It's stir-fried pimientos (a type of Spanish sweet pepper) with olive oil, from a city called Padrón. Located just south of Santiago de Compostela, Padrón hosts the Pimientos de Padrón festival on the first Saturday in August. I decided to visit Padrón to see the festival just before leaving Spain.

The festival takes place in a very small village. The audience was local residents, with no tourists except us. I participated in the festival and was rather excited wearing the Pimientos de Padrón T-shirt that I had received as a farewell gift. Because of that, I was photographed and featured in a local Galician newspaper article. It's the

Photo 21　Pimientos de Padrón festival

Photo 22　Pimientos de Padrón

perfect memory to end my time in Spain (Photos 21, 22, and 23).

4. In Closing

Writing this essay about my life as an expatriate gave me a good opportunity to reflect on the past six and a half years.

Despite suffering from the unprecedented situation of the COVID-19 pandemic, during which no one could have anticipated the changes that would occur, I was able to complete my assignments abroad without encountering any major problems. This was thanks to my colleagues, with whom I shared the expatriate experience in Europe.

Fortunately, I worked with excellent supervisors and staff in both Munich and Pamplona. Even when exploring a new style of work, I was able to make the right decisions. I was also fortunate to receive cordial support for business and personal matters. I am reminded again of how worry-free I was able to work.

I would like to take this opportunity to express my sincere gratitude to everyone who supported me during my time abroad.

I hope we will work together again someday.

Before the pandemic outbreak, I lived in Germany and Spain with my family. After the outbreak, however, I was an expatriate alone. At the time, my son was still preschool-aged and cried every time I left for Spain after temporarily returning home. I am sorry that I made him sad.

Photo 23　T-shirt I received as a farewell gift

Before leaving, I held my son's hand that was tightly gripping mine. I felt so grateful for his tolerance. I silently vowed that we would continue together.

I could not have completed my assignments abroad without my family's understanding. I cannot thank my wife enough for taking on most of the child-rearing and daily life responsibilities in the foreign countries. Additionally, she had to raise our son alone while I was away.

Now that I am back home, I want to gradually make up for the days we could not spend together.

I hope that the three of us will visit Munich and Pamplona together someday and create family memories based on our expatriate experience. This is one of my life goals.

Author

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Joined the company in 2013. Sales Dept. No.1, Central Japan Business Unit, Sales Div. Engaged in sales to Toyota Motor Corporation.

Glossary

Fine Bubbles

Refer to Application of Ultrafine Bubbles to Grinding Processes (page 21)

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1 What Are Fine Bubbles?

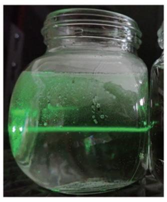
The term “fine bubbles” (FBs) is a general term for bubbles less than 100 µm in diameter. Bubbles with diameters greater than 1µm are called microbubbles (MBs) and those with diameters less than 1 µm are called ultrafine bubbles (UFBs). This terminology is defined by the International Organization for Standardization (ISO) [1]. Their properties are shown in Table 1. Large-diameter MBs appear cloudy and are visible to the naked eye. They rise slowly and eventually disappear. On the other hand, UFBs with small diameters are colorless, transparent, and cannot be visually identified. When water containing UFBs is irradiated with the light from a laser pointer, the laser light is scattered, allowing the trace to be followed. UFBs remain in the liquid without rising. They can remain there for a long time, from several weeks to even several months under certain conditions [2].

The use of FB technology is being promoted in a wide range of fields, including the environment, agriculture, food, fisheries processing, cleaning, general industry, and beauty [3]. Its major applications include wastewater treatment, food freshness preservation, semiconductor parts cleaning, and machining. The effect of MBs began to be reported in the 1990s and that of UFBs in the mid-2000s. One of the leading countries in FB technology is Japan [4].

It is said that the practical effects in the above-mentioned fields are due to the physical effects of FBs including gas dissolution effects [3], gas encapsulation effects [3], physiological activity effects [5) 6)], friction reduction and lubrication effects [6) 7)], and adsorption and purification effects [5) 6)].

Today, there are various types of FB generators. The main types include pressurized dissolution type, high-speed vortex flow type, static mixer type, microporous type, ultrasonic type, and ejector type [3) 5)]. FB generators are superior or inferior in price, structure simplicity (easy maintenance), and FB concentration depending on the type, with their own advantages and disadvantages.

Table 1 Definition and properties of FBs

Designation	UFB	MB
Bubble diameter	Several tens of nm to 1µm	1 µm～100µm
Visual detection	Invisible (colorless, transparent) 	Visible (cloudy) 
Dynamics	Remain in water for long time.	Rise very slowly and disappear.

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Glossary

Internal Gear Pump

Refer to Construction of CFD Analysis Technology for Internal Gear Pumps (page 31)

SUZUKI Kazunari Elemental Technology Sect., Basic Technology R&D Center, Engineering Div.

