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Foreword

Seeing is Believing

YAMABE Masashi*

Science and technology advance very quickly. You may be astonished when you realize that what you once dreamed of has actually become available as a commercial product, one after another.

50 years ago, Osamu Tezuka, who created the famous manga "Astro Boy" ("Tetsuwan Atomu" in Japanese), amazingly predicted the world today. I guess what Tezuka predicted at that time was dismissed right away by people, saying "that's absolutely impossible!" He was not a predictor, but as a scientist he must have humbly stared at the advance in technology and logically predicted the future. He probably kept a close eye on unnoticed scientific seeds that were usually dismissed by people as "just a dream". I think he saw such a dream as reality in his mind.

In the latter half of the 1980s, one of my friends from school called me. As we exchanged small talk with each other, the conversation focused on his job. He was involved in the development of smaller, lighter batteries for cell phones, saying "the age in which everyone carries a cell phone in their pocket will definitely come ". I said for certain; "Such a thing will never come true! Such an age will never ever come, or such technical development is impossible! First of all, there is no way that a secondary battery with such high energy density can become a reality". Surprisingly, however, the technology was gradually commercialized in the 1990s. I was among those who regularly used such a cell phone, and it was only within 10 years of that conversation with him. I, as an engineer, deeply regretted what I had thought. Thereafter I have always tried to directly see (look at) technical challenges with my own eyes before thinking, instead of judging only with my knowledge.

My research theme is manufacturing (or "Monozukuri") of plastic products. In this field we can hardly see (look at) the manufacturing process or mechanism directly because the industry uses molds and large machinery. Researchers during discussion often encountered a scene where they could not share the same image. Sometimes they spoke in a pessimistic or negative way like, "You'll never be able to do that!". Today, the resin flow analysis technology using computer simulations has advanced to enable you to "visualize" the resin flow behavior inside the molds, although it is a simulation image. We, who are involved in the technology, have successfully shared the visualization as a breakthrough communication tool. However, another question has arisen; "Is this visualized simulation really true"? Then, we have eventually come to believe it is essential to directly see (look at) the behavior so as to propose a mechanism that can be understood by everybody. This direct visualization has finally been achieved with the cooperation of Prf. Hidetoshi Yokoi of University of Tokyo, and Prof. Isao Sato of Tokyo Institute of Technology. Now we have just succeeded in actually visualizing the resin flow inside molds at last. "Seeing is believing". These visualized images have not only enabled us to share technical matters, but have also appealed persuasively to those who took a negative stance, leading to a contribution to the industry.

This seeing (looking at) is not limited to visualization of phenomena inside molds. Isn't it necessary for engineers to actually see (look at) various problems occurring on the site, eliminate any pessimistic or negative ideas, and positively address technical challenges above all? It is a substantial loss for you to shatter your dreams of future technology with your own prejudice or pessimistic/ negative way of thinking. I hope I can continue to always address further technical development with flexible ideas while placing importance on "seeing" (looking).

* Department of Mechanical Engineering, Kanazawa Institute of Technology

Editorial

Trend and Outlook of Hydraulic Technology

SAKAMA Sayako*

1. Introduction

"Hydraulics" can deliver higher power with smaller equipment compared to electric, pneumatic or other drive systems. Therefore hydraulic technology finds extensive applications in various industries requiring high power. However from the viewpoint of energy saving, noise reduction and cleanliness, a shift from hydraulic systems to electric (or motor driven) systems has been promoted in all industries. This motorization is expected to be further accelerated in the future. Here arises the question: Is there a possibility that all hydraulic systems will be replaced by electric systems some day? This article compares the trends of technical development between hydraulic and electric equipment to discuss the future direction of hydraulics.

2. Comparison of Characteristics Between Hydraulic and Electric Actuators

Hydraulic actuators can deliver high output (power density) per unit mass. It is well known that even a small hydraulic actuator has relatively high output. But, do you know how much higher the power density of hydraulic actuators is compared to other types of actuators? This article first compares the physical properties between commercial hydraulic and electric actuators based on some performance indexes (i.e., torque, power density and power rate) and then generally describes the characteristics of these actuators.

Note that all research results included in this article are those of rotary actuators and that the data has been extracted from catalogues of commercial actuators. In the comparison, electric actuators are classified into three types: AC, brushless DC and DC motors. Hydraulic motors are classified into three types: bent axis type axial piston motors, swash plate type axial piston motors and radial piston motors.

The first comparison is rated torque relative to the mass of various actuators. Fig. 1 shows the relationship between the mass m [kg] and the rated torque T_r [Nm]. The data of the motors is plotted in the figure with the mass on the horizontal axis and rated torque on the vertical axis. For convenience sake, actuators of 10^3 kg or more are classified into super large size, 10 to 10^3 kg into large size, 10^{-1} to 10 kg into middle size, 10^{-3} to 10^{-1} kg into small size, and 10^{-3} kg or less into super small size for easier comparison. In the mass comparison of the actuators, hydraulic radial piston motors are located in the region of large to super large size and axial piston motors in middle to large size, while electric AC servo motors are found in the region of middle to super large size, and brushless DC and DC servo motors in super small to middle size. The figure indicates that electric actuators are distributed over a wider area than hydraulic actuators.

When looking at the relationship between the mass m [kg] and rated torque T_r [Nm] of actuators, hydraulic and electric motors are likely to be plotted along the line of $T_r \propto m^{4/3}$ respectively. The larger the mass is, the higher the rated torque. The figure also shows that the line along which electric actuators are plotted extends parallel to the line along which hydraulic actuators are plotted at higher levels by nearly one order of magnitude. In other words, hydraulic actuators can deliver a higher torque by nearly ten times that of electric actuators of the same mass.

The next comparison is on the relationship between the mass m [kg] and the power density P_d [W/kg] among actuators. The power density is the result of dividing the rated output of an actuator by the mass. An actuator with a higher power density can be evaluated as being able to delivery higher power even with its small size. Fig. 2 shows the relationship between the mass and power density of actuators.

When comparing the power density between electric and hydraulic motors in the middle to large size region, hydraulic motors show a higher power density by one to nearly two orders of magnitude. However, hydraulic motors of a higher mass are likely to have lower power density. According to the figure, there is no big difference in power density between hydraulic motors and AC motors in the super large size region. The fact that

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hydraulic motors have an almost same level of power density as that of AC motors, in spite of the substantial higher rated torque, is attributable to the difference in motor speed. The motor output is calculated by multiplying torque by speed. Super large size hydraulic motors can generate a ten times higher torque than AC motors of the same size region, but rotate at an about one tenth lower speed than AC motors. Which motor is more suitable depends on which factor has higher priority, torque or speed.

The final comparison is on the indexes representing motor responsivity. Power rate Q [W/s] is used to compare performance between hydraulic and electric motors. The power rate is the result of dividing the square of the motor rated torque by the moment of inertia. A motor with a higher power rate offers superior responsivity. Fig. 3 shows the relationship between motor weight and power rate. According to the figure, hydraulic motors show power rate levels quite different from those of electric motors, implying that the former is superior in responsivity to the latter.

3. Changes in Performance of Hydraulic and Electric Motors and Their Future Outlook

The previous section compared hydraulic motors to electric motors using three indexes: motor rated torque, power density and power rate. The comparison has revealed that hydraulic motors have higher performance than electric motors in all of these indexes. For mechanical systems that require small high-power motors, it is generally difficult to replace all hydraulic motors with electric motors under present circumstances. Then, can you say with assurance that all hydraulic equipment will never be replaced with electric

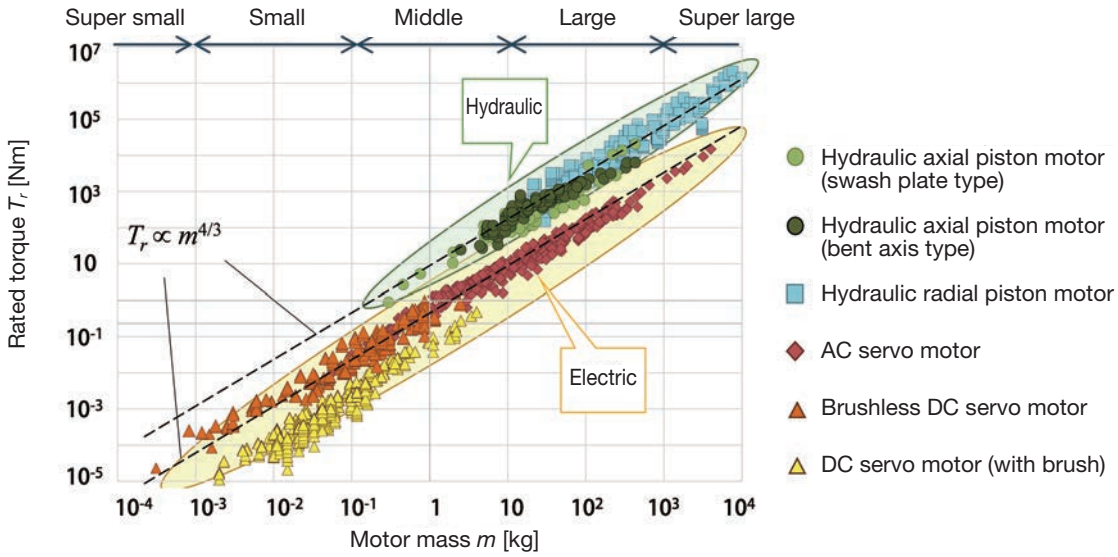


Fig. 1 Comparison of rated torque between hydraulic and electric actuators

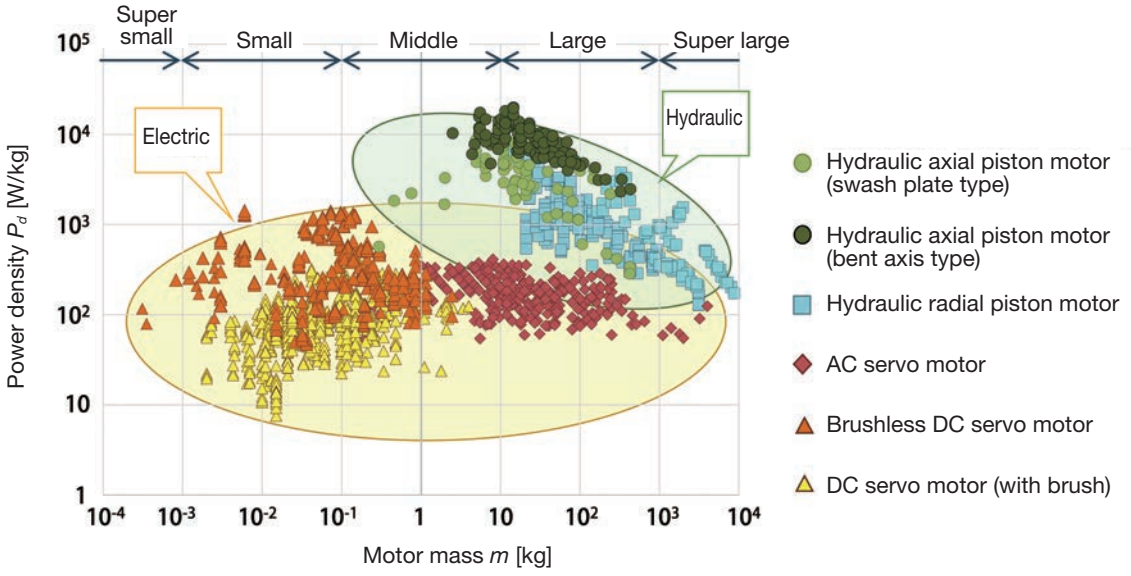


Fig. 2 Comparison of power density between hydraulic and electric actuators

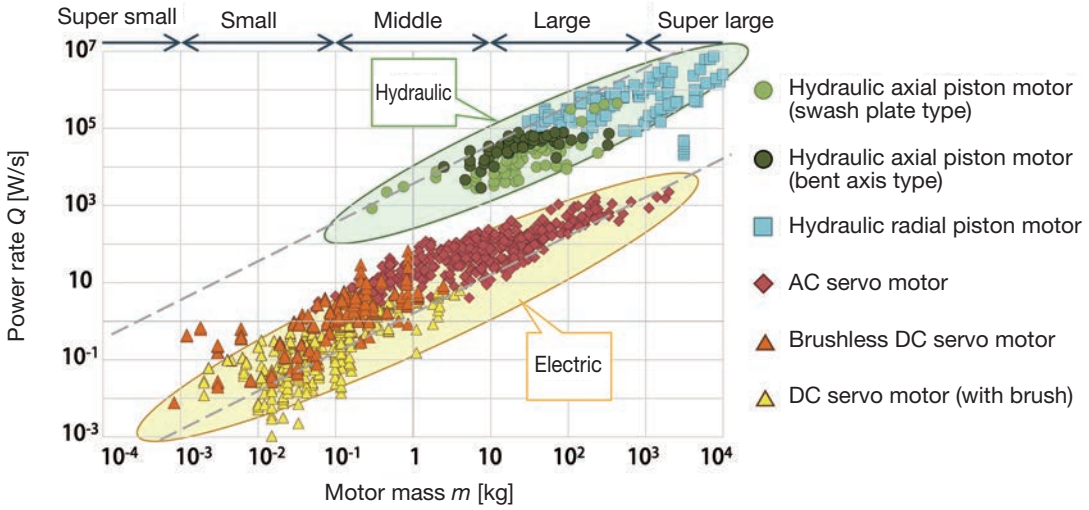


Fig. 3 Comparison of power rate between hydraulic and electric actuators

equipment? Now, in order to predict future changes in performance of hydraulic and electric equipment, the data used for comparison in the previous section should be added to old data to grasp the changes in power density of hydraulic and electric motors.

Fig. 4 shows changes in power density of hydraulic and electric motors. From the time before the 1970s that was the golden age of hydraulic servo to the present, hydraulic motors have shown overwhelmingly higher power density values than electric motors. When comparing the changes in power density, however, electric motors have experienced a steeper increase in power density. Hydraulic motors have also seen a certain increase in power density, but no notable change in recent years. On the other hand, electric motors have continuously increased in power density, resulting in a substantially higher level by one order of magnitude or more than the level of 30 to 40 years ago. If the performance of electric motors continues to grow at this rate, I cannot say that the power density of electric motors will never exceed that of hydraulic motors. Still, when you take a closer look at the data for electric motors, it is brushless DC motors that have recently experienced a rapid increase in power density. That is, super small to middle sized electric motors have seen a substantial increase in power density. With the focus placed on changes in power density of AC motors in the middle to super large size region, no substantial change has occurred since the 2000s. As shown in Fig. 2, current hydraulic motors are mainly used in the middle to super large size regions. It can be thus concluded that the possibility of replacing hydraulic motors with electric motors is low unless AC motors are rapidly improved in performance.

4. Outlook of Hydraulic Technology

Recently the power density of hydraulic motors has not changed a lot as stated in the previous section, but there used to be a trend of growing power density until around 2000. This trend was attributable to the development of higher-pressure hydraulic equipment. Fig. 5 shows changes in power density and rated pressure of hydraulic pumps for construction machinery. The rated pressure increased by 1.5 times in 25 years from the 1975 level. Accordingly, the power density increases two-fold or more. Hydraulic equipment was expected to have even higher pressure in the latter half of the 2000s [1], but in fact they don't. To achieve smaller hydraulic equipment with even higher power, it is necessary to raise the pressure of hydraulic systems. However, a hydraulic system with higher pressure would lead to a higher load on the equipment. It is thus indispensable to actively promote fundamental research for better measures against contamination, air and noise, as well as improved sealing and cooling technology. However, there are no sufficient studies related to hydraulic technology in Japan. Fig. 6 shows the result of a survey on the number of lectures by field presented by the Japan Fluid Power System Society [2] from 1998 to 2010 [3]. The figure shows a trend of a decreasing number of lectures on hydraulics related themes, implying a lower number of universities and research institutes involved in hydraulics related studies in Japan.

Recently, hydraulics has begun to receive attention again from disaster relief and robot engineering fields. Some research and development projects in these fields include studies for the purpose of improving the performance of hydraulic components [4]. To activate hydraulics related studies and develop hydraulic technology, it is also necessary to find some effective applications that can gain the spotlight among many engineers and researchers.

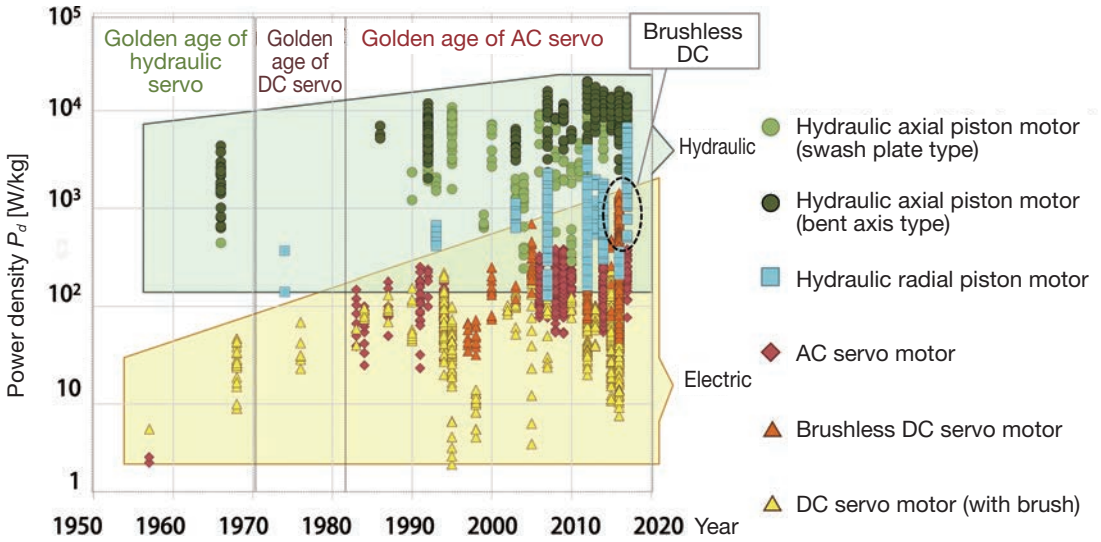


Fig. 4 Changes in power density of hydraulic and electric actuators

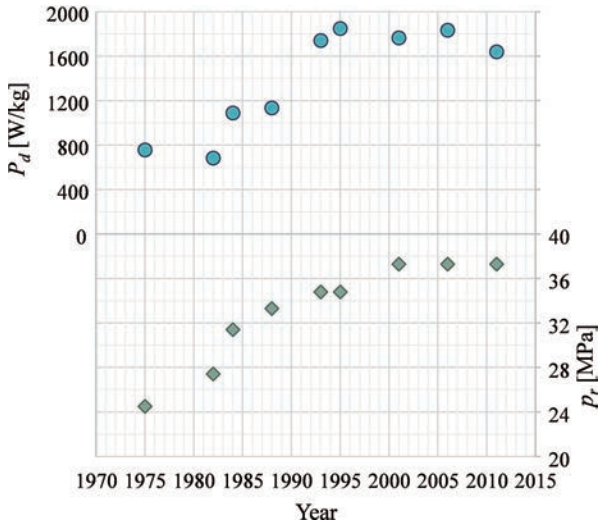
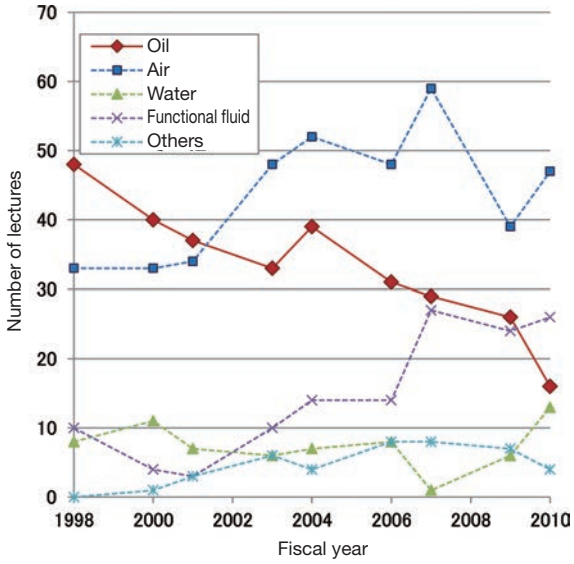


Fig. 5 Power density and rated pressure of hydraulic pumps for construction machinery



Note) Data for the fiscal years in which international conferences were held has been excluded.

Fig. 6 Changes in the number of lectures by field presented by the Japan Fluid Power System Society

5. In Closing

Since it is difficult for electric actuators to generate such a high power that can be delivered by hydraulic actuators, the best current choice to deliver high power under limited size and weight conditions is hydraulic actuators as stated above. To further develop hydraulic technology, universities and research institutes are required to discuss new ways of using hydraulic technology, making use of the strong points of hydraulics, and to propagate the technology. To this end, technical development satisfying the needs of society is required. Industry-university collaboration will become even more important.

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Essay

KYBT Expat Experience Report

SETOGUCHI Kazuhiro

1. Introduction

From September 2014 to June 2017, I worked overseas at our group company KYB (Thailand) Co., Ltd. (KYBT). This was the first time living overseas for me, my wife and two children (who were two years old and nine months old at the time).

The people of Thailand are very friendly towards children, and my children were often greeted warmly by many Thailanders when we went out. My children received small trinkets such as tumblers and stuffed toys, probably items used as giveaways, at the supermarket we often shopped at. I have a memory of the first time we went out to eat. Eating out with children is not an easy task, and the local staff at the restaurant went out of their way to look after my children while we dined. However, I was taken by surprise when they scooped up my children and took them to the backyard of the restaurant. That made me extremely nervous, and I recall not being able to relax and eat my meal in peace.

It may be because of this culture that Children's Day in Thailand is a major event. I remember when the department store EmQuartier brought in famous overseas heroes to entertain children (Photo 1). It was almost as though we were in Hollywood!

Photo 1 Children's Day event

2. Life in Thailand

There are approximately 70 thousand Japanese living in Thailand, and Bangkok is home to over 50 thousand of them. For this reason, there are many restaurants and supermarkets geared towards Japanese residents, enabling us to live comfortably there, just like back home. The prices of Japanese food in Thailand are about the same as of that in Japan. Other items (which have been imported from Japan) are approximately three times more expensive.

Many Japanese people reside in an area called Sukhumvit (Photo 2). Most of the Japanese residents can be found in the area east of Asok, such as Phrom Phong, Thong Lo and Ekkamai, but there has been a recent surge of Japanese expats in the further eastern areas of Phra Khanong and On Nut. For daily transport, taxies, songthaews (mini-trucks altered to sit passengers in the truck bed), motorcycle taxis and BTS (Bangkok Mass Transit System) are used.

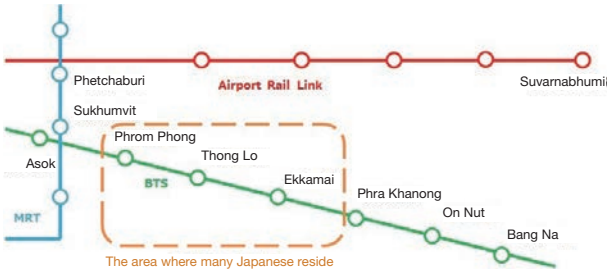

Photo 2 BTS route map (for the Sukhumvit area)

There are supermarkets all over the city for shopping, and there are many convenience stores within walking distance, just like Japan, so there was never trouble in buying things.

Transport to and from Japanese schools and kindergartens was by bus, and because these buses only operate in certain areas, the price for family-geared properties has seem to be going up. The number of housing properties going for over 80 thousand baht (approximately 250 thousand yen) per month has increased.

Factors that we focused on when selecting our home was having hospitals and supermarkets within walking distance, and possibly to have a home that was more spacious than our home in Japan. The drainage system in Sukhumvit is extremely poor, and major rainfall often caused the roads to flood and traffic congestion. The worst traffic jam I experienced took me three hours to get to a location that usually took only 15 minutes. As you can see, traffic was always congested in the city, so having a hospital within walking distance was helpful many times.

Tap water in Bangkok is unfit for drinking, unlike the water in Japan. To prepare for water shortages, our family used the water delivery services offered by Club Thailand. This company operates a water delivery business and has golfing reservation services as well. Users must pay an annual fee, but having a Club Thailand card (Photo 3) offers perks such as complementary drinks at Club Thailand stores (located near the first supermarket to cater to Japanese people, the Fuji Supermarket, allowing shoppers to drop by between shopping). The card also offers discounts at restaurants, and is a convenient card to have, even if you do not play golf.

Photo 3 Club Thailand member's card

3. Thai Cuisine

Thai dishes are often spicy and flavored with cayenne pepper. Never underestimate the spiciness of Thai cuisine—the locals say the spicier it is, the better.

The first time I tried some local dishes, I couldn't help but exclaiming, "This is too spicy! Just being hot and spicy does not make food good!" As you can see, it is better to notify the chef to "hold the spiciness" if you are not extremely confident with spicy dishes.

Saying "mai pet" will have them leave out cayenne pepper from your food (still, there is often some put in the food despite this).

Thail locals often season their food to their liking. Therefore containers of nam pla (fish sauce), sugar, chopped peppers in vinegar and powdered peppers are always set on the table. Enjoying dishes in your own unique flavor is typical in Thailand. I wholeheartedly recommend enjoying the "spicy, sour, sweet and savory" flavors found in Thai food.

If you enjoy Thai cuisine, you will probably want to try out the food stalls as well. However, I generally do not recommend eating at food stalls. The ingredients are often stored in the scorching daytime heat, and the water used to wash the dishes is not sanitary. One hears many tales of people getting sick from the water.

Instead of food stalls, I would like to recommend the food courts found in department stores. Food courts often feature popular local restaurants and are more hygienic as well. They are more expensive than food stalls, but more affordable than stand-alone Thai restaurants. Customers can also try food from many different restaurants as well.

These food courts usually have a system where customers pay with prepaid cards. These cards can be purchased at ticket centers in the food courts. Any money left over on the prepaid cards can be reimbursed at the same ticket center within that day.

My family always had weekend lunch outings at the Emporium or EmQuartier.

My favorite dish was Pad Thai (Thai fried noodles) with oysters, or Som Tum Thai (salad with green papayas) (Photo 4). I miss these dishes, even now!

Photo 4 Som Tum Thai

By the way, do you know the different meats that are consumed in Thailand? The people of Thailand prefer chicken and pork, and beef is not very popular there. The chicken is especially fresh in Thailand, and there are many Gai Yaang (BBQ chicken) stalls on the street. However, I recommend trying out Kentucky Fried Chicken in Thailand as well.

I especially recommend the Kentucky Fried Chicken branches in Phrom Phong's Big C or Gateway Ekamai. The turnover rate for these two stores is very fast, and they offer soft and juicy fried chicken. Customers can select from fried chicken seasoned with pepper or the

original type (order the original type if you want to have fried chicken similar to that in Japan).

4. Working in Thailand

The first obstacle one faces when working in Thailand is the language. The Thai language uses characters such as "ภาษาไทย". When seen from a Japanese point-of-view, these characters look like doodles. It is almost impossible to read or understand any of them. As for pronunciation, the language features five different tones (the same words have five different meanings depending on the tone in which it is spoken) which unaccustomed Japanese people find very difficult to tell apart. Conversation becomes difficult when one cannot understand what is being said. Staff members at factory manager level may have a moderate grasp of English, but conversation on-site and in daily life is all done in Thai. Just having a moderate grasp of English offers a great peace of mind in this situation. If there are any opportunities to use English in your work, I wholeheartedly recommend studying it.

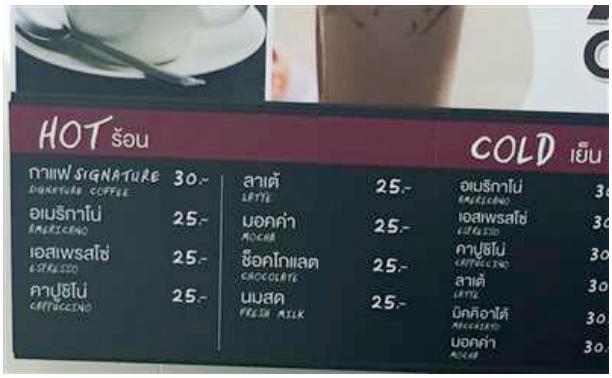

Photo 5 Difference between Thai and English

I could not say that all the Thai people I met had a good command of English—however, they spoke it with confidence. Communication can be made without perfect grammar, so I believe that Thailand is the perfect place for Japanese people to practice speaking and build confidence, which is often difficult for us.

Thai English is spoken with a unique "Thai accent", which makes it difficult to understand at times. However, this type of accent can be seen in other countries as well, so there is no need to worry. One can have the speaker write the content down on paper if there is trouble comprehending the accent.

If you have trouble talking, I recommend starting communication by jotting down what you want to say on a piece of paper. My English was extremely poor, so I started off by writing down notes of what I was going to say and referring to those notes while I was talking (my written English was terrible as well, but still better than my spoken English…). In any event, I set myself off to get accustomed to speaking, instead of overthinking and becoming nervous as a result

Although my current TOEIC scores are dismal despite my frequent use of English, I believe that I have been able to successfully communicate with people from Asian countries (such as people from Thailand, Indonesia, and Malaysia, who I met through work).

5. Entertainment and Travel in Thailand

When asked about things to do in Thailand, I believe many people think of golf. There is a multitude of golf courses to choose from around the Bangkok area. The golf season lasts all year round, and golf courses which Japanese people often frequent offer caddies as well for approximately 3000 baht a day (10,000 yen) on weekends. Carts cost an additional 700 baht (approximately 2,500 yen). Many golfers prefer to walk and not use carts, as most Thai golf courses can be played without carts. One can play from six in the morning, go through 18 holes without lunch, and finish before noon, if all goes well.

If you have never tried golf before in Japan, Thailand is an excellent place to start learning. The warm climate loosens up your body, and the courses are more level and easier to swing in than Japan. There are many people who enjoy golf every weekend, due to this wonderful environment.

Photo 6 Professional golf tournament at the Amata Spring Country Club

You may be worried that playing so much golf will be exhausting—but there is no need for concern, as Thailand has excellent massage salons. Authentic Thai massages charge approximately 300 baht (1,000 yen) an hour, which is very reasonable compared to massages in Japan. There are many massage plans one can choose from, but the most popular ones are the Thai massages or foot massages.

A Thai massage evenly loosens up the entire body, and a foot massage focuses on the area below the knee such as the calves and shins. A 90-minute foot massage after golf is very nice.

As for travel, I have heard many stories of people traveling overseas. I cannot say much about this subject, as I have not travelled extensively, but it seems that the Maldives and Bali are very popular. Neighboring Cambodia and its world heritage site Angkor Wat is also a common travel site.

There are many all-inclusive tours going to domestic locations such as Phuket, Chiang Mai, and Krabi, but our family always headed toward Pattaya.

Pattaya is a three-hour drive from Bangkok, allowing easy access with children. We always rented a vehicle with a driver for transport. We would always book a hotel with a large/good selection of pools and just kick back and relax at the poolside, because doing various activities with toddlers was not an option.

Although this is slightly off topic, condominiums in Thailand often come with pools and parks, so it may be feasible for families with smaller children. Thailand is hot all year round, so there is a need to secure a place indoors where children can exercise and play.

Another place that children enjoy is the zoo. Our family often visited Bangkok's Safari World, where one can feed the herd of giraffes (Photo 7). Please note that toddlers may become frightened as so many giraffes come to feed.

Photo 7 Giraffes at Bangkok's Safari World

6. In Closing

This was my first experience living in Thailand, and my wife's support was crucial in allowing me to focus on my job. I am very grateful for her, and for having her bring our two little boys with us. There were many instances that I had to work on weekends as well, leaving her to take care of the children.

We returned to Japan just when our children started kindergarten and became slightly more independent than before. Because of this, I believe our family was not able to experience the full charms of Thailand, so I am looking forward to visiting again on our own.

I would like to take this opportunity to thank my KYBT colleagues, the local and resident staff, and everyone who supported me and allowed me to have this wonderful experience in Thailand.

Author

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Essay

Memory, Foundation of KCH [KCH: KYB (Kayaba) Cylinder High Pressure]

HARA Sadaaki

1. Introduction

In mid-November 2017, I began writing this essay in Hanoi, 3600 km southwest of Tokyo where a cold air mass had reportedly just moved into, while Hanoi had comfortable weather after the heat of summer had passed. Hanoi City is located in the north region of Vietnam and has four seasons, including a short spring and fall. It is rather cold here in the winter with some days below 10°C. In Vietnam, where local people traditionally celebrate the Lunar New Year, I cannot feel the typical atmosphere of the end of the year in Japan where people are quite excited about spending the New Year holidays in spite of the cold weather. New Year's Eve in Vietnam is just a usual night, even if I watch the Japanese annual contest between male and female popular singers on New Year's Eve on TV. To me, a typical company male, this is actually my first overseas assignment. I am soon going to enter my second December since being stationed in Hanoi.

Vietnam is a country where motorcycles are very popular. Among the population of nearly 100 million, 1 in every 2 people has a motorcycle, and 1 in every 1.6 workers has one. Motorcycles are the most popular means of transport here. KYB Manufacturing Vietnam Co., Ltd. (hereinafter "KMV"), for which I work as Site Manager, is a base for producing and selling motorcycle suspensions. Of the 3 million motorcycles annually delivered to the Vietnam's domestic market, about one third use KMV suspensions. Fortunately, KMV celebrated its 15th anniversary in October 2017.

Big Vietnamese cities, including Hanoi, are flooded with motorcycles. The traffic jams have been exacerbated by the increased number of automobiles driven by local people with higher incomes. It is quite difficult to find a vacant parking lot in the heart of the cities. The government has announced a regulation to close these areas to passenger cars, but the regulation seems to be reviewed with some suggestions and requests from different fields. They will probably reconsider this issue with the idea that the regulation to keep the heart of the cities free of motorcycles in particular, which are the people's major means of transport, would increase the risk of deactivating economic activity.

Photo 1 Development of new transportation systems and multi-level crossings (Hanoi City)

Photo 2 Example of large-scale residential area development

Photo 3 Examples of Japanese hydraulic excavators under operation (Hanoi city)
Top: Building redevelopment, Bottom: Road widening

The government is also trying to improve the urban

transportation situation by introducing a new railway-based transportation systems as well as road improvement. Some major intersections in the cities have been changed into multi-level crossings, and the traffic is on its way to being relaxed (Photo 1). Higher incomes have also driven the demand for apartments designed for the rich. Many civil construction projects are going on in the country (Photo 2).

In these construction sites, heavy equipment, including Chinese or Korean manufactured hydraulic excavators that are familiar to me, catch my eye. Among them, some Japanese equipment also exists, including many used ones that were once popularly used in Japan (Photo 3). Sometimes I happen to find KCH. They are old models but have no oil leakage. I am proud to see them.

I remember that Kayaba Industry Co., Ltd. (current KYB) faced an uphill battle in modifying its hydraulic equipment so as to be compatible with the increasingly-higher-pressure base machines in 1979 when I joined the company. I was assigned to Development & Experiment Sect., Hydraulics Engineering Dept. No.3 in Gifu South Plant (current Experiment Sect. No.2, Development & Experiment Dept., Engineering Headquarters, Hydraulic Components Operations; hereinafter abbreviated as "South Hydraulic Experiment") that was working toward the goal of solving the cylinder oil leakage problem. I was involved a little in the development of KCH that was announced in 1984.

"No leak, no rust, no break" is synonymous with KCH. In this essay, I will mainly recall how the seal system, which was one of the features of KCH for leakage prevention, was established, and some other stories that cannot be found in any documented reports.

2. The Road to KCH

In the latter half of the 1970s, hydraulic excavators came to have a higher relief pressure. 25 MPa was a hurdle for KYB at that time. One of the strong points of KYB was the in-house manufacturing of seals. But these original seals (packing) were severely criticized by customers. They said "Kayaba packing is poor", with which we always felt frustrated. The severe criticism also served as a springboard for development.

The basics of the KCH seal system have not been changed since its emergence, except in fine details. The KCH seal system consists of two subsystems: a rod seal system using buffering, and a piston seal system with seal rings. These are complemented by an integrated bolted cylinder head (hereinafter "CH") and a separate piping type high-precision cylinder tube. The long-lasting basics imply that the cross-functional standardization activity in the development stage was successful.

KYB dramatically changed its way of developing cylinders when becoming KCH. The most important was the introduction of the idea of dynamic external load, which substantially changed the design tools and experiment methods. This overturned the recognition of employees who absorbed customer' criticism of "Kayaba packing is poor", and indirectly blamed the leakage on internally manufactured seals, eventually opening the door to the no-leak cylinder. First, the following section describes this situation.

3. The Grass is Greener on the Other Side

My workplace at South Hydraulic Experiment was in the office of Development & Experiment Dept. for buffering including shock absorbers (SA) and front forks (FF). It was located at the southeast corner of the plant #5, which is now part of the production site of Gifu South Plant. The office had no partitioned walls, partly because it was just old and narrow. In spite of that they belonged to different departments, these two functions worked in the same space where one clearly heard what others, even from the other function, were discussing. Fortunately, this open environment helped us exchange information across departments. Personal computers, sequencers and just-digitized measurement equipment that were all still very expensive were introduced into the workplace. As soon as we heard that a department had introduced the latest-type equipment, we crowded into the department to see it directly. We also held voluntary study sessions to get ready for using such equipment within our department.

In the office, the measurement equipment control was managed by Chief T, who was practically so good at telecommunications that even engineers from a leading measurement equipment manufacturer were amazed by his expertise. Under the influence of Chief T, who was said to have honed his technical skill through on-the-job training (OJT), the office had many employees who exceled in electronics to become a unique existence throughout the company. I, as one of those who received a stimulus from him, read through the 8-bit microprocessor Z80CPU manual of several hundreds of pages in only two days, probably because I was just young. The manual was quite interesting. This experience helped us to electronize the experiment work, and also made me among the first internal instructors on microcontrollers.

We also had frequent information exchanges after work without being conscious of the barrier between the departments. We often gathered at our usual restaurant. The usual restaurant means that we did not have as many choices as we have these days. Working together in a small space, which is hardly seen nowadays, might have produced a good effect of "a web of different people at different hierarchical levels".

At that time, the Shock Absorber function already put into effect the product usage verification based on actual vehicle measurement. The obtained measurement data was subjected to various analyses, including frequency and correlation analyses, to actively study how the design

elements were associated with the riding comfort and durability of actual cars. Motorcycle function implemented the actual vehicle measurement with fewer burdens on motorcycles and their riders by commercializing radios (telemeters). This product usage verification was also linked to bench tests and computer simulation. The current reliable evaluation of product usage under various road surface conditions in the KYB Development & Experiment Center is based on these accumulated efforts.

In Shock Absorber function, test vehicles were driven up to the side of the office to be ready for measurement. They were subjected to driving tests and fine measurement. Some said "SA and FF are easy because they are small and light". Measurement of an actual large hydraulic excavator weighing over 20 tons, or an actual hydraulic cylinder almost exceeding 100 kg is not easy at all. We at South Hydraulic Experiment may have gazed at "the grass on the other side" and envied it in a sense.

4. Toward No-Leak Hydraulic Cylinders

It was unavoidable for customers to complain "the seal is bad" because the seal system actually had oil leakage. Probably, there was an atmosphere also in the company that everyone left the matter only to Seal function.

How you work depends on your boss. Under the guidance of Manager M, who had belonged to a department involved in mechanical equipment for marine applications, moved to our Engineering Dept., the hydraulic cylinder usage verification activity was activated. From his experience in integrating hydraulic devices into a system, Manager M motivated us to implement the concept that "to solve a quality problem, first grasp the product usage". He appointed Mr. O, who was a resident of "the grass on the other side", as Development & Design Sect. Manager, partly in order to deeply instill the usage verification, as the Shock Absorber function did, and carried out many actual measurements of hydraulic excavators as the base machine. It was still an age in which vacant space was available on the premises. We did actual excavation measurement quite freely, although it was not easy.

A hydraulic excavator usually has three cylinders: a boom cylinder, arm cylinder and bucket cylinder. Five to eight measuring points for pressure, displacement, acceleration, stress and other parameters are set on each cylinder. The total number of measuring points per machine exceeds 20 in some cases. Since it is impossible to conduct measurement at all the measuring points at the same time, partly because of the limited number of channels of the recording equipment, the same operation is repeated for measurement over and over again by changing the measuring points of each cylinder. The hard-wired measurement required a dedicated 50m cable for each measuring point. We repeated measurement by manipulating a bundle of about 15 cables, including those for simultaneous measurement channels, and spares as the hydraulic excavator moved. The cable bundle was heavy and the excavation site had poor footholds. The measurement work was very hard, particularly during the summer and winter. The whole process including cleanup of the hard-wired measuring equipment, which was changed to a wireless type later, using actual hydraulic excavators was so heavy work. Cleanup means to wash the many muddy cables as long as 50m, inspect/repair their electric properties, and store them for next use.

This hard-won result of the actual machine measurement provided essential material for the "Hydraulic Cylinder Quality & Technology Development System" compiled by all the members of Engineering Dept., including Section Manager O. The basis of the current KYB cylinder development style typified by the vibration/sliding endurance test (Photo 4), which is one of the features of bench test evaluation was established.

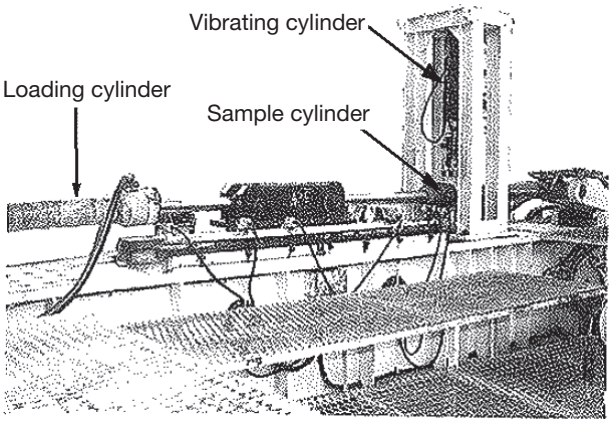

Photo 4 Vibration/sliding endurance test [1)]

The product usage verification activity brought a finding that oil leakage is strongly affected by the dynamic side rigidity of the cylinder and the contact stabilization of the seal lip. The activity also revealed that contact stabilization is affected not only by the follow-up performance of the seal lip but also by the fitting tolerance and elastic deformation of the parts around the cylinder head. These findings resulted in the establishment of the "contact interference evaluation method" as a design tool. The surrounding structure of the cylinder head of the old model high-pressure cylinder, which had increased in the number of parts to achieve higher pressure, was disadvantageous for contact interference. The base for the CH development was built in this way.

Apart from the verification of product usage on the actual machine, speeding up the in-house experiments was another challenge. Even bench test evaluations using actual cylinders involves time and cost issues. In the KCH development process, the element test focusing on the evaluation items for each part, which has been developed from the "hydraulic cylinder quality and

technology development system", was encouraged. Pressure, speed and other parameters were changed to achieve linear or planar evaluation, not point evaluation, for wider application of the result and fewer experiments.

In relation to the newly developed evaluation system, an activity was promoted to develop a test manual to allow coding of test data, including those that had been proven using a standard format (called "test coding"). By actively using the just-disseminated PCs, we tried eliminating handwriting recording. Although the office building was quite old, the office room looked like a sophisticated technical office today. The full-scale use of computer assisted design (CAD) in Design function was also launched in this age. The creation of a development environment leading to the current situation had begun.

5. Experience and Track Records as Obstacles

Valuable experience or track records may be an obstacle to development. The introduction of CH was rough sailing.

The complexity around the cylinder head of the old model high-pressure cylinder was attributable to the additional buffering. However, I can say that the actual cause was the obsession that "the U-ring must be installed in the split groove along with the backup ring". For installation in the integral groove, the donut-shaped backup ring cannot be assembled into the groove unless it is cut at a location. I know that the cut ring has lower durability from my experience. The U-ring is difficult to install, which lowers productivity. Large deformation of the U-ring, even if installed, is a discouraging factor of performance. Furthermore, chips in the integral groove cannot be easily expelled during machining, making it difficult to evaluate the surface roughness. The existing manufacturing process would be a potential limitation. Many negative opinions like these arose against the new structure.

However, a higher-pressure cylinder can be more slender for the same required thrust, so it naturally has lower side rigidity with the dynamic external load taken into account. The old model high-pressure cylinder happened to have a failure in a customer's actual machine evaluation test that the cylinder head came into contact with the piston rod, resulting in dented/peeled plating. Finally, the customer decided to also use CH according to the contact interference evaluation method.

The installation of the U-ring into the integral groove, about which deep anxiety had existed, was resolved too. Seal, Production Engineering and Manufacturing functions established a seal installation procedure that would not cause any performance failure while evaluating the balance among the U-ring material properties, the cross-section size and other factors against the applicable piston rod diameter. The single cut in the backup ring was proven to have no problem, making the implementation of the integrated CH within sight.

I remember that the piston issue was even harder. The critical challenge related to the piston of the higher-pressure cylinder was the burning of the U-ring seal. The pressure chamber of the cylinder has two sub-chambers divided by the piston. Each of these sub-chambers is the end of the hydraulic system of the base machine. In this deadlock, if air bubbles in the cylinder pressure chamber are adiabatically compressed to have a higher temperature under certain circumstances, the hydraulic oil could burn. The U-ring exposed to the pressure in the chamber may be damaged by the heat. This burning may break the seal, causing oil leakage. It is essential to eliminate any air bubbles from the pressure chamber. It is also important to enhance the burning resistance of the piston seal.

Manager M also led work on an international comparison. In cooperation with Section Manager H of Seal function, Manager M promoted an investigation of actual cylinders and seal systems for construction equipment made by European and the U.S. manufacturers gaining a head start in higher-pressure systems. The European and the U.S. manufacturers had already introduced the seal ring installed in the integral groove of the piston. The seal ring was not exposed to the hydraulic chamber, which seemed to be more unlikely to burn than the U-ring. The seal ring used was a combined bidirectional seal system that can seal against the pressure from both directions with a single piece of seal. Over the sliding surfaces of the seal are plastic slipper rings, such as PTFE (fluoroplastics) kneaded with nylon and reinforcing aggregate. Each of the slipper rings is pressed against the sliding surface by the pressure applied by the expander ring (rubber-like elastic body) inside the groove into which the slipper ring was installed, delivering a good sealing performance.

Because the sliding surface of the seal uses plastics instead of rubber, KYB had the strong belief that "the seal ring cannot be introduced without a measure against pressure blow-by".

As one of the means to alleviate the blow-by phenomenon, the initial seal ring had a large clearance between the member facilitating the pressure transfer to the expander ring and the integral groove. In addition, an expander ring with a larger cross section was preferred.

In terms of bearings, the proven piston ring used in the old model high-pressure cylinder was used as it was. The integral mount groove of the seal ring was modified to have a large clearance to accept any protrusion of the seal ring to prevent the galling caused by direct contact with the cylinder tube. As a protrusion countermeasure, an endless type backup ring made of urethane rubber was provided. This was named T-shaped seal ring after the cross-section profile of the expander ring, creating the original seal ring type piston (Fig. 1).

The bearing is located on the side of the hydraulic

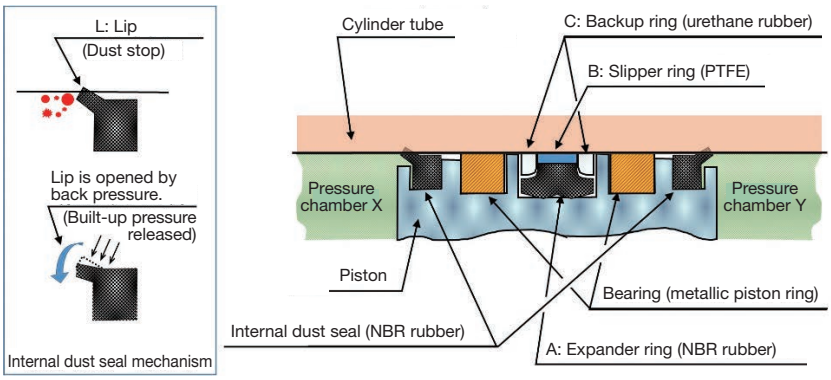

Fig.1 Original seal ring type piston structure with internal dust seal

system because a single seal ring can adequately serve as the piston seal. We thought this would also be an obstacle in preventing burning of the seal ring. In other words, the bearing was unavoidably exposed to the pressure chamber. Then, Engineering proposed that Manufacturing enhance the contamination control level in order to improve the cleanliness of the product. We determined the cleanliness in each process and evaluated the contamination sensitivity (i.e., the relationship between contamination and performance degradation), based on which, we set up a goal of the contamination control level to be achieved in the manufacturing process. However, it invited resistance from Production Engineering and Manufacturing. They said "the goal cannot be achieved with the existing process" and "it is difficult for the existing piping system and cylinder tube following the conventional welded structure to eliminate welding spatter" respectively.

Certainly the potential U-ring burning prevention by placing shielding in front of the U-ring on the pressure chamber side had never been realized. This was because it was unavoidable to let welding spatter being caught in the clearance between the shielding and the cylinder tube, causing severe galling. In fact, large spatter had sometimes existed in the cylinder before the emergence of KCH, which is incredible today though. As long as any foreign substance such as spatter was allowed to exist in the cylinder, it was unavoidable to use the U-ring as a lip seal in spite of the burning risk involved.

Anyway, contamination control was essential to realize the seal ring system. Quality Assurance Dept. Manager A at that time agreed with us, but showed a negative attitude toward higher-level contamination control, holding on to his standpoint that "the issue should be managed by Design" in the initial stage. Finally after serious pondering, Manager M came up with the idea of "developing an internal dust seal". Fig. 1 shows a sketch of the original seal ring type piston structure including the internal dust seal. Parts A, B and C make up the T-shaped seal ring. The internal dust seal expels any spatter with its lip. Should a pressure build-up occur between the seal ring and the dust seal, the lip will open to release the pressure.

I remember well that I talked to Manager M and Quality Assurance Dept. Manager A to "improve contamination control because the idea of an internal dust seal was not rational from the viewpoint of U-ring burning prevention", although I was just a young fellow. My opinion was rejected right away. But, the company eventually gave up using the internal dust seal in a subsequent development assessment. This was because, roughly speaking, the pressure build-up between the internal dust seal and the seal ring generated high back-pressure loading exceeding the pressure release capacity, causing the internal dust seal to come off the groove and drop into the pressure chamber. This event could not be resolved.

I noticed later that Manager M had rejected my opinion right away in front of Quality Assurance Dept. Manager A because Manager M had wanted to dare to show off the reality to Manager A that the internal dust seal would fail. That was his conscious choice in order for Production Engineering and Manufacturing, including the Quality Assurance Manager, to turn around to tackle the full-scale contamination control.

Thereafter the T-shaped seal ring was found to have a disadvantage that the space around the seal and urethane rubber backup ring may contribute to burning. Some improvements, including blow-by prevention, were made to develop an optimal two-part system in which the existing slipper ring and O-ring were integrated into an expander ring. This optimized structure is still used today. The bearing was also improved by changing the metallic piston ring into a PTFE slide ring, establishing the high-pressure piston seal system.

Aimed at achieving a no-leak cylinder, the seal system has overcome several barriers to bring about a cylinder structure model and related production innovation.

Fig .2 shows how the seal system has changed on the occasion of KCH. Fig. 3 shows the structural features of the initial KCH model (KCH-1).

6. Visualization

The development of the KCH seal system involved

Year	Model	Pressure	Cylinder head seal system	Changes	Purpose	Piston seal system	Changes	Purpose
1984	High-pressure type (old model)	24.5MPa	① Cylinder head ② Holder	Conventional high-pressure cylinder model for construction equipment ① Screw-in type ② Non-ferrous material		③ Main seal ④ Bearing	Conventional high-pressure cylinder model for construction equipment ③ Dowty U-ring type ④ Metallic piston ring	
1986	KCH-1	26.0MPa	① Cylinder head ② Buffering ③ Between seals	First model development ① Simplified shape (bolt-up structure) ② Reinforced PTFE ③ Bronze overlaying	Cost reduction Galling prevention	④ Main seal ⑤ Inner bearing ⑥ Outer bearing ⑦ Between seals	First model development ④ Seal ring structure (PTFE + NBR) ⑤ PTFE ⑥ PTFE ⑦ Bronze overlaying	Prevention of seal burning due to adiabatic compression Supporting higher pressure and higher speed Galling prevention
1990	KCH-2	28.0MPa	① Buffering ② Between seals	① Use KYB product ② Bronze overlaying ⇒ Changed into plastic bearing	Cost reduction Cost reduction	③ Inner bearing ④ Outer bearing ⑤ Between seals	③ Phenol resin ④ Reinforced PTFE ⑤ Bronze overlaying abolished (③ Bearing material with higher strength)	Cost reduction Cost reduction

Fig. 2 Changes in KCH seal system: Initial stage [Source: Reference 2)]

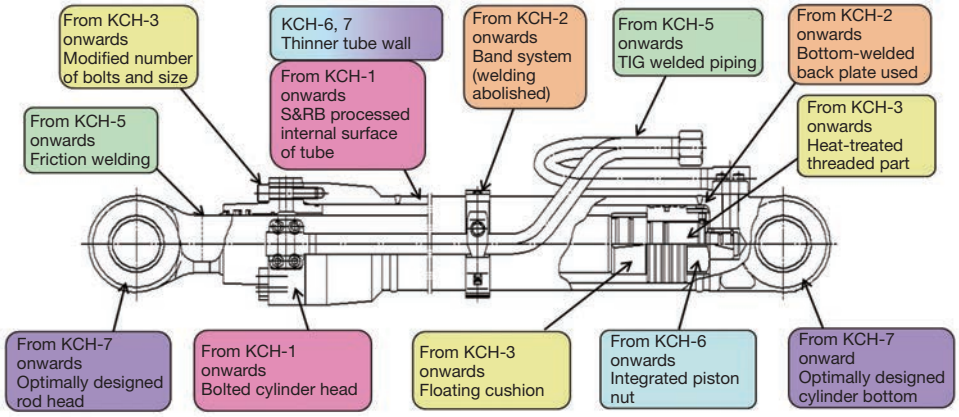

Fig. 3 Features of major KCH components [Source: Reference 2)]

many challenges. I would like to close this essay with a particularly impressive challenge.

The pressure build-up, which was troublesome in the rod seal system completion stage, was a phenomenon that an ultra-high pressure of several hundreds of MPa occurred between the buffering and U-ring seal as the cylinder moved to and fro. A key to solve the problem was to strike a balance between input and output of the lubricating oil film over the seals. South Hydraulic Experiment was required to "visualize" the oil film thickness, and the task was assigned to me.

In those days, attempts to assess the oil film thickness on the seal using the solving inverse problem of lubrication theory were made by some seal manufacturers and universities. According to references, the method was intended to estimate the oil film thickness from the contact pressure distribution of the reciprocating seal in the sliding direction obtained by using slits and the static pressure. The theory holds that the minimum oil film thickness depends on the slope of the contact pressure distribution.

KYB had already used another method to obtain the contact pressure data with piezoelectric elements in its Technology R&D Center. I also tried the method. Piezoelectric elements can be used to drive voltage that is dependent on the force change rate. The output of scanning in the sliding direction is generally proportional to the pressure distribution variation, from which the slope of the contact pressure distribution can be obtained. I used a piston rod embedded with handmade sensors to carry out measurement.

The sensor output is difficult to be determined due to the differentiating component of the contact pressure distribution. The output data may be integrated to provide an easy-to-determine contact pressure. I programmed the signal post-processing by using a just-introduced 16-bit PC while the Technology R&D Center used an analog IC integrator. The machine language I assembled using an assembler that I had just learned how to use was also useful.

The slope data of the contact pressure distribution for various seals was collected in a short time. As a result,

the slope of the contact pressure distribution that theoretically decides the oil film thickness was successfully visualized, although the thickness itself could not be measured. The visualized information was used to resolve the pressure build-up problem, contributing to KYB buffering development and in-house manufacturing.

Seeing is believing. That was my first job to strongly realize the effectiveness of visualization. The job was also impressive since the knowledge on electronification and microcontrollers I obtained upon receiving stimulus from my colleagues helped a lot. Fig. 4 shows how to measure the contact pressure distribution.

Accurate visualization is now available on computer systems in various fields. This is a kind of virtual reality (VR). I am not going to deny VR technology, but I hope that engineers will effectively apply the visualization without neglecting verification in the real world.

7. In Closing

KCH has been sent out into the world with these efforts by many of those concerned. The experience has rippled through the design and even production innovation of other KYB hydraulic cylinder series, including mid- and low-pressure cylinders. KCH has also been reduced in weight and improved in pressure resistance to meet customer needs after its emergence. KCH has even been applied to super-large construction equipment without changing the basic concept. The manufacturing innovation may have enabled overseas production. New models include one featuring absolute stroke sensing, which makes me feel that the KCH's future is promising.

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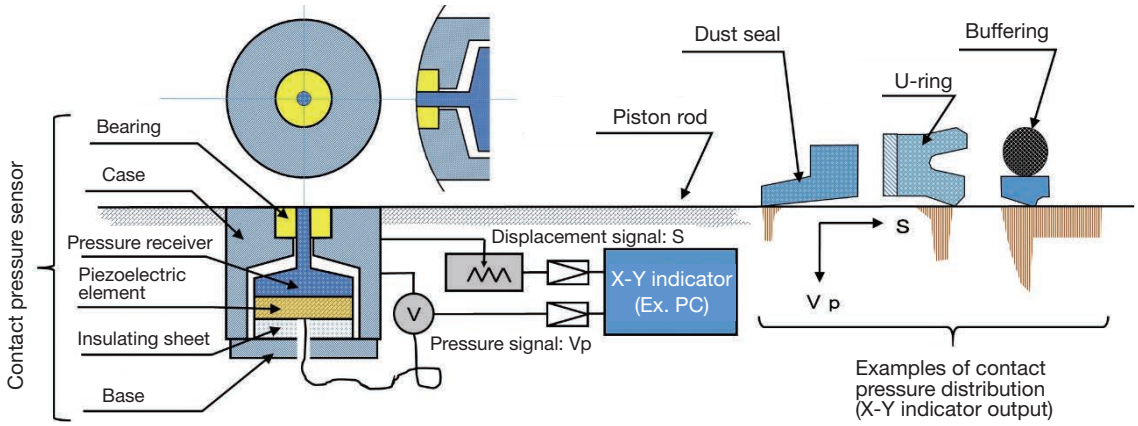

Fig. 4 Measurement of contact pressure distribution

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Explanation

Application Examples of Data Mining

TAKAMATSU Shinichi

1 Introduction

Data mining is a technology that applies data analytics such as statistics and machine learning to large quantities of data in order to obtain useful findings including potential trends and patterns. When the technology works well, unwritten knowledge noticed by experts through their experience, namely intuition or knack, could be formulated and transformed into formal knowledge, and any correlation between unknown events could be identified and become a foundation for innovation. Data mining literally means to "mine" "data" as if like digging a vein of gold. The technology has become increasingly important in a modern world flooded with data.

Fig. 1 can help you imagine how much this field has been gaining attention easier. In total five terms were selected for research purpose and how many times these terms were searched over the Internet every week in the past five years was counted. The proportion of the search count of the terms is shown in the figure with the maximum value during each period taken as 100. The five terms consist of three terms related to the technology (i.e., "data mining", "data analytics" and "data science"), one term representing KYB's core technology for reference purposes ("hydraulics"), and the other term expressing the impossible dream of mankind ("immortality"). The figure implies the people's trend of being interested in realistic topics. The terms related to the technology have gained more attention than that for mankind's dream, even though we finally live in an age in which we could scientifically discuss the possibility of achieving immortality using iPS cells. The term data mining, which was conceptualised in the 1980s, has received attention to almost the same extent as hydraulics, which is a long-lived technology since the age of the industrial revolution. Attention to synonyms data analytics and data science has dramatically increased. These three data-related terms are gaining much attention, equal to or above that for hydraulics or immortality.

With a focus placed on data mining as a technology for effective application of data, namely information, KYB promotes technology application and human resource development with an aim of achieving company-wide dissemination and establishment of the technology. Although this effort has just begun, I would like to describe the significance of the effort and introduce part of its technical results in this paper.

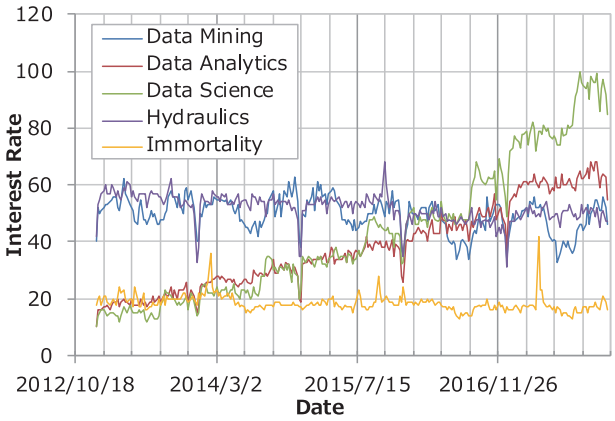


Fig. 1 Trends of word searching with Google (author's own survey)

2 What is Information?

Many of those who take notice of the keyword "data mining" have probably learnt that data scientists are said to have "the sexiest job of the 21st century" [1]. This expression originated in the phrase that "the sexiest job in the next 10 years will be statisticians" [2] said by Hal Varian, chief economist of Google, in 2009. The phrase predicting the coming of an age in which data analysis is critical was instantly propagated worldwide partly because of its vivid sound of words. Now it may be an even depreciated rhetoric with which you could be tired of hearing. Even if you do not know this phrase, you can hardly live your daily life without hearing the words big data, artificial intelligence (AI) and Internet of Things (IoT). There is no doubt that everybody can see or hear these words somewhere in society. A common concept that lies behind these words is information.

The word "information" is translated into Japanese as "jo-ho". "jo-ho" used to be a military term that originated in the "French Infantry On-site Exercise Standard", translated by the General Staff Office of the Japanese Imperial Army in 1876 [3]. The translated version of this Standard included an expression of "teki-jo-ho-koku" ("enemy

information report"), and this expression was abbreviated as "jo-ho" ("information"). The original word "information" means "to give form to the mind" or to inform of details or circumstances of a matter. As you may imagine from the origin of the word, information is any entity that brings the receiver a new idea or criterion, and is defined as "any entity that resolves uncertainty of knowledge on matters" [4].

For example, under a cloudless sky, information that it will be still clear one hour later is not valuable because it is quite likely, but information that heavy rain will come one hour later is valuable because it is unlikely to happen. The latter, if obtained beforehand, can be used as a criterion to determine proper action to be taken, such as bringing an umbrella.

That is, information has a higher value when it predicts what is unlikely to happen, or "an event with a low probability of occurrence". The concept of information quantity can be interpreted as the degree of unexpectedness [5]. Therefore, information quantity is highest when it certainly foresees an event by resolving very difficult uncertainty, although such information can't be easily obtained.

3 Trends of Data Mining

As a model clearly presenting the significance of information, this section introduces the DIKW model (Fig. 2) showing the hierarchy of data, information, knowledge and wisdom.

In this model, information as a generic term is divided into "data", "information", "knowledge" and "wisdom" in the form of a hierarchy where a higher-level component is the more important element. The model implies that, for example, numerical "data" such as time, atmospheric pressure and coordinates can be integrated and compiled into "information" expressing a change in pressure distribution with time, to which "knowledge" that low atmospheric pressure causes bad weather can be applied to produce a weather forecast, which may lead to "wisdom" of bringing rain gear for a certain level of probability of precipitation or higher.

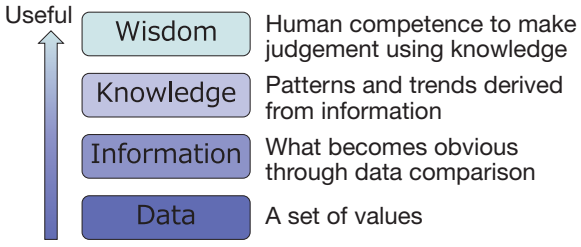


Fig. 2 DIKW Model

Exerting "wisdom" in this way supports an appropriate judgement for bringing about a desired outcome and offers a greater advantage compared to cases of not exerting "wisdom". In order to capture useful "wisdom", "data" and "information" should be organised and accumulated in such a manner that can be refined into available "knowledge". This is the real reason for obtaining information.

This importance of information has always been recognised. However, there were only limited means of effectively using information because both collection and analysis of information were not easy.

With recent rapidly advancing science, the limitations have been substantially alleviated. As shown in Figs. 3 and 4, data processing speed has been dramatically improved with advanced computer systems and miniaturisation technology for integrated circuits has advanced to achieve explosive growth in the data storage size. In addition, the penetration of the Internet and the improvement of sensors now make it possible to accumulate and analyse huge quantities of data that could not be collected or handled before. Today, data mining has gained the spotlight as a technology that can efficiently analyse a number of automatically collected data sets. Engineers engaged in such data mining are wanted as data scientists.

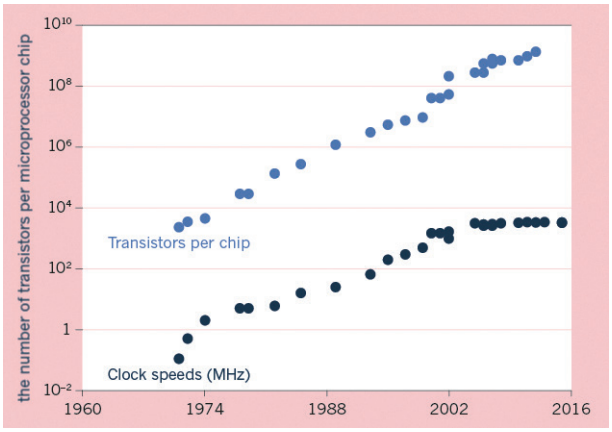


Fig. 3 Improvement of data processing capability of computer systems [6]

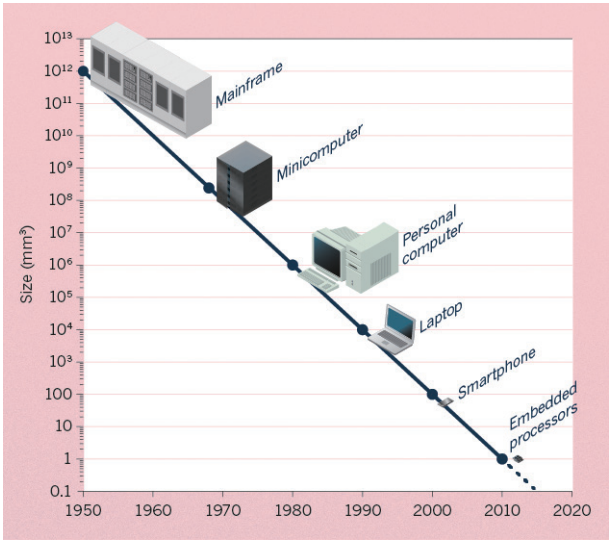


Fig. 4 Shrinking size of integrated circuits [6]

4 Physical and Statistical Models

In conventional product development using engineering means, the object is represented by a physical model and an equation is established, which is parametrically analysed to find an optimal value. This approach can produce more accurate results under simpler conditions. In reality, however, experimental or modelling errors are unavoidable, which directly leads to less accurate analysis. Thus, a physical model established according to textbooks is insufficient and generally modified with various knowhow introduced.

Unlike physical modelling to pursue the true value generation structure, statistical modelling used in data mining is based on a totally different idea. The purpose of statistical modelling is to successfully approximate the relationship between input and output regardless of the mathematical formula structure or the system of units. Equations obtained as a statistical model are not theoretically persuasive like the governing equations that describe phenomena according to physical law. They may be a heretic approach from the standpoint of engineering, but can disclose hidden patterns embedded in complex real phenomena and often work well as a method to dig up new findings.

Physical and statistical models can be compared to each other and evaluated as shown in Fig. 5. In physical modelling, input is subjected to an operation based on the governing equations for deductive processing to derive output. For example, a combination of input and operation as in "(1 + 2)" is used to determine the output "3". On the other hand, statistical modelling uses a set of input and output to estimate an operation that properly associates them with each other as an inductive approach. After the set of input and output "(1 2) = 3" is simply identified, the appropriate operation ("+") that can associate them with each other is estimated.

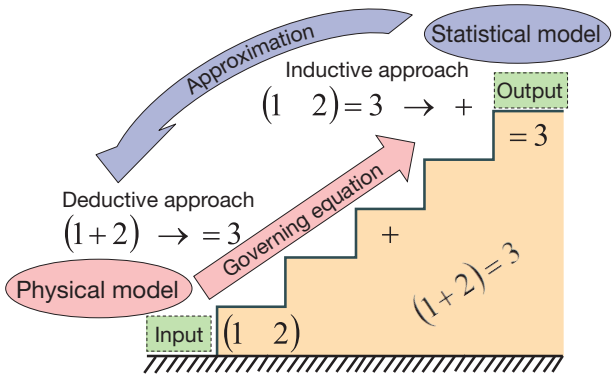


Fig. 5 Physical and statistical models

As stated above, physical and statistical models use totally different approaches to handle phenomena. Conventionally, sociology, medicine, psychology and other fields that handle phenomena with low reproducibility have often used statistical modelling, and the engineering field has applied physical modelling exclusively in many cases since it handles phenomena in which certain patterns can be found. However, the governing equations that form the basis of engineering are just formulas systematised from some of the patterns universally identified in natural phenomena, not a faithful description of actual complex phenomena. With recent leaps in data accumulation and processing technology as described in the previous section, it can be expected to obtain findings categorised in knowhow that can't be included in the governing equations by applying statistical modelling to actual input and output as a secure fact.

5 Case Examples

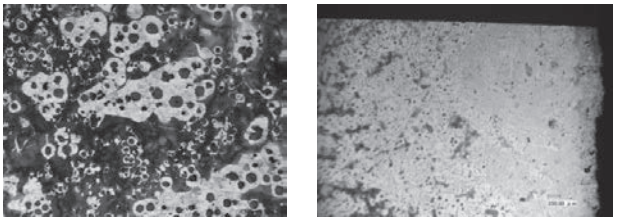
With consideration given to the significance of applying data mining technology to its efforts in the manufacturing industry, KYB promotes an activity to ensure company-wide dissemination and establishment of the technology. This activity includes applying the technology to various issues picked up from different departments in the company, discussing the results with engineers from relevant departments to obtain new findings efficiently, and refining the findings as they can be converted into the company's original technology.

Some of the activity cases to which the technology was applied guided personnel to resolve issues that would have otherwise not been clarified with conventional technology. Some others contributed to early development of proposed countermeasures. From these successful cases contributing to business operations, some examples are extracted and introduced below:

5.1 Measures against abnormal tissue in castings

Castings are one of the products that can't easily ensure stable quality due to several intertwined factors, including material components, shape and temperature. KYB has introduced a Quality Traceability System (QTS) installation line making full use of IoT into the KYB-YS Co., Ltd. plant, which is one of KYB's affiliates, establishing a system to accumulate several hundreds of data sets for each casting product.

KYB-YS had frequently had castings with abnormal tissues (Photo 1) in a period, and had got into a situation



(a) Normal tissues (nodular graphite)

(b) Abnormal tissues (flake graphite)

Photo 1 Normal/abnormal tissues in castings

where the cost incurred for disposal of these castings was too much to be overlooked.

The company had technical discussions about this quality failure with foundry experts. In order for graphite to form normal tissues, graphite must be spheroidised. The experts suspected the presence of an element that would prevent the spheroidising because the abnormal tissues had been found only in limited locations around where combustion gas was generated. Some other hypotheses based on their technical knowledge were also developed. However, measures derived from these hypotheses did not finally solve the failure at the root, although they brought about a certain effect. Then, they singled out the data mining technology to take a bird's eye view of the overall QTS data.

During various analyses conducted at the initial stage, QTS data for various information items, including the temperature of melt (molten metal) during casting, and the quantity of the elemental components were processed and organised into 110 variables that can be subjected to quantitative analysis. However, no obvious cause of the failure was found in this analysis. Casting is so subsensible that can be said to be like a creature. Technicians have to additionally tune the regular casting conditions according to variations in temperature, humidity or other factors of the day. With this feature taken into account, another way of thinking was emerging. The data was then stratificated by time and by product and applied with the decision tree and other analysis approaches that can examine the branching condition to determine whether failure occurs or not. As a result, the condition for abnormal tissues to occur was gradually revealed. That can be shown in Fig. 6 if permitted to be simplified with the detailed conditions omitted. This scatter diagram shows the casting temperature and time of casting process on the two axes for a product whose data has been stratificated for a certain period. Faulty parts are likely to relatively come together in the upper left area of the diagram compared to the satisfactory parts. This implies that a shorter casting time at a higher temperature leads to a higher failure rate.

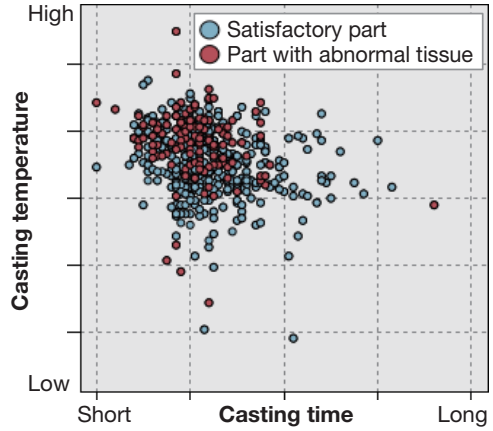


Fig. 6 Trends of occurrence of abnormal tissues

However, this finding alone does not directly lead to an effective measure. At the actual manufacturing site, changing a manufacturing condition will always cause a reciprocal phenomenon resulting in failure. It is essential to determine the manufacturing conditions by striking a balance among various phenomena. For decision tree analysis, it is possible to make analysis with consideration given to the occurrence of reciprocal phenomena caused by changing the condition. That is, the abnormal tissues could be reduced without affecting other factors. In fact, the decision tree analysis worked effectively in this case. The casting time and temperature as well as any given important factors were efficiently screened out. An equilibrium point of changing the conditions was sought in collaboration with the experts, which successfully eliminated failure.

5.2 Determining the concrete mixer state

Concrete mixer trucks (hereinafter "concrete mixers"), which are one of the products sold by KYB, play an indispensable role in the construction industry. Ensuring efficient operation will bring great merits. For the purpose of enhancing the operation efficiency of concrete mixers, KYB has promoted an effort to grasp the operating status of concrete mixers by using measurement signals retained by themselves.

In this effort, the sensors originally mounted on the concrete mixer were used to collect sensor signals on drum rotation speed, drum driving pressure and other parameters. The collected signals were processed into a time series data set consisting of 27 variables. The data was analysed to comprehensively interpret the relative behaviour of the variables. A challenge for interpretation is to determine the state of the concrete mixer at a specific time. Table 1 shows the outline of the data:

Table 1 Data used to determine the concrete mixer state

Time	State			Variable		
T	Y_1	Y_2	…	X_1	…	X_{27}
t_0	TRUE	FALSE	TRUE	…	…	…
t_1	FALSE	FALSE	TRUE	…	…	…
…	…	…	…	…	…	…

Since the concrete mixer state can be freely manipulated during testing, it is possible to put correct data in the columns under "Y" for state determination in Table 1. For actual operation, such data can't be obtained and only the variable X acquired from the sensor signals has to be used to estimate the actual state of the concrete mixer. However, the relationship between variables may substantially vary by the loading amount of fresh concrete of the concrete mixer, or by the load quantity handled by the operator, even if the mixer itself is in a same state. It was thus difficult to establish a universal criterion to determine the mixer state. None of the conventional methods successfully established a criterion for accurate evaluation.

Then, data mining was applied to find an evaluation criterion. As a result, it is now possible to determine the state at an accuracy of about 90% for linear discrimination, or at nearly 100% for non-linear discrimination by machine learning. The linear discrimination implies which variable is important for evaluation, so it can be used for discussion about technical issues. On the other hand, the machine learning approach does not provide an obvious evaluation criterion while offering high discrimination accuracy. So, this approach is not suitable for discussion from an engineering aspect. In this case, to contribute to engineering-based technical advance while ensuring high-accuracy determination, the different approaches have been finally combined in a way suitable for the purpose of solving the issue.

5.3 Pursuing optimal manufacturing conditions for oil seals

In the development of oil seals applied with new manufacturing technology, the new manufacturing process not included in the conventional technical knowledge led to unstable product quality, leaving many nonconforming parts among injection moulded prototypes. The number of quantities of state related to manufacturing conditions, as many as 50, such as temperature and pressure of different parts, were recorded in the injection moulding machine along with accumulated status data related to many faulty prototypes. These data sets were found to have no simple trend from which any relationship could be derived by thinking alone. The development team had difficulty determining the manufacturing conditions for ensuring stable quality.

Then, several analyses were made on the occurrence/non-occurrence of failure. The results are shown in Table 2. In total four analysis approaches created their own model for determining the occurrence or non-occurrence of failure. The table summarises, among the 50 kinds of quantity of state, which one the models focus on as a critical variable. All the four analysis approaches derived their model from different statistics as a basis. Since which statistic was suitable for the basis was unclear in this case, all the analyses were generally conducted to see what happened. Even though it was an ad hoc approach, the variables selected in each of the four analyses were compiled and the results were reviewed as a whole, which naturally presented some variables on which importance was placed by all the analysis approaches.

The results above represent a trend found only through data analyses with the statistical models applied, not based on any technical knowledge related to injection moulding. Still, this approach squeezes the 50 kinds of quantity of state down to as low as 14 and even gives them a degree of importance.

A group of squeezed-down number of kinds of quantity of state prioritised according to importance like this can be individually reviewed from an engineering viewpoint. Then, each quantity of state was subjected to evaluation by engineers, which revealed that there was no inconsistency in failure mechanism among them. These several kinds of quantity of state were assigned to an orthogonal array according to the design of experiments for further research. As a result, truly important manufacturing conditions were identified and the failure rate was substantially reduced. This is a successful case in which a combination of data mining and design of experiments refined an analytically found data trend into technical knowledge, resulting in efficient problem solving.

Table 2: Matrix of importance of 50 variables

Reference No.	Selected variable	Analysis approach				Importance (number of circles)
		Discriminant analysis	Decision tree ①	Decision tree ②	Decision tree ③	
1	X_1	○	○	○	○	4
2	X_3	○			○	2
3	X_4	○	○	○		3
4	X_5			○		1
5	X_7			○		1
6	X_8		○	○	○	3
7	X_{10}				○	1
8	X_{31}	○	○	○	○	4
9	X_{32}		○	○		2
10	X_{33}				○	1
11	X_{46}		○	○		2
12	X_{47}	○	○	○	○	4
13	X_{48}	○		○	○	3
14	X_{49}		○	○		2

6 In Closing

6.1 Concluding remarks

Qin Shi Huang, who was the first emperor of a unified China, and also famous for his search for an elixir of immortality, arrogated the first-person Chinese pronoun "朕" for his exclusive use. Since then the word "朕" has become the first-person pronoun exclusively used by absolute monarch. One who calls himself/herself "朕" means one who governs the whole nation. The word "朕" also means a "sign". It is interesting to see a significative relationship between the two words: a sign governs the whole.

Data mining may be a technology to search the "sign" efficiently. The technology is used to pick up subtle signs from a sea of information, not to find an untouched treasure. What is found needs to be refined until it is available as a pattern. Particularly for a manufacturer like KYB, it is indispensable to have the capability to technically interpret the result obtained as a statistical model, to figure out what it really implies, and to transform it into a physical model. If we neglected these, we could certainly be able to apply unknown patterns to practical fields for a short time, but would not be able to obtain an extensive applied science elucidating the full facts, eventually failing to

accumulate true expertise, and even inhibiting development in the long view.

The amount of information available in this modern age is too much for us to handle. A large volume of information is discarded without being processed at all (Fig. 7).

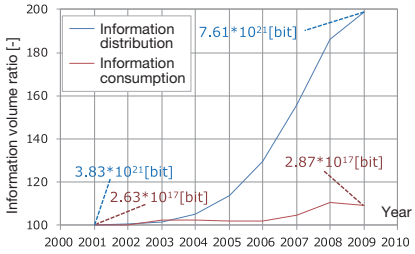


Fig. 7 Changes in information volume using the value in 2001 as a base of 100 [7)]

Information like this that never sees the light of day may include embedded patterns or rules with high repeatability, although they are too complex to be interpreted easily. Particularly when different information sets that have been independently handled in separate fields are integrally analysed, it is highly expected that any unknown relationship can be identified. This was originally a long-established pattern of invention or discovery. Therefore, I believe it is essential to develop a base to collect information, including IoT, and establish a flow of processes, including from accumulating information, allowing efficient discoveries to take place through data analysis, and refining them into reliable manufacturing technology. From this standpoint, KYB still has many apparent inadequacies indeed. First of all, I would like to begin the first steps toward the dissemination and establishment of data mining by promoting an awareness raising activity to open the door.

"If you want to achieve a triumph, you must work hard to do the small things. Many drops make a shower. Generally, nobodies always want to succeed and neglect doing the small things. They feel sad about being unable to do what is difficult and do not do what is easy. That is the reason why they can't finally achieve in anything". [8)] These words are really a wisdom.

6.2 Acknowledgement

On this occasion I would like to thank the cross-departmental team members involved in the technology dissemination activity and their supervisors as well as many those who extend support by providing information about actual cases to which the technology was applied. Without their cooperation, I think this activity would still be groping in the dark. I would like to appreciate here that the activity has taken root as a wide-spread profound effort.

6.3 Additional note

Apart from natural science including technology, this additional section introduces what the phrase "significance of a sign" sometimes suggests in the humanities, which may reflect the significance of finding relationships by integrating different fields. I hope the reader will discuss the issue based on the concept of data mining that derives patterns from signs.

The elixir for immortality Qin Shi Huang obtained was mercury. He is said to have died from elixir poisoning. Mercury had been considered as a mysterious material from ancient times and was also positioned as a very important material in Western alchemy. Alchemy is the study aimed at sublimating material, body and mind to a complete existence as like gold, and was started with a stimulus from gold's physical rarity and stability. Mercury has the physical property that it can evaporated from gold amalgam to produce gold plating. Ancient people with no idea of specific weight must have been dazzled by the property of mercury that implies a sign of completeness.

A famous novel on alchemy [9)] presents a theme that one who listens to signs will open a way to realise a dream. This novel is a literary work of enduring value often is compared with The Little Prince [10)] whose theme is "the precious things can't be find by eyes", and whose precept is "the significance of looking at things with one's heart."

Do you understand what I mean? The humanities also have unreachable goals such as completeness and dreams. Like natural science, it is full of challenges and failures. Many masterpieces that arouse people's sympathy have one thing in common, that, to reach these goals that are generally difficult to find, one must have an attitude of trying to look at what you can't see with your eyes. This way of thinking is similar to the concept of serendipity [11)] in natural science, that deriving something from failures will probably bring a big discovery.

Finally, even though it may be an unnecessary addition, I would like to conclude this article by referring to the word "significance". The prefix of this word is "sign".

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Technology Introduction

Research on Excavator Posture Estimation Technology with Image Processing

OMOTE Masaya

1 Introduction

Recently construction equipment is required to have advanced safety functions such as fall prevention. Future construction equipment is estimated to be automated more than ever and will be required to address the rising need for stability during high-speed operation. Under this situation, I decided to launch an effort to improve excavator safety using ZMP Note 1) as an index of excavator stability. To calculate ZMP, however, a number of sensors of different types, including angle and acceleration sensors need to be installed on the rotating platform, boom, arm and bucket of an excavator, which would configure a complex system. On the other hand, recent lower-priced cameras and improved communication and data processing capabilities have contributed to the wide-spreading of sensing technology using cameras and image processing. This study has developed a method of identifying the posture of an excavator necessary for calculating ZMP with a relatively simple system configuration using cameras and image processing. This report will introduce the excavator posture estimation technology using image processing addressed in the study.

Note 1) Zero Moment Point. ZMP is defined as the point where the total of gravity, inertia and external forces applied to a machine installed on a road surface does not produce any moment (zero moment).

2 System Overview

2.1 Hardware configuration

Cameras used to capture images for image processing were installed in the rotating platform (cabin).

Since multiple cameras should be used to determine the detected angles in this study, a camera model equipped with an external trigger function that allows all cameras to operate at the same time was selected. To capture clear images, even under infrared rays from sunlight, a near-infrared lens was selected.

2.2 How to estimate posture with image processing

To estimate the posture of an excavator, the link length and angle of the rotating platform, boom, arm and bucket of the excavator are needed. Link length refers to the direct distance from one rotation axis of a moving element of the excavator to the other rotation axis of the same part. Link angle refers to the rotating angle of a moving element. Since the link length can be measured in advance, this study used image processing to determine the link angle (Fig. 1). To determine the link angle, the link images captured by the cameras were first subjected to image processing to detect the target edge. Then, the angle between the target and known edges (Fig. 2) were calculated.

Target edge means an edge that cannot be detected without image processing. Known edge is an edge whose position is obvious even without image processing. Any boom that turns about the rotating platform mounted with the cameras can be the known edge. On the crawler, the frame of a camera can be used as the known edge. Once the target edge of the boom is detected with image processing and the detected boom angle is calculated, the boom edge can be used as the known edge to determine the detected angle of the arm rotating about the boom. The reason for the boom edge being able to be used as the

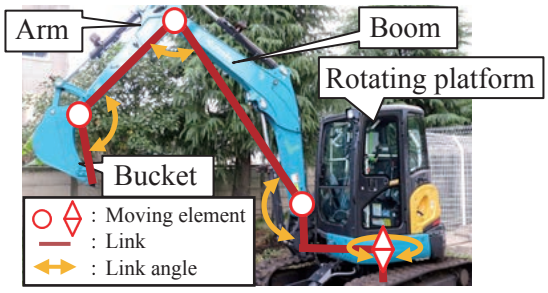

Fig. 1 Link angle

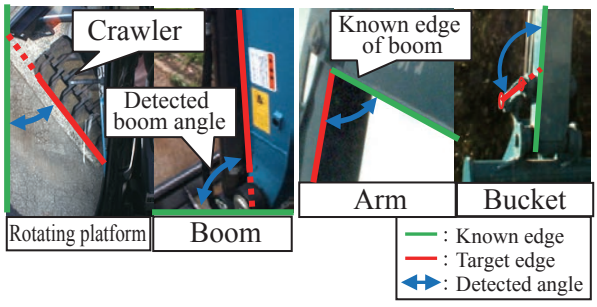

Fig. 2 Detected angles

known edge is because, by mapping the relationship between the detected boom angle and the position of the known edge of the boom on the image beforehand, calculating the detected boom angle will automatically determine the position of the boom from the mapped information.

3 Calculation of Detected Angles

Detected angles are calculated as follows:

(1) Detected boom angle

For detection of the boom angle, the target boom edge is detected with image processing. Then, the detected boom angle between the detected target edge of the boom and the screen frame is calculated.

(2) Detected arm angle

Since the detected boom angle has been calculated in (1) above, the position of the known edge of the boom is automatically available. The target arm edge is detected with image processing. Then, the detected arm angle between the estimated known edge of the boom and detected target edge of the arm is calculated.

(3) Detected bucket angle

Since the detected boom and arm angles have been calculated in (1) and (2) above respectively, the position of the known edge of the arm is automatically available in the same manner as the known edge of the boom. It is now desired to detect the target bucket edge with image processing, but the bucket has a complex shape and has no straight edge. So, the link joint region between the bucket and arm (Fig. 3) should be detected with image processing. A straight line is calculated from the two points in the center of the region. Then, the detected bucket angle between the straight line connecting the detected two points in the joint region and the estimated known edge of the arm is calculated.

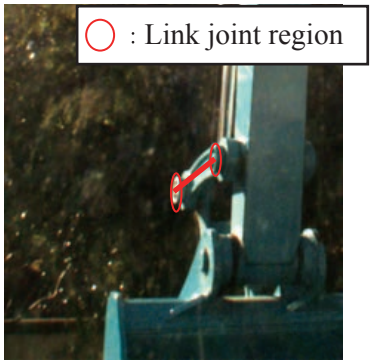

Fig. 3 Link joint region

(4) Detected rotating angle

The target edge of the crawler is detected with image processing. The detected rotating angle between the detected target edge of the crawler and the screen frame is calculated.

4 Detection of Target Edges

Target edge detection can be roughly classified into two types: image processing and edge/region identification.

4.1 Image processing

Image processing is applied to the excavator components according to the following procedure:

(1) Boom, arm and rotating platform

In the image captured by cameras (Fig. 4 ①), lens distortion is eliminated to produce a corrected image (Fig. 4 ②). Next, the image is processed to extract edges on the screen (Figs. 4 ③, ④) and to remove rough screen edges (Fig. 4 ⑤). In this process, all edges are removed except several top ones in a descending ranking that seamlessly extend as a single edge with the highest pixels. Finally, among the remaining edges, the straight ones are selected (Fig. 4 ⑥).

(2) Bucket

The lens distortion correction is made on the image captured by cameras. Next, the link joint region is extracted.

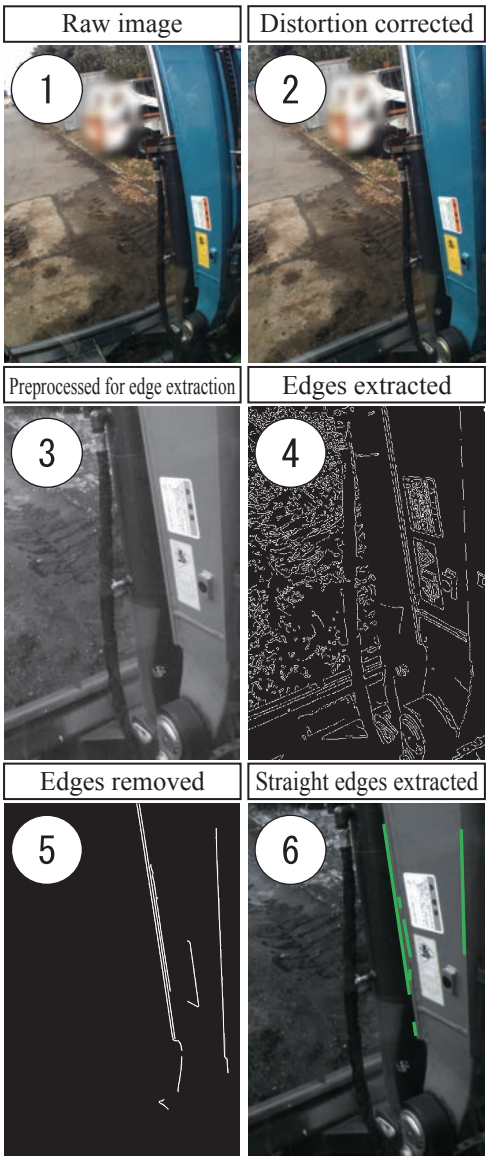

Fig. 4 Example of image processing (boom)

4.2 Edge/region identification

Extracted edges and regions are processed for final identification. They are identified by determining the relationship with a specific circle or by weighting.

4.2.1 Specific circles

Fig. 5 shows images of the boom, arm and bucket captured by cameras from the side and an image of the crawler captured from the top, on which their target edges/regions, as well as specific circles and their center point, are overlaid. The center point of each specific circle is located on the rotation axis of the moving element of the relevant part. Target edges on the same part perform a circular motion about the center of the specific circle. The circumference formed by this circular motion is the specific circle. All target edges of the boom, arm or crawler are a tangent of the specific circle at any link angle. The link joint region of the bucket is within the specific circle at any link angle.

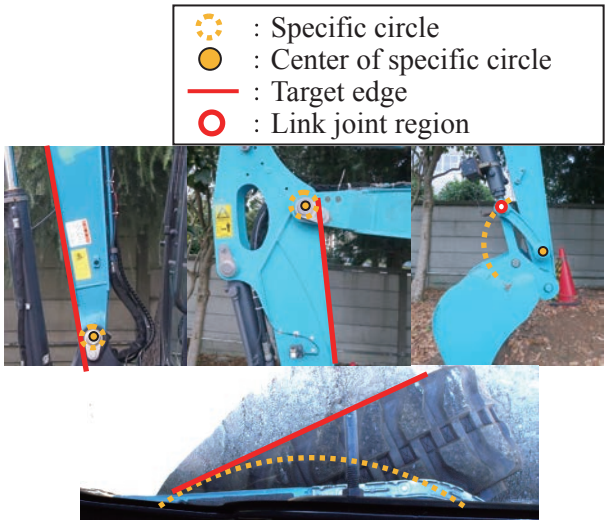

Fig. 5 Target edge and specific circles

4.2.2 Weighting procedure

Weighting is a data evaluation process for ranking a set of data by evaluation item, giving them a score according to the ranking and finally evaluating them with a total score. Among the group of edges detected with image processing, the highest ranked edge is identified using this weighting process.

The evaluation items are listed below (① to ③) and how edges are identified by weighting is shown in Fig. 6.

① How long is the edge?
② How close to the specific circle is the arm?
③ How close to the approximate position where the boom edge intersects with the arm edge on the screen (the intersection point) [Note 2)] is the end of the edge?

Note 2) Point of intersection is estimated according to the relationship between the boom angle and approximate intersection point that has been mapped beforehand as in the case of a known edge.

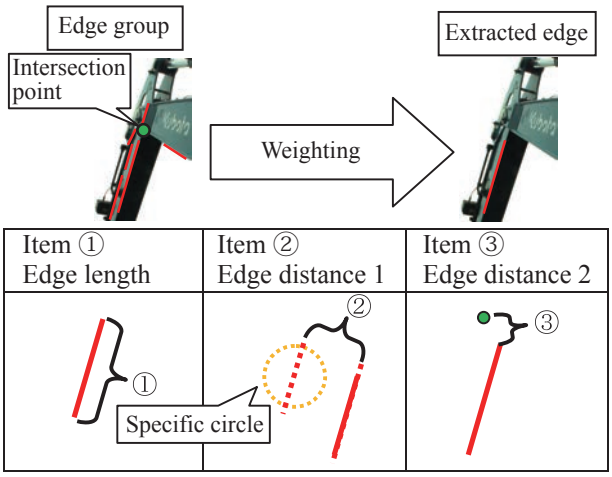

Fig. 6 Weighting items

4.2.3 Identification procedure

(1) Boom

Edges that can be a tangent of the specific circle (Fig. 5) are selected. Of these, the longest edge is selected.

(2) Arm

From the relationship between the detected boom angle and the center of the specific circle on the boom (Fig. 5) that has been mapped onto a table, the position of the center of the specific circle is estimated. Of the straight lines, those that can be a tangent of the specific circle are selected. These selected straight lines are weighted, from which the edge with the highest score is selected.

(3) Bucket

From the relationship between the detected arm angle and the center of the specific circle on the arm that has been mapped onto a table, the position of the center of the specific circle is estimated. Of the link joint regions, the one that passes through the specific circle is selected.

(4) Rotating platform

Edges that can be a tangent of the specific circle are selected. Of these, the longest edge is selected.

5 Calculation of Link Angles

When the detected boom/arm/bucket angle is calculated, this will uniquely determine the link angle. Based on the relationship, the link angle can be determined from the detected angle by simple conversion.

To calculate the link angle of the rotating platform, a combination of the two cameras used for detection and

Table 1: Rotating platform link angle chart

Platform orientation (quadrant)		1st, 4th	4th, 3rd	3rd, 2nd	2nd, 1st
Angle detecting Camera	Camera ①	×	○	×	○
Camera	Camera ②	○	×	○	×
Platform link angle rage θ		315°-45°	45°-135°	135°-225°	225°-315°

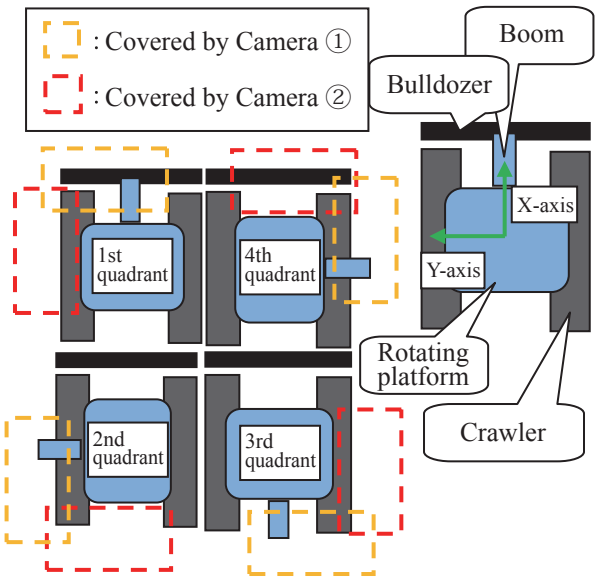

Fig. 7 Camera coverage for various rotating angles

orientation of the platform can be used to calculate the link angle. Table 1 gives a matrix of the combinations. Fig. 7 shows the positioning of the shooting areas of the cameras at different link angles of the platform: 0°, 90°, 180° and 270°.

Table 1 is based on an assumption that the excavator has a coordinate plane with its longitudinal axis as the X-axis and lateral axis as the Y-axis when viewed from the top. The coordinate plane is divided into four areas: 1st to 4th quadrants. The angle detecting cameras are those shooting the crawler. The table indicates the active camera for quadrants with marks ○ and ×. The platform link angle range represents a range of the link angle θ of the platform for each set of 1st to 4th quadrants.

6 Detection Results

Table 2 shows the results of detection of the excavator parts moving within their own movable range with image processing. The "detection rate" indicates the ratio of the number of images in which the target edge can be detected to the total number of images used for detection. "Detection" means the maximum error between the detected link angle and actual link angle Note 3).

The detection result indicates that the detection accuracy for the bucket and platform that are relatively close to the cameras is higher than that for the boom and arm. The reason for the higher accuracy may be that images of an edge closer to the cameras can be captured with more pixels, and even a shift of the edge by a single pixel would seldom affect the accuracy. Also, an edge closer to the cameras can be detected as a longer one, and even a shift by a single pixel would seldom affect the accuracy as well.

Table 2 Detection result

(Number of verified images) / Evaluation item	Boom (250)	Arm (127)	Bucket (149)	Platform (475)
Detection rate (%)	83.94	74.80	89.25	100.00
Detection [deg]	±0.58	±1.46	±3.11	±0.98

With the current detection rate, it is actually difficult to evaluate ZMP in real time. Still, the machine's ZMP can be adequately evaluated offline with the current detection level. Therefore, it is relatively easier to evaluate machine stability compared to cases of installing various sensors.

Note 3) Refers to the link angle measured using reference sensors installed separately.

7 In Closing

This study used the combination of cameras and image processing techniques to estimate the posture of excavators, instead of angle and acceleration sensors generally used for the same purpose. Although the technology still involves some difficulties in detection accuracy and rate, the study has confirmed that the posture detection system using this technology can be established to estimate excavator posture at an acceptable performance level from inside the cabin with environmental resistance advantage.

The image processing technology using cameras confirmed in this study may replace existing various sensors depending on the application. Recently the combination of cameras and image processing has been introduced to systems in various industries. It is important for KYB to assess the possible effects or added value produced by the combination of cameras and image processing applied to KYB system products. With this in mind, I would like to continue addressing the development of new products and technology.

Author

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Joined the company in 2009.
Motion Control R&D Sect., Basic Technology R&D Center, Engineering Dev.
Mainly engaged in development of sensing technology with image processing.

Technology Introduction

Development of 2D Code Marking Technology with Machining Center

KASUDA Takaaki

1 Introduction

Direct marking of model/lot numbers, serial numbers and other manufacturing information (hereinafter "production information") on products or parts has been carried out since long ago to ensure traceability. This is called direct part making.

Recently, as more and more information needs to be marked in a smaller space, two-dimensional (2D) codes are often used.

It is desirable also for KYB Sagami Plant to implement 2D code marking. However, the need for introducing a new dedicated system for marking made it difficult for the Plant to conduct due to the cost and space limitations. We have since developed a marking technology using an existing machining center (hereinafter "MC") installed on the machining line to achieve 2D code marking at a lower cost with no space limitation. This article will introduce this marking technology.

2 Overview of Developed System

2.1 Overview of direct part marking

Examples of direct part marking are shown in Fig. 1.

Direct part marking may have a variety of purposes including product identification and quality/production management. It has been spread widely, not only in the manufacturing industry but also in many other different fields.

Fig. 1 Direct part marking applied to various fields

2.2 General features of direct part marking

Direct part marking generally uses alphanumeric characters and/or barcodes. Recently the 2D codes typified by the QR code or data matrix have been introduced in many cases.

2D codes have the following merits:

① Much information in small space (highly concentrated information)

② Resistant to soiling/damage and readable by a code reader with few errors

On the machining line in Sagami Plant, machined parts are provided with marking of production information in alphanumeric characters. However, the need for 2D code marking is growing with a higher number of part numbers and a greater variety of production information to be marked.

2.3 General marking techniques and their downside

On the machining line, cast iron parts are machined by the MC. These parts can be marked mainly in two ways. The two techniques have the following features:

(1) Laser marking

A laser marker is used to melt and remove part of the surface of the target piece to make a tiny concave sequentially, thereby expressing alphanumeric characters or 2D code.

This is the most popular marking technique in recent years because it can be used for a wide variety of materials from metal to plastics.

(2) Stamping

Stamping is a kind of plastic working technique that uses a tool called a "punch" to make a punched inscription. A single punched inscription consists of a semisphere concave (hereinafter a "dot"). Arrays of multiple dots can express alphanumeric characters or 2D code.

Next, the estimated cost and space needed to introduce these techniques to the machining line are shown in Table 1.

Money is necessary, but space is more important for the machining line that may often be under great space constraints. The plant has to manage to secure space to install a new marking system.

Table 1 Comparison of major marking techniques

	Laser marking	Stamping
		
Base price	3 million yen	1 million yen
① System price (estimate)	6 million yen	4 million yen
② Additional space	+3.0 m²	+3.0 m²

* System price = Base price + Price for attached facilities + Layout cost

2.4 Development of new marking technology

Then, I got the idea of making similar punched inscriptions by machining with the MC from the dot profile made by stamping. If this idea is realized, marking equivalent to stamping becomes possible with the existing MC, creating breakthrough marking technology with no space constraints.

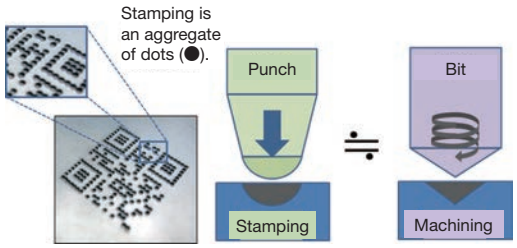

Fig. 2 Outline of new marking technology

3 Purpose

To develop 2D code marking technology with no space constraints for the existing machining line

4 Goals

① Additional space: 0 m²
② Marking time: Equivalent to stamping
③ Cost: Equivalent to stamping

5 Requirements

① The technology shall be able to be retrofitted to the existing MC.
② The technology shall be of general-purpose type for future applicability to various products.

6 Development

6.1 2D code marking element test

6.1.1 Machining test

As an element test, the MC was used to engrave a 2D code imitating stamping.

The test procedure is shown in (1) to (4) as well as in Fig. 3.

(1) Decide the character string to be marked (32 alphanumeric characters for testing purposes).
(2) Convert the character string into a 2D code using a personal computer (hereinafter "PC").
(3) Plot the 2D code on an X-Y coordinate and manually write a program for machining the black dots.
(4) Use the program to carry out machining with the MC.

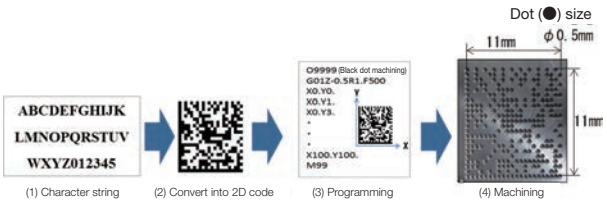

Fig. 3 Element test procedure using MC

6.1.2 Reading test

In the reading test, the engraved 2D code was read by a code reader, which verified the readability.

6.2 Development of mass production system

In actual mass production, production information consists of variable character strings for model, part, lot and serial numbers. Naturally there is an infinite number of combinations of character strings to be converted into 2D codes and accordingly there would be an infinite number of machining programs (Fig. 4).

Therefore, the technology cannot be applied to a mass production line unless steps (1), (2) and (3) in 6.1.1 are automated.

Fig. 4 2D code for mass production

6.2.1 Developing a system to automatically create machining programs

To make it possible to apply the technology to a mass production line, discussions were made on automation of steps (1), (2) and (3):

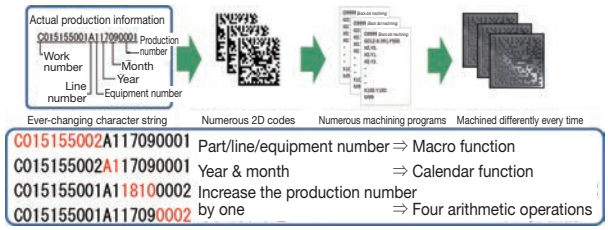

Fig. 5 Automatic generation of character strings

(1) Automatic generation of character strings
Automatic generation of an ever-changing character string can be realized using macro, calendar and four arithmetic operation functions of the MC controller.
(2) Conversion of the character string into 2D code
Similarly, only the MC controller functions were used to try to convert the character string into a 2D code. This trial revealed that conversion is impossible because of the advanced mathematics required for conversion.

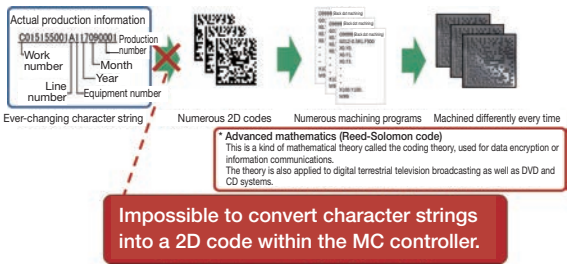

Fig. 6 Conversion of character strings into 2D codes

(3) Generation of machining programs from 2D codes
It is also impossible to automatically generate a machining program from a 2D code, which is a graphical pattern, by using the functions of the MC controller only.

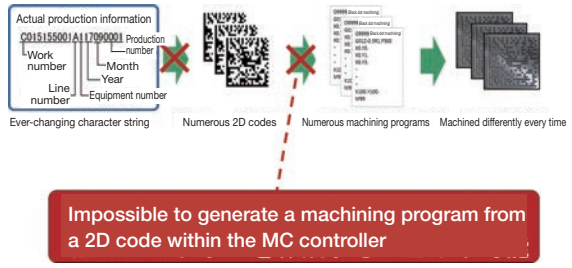

Fig. 7 Conversion of 2D codes into machining programs

Then, we developed a system to enable steps (2) and (3), which cannot be implemented within the MC controller alone, using a PC that is connected to the MC via LAN cable.

This system has the following merits.

Since the MC⇔PC connection is established via Ethernet, the PC can be placed anywhere. In extreme cases, the PC could be installed in a space that cannot be used for any other purpose in an office or on the line.

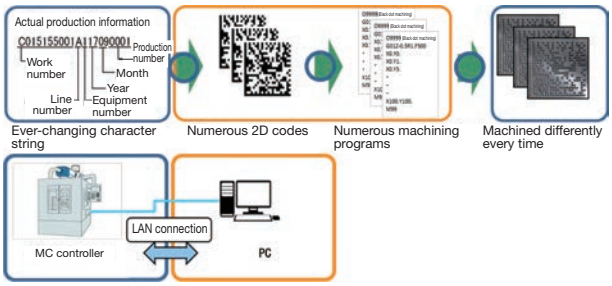

Fig. 8 Outline of 2D code marking technology

- This PC is lightly loaded since it is only used for conversion. Therefore, a general-purpose PC can be used to establish the system, which is very inexpensive.
- Like regular networks, a single PC can be connected with multiple MCs, which makes it reasonable to establish the system.

6.2.2 Establishing mass production system with an eye toward horizontal expansion

The basic system concept was completed. Next was to build a mass production system so that the technology can be actually applied to mass production lines.

To the end, a dedicated software program [Note 1)] (hereinafter the "software") was developed.

The software must have four functions: (A) to upload character strings from the MC controller to the PC, (B) to convert the character strings into a 2D code, (C) to convert the 2D code into a machining program, and (D) to download the machining program from the PC to the MC controller. The functions (A) to (D) must take place fully automatically.

It was confirmed that it actually took less than 1 second for the software to convert the 2D code into a machining program, proving that the technology can be applied to mass production lines.

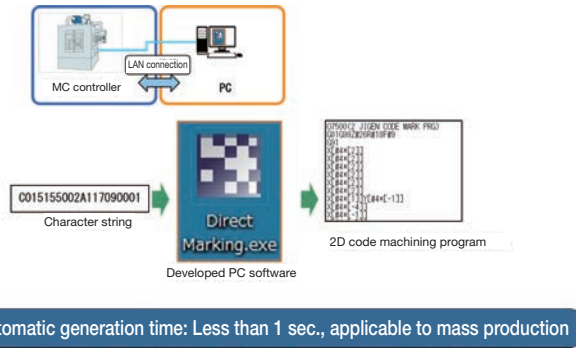

Fig. 9 Overview of mass production system

Furthermore, the software is designed to have the following features with an eye toward mass production and horizontal expansion:

① Automated system

In general, an automated mechanism is shut down when failure occurs. This system is designed to have a system flow that, if 2D code marking fails due to, for example, a broken LAN cable or PC failure, the MC used for marking is shut down.

The system also visualizes where the failure exists, if it occurs, by activating an alarm on both the PC and MC.

② Commissioning and recovery

The software is designed to allow easy expansion to other lines and recovery after failure.

③ Versatility

This software has already been subjected to tests of connection to MCs of several other manufacturers, proving its ability to be retrofitted to existing MCs.

Note 1) This software has been developed jointly with a software manufacturer. Patent is pending.

6.3 Evaluation after mass production

The mass production system was established as stated above and then applied to the machining line. Photo 1 shows a sample 2D code marked with this system.

It has also been verified that the 2D code marking time is almost equivalent to that of stamping.

Costs incurred for establishing the developed software was about one tenth of that for stamping equipment.

Photo 1 Marking provided by this system

7 Results

All goals were achieved.

① Additional space: 0 m^2
② Marking time: Equivalent to stamping
③ Cost: One tenth of that for stamping

8 Summary and Future Tasks

The establishment of this system has made it possible to carry out 2D code marking even on existing machining lines without substantial capital spending.

From now on, I would like to apply the system to applicable machining lines and collect production information and quality data of the machining equipment, contributing to further quality and productivity improvements.

9 In Closing

On this occasion, I would like to thank the software manufacturer and related departments that extended cooperation in establishing the system, as well as all those who gave us guidance and support.

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Technology Introduction

Development of 3D Dimension Inspection Device by Image Processing

HARADA Kouta

1 Introduction

KYB's automobile shock absorber (hereinafter "SA") consists of multiple parts welded together. SAs are to be installed on vehicles by fastening with bolts (Fig. 1). Prior to shipment, SAs are subjected to dimensional inspection by manual measurement to verify the position of the mounting holes to be used for installation on vehicles and the outside dimensions. However, this way of inspection involves human error and would impose a higher burden on measurement personnel as the lot size is becoming smaller. To solve these problems, a 3-dimensional (3D) dimension inspection device using image processing has been developed. This article introduces the device.

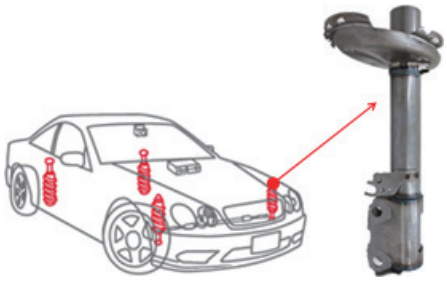

Fig. 1 Shock absorber

2 Purpose

To develop an automatic inspection device capable of measuring 3D dimensions (hereinafter the "inspection device") and introduce the inspection device to improve the quality assurance level.

3 Required Functions of Inspection Device

The inspection device is required to have the following three functions. We have developed an inspection device equipped with all these functions:

①Capable of 3-dimensionally (X, Y, Z) measuring the position and angle of target parts

②Capable of freely selecting the measuring position to support measurement of various models (Required measuring positions vary by target vehicle model).

③Automatic measurement and pass/fail evaluation

4 Measuring Objects and Measurement Items

Fig. 2 shows the measuring objects and names. Table 1 shows the measurement items for the target parts. The parts are welded onto an outer casing. Installation position and angle vary by model, and the measurement position varies by model accordingly. Therefore, measurement must be carried out in many directions. Furthermore, in addition to hole measurement, in-plane points measurement is also required.

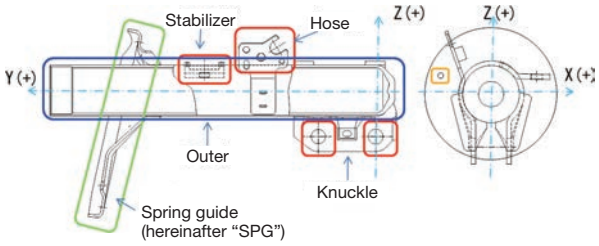

Fig. 2 Measuring objects and names

Table 1 Measurement items

Measuring object	Measurement item
Knuckle, hose, stabilizer (bracket)	Hole position and angle
SPG rotating direction	Hole position
Inclination of SPG	Position of 3 points on a plane
Outer casing	Position of cylindrical shaft

5 Overview of Inspection Device

5.1 Measurement methods used

The measurement device uses non-contact measurement techniques to enhance the degree of freedom. Among the three measurement methods listed in Table 2, the optimal one is selected for each measuring object.

Table 2 Measurement methods

Measuring object	Measurement method
Knuckle, hose, stabilizer (bracket)	Optical cutting (image processing)
SPG rotating direction	Stereo measurement (image processing)
Inclination of SPG	Measurement using laser displacement sensors
Outer casing	Measurement using laser displacement sensors

5.2 System configuration

Fig. 3 shows the system configuration of the inspection device and Photo 1 shows a fabricated device. The features of the inspection device are described below. The functions will be explained in detail in a separate section.

①The introduced measurement system is designed to measure a rotating product. This allows the device to have a lower number of cameras, leading to a lower increase in cost and easier maintenance.

②An algorism to enable high-precision measurement of the position of holes made by pressing has been developed and implemented (with the optical cutting method applied).

③A measure to reduce the possible effects of ambient temperature variations on measurement accuracy has been taken so that in-plant measurement can be conducted.

④Inspection result visualization and data analysis functions have been implemented to allow early detection/analysis of failures.

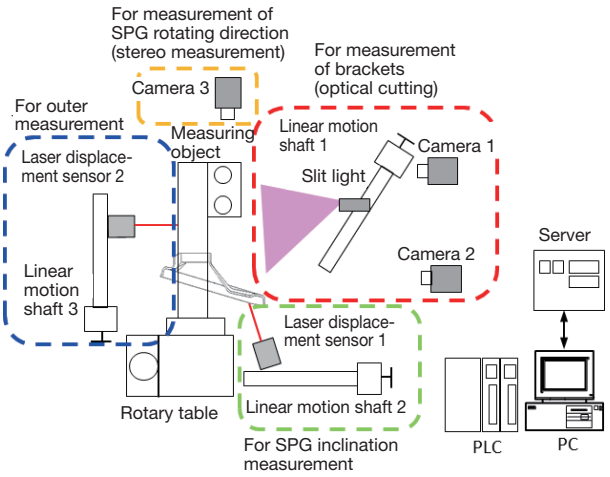

Fig. 3 System configuration

Photo 1 Appearance of inspection device

5.3 Operation flow

Fig. 4 shows the operation flow of the inspection device.

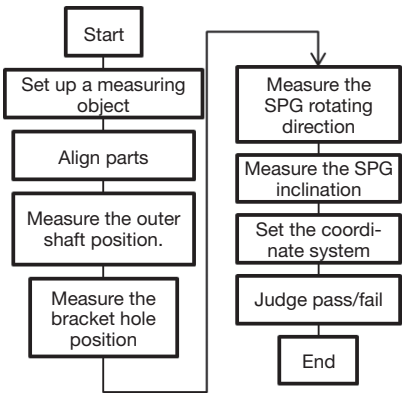

Fig. 4 Operation flow

6 Principles of Measurement of Optical Cutting Method

This section explains the principles of measurement of the optical cutting method, which is the main technique used in the inspection device. [1)]

There are three minimum elements for the device to implement optimal cutting: a camera, slit light projector and measuring object (Fig. 5). Measurement should take place in steps; ① Irradiate the measuring object with the linear slit light, ② Shoot the slit light projected on the inspection work from another direction; and ③ Acquire the 3D positional information about the target from the captured images and the relationship between the slit light irradiated position and camera position using the principles of the triangulation technique.

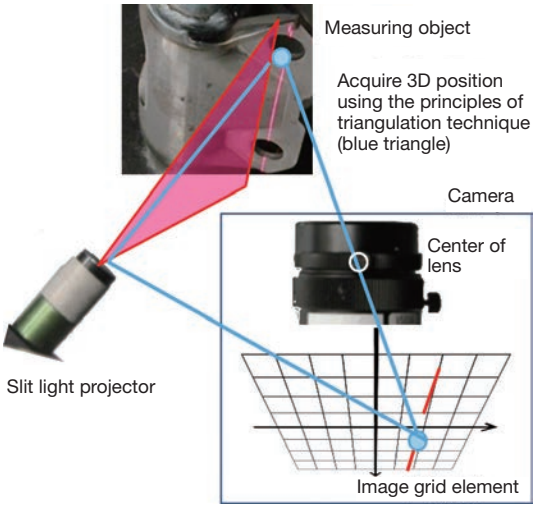

Fig. 5 Principles of measurement of optical cutting method

7 Features of Inspection Device

7.1 Measuring the turning product

For measurement with the minimum device elements

described in section 6 using the optical cutting method, the measurement range is only limited to the plane where the slit light is projected. However, this inspection requires measurement in a 3D space. That is, the measurement range must be expanded. Then, the inspection device uses a drive to move the slit light projector along a single axis and a rotating mechanism to turn the measuring object. This combination achieves the required measurement range.

The use of this configuration makes it possible for the inspection device to have the minimum number of components including cameras and slit light projectors, leading to a lower increase in cost and easier maintenance.

7.2 High-precision measurement algorism for pressed holes by optical cutting method

In the optical cutting method, the 3D position data acquisition range for a single beam of slit light is limited to along the slit light, as explained in section 6. For general hole position calculation using the optical cutting method, thus, multiple slit light beams are used to detect the endpoint where the slit light beams disappear in the hole by image processing and calculate the hole position as shown in Fig. 6.

In this method, however, the calculation of the center of the slit light always involves an error attributable to the irregular reflection of the light at the hole edge and the width of the slit light. These problems made it difficult to accurately detect the endpoint of the slit light (Fig. 6) , which resulted in the hole position measurement error.

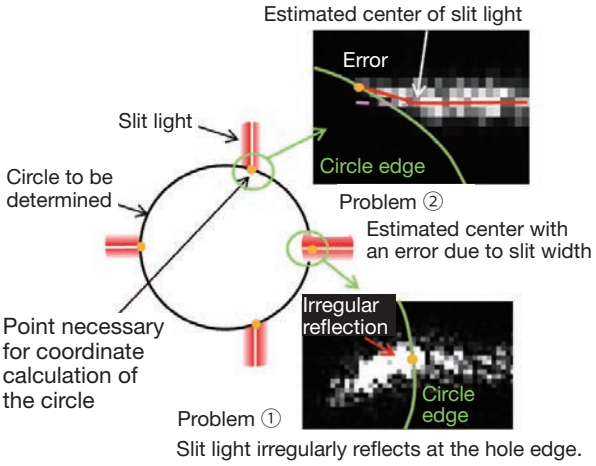

Fig. 6 Error factors for hole position measurement using optical cutting method

In this development project, these problems were solved by developing a positon calculation algorism (Fig. 7) based on the fact that the holes are made on a plane. This algorism allows that, once the 3D information of the plane of the target object is acquired, the characteristics of the images of the target object captured by monocular cameras can be used to obtain all the 3D positional information. The algorism can be applied not only to the optical cutting method, but also to other widely-expanding technology that allows 3D measurement of planes, including the stereo and optical radar methods.

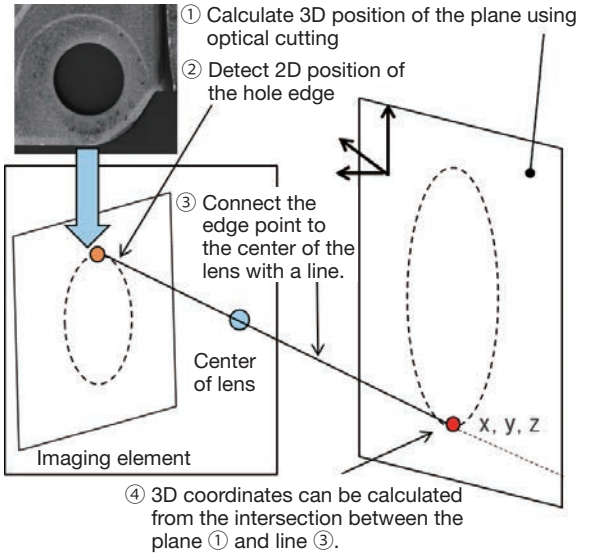

Fig. 7 Developed hole position calculation algorism using optical cutting method

7.3 Measures against effects of ambient temperature variations on measurement accuracy

Commercially available contact 3D measurement equipment is recommended to be used in spaces where the ambient temperature is controlled, in order to maintain measurement accuracy. However, it is unavoidable for this new inspection device, which is for in-plant use, to be exposed to a temperature variation of several tens of degrees Celsius throughout the year. The exposure would affect measurement accuracy. As an example, Table 3 shows the result of a simple trial calculation of the effect on accuracy:

Table 3 Simplified evaluation of effect of temperature variations on accuracy

Trial calculation condition	Distance between camera and measuring object	450 mm
	Fixed frame material	Steel
	Coefficient of linear expansion of steel	12×10^{-6}/K
	Temperature variation	10°C
Deviation from the distance between camera and measuring object due to temperature rise		0.054 mm

According to the table, a temperature variation of 10°C causes a deviation from the original position of the measurement equipment as large as 0.054 mm. Since the optical cutting method used in this inspection device is based on the principles of the triangulation technique that determines the position of an object from the positional relation with the camera, slit light projector and object, the effect of the positional deviation on measurement

accuracy would be a problem. In addition, the inspection device carries out measurement while rotating the product, so the effect of temperature variations would be increasingly more severe. Measures to prevent the temperature variation are needed. The following describes the two measures against temperature effect we have actually taken.

① Using a low-expansion frame material

The amount of expansion of the frame due to temperature variation is proportional to the coefficient of linear expansion of the material. Then, we use a low-expansion material whose coefficient of linear expansion is 3 x 10^{-6}/K (1/4 of that of steel) in the frame of the inspection device.

② Measures to reduce frame temperature variations

The low-expansion material used in the frame is certainly unlikely to elongate, but the amount of elongation is not 0 (zero). To reduce the temperature variation of the inspection device frame, the frame is surrounded by a fence within which a compact air conditioner is installed. This provides an environment where the frame is unlikely to encounter temperature variation (Fig. 8).

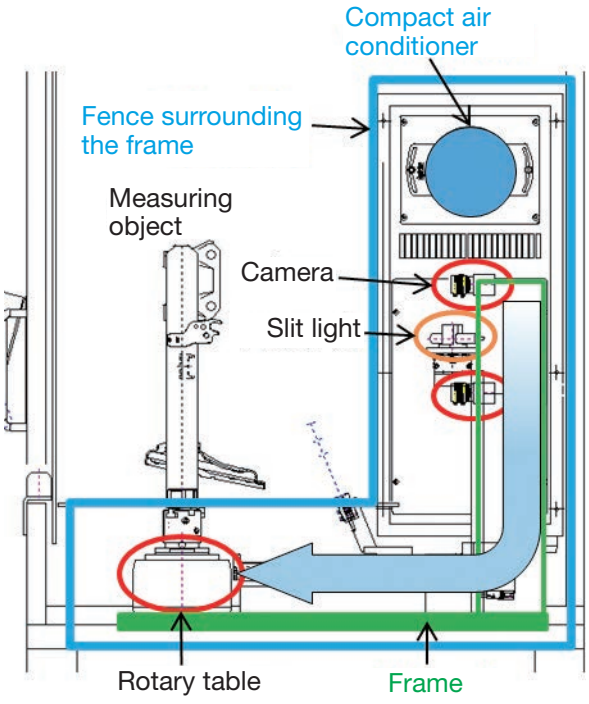

Fig. 8 Measures to reduce frame expansion due to ambient temperature variation

7.4 Inspection result visualization and data analysis

The inspection device monitor displays measurement results in the form of measurement and specification values for each measurement item and the results of pass/fail evaluation. The background color will change when NG or Action Note 1) results are given, allowing the operator to identify the faulty part at a glance. The history can also be viewed on another screen (Fig. 9). The measurement results can be centrally controlled by a control terminal software program [2]. Collected data can be displayed using the software in the form of trend data graph, histogram, standard deviation, Cp and Cpk. The software can also be used to identify data variations or as material for improvement.

Note 1) "Action" is given to a conforming product with a deviation from the design value by a certain amount. This evaluation result is intended to grasp the trend before nonconformity occurs.

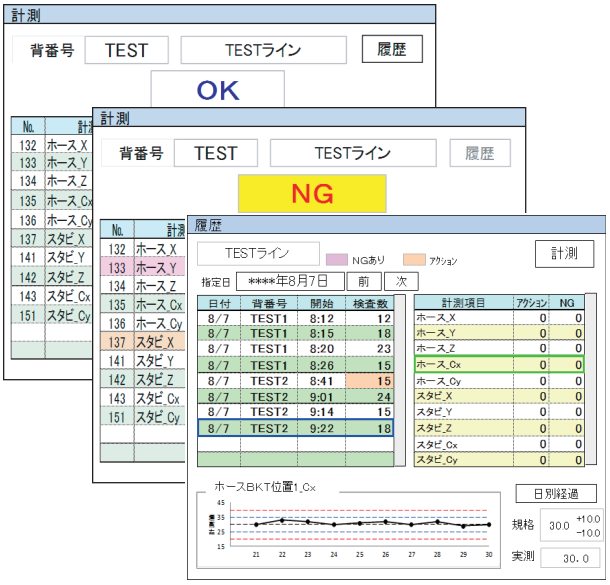

Fig. 9 Measurement result screen

8 In Closing

The 3D dimension inspection device capable of automatically measuring many different models of SAs has been developed and introduced, contributing to improved quality assurance.

In addition, the device is provided with inspection result visualization, data collection and data analysis functions. It is desirable to effectively use the data for early detection of failure and improvement activity for higher quality and higher productivity.

Finally, on this occasion I would like to deeply thank assistant professor Kunihito Kato of Gifu University, who was involved in the joint research [3], and the members in his office who extended great support and cooperation to this development project, as well all others who were involved.

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Technology Introduction

Development of Electric Power Steering Evaluation System

ANDO Koji, MUROHASHI Atsuo, FUJIKAKE Mitsuhiko, HORI Takeshi

1 Introduction

With the recent worldwide voice for environmental considerations, the automobile industry has rising expectations for electric vehicles (hereinafter "EVs").

The U.K. and France announced to ban the sales of internal combustion engines by 2040. When I visited the 2017 Frankfurt Motor Show, I could not help being aware of the oncoming of the age of EVs.

Furthermore, the development of autonomous cars has rapidly advanced throughout the world. Recently in Japan, I have sometimes heard news about autonomous car driving tests on public roads.

As the development of EVs and self-driving technology advances, it is urgent to improve the performance and reliability of electric power steering (hereinafter "EPS") technology.

The Experiment Section is addressing the development of evaluation techniques and test equipment with the aim of improving experiment reliability and efficiency as in the product development.

Like the pump experiment equipment introduced in KYB Technical Review No. 55, this article introduces efforts by the Experiment Sect. focusing on the development of an EPS evaluation system.

2 Product Introduction

2.1 What is EPS?

EPS is a system intended to reduce the driver's effort in steering with the assistance of an electric motor.

EPS takes various forms and can be roughly classified into:

① Column assist type
② Pinion assist type
③ Rack assist type Note 1)

Note 1) The rack assist type can be further divided into direct drive, belt drive and dual pinion types. For the purpose of this article, the rack assist type is referred to as "dual pinion EPS".

The dual pinion EPS (Photo 1), which is one of the major products of KYB, is often installed at the lowest position in the engine room. The dual pinion EPS may be exposed to heat from the engine or muffler. On the other hand, vehicles equipped with EPS are also delivered to areas with an extremely cold climate. EPS must endure rapid temperature change and needs to guarantee the operation in a wide temperature range from 120°C to -40°C.

EPS may also be exposed to muddy water or contaminated water that has melted from the road deicer during winter. Under extremely severe service environments like these, EPS is required to have higher waterproof and rustproof properties.

Once a car accident occurs, EPS may be alleged to have caused the accident and could be the focus of a suit. Thus, EPS is naturally required to meet stringent reliability test requirements. It is also necessary to visualize phenomena related to EPS.

Furthermore, drivers feel the performance of EPS directly with their "hands". In this sense, EPS is a component whose sensory performance like "steering feel" is tested.

Under the situation, we have promoted the development of KYB's original testing system for the purpose of establishing a test bench that can exactly reproduce severe test conditions, quantifying the sensory performance and visualizing phenomena.

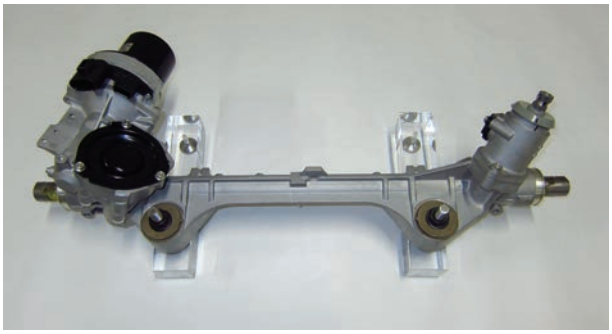

Photo 1 Dual pinion EPS

2.2 EPS structure and operation

Before getting down to the subject, this section explains

a little bit more about how the Dual pinion EPS works.

EPS generally consists of the components shown in Fig. 1. The operating sequence is as follows:

① Driver operates the steering wheel.
② The wheel steering power (hereinafter "steering torque") is received by the stub shaft.
③ The torque sensor detects the steering torque.
④ Torque signal is sent to the ECU Note 2).
⑤ ECU supplies power to the assist motor according to the torque signal.
⑥ The reduction gear augments the torque from the assist motor to provide steering assistance.
⑦ The torque is transferred to the pinion gear that is integral with the reduction gear. The rotary motion of the pinion gear is converted into a linear motion by the rack & pinion.
⑧ Thrust generated by the rack is transmitted via the tie rod to push the knuckle arm, generating a steering angle for the tires.

By repeating the sequence above, EPS will assist driver in steering.

Note 2) Stands for Electric Control Unit.

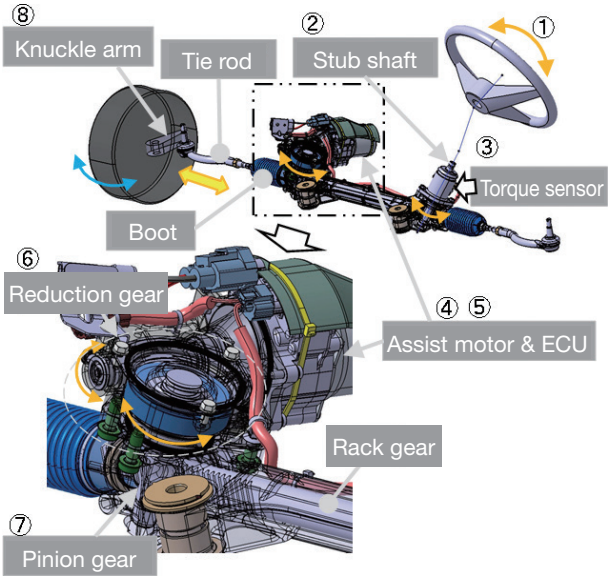

Fig. 1 Components of Dual pinion EPS

3 Introduction of Testing Systems

3.1 Muddy salt water resistance testing machine

3.1.1 Development background and overview

As described in the product introduction section, this is a testing machine that carries out an endurance running test on EPS while pouring muddy salt water over them in order to evaluate rustproof and sealing properties.

To guarantee the safe operation of EPS, it is particularly important to ensure the sealing performance to prevent the exposure of the motor and ECU to water.

For example, the boot, which is designed to expand or contract by steering, may have negative inner pressure to absorb water from the outside.

This example implies that only the simple water immersion or sink test is not sufficient. Rather, spraying muddy salt water over EPS while steering is a way of evaluating rustproof and sealing properties under most conditions similar to the actual situation.

Previously, the sealing property evaluation test using muddy water was carried out independent of the rustproof property verification test using salt water. However, another need of verifying the resistance to the road deicer or snow melting agent scattered on roads during the winter season also arose. Furthermore, in the previous sealing property evaluation test using muddy water, a suitable simplified water tank was prepared for each test sample. This test involved some problems that salt water spilled and that the mist containing salt water caused salt damage to the surrounding of the test area.

With considerations given to these problems, this testing system has been developed. The new system can provide endurance operation of EPS by giving the tire reaction and steering torque from the steering wheel to the right and left tie rods while spraying muddy salt water of a specified concentration over the sealed sections of EPS.

3.1.2 Features of testing machine

(1) Automatic control of muddy salt water concentration

It takes about one to two months for an endurance test to be completed. To prevent any variations in concentration of the muddy salt water for spraying due to evaporation during the test, the testing machine features the automatic concentration control function that monitors the water level in the water spray tank and automatically controls the concentration by automatic water supply.

The water in the tank is continuously mixed by a jet to prevent sedimentation of mud.

(2) Rust prevention of the system

Since the spray water contains salt, the test chamber of the system is made of stainless steel to prevent rust of the system itself. The chamber encloses the test sample EPS. Still, small amounts of water vapor containing salt leak from the chamber. Then, the chamber is further surrounded by another stainless steel casing to make up a double structure. Ventilation fans to release the vapor to outside are also installed.

(3) Effluent filtering

The used muddy water contains salt. For environmental consideration, a filtering mechanism to remove the salt content is installed on the discharge side.

(4) In-chamber washing mechanisms

After testing, any scattered muddy salt water is deposited on the inner surface of the chamber. The two washing functions listed below are provided for easy maintenance of the system.

① A spray nozzle for automatic washing is provided on the chamber roof (Photo 2).
② A high-pressure cleaning gun is installed for easy removal of precipitated salt.

(5) Test observation

The test chamber needed to be of enclosed type in order to protect other test equipment in the test room. However, the enclosed test chamber made it impossible to visually check the internal test conditions.

Providing an observation window was an option, but it was easily expected that the window would be dirty with mist deposit for instance, making it impossible to visually check the test progress. Then, a CCD camera was installed in the test chamber to allow operator to see what was going on inside the chamber (Photo 3).

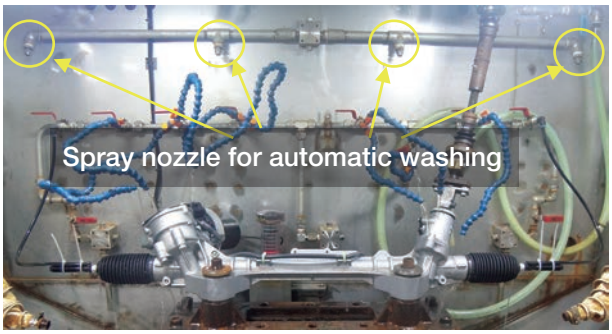

Photo 2 Internal of muddy salt water endurance test machine

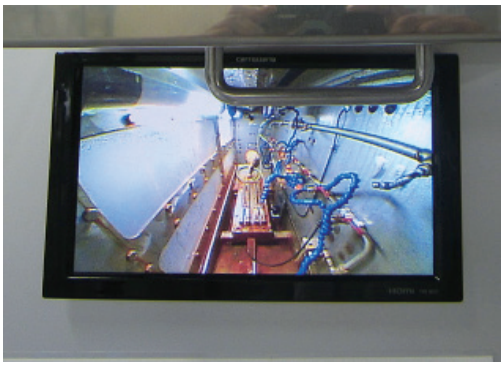

Photo 3 Image of testing machine internal captured by CCD camera

3.2 Rack bend testing machine

3.2.1 Development background and overview

This testing machine is used to verify the load with which the steering system fails when the vehicle hits a curbstone or other obstacles.

The steering system is an important vehicle component to take charge of "turning", which is one of the three major elements of vehicle movement: run, turn and stop. It should be avoided until the end that the steering system no longer functions.

To protect the steering system, a mechanism has been provided that, in case of an accident such as hitting a curbstone, causes the suspension parts to fail first to keep the steering parts from being damaged.

The purpose of the rack bend testing machine is to verify that the steering system has higher rigidity and higher strength than these suspension parts.

Conventionally, it was necessary to prepare a special test jig (frame) for each vehicle model so that the on-vehicle layout can be reproduced for testing. Now this is no longer necessary thanks to the developed testing machine.

3.2.2 Features of testing machine

To satisfy the requests by automobile manufacturers, the testing machine has the following features to verify the strength of the EPS installed and used under various conditions:

(1) Horizontal tension and compression mechanism

Since general tension and compression testing machines apply a load in the vertical direction, EPS samples have to be set in such machines with poor workability. KYB's rack bend testing machine in turn is designed to apply a load in the horizontal direction and to secure EPS on a horizontal surface plate for improved workability.

(2) Higher degree of freedom in loading angle

The test is conducted on various vehicle models under various situations. This means that the testing machine must support a wide range of load input angles. The load point of EPS is the inner ball joint in the rack end. Loading orientation varies by specification. In addition, EPS is an oscillating component, so its properties may vary by the section modulus of the rack and/or bend angle of the tie rod.

To allow the operator to easily set the specified load input orientation, the fixed part of EPS uses a rotary table for flexible adjustment. In addition, a mechanism for setting the crosshead position by sliding laterally is provided (Photo 4).

(3) Double screen display

A display screen is provided for controlling the testing machine and another for data logging to allow the operator to easily view the operation and instantaneous data.

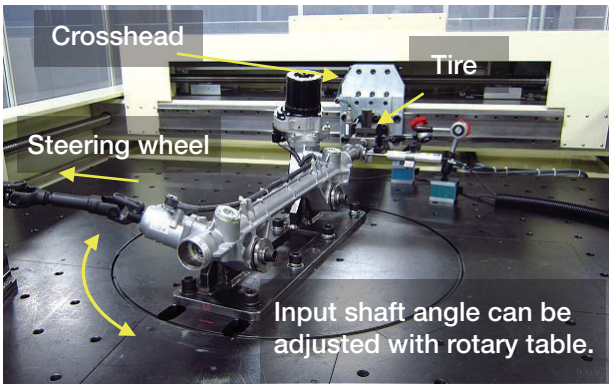

Photo 4 Rack bend testing machine

3.3 Reduction gear endurance testing machine

3.3.1 Development background and overview

The reduction gear is an important vehicle component and may be considered as the heart of EPS. The reduction gear is mainly made of plastic for various reasons including unusual sound control, strength and elasticity. Plastic

gears are so delicate that accuracy depends on atmospheric humidity.

This testing machine has been developed to reliably identify any changes including microcracks occurring during endurance running and performance variations caused by overheating (Photo 5).

A testing machine that can flexibly adjust the shaft crossing angle was also needed to develop the angular reduction gear, which is one of the featured products of KYB. The angular reduction gear has a benefit of improving the degree of design freedom in on-vehicle layout.

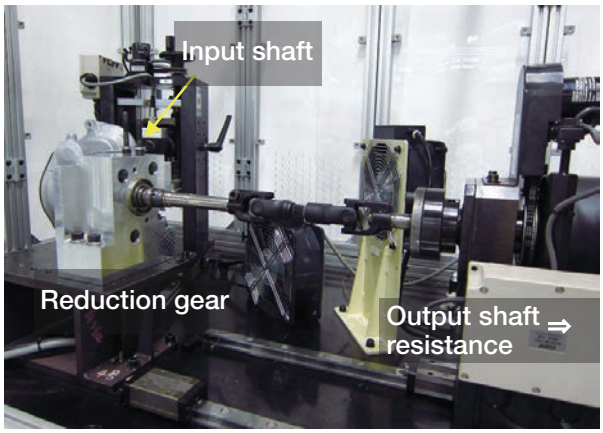

Photo 5 Reduction gear endurance testing machine

3.3.2 Features of testing machine

(1) Automatic stop after minute torque variation

The machine is designed to be stopped when a minute torque change (variation) on the input side is detected. This function helps determine the breakage initiation of the gear, leading to proper identification of the cause of breakage initiation.

(2) Higher degree of freedom in test condition adjustment

This testing machine allows seamless adjustment of the shaft crossing angle and loading torque adjustment in minute increments.

(3) More accurate control of input shaft rotation angle

When the reduction gear (worm wheel) of EPS rotates three to four turns at most, it will reverse the direction of rotation as it shares the shaft with the steering wheel. The testing machine is designed to be able to faithfully reproduce this reversing during an endurance test. However, the reversing point, if it is fixed at the same point, will have a highly concentrated load and the gear will start to break at the reversing point in many cases.

In an actual vehicle, a gear always having the same reversing point never occurs. Therefore, an action is needed to provide two or more reversing points depending on the actual operating conditions.

The newly developed endurance testing machine can closely control the rotation angle of the input shaft, thereby allowing distributed reversing points. Thus, the endurance test can be conducted in a similar way to the actual situation.

3.4 Unusual sound evaluation testing machine (evaluation of inversely input unusual sound)

3.4.1 Development background and overview

Since EVs run silently without issuing engine sound, the requirements for EPS "sounds" (such as operating sound, control sound and rattle sound [Note 3)]) have become more severe.

Vehicles are also likely to deteriorate earlier when they run under a high- or low-temperature environment depending on the destination. The need for identifying the source of unusual sounds, the sound level and cause of the sound quickly and exactly led to the development of this testing system.

Note 3) Refers to the "tooth hammer" that may occur in the gear section. The rattle sound may cover all kinds of "hammers" if the cause is unclear.

3.4.2 Features of testing machine

(1) On-bench reproduction of running vehicles

The unusual sound evaluation system (Photo 6) was developed to achieve on-bench reproduction and evaluation of unusual sounds equivalent to actual ones by applying vibration with a tire input load of an actual value measured during driving on a bad road.

[Vibrating procedure]

① Install an inertia plate equivalent to the steering wheel on the input shaft.

② Vibrate EPS using a shaker via the tie rod.

The system can acquire the measured waveform during actual running at high sampling frequencies, making it possible to reproduce the vibration more similar to actual vehicle conditions.

To faithfully reproduce vibration with unusual sound of product, a low-friction seal cylinder is used.

This helps cancel the cylinder sliding load and vibration of the testing machine due to the cylinder seal.

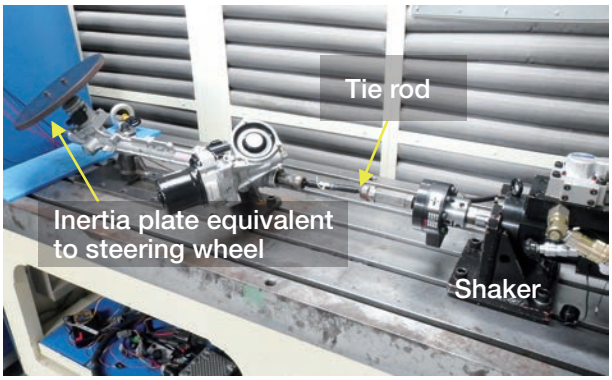

Photo 6 Unusual sound evaluation testing machine

(2) Automated measurement

To obtain stable measurement results, the feedback control that automatically adjusts the input load to a specified value has been included in the control program.

Furthermore, the procedure from the test sample setting on the bench to vibration data measurement has been automated (Photo 7).

Photo 7 Display of automatic measurements

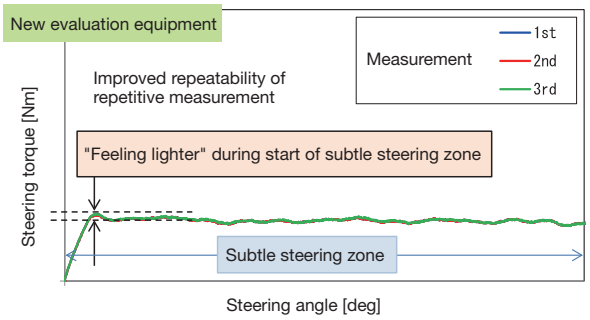

Fig. 2 "Feeling lighter" and repetitive measurement waveforms

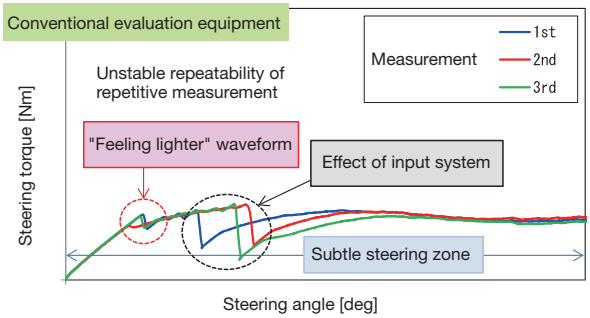

Fig. 3 "Feeling lighter" waveform obtained with conventional evaluation equipment

(3) Lower measurement variations and higher measurement accuracy

The system is designed to be allowed to carry out measurement only if the input load is within a specified range. These specification help reduce measurement variations and improve repeatability.

Now it is under discussion to allow the unusual sound evaluation test under a high- or low-temperature environment to meet the demand for on-bench reproduction of all types of environments similar to actual vehicle conditions.

3.5 System performance evaluation equipment

3.5.1 Development background and overview

In order for automobile manufacturers to be able to use KYB products in their next models, KYB proposes them to improve the steering feel. At this moment, evaluation of the steering feel is solely dependent on sensory evaluation by test drivers. To quantify the sensory performance, we are addressing the development of system performance evaluation equipment.

3.5.2 Quantifying the steering feel

We aim to evaluate driver steering feel by quantifying, for example, whether turning the steering wheel will smoothly change the steering torque or angle (no discontinuous change).

EPS tuning requirements depend on the vehicle specifications/concept or where the vehicle is delivered.

A recent challenge is to achieve a steering feel with which the driver can maneuver a vehicle only with a very minute steering angle, which leads to easy driving. As an example, the result of a measurement of "feeling lighter" Note 4) during the start of the subtle steering zone is shown below (Fig. 2).

Note 4) A phenomenon that the steering feel gets lighter at the moment when the vehicle starts to move as the driver has begun turning the steering wheel

3.5.3 Features of equipment

(1) Operation test in the subtle steering zone

For characterization of the subtle steering zone, it is very important to ensure the accuracy of the input shaft angle of the input system. The conventional input system (driven via the reduction gear) only worked unstably and could not reproduce the input shaft angle stably, making it difficult to achieve quantitative evaluation of "feeling lighter". Partly because of the input system motor inertia and ripple, the waveform of "feeling lighter" achieved through repetitive measurements showed variations (Fig. 3).

The newly developed evaluation equipment uses a direct drive motor type input shaft to enable stable operation in the subtle steering zone and high-precision control over the input shaft angle.

(2) Supporting complex steering patterns

An optional operation waveform program has been introduced to allow high-accuracy reproduction of complex steering patterns measured with actual vehicles.

The new equipment also supports angle control and torque control and can now flexibly respond to a variety of customer needs.

(3) Supporting steering system evaluation

For bench testing on the steering system, the layout equivalent to the actual vehicle, the input system, the column mount, the steering gear mount and the tire-equivalent loading device can be freely arranged on the surface table (Photo 8).

With these features, the equipment can accurately test the operation during the initial stage of the subtle steering zone including "feeling lighter" repeatedly on bench, which has been difficult to reproduce with any conventional equipment. The evaluation result can be quickly and accurately feedback to Design toward achieving higher product performance.

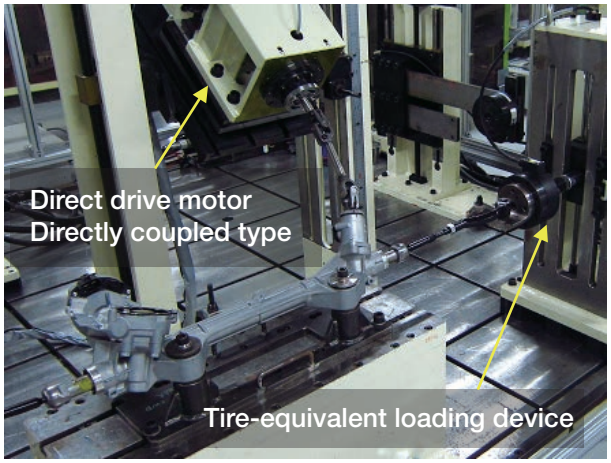

Photo 8 System performance evaluation equipment

4 Conclusions

The test equipment introduced in this article have been developed to achieve higher accuracy, higher reproducibility and higher efficiency. They can allow us to complete the series of evaluation tests prior to mass production in a shorter period than before as well as to obtain accurate test results.

We believe that this evaluation equipment will eventually help us deliver safer, more reliable products to customers.

There are still many challenges, but we would like to strive to develop and further improve evaluation techniques in addition to product development.

5 In Closing

With a focus on the development of EPS evaluation equipment, this article has introduced the efforts by the Experiment Dept.

To develop high-reliability, high-performance products, it is required to develop evaluation methods and improve measurement accuracy.

We are committed to raise our expertise and knowledge level and continue playing the role as the Experiment Dept.

Finally, on this occasion, we would like to deeply thank the affiliates and those concerned involved in the development of the testing machines as well as all those who extended guidance and support to us.

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Product Introduction

Development of Electric Power Steering Responsive to Next-Generation Needs

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1 Introduction

The demand for electric power steering (hereinafter "EPS") has been on the increase in recent years. The EPS market annually sells 60 million units. Vehicles equipped with EPS are on pace to account for nearly 60 percent of total vehicle production. The steering feel and assistive output of EPS has always been said to be inferior to that of hydraulic power steering (hereinafter "HPS"), which was the dominant product in the power steering market. Behind the increasing demand for EPS there have been great efforts by EPS manufacturers to make up for the gap.

The recent tremendous advance in electronic control technology has dramatically sophisticated automobiles. EPS uses an electronic control system to drive the motor and can be added with extra functions that could not be achieved with HPS. With this feature, EPS can more easily be combined with other vehicle devices, offering higher contribution to integration control. For vehicles with more and more additional functions, EPS is an indispensable device.

Demand for EPS is expected to grow continuously. EPS development is entering a turbulent stage. We, as engineers, are responsible for constantly launching even better products and should never be satisfied with the current situation. This article introduces an EPS system we have developed in order to meet the demand for next-generation EPS (Photo 1).

2 Desired Next-generation EPS

To ensure that drivers can enjoy safe, environmentally-friendly driving with low fuel consumption, EPS is required to have the following features:

① Improved steering feel
② Smaller, lighter unit
③ Improved safety

2.1 Improved steering feel

Drivers can enjoy driving when they can control the vehicle at will. The feeling can be expressed by sensibilities such as comfortability or satisfaction.

An EPS system that transfers the steering input to the tires as the driver likes is ideal for the vehicle. Such an EPS can achieve the ultimate steering feel.

2.2 Smaller unit

The EPS system needs to be reduced in size and weight to be installed in a smaller space due to the increasing number of vehicle devices for additional functions, and to meet customer demand for improved fuel consumption.

2.3 Improved safety

Recently, automotive electrical and/or electronic systems are required to conform to the ISO 26262 standard. With an eye toward autonomous driving, the EPS system needs to achieve an even higher safety level.

Photo 1 Newly developed EPS

3 Improved Steering Feel

The force transfer route for the rack bar (Fig. 1) to start moving was analyzed for improvement. With a focus on the elements listed below, the rack bar has been improved to be able to smoothly start moving:

① Rack & pinion section
  A) Pressure pad sheet
  B) Pressure pad elastic ring
② Input shaft section
③ Reduction gear
④ EPS tuning with various controls

3.1 Rack & pinion section

A) Pressure pad sheet

Input of steering force from the steering wheel to the rack & pinion (hereinafter "R&P") engagement section (Fig. 1) is converted into a force in the lateral direction of the vehicle, causing the rack bar to slide. A key point of the improvement is how the rack bar can be moved smoothly.

The R&P engagement section includes a part called "pressure pad" to maintain the engagement. The pressure pad is in contact with the rack bar via a resin sheet on which the rack bar is sliding. To ensure smooth movement of the rack bar, a low μ sheet material has been searched for lower sliding resistance. Finally a Teflon sheet material has been selected. In fact, another Teflon sheet that was used in an HPS system was trialed in an EPS system, but replaced with a nylon sheet with high wear resistance because the Teflon sheet had low durability due to fretting. Now, the new Teflon sheet can offer better durability and sliding performance by changing the contact area with the rack bar and using another additive, mostly achieving the target steering feel.

B) Pressure pad elastic rings

The pressure pad bears the spring load and plays a role as an engagement support to press the rack bar against toward the pinion shaft (Fig. 2). This will reliably follow any wear between the gears, constituting a steering structure free from rattle. To ensure the following of the rack bar by the pressure pad, a clearance must be provided between the pressure pad and the housing (Fig. 3). In this configuration, when the pressure pad moves in the radial direction even slightly, the contact between the sheet and rack bar would inevitably change. Then, elastic rings are installed on the perimeter of the pressure pad to provide self-aligning in the radial direction. This achieves the stable steering feel.

The elastic rings also have a role of damping the sound caused by the pressure pad when making contact with the housing. The elastic rings can offer the noise prevention effect.

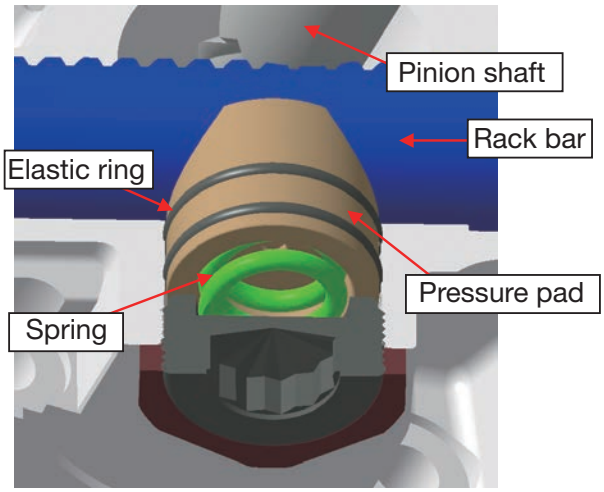

Fig. 2 Engagement support

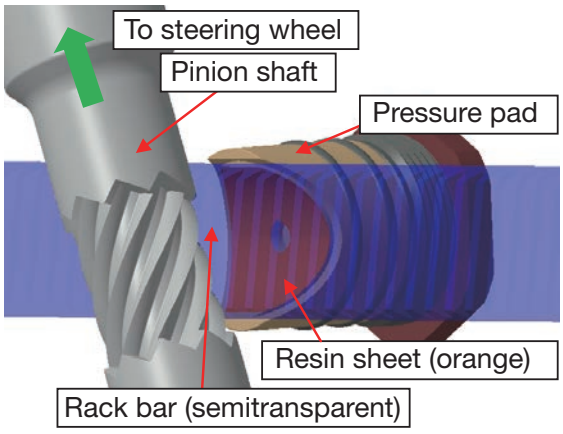

Fig. 1 R&P engagement section

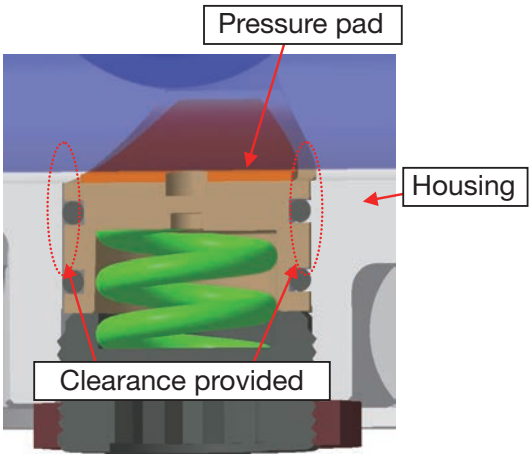

Fig. 3 Clearance between pressure pad and housing

3.2 Input shaft section

The EPS system includes a component called the input shaft consisting of a stub shaft, magnet, torsion bar, magnetic circuit, bushing and pinion shaft (Fig. 4). The input shaft takes the steering force from the steering wheel and reads out the torsional angle of the torsion bar with a torque sensor.

The steering force is transferred to the stub shaft serration-engaged with the column shaft as a turning force. The stub shaft will create a rotary phase difference from the pinion shaft by the amount according to the load via the torsion bar. To ensure reliable transfer of the turning force, the stub shaft bearing, which is called a bushing, has been improved to achieve higher transfer efficiency.

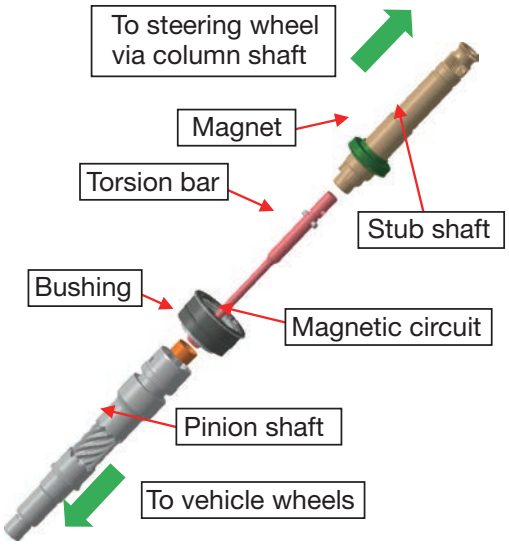

Fig. 4 Developed view of input shaft

3.3 Reduction gear section

The reduction gear section, which consists of a worm shaft and plastic wheel, uses a non-backlash mechanism (Fig. 5) on the end of the worm shaft to provide a pushing force toward the plastic wheel with a coil spring. The pushing force is intended to maintain a uniform engagement backlash, even if there is a dimensional change between the gear shafts due to wear or expansion of the plastic wheel. In this non-backlash section, a reaction force will be generated (Fig. 6). The magnitude and orientation of the reaction force depend on the steering direction (right or left). Through an analysis on the direction and magnitude, the structure of the non-backlash mechanism has been improved to generate the pushing force in the direction that is the resultant of the two vectors of engagement reaction forces for steering right and left. This improvement has eliminated the right-to-left difference.

The right-to-left difference means that there is a difference in steering force between steering right and steering left. This is one of the factors of an uncomfortable steering feel.

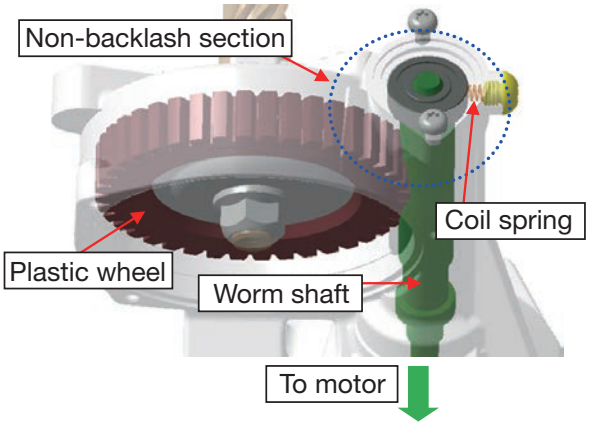

Fig. 5 Non-backlash mechanism

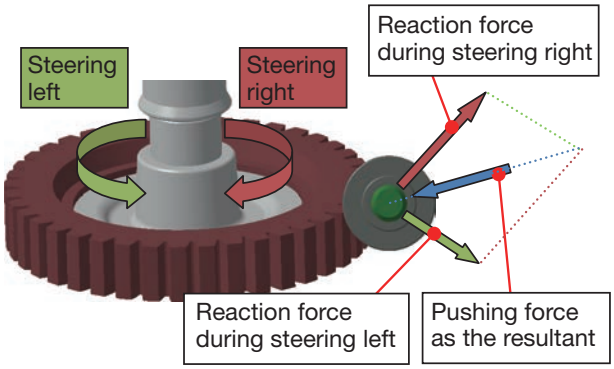

Fig. 6 Reaction forces generated in the non-backlash section

3.4 EPS tuning with various controls

EPS can achieve a variety of steering characteristics and steering feel by using electronic control. Examples of controls contributable to higher performance are listed below:

① Assist control - Determines the steering characteristics
② Phase compensation control - Prevents vibration during steering
③ Damping control - Suppresses minor vibration
④ Inertia compensation control - Improves steering responsiveness
⑤ Wheel return control - Improves steering wheel return characteristics

Parameters for the controls above have been adjusted to achieve an optimal steering feel suited to the vehicle.

4 Smaller, lighter unit

Recent EPS development efforts for smaller, lighter units have a trend of integrating the ECU into the motor. This is called a power pack. ECU has been substantially reduced in size with the advance in electronics technology, resulting in the emergence of the power pack. This has eventually downsized EPS and considerably improved

its vehicle mountability.

There are two types of power pack in terms of structure: rear mount type in which ECU is installed behind the motor shaft (Photo 2) and front mount type in which ECU is installed in front of the motor shaft (Photo 3), when viewed from the interface with EPS. These two types have their connector sections in different positions depending on ECU location. The former can locate the connector section coaxially to have a smart profile in the longitudinal direction although the shaft is quite long. The latter has the connector section protruding in the radial direction, resulting in a larger dimension in the radial direction and a shorter shaft length.

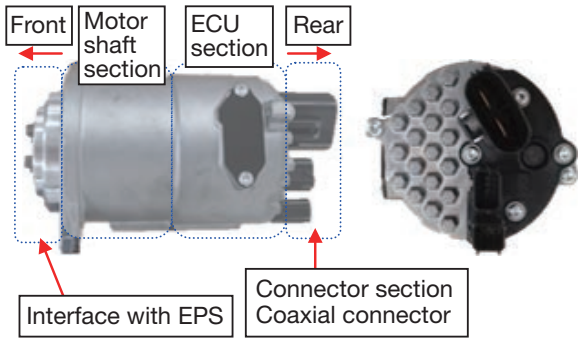

Photo 2 Rear mount power pack

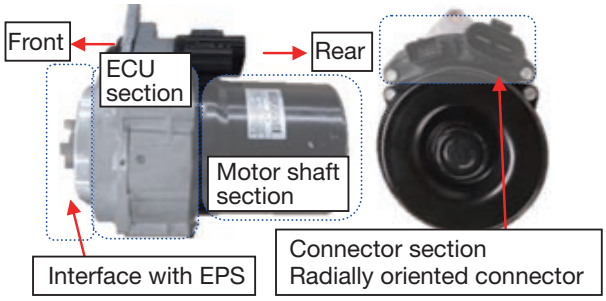

Photo 3 Front mount power pack

Which type is superior in vehicle mountability cannot be simply determined because it depends on the vehicle layout requirements. Anyway, the newly developed rear mount type provides a wider choice of options for various vehicle layouts.

5 Improved Safety

To prove compliance with the ISO 26262 standard on safety of automotive electrical and/or electronic systems, it is important to define the internal development process based on the standard and carry out product development according to the process. The new product has been verified to meet customer safety requirements through functional safety assessment. In the assessment, a check list containing about 650 check items according to ISO 26262 was used. The design and verification documents prepared in the development process were used to explain that the product passes all the check items in the check list. Thus, all those concerned including the customer and business partners have confirmed the compliance with the standard and the satisfaction of the safety requirements.

6 In Closing

Vehicles equipped with the new EPS have been highly valued by journalists who tried the vehicles. I have also frequently seen end user comments on the vehicles that they were impressed by the driving performance. Each of these has convinced me that the development has raised the level of the KYB EPS to a new height that is closer to the desired next-generation EPS. I would like to, on this occasion, thank all the people who extended cooperation in developing the product.

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Product Introduction

High Pressure Aluminum Vane Pump for Power Steering of Trucks

SHIOZAKI Hiroshi

1 Introduction

The hydraulic power steering system (hereinafter "HPS" Note 1)) uses vane pumps as its hydraulic power source (hereinafter these vane pumps are referred to as "PS pumps"). KYB operates in the global PS pump market with annual production of two million units mainly for passenger cars.

The leading model of KYB's PS pump lineup is 4K (4th generation) Note 2). The 4K Series is used by many automobile manufacturers both inside and outside Japan. However, passenger cars started to use the electric power steering system (hereinafter "EPS" Note 3)) around 1990 for energy saving. Then, KYB has promoted to develop higher-pressure, higher-capacity 4K PS pumps (refer to Glossary "Making KYB Vane Pumps into a Series Product" on page 52) as new business models for trucks markets where HPS is expected to remain popular. Specifically, the new models include 4KS2, 4KL, 4KL2, 4KL3 and 4KL5 (Table 1).

With the need for offering products to European automobile manufacturers, KYB has just developed 4KT5 that is interchangeable with competitors' counterparts. The emergence of 4KT5 makes it possible to replace competitors' counterparts with this KYB product. This article introduces the outline of the development.

Note 1) Stands for Hydraulic Power Steering.

Note 2) Aluminum-body PS pump

Note 3) Stands for Electric Power Steering.

2 Background of Development

2.1 A challenge to KYB PS pumps for trucks

The KYB PS pump model that can meet the general specifications of large trucks is 4KL5 (Table 1). However, 4KL5 is designed to be installed onto the engine with its brackets having a shape different from that of competitors' products popularly used by many European automakers. This has been a barrier for KYB to offer its PS pumps to European automakers.

Specifically, the flow control valve (hereinafter “FCV” Note 4)) of 4KL5 is arranged orthogonal to the shaft axis (Fig. 1). As a result, the engine mount of 4KL5 may interfere with FCV depending on the installation position. For competitors' products in turn, FCV is arranged parallel to the shaft axis and the engine mount is unlikely to interfere with FCV.

Furthermore, KYB received an inquiry from a European truck manufacturer for PS pumps beyond the 4KL5 specifications. The company then decided to develop another model named 4KT5 aimed at achieving the requested pump specifications.

Note 4) Stands for Flow Control Valve.

2.2 Aims of 4KT5

In designing 4KT5 as a PS pump for medium/large trucks, the development team had the following aim:

2.2.1 Compatibility with European automaker trucks

In general, PS pumps for trucks must meet severe layout requirements since they can be directly installed to the

Table 1 KYB PS pump lineup

	For passenger cars and small trucks					For medium/large trucks		
Pump model	4KS	4KW	4KS2	4KL	4KL2/3	4KL5	BB	1K
Body material	Aluminum alloy die-cast						Iron casting	
Basic Displacement [cm^3/rev]	Max. 9.6	Max. 9.6	Max. 11.2	Max. 14.0	Max. 15.0	Max. 23.0	Max. 32.5	Max. 20.0
Relief pressure [MPa]	Max. 12.0	Max. 11.8	Max. 12.8	Max. 12.8	Max. 15.0	Max. 20.0	Max. 14.7	Max. 13.7
Control flow rate [L/min]	Max. 9.0	Max. 8.5	Max. 11.5	Max. 12.0	Max. 16.0	Max. 23.0	Max. 30.0	Max. 20.0

engine. This means that layout performance is essential. The new model has the mounting brackets in a shape equivalent to that of competitor products used by many European truck manufacturers, offering an equivalent layout performance as well.

2.2.2 Lower cost

To achieve lower material costs and lower working costs, the new model uses an aluminum die-cast body and sintered cam ring. Existing PS pump production equipment can be effectively used.

2.2.3 Higher capacity and higher pressure

The target maximum pressure was set to 22 MPa and the target maximum basic discharge was set to 28 cm^3/rev.

The existing cam ring and rotor of 4KL5 have been diverted for the new model to ensure part sharing. In addition, the pump has been enlarged in the direction of thickness of the cam ring for larger capacity. The suction port of the cam ring has been improved in profile to be able to accept higher pressure.

3 Basic Specifications, Structure and Features

3.1 Basic specifications and structure of 4KT5

The basic specifications and structure of 4KT5 are shown below (Table 2, Fig. 1).

Table 2 Basic specifications of 4KT5

Pump model	4KT5		
Body material	Aluminum alloy die-cast		
Basic Displacement [cm^3/rev]	～17.0	～25.0	～28.0
Relief pressure [MPa]	Max. 22.0	Max. 20.0	Max. 18.5
Control flow rate [L/min]	Max. 20.0	Max. 25.0	

In development, the following considerations were given in designing the new model:

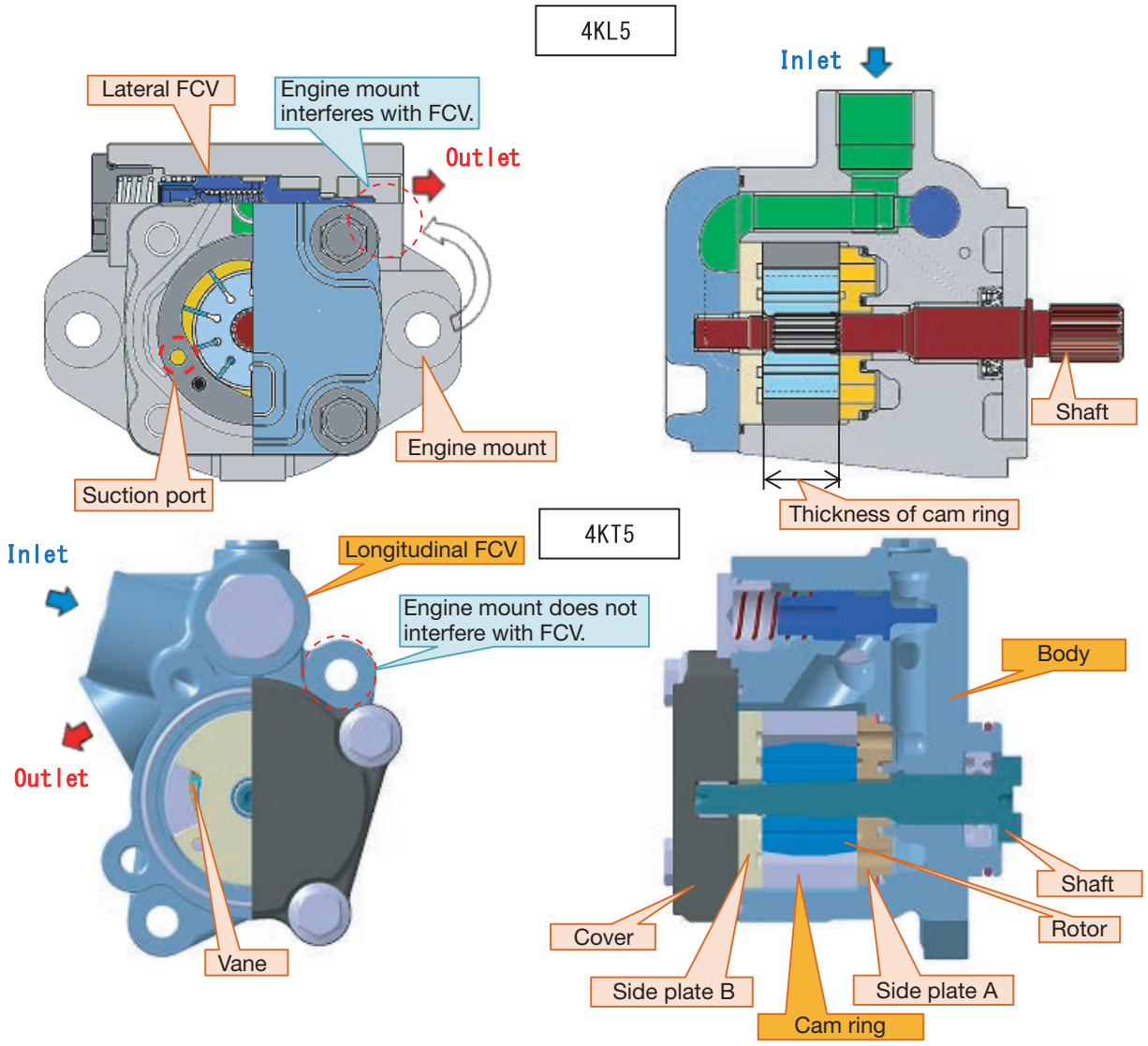

Fig. 1 Pump structure

3.2 Higher pressure resistance of components

3.2.1 Pressure-resistant body

For cost reduction, the pump body needs to be made of aluminum die-cast to reduce cutting allowance. In addition, the strength has been improved with heat treatment to achieve the resistance to a higher pressure (22 MPa).

To ensure the pressure resistance of the body internal high-pressure chamber and of the discharge oil passage, passage design has been optimized through FEM analysis to reduce internal pump stress, thereby achieving durability (Fig. 2).

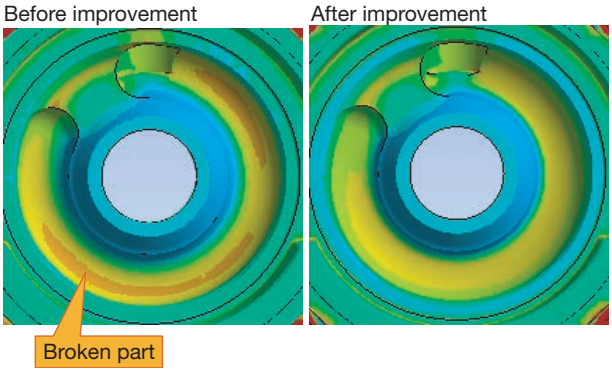

Fig. 2 Body strength improvement

3.2.2 Higher pressure resistance of internal components

In the built-in cartridge assembly [Note 5)], the cam ring is applied with a pushing force by the vanes. The new model designed to the higher-pressure specifications will have an increased pushing force. It is feared that the cam ring will have seizure or wear. Then, vane lift has been reduced so that the cam ring and vane tip have a lower PV value in order to prevent seizure.

Note 5) Consists of a cam ring, a rotor and vanes. When the rotor engaged with the shaft rotates, the vanes protrude in the radial direction and slide against along the inner circumference of the cam ring. As the internal chambers increase or decrease in volume, the pump sucks or discharges hydraulic fluid.

The conventional 4KL5 draws the oil into the body and guides the oil into the vane chambers via the cover core. For the purpose of improving the suction performance, a suction port is provided in the cam ring to feed the oil from the cover toward the side plate A.

The new model 4KT5 has a modified suction oil passage. With the longitudinal FCV introduced, the pump is designed to guide the oil drawn into the body to the vane chambers via the outer circumference of the cam ring (Fig. 3).

This new design eliminates the suction port provided in the cam ring (Fig .4). To increase strength, the cam ring of the new model no longer has a suction port and is thicker for lower stress. These changes prevent breakage caused by the higher pressure.

Consequentially, it is possible to use sintered material in the cam ring even with high-pressure specifications (22 MPa) of 4KT5.

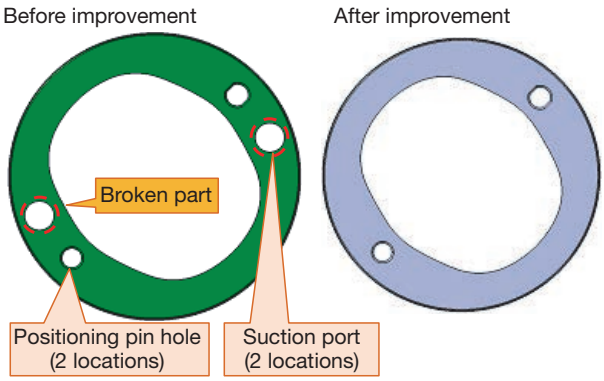

Fig. 4 Cam ring design

3.3 Higher efficiency

A higher-pressure pump is likely to have seizure between the rotor and the side plate. To prevent seizure, the clearance between the rotor and the side plate must be increased. However, the larger clearance is likely to lead

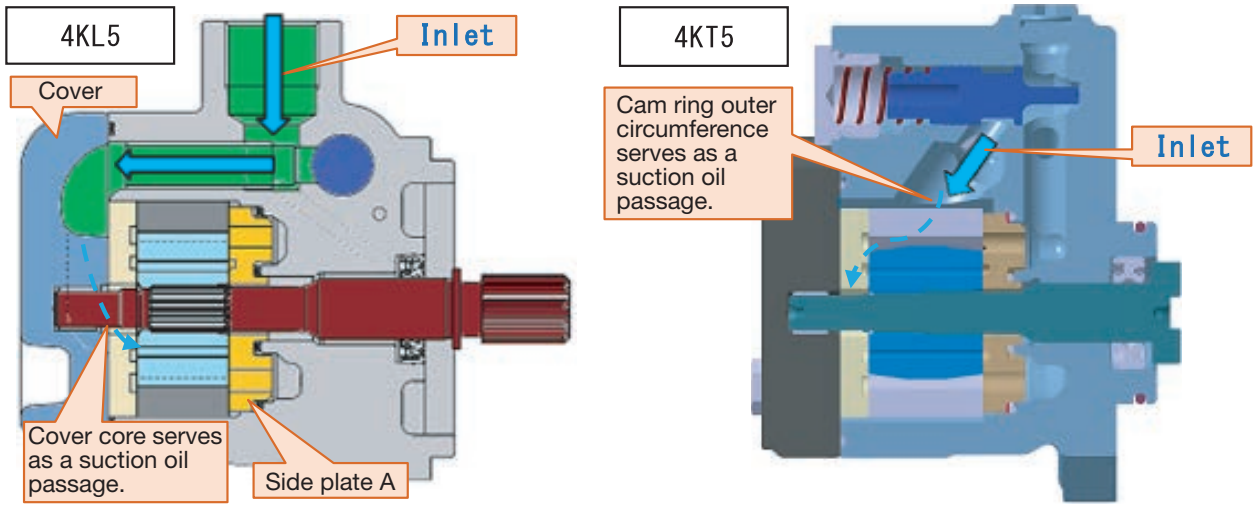

Fig. 3 Comparison of suction oil passage design

to lower volumetric efficiency under a high pressure.

4KT5 is designed to be able to maintain the high efficiency even under a high pressure to ensure pump energy saving. As a result, 4KT5 has higher volumetric efficiency than competitor products by up to 20 percent (Fig. 5).

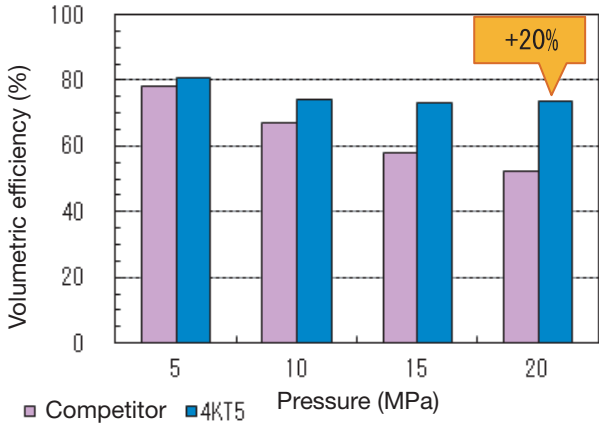

Fig. 5 Comparison of volumetric efficiency (500 rpm, 80°C)

3.4 Lower noise

One of the harmful effects of the higher-pressure specifications is larger noise under the low-speed and high-oil-temperature conditions. To search for noise reduction measures, how noise increases under a high pressure was analyzed.

Measurement of the pump chamber internal pressure and frequency analysis were conducted and noise reduction measures were taken. As a result, 4KT5 has less noise than its competitors (Fig. 6).

3.5 PS pump drives and bearings

In response to various needs of truck manufacturers, both the plain and rolling bearing types are available so as to be compatible with different drives such as gear or coupling driven systems.

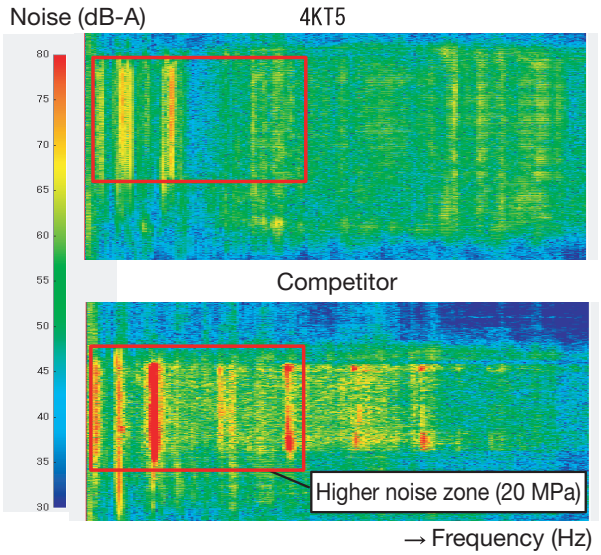

Fig. 6 Noise comparison (500 rpm, 120°C, 20 MPa)

4 In Closing

The development of the 4KT5 PS pump for medium/large trucks has been completed. This higher-pressure, higher-capacity 4KT5 has mounting brackets compatible with European trucks and achieves higher efficiency and lower noise than competitors. The use of the aluminum die-cast body and sintered cam ring leads to cost reduction.

Finally, on this occasion, I would like to deeply thank all those who were involved in this project.

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Glossary

Making KYB Vane Pumps into a Series Product

Included in the High Pressure Aluminum Vane Pump for Power Steering of Trucks (page 47)

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1 Major PS pump models

KYB has the vane pump product lineup for hydraulic power steering (PS) listed below to meet customer needs. The following introduces major models and their features:

1. BB

A high-delivery volume, high-pressure cast iron model for medium to large trucks. The bottom of the pump body is round as its name "B"ottle "B"ottom implies. BB has been continuously manufactured for about 40 years since the late 1970s.

2. 1K

A high-pressure cast iron model for small to medium trucks. 1K has been manufactured since the early 1980s and is the original of the subsequent "K" series.

3. 3K

A 1K-based smaller cast iron model for passenger cars.

4. 4K2

An aluminum-body model for passenger cars. 4K2 used the aluminum die-cast body for the first time in the world.

5. 4KS ("S"mall/"S"tandard)

A model for passenger cars with an aluminum cover. 4KS is a standard model manufactured in both domestic and international production sites.

6. 4KW ("W"orld No.1)

An aluminum model for mass production on dedicated high-speed production line.

7. 4KL (“L”arge)

An aluminum model with a higher delivery volume for medium to large passanger cars including sport utility vehicles (SUVs).

8. 4KL3

An aluminum model with an even higher pressure for medium trucks.

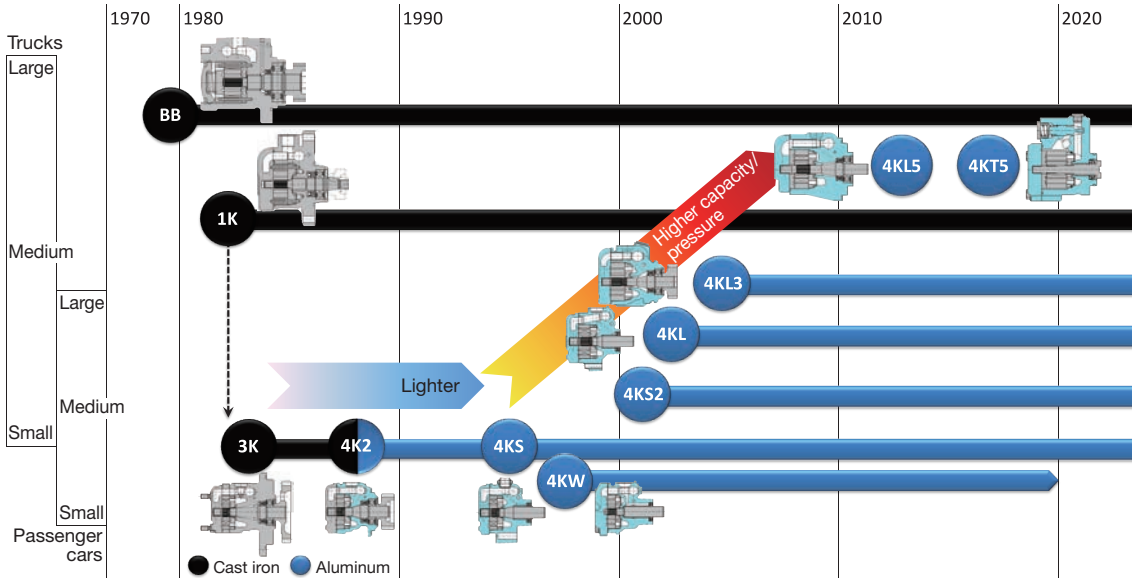


Fig. 1 Historical lineup of PS pumps

Product Introduction

Hydraulic Track Motor for 20t Class Excavator MAG-170VP-4000H

SUGIMOTO Junichiro, SAKAI Yuki

1 Introduction

With the recent rising awareness of environmental conservation, the demand for energy saving has increased year by year. The construction equipment industry has promoted exhaust gas control and the development of energy-efficient equipment.

The industry's conventional development of energy saving technology has been mainly concentrated in hydraulic systems. Actuators have not been the target of the development.

From now on, energy conservation is expected to be further promoted. It is a challenge to effectively use the engine output power without waste.

The engine size of construction equipment is decided by power consumption during traveling. Improving the efficiency in the traction motor will reduce pump output power. It has become necessary to develop a high-efficiency motor with which fuel consumption can be reduced. In addition, as the operation environment has recently been diversified, today's construction equipment is frequently used in severe environments. They are also required to offer improved durability.

We have then developed a higher-efficiency hydraulic traction motor for 20t class excavators. This article describes the structure, specifications and efficiency of the motor.

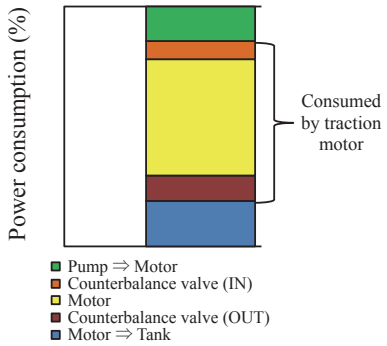


Fig. 1 Breakdown of power consumption

2 Market Demand

2.1 Demand for energy saving

Fig. 1 shows a breakdown of energy consumption by 20t class excavators during normal travelling (low pressure, maximum flow rate) at 2nd gear mode (high-speed):

With power consumption including the energy lost in the piping of an actual vehicle taken as 100%, the traction motor consumes about 65% power. To reduce pump output power, it is a must to improve the efficiency in the traction motor.

3 Product Specifications

3.1 Requirements for this new product

This product is a hydraulic motor equipped with a case-rotating reduction gear for crawlers and consists of three units: control valve, swash plate piston motor and reduction gear. Fig. 2 shows the appearance of the product and Fig. 3 shows the cross-sectional configuration.

This is a full-model-changed product to meet market demand (energy saving and improved durability). The development requirements are as follows:

① Improve mechanical efficiency from the conventional product by 8.0 % or more.
(Ensure that the improved mechanical efficiency exceeds the competitors).

② Achieve higher heat balance performance than

Fig. 2 Appearance of product (MAG-170VP-4000H)

conventional products.

③ Establish a new evaluation calculation technology, a technique to ensure certain friction properties and a machining technique to achieve higher efficiency.

④ Ensure that the new product is interchangeable with conventional counterparts.

⑤ Improve the seal performance of floating seals.

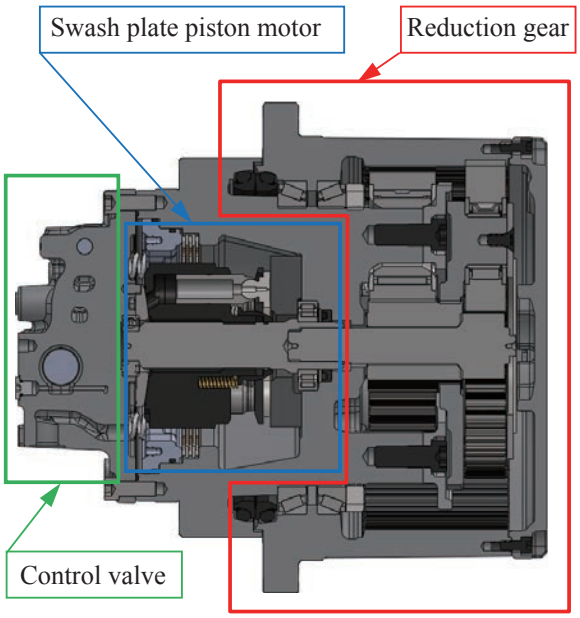


Fig. 3 Cross section of hydraulic traction motor

3.2 Product specifications

The product specifications are shown in Table 1. The maximum pressure and maximum speed remain the same as conventional specifications. The maximum output torque is higher than that of conventional products (MAG-170VP-3800G Series) by about 5 % and can support a diversified operating environment. The maximum motor capacity is set to 192.7 cm^3/rev. so that the maximum output torque can be attained at maximum pressure.

Table 1 Product specifications

Max. motor capacity	cm^3/rev	192.7
Reduction gear ratio		43.240
Reduction gear type		Simple planetary gears (double)
Max. motor speed	rpm	2700
Max. rated pressure	MPa	34.3
Max. output torque	kN·m	39.2
Product weight	kg	265
Parking brake function		Equipped as standard
Parking brake torque	kN·m	25.1
Relief valve		With shockless function
Speed change gear		Equipped as standard Note 1)

Note 1) Either automatic or manual speed change can be selected.

4 Technical Challenges for Improved Efficiency

4.1 Efficiency performance

In general, efficiency of hydraulic track motors can be divided into volumetric efficiency and mechanical efficiency (torque efficiency). The volumetric efficiency refers to the ratio of the actual motor speed, which is affected by leakage or compression loss in the sliding parts, to the theoretical motor speed. Mechanical efficiency indicates the actual output torque, which is affected by frictional loss in the sliding parts, oil resistance to stirring and oil passage loss, to the theoretical output torque.

The efficiency contributing to lower pump output power (= lower fuel consumption) is overall efficiency. An equation that "Volumetric efficiency x Mechanical efficiency = Overall efficiency" holds. Fig. 4 gives an efficiency diagram for the conventional product (MAG-170VP-3800G).

For effective reduction of the power consumption loss, it is a must to improve efficiency in the normal travelling zone (low pressure, high speed) (the section enclosed by a red line in the figure below) that is most frequently used.

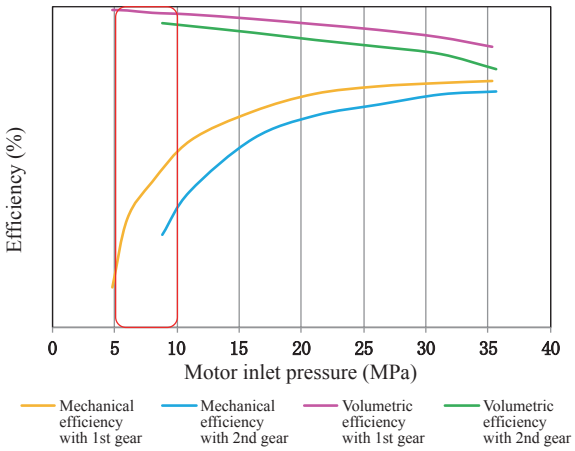


Fig. 4 Efficiency diagram for conventional product

4.2 Efficiency improvement

For the conventional product (MAG-170VP-3800G), its components consume power as shown in Fig. 5.

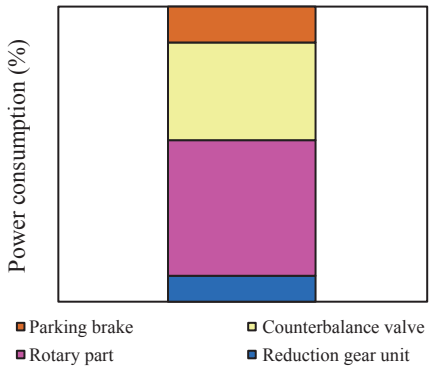


Fig. 5 Power consumption of traction motor

The rotary part and counterbalance valve units account for about 80 % of total power consumption. Since the majority of power consumption is lost in relation to mechanical efficiency according to Fig. 4, a focus was placed on the improvement of mechanical efficiency of these units.

5 Hydraulic Track Motor Design

5.1 Using a spherical rotary part

The rotary part is the core of the hydraulic track motor. The design of this critical part decides the efficiency, durability and robustness. The hydraulic track motor for travelling is required to resist the surge pressure during quick operation on slopes, resist the seizure during high-speed rotation and ensure efficiency stability. The motor needs to be designed to meet these requirements. While the conventional product uses a plane rotary part, the new product uses a spherical rotary part in order to improve efficiency.

As shown in Fig. 6, the spherical rotary part has a spherical valve plate (hereinafter "V/P") designed to make spherical contact with the cylinder block (hereinafter "C/B").

This product has been tried to be optimally designed with a focus on achieving higher efficiency while maintaining the durability and seizure resistance levels of conventional products.

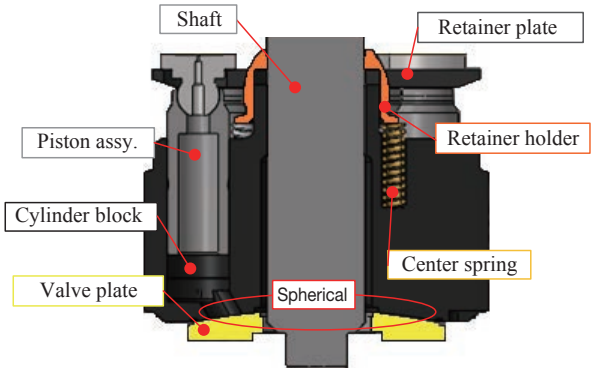


Fig. 6 Cross section of spherical rotary part

We focused attention on the fact that the shaft distortion varies by the pressure applied (the C/B position varies accordingly), thereby affecting the contact force (contact radius) between the C/B and the V/P.

When a high pressure is loaded, the shaft distortion is large to cause a higher contact force on the outside of the V/P. When a low pressure is loaded, the shaft distortion is small to cause a higher contact force on the inside of the V/P, leading to a loss of the sliding friction torque. Then, we provide a difference in spherical radius (hereinafter "SR") between the C/B and V/P (C/B SR > V/P SR). This will alleviate the strong contact on the outside of the V/P under high loading and reduce the torque loss generated under low loading, eventually contributing to higher mechanical efficiency. However, the difference in SR means that there is a clearance between the C/B and V/P. So, the leakage from the clearance will increase, resulting in lower volumetric efficiency. In order to enhance mechanical efficiency while suppressing the decrease in volumetric efficiency, it is essential to optimize the SR and SR difference to be suitable for shaft rigidity.

Usually huge amounts of time and money are needed to accomplish optimization verification. Then, we developed a model shown in Fig. 7 and created an analysis program that calculates the force on each part at any given rotation angle, with the aim of enhancing design efficiency.

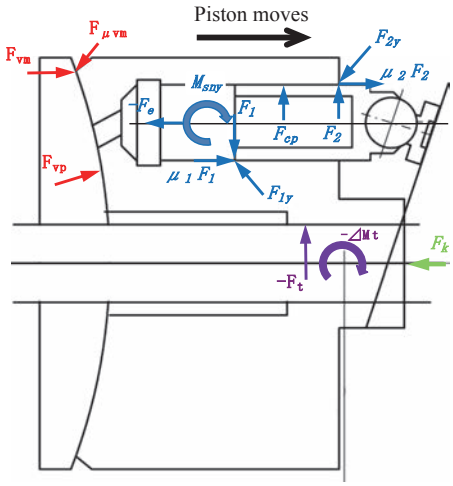
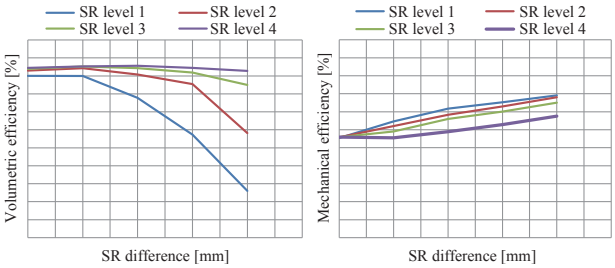


Fig. 7 Hydraulic balance calculation model

We entered the dimensions and pressure of each component in the program to determine the efficiency of the C/B and V/P separately, which was then subjected to an analysis using the model above. The results are shown in Fig. 8.



(1) Volumetric efficiency (2) Mechanical efficiency

Fig. 8 Relationship between SR difference and efficiency

When the SR is smaller and SR difference is larger, volumetric efficiency is lower while mechanical efficiency is higher. This model was used for optimization to successfully improve mechanical efficiency without lowering volumetric efficiency.

5.2 Changing the counterbalance valve

As shown in Fig. 1, the counterbalance valve (hereinafter "CV") accounts for about 18 % of total power consumption. Then, we tried to develop a plan to enhance mechanical