1 What is an Internal Gear Pump?

An internal gear pump is a type of positive displacement pump. Inside the pump body, an internal gear meshes with a part of an external gear, and they rotate together to move the displacement chamber formed by the gears and the body, thus providing the pumping action. There are two types of internal gear pumps: those with a crescent shaped partition separating the discharge area from the suction area and those without a partition. In general, both types have the advantages of a simple structure with a low number of parts, are available at reasonable prices, and can be used in a poor operating environment because they are unlikely to be affected by dirt (Figs. 1 and 2). Therefore, they are used in various fields, including construction, agricultural, and industrial machinery, as well as hydraulic power units.

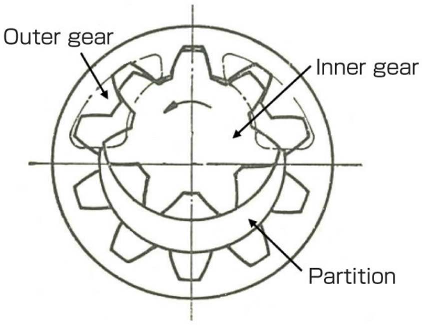

Fig. 1 Internal gear (with a partition) [1)]

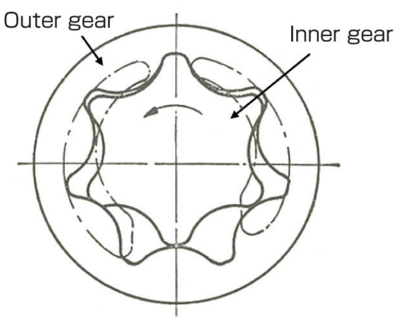

Fig. 2 Internal gear (without a partition) [1)]

2 Pump Efficiency

2. 1 Overall Efficiency

Overall efficiency is a measure of how effectively the power supplied to the pump is converted into fluid energy. It can be expressed as the product of the volume efficiency and the mechanical efficiency, etc. These efficiencies vary with oil viscosity μ, pressure difference between suction and discharge Δp, and pump speed n, as shown in Fig. 3.

2. 2 Volume Efficiency

Volume efficiency is calculated by dividing the actual discharge flow of the pump by the theoretical discharge flow. A higher volume efficiency means that the required flow rate can be achieved with less power. Volume efficiency can be reduced primarily by leakage or flow losses due to the inclusion/occurrence of bubbles in the pump.

2. 3 Mechanical Efficiency

Mechanical efficiency is calculated by dividing the theoretical pump torque by the actual shaft torque. A higher mechanical efficiency means that the pump can be driven with less power. Mechanical efficiency can be reduced primarily by friction losses due to solid or viscous friction inside and outside the pump.

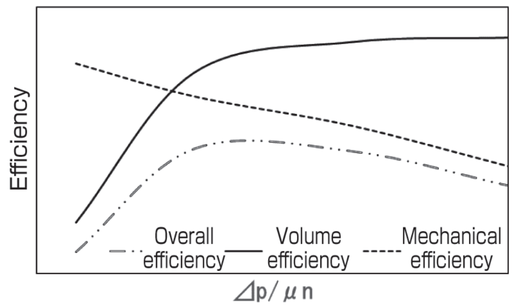

Fig. 3 Example of pump efficiency curves

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Editors Script

The KYB Technical Review has reached a milestone with its 70th issue. This milestone is the result of the continual contribution of internal and external authors who have consistently provided excellent articles. I would also like to thank and appreciate the editorial board members who supported these publications behind the scenes. Most importantly, we must thank our readers.

This issue features a special program on the future prospects of each engineering department. When considering future growth or contributions to society, companies naturally intend to create new things. Recently, I have noticed that new terms, such as “added value creation” and “co-creation”, have become part of our daily lives. These acts are, of course, perfectly acceptable and should even be encouraged. However, they have made me realize anew that, before creating or being motivated to create, we must have a starting point: imagination.

For example, the foreword “A Prospective on the Future of Fluid Power Technology in Off-Road Applications” by Prof. Vacca and the editorial “Mechatronics: In the Mind's Eye of an Engineer” by Prof. Tanaka truly focus on engineers' imagination. I found these articles very interesting.

Currently, I feel it is difficult to foresee what the world will be like in just ten years. In the tech field, particularly the AI area, which is surging in popularity, many bold statements have been made. For example, Masayoshi Son, the chairman of SoftBank Group, stated that “in ten years from now, ASI (artificial Super Intelligence) will be 10,000 times smarter than humans”, and prominent figures in other industries have stated that “by around 2025, AGI (Artificial General Intelligence) surpassing human intelligence is expected to be realized”.

I wonder what kind of future we will be living in. While expecting a future far beyond my imagination, I find myself unable to change, unconsciously wishing for a future within my imagination or fearing otherwise.

(ITO Takashi)

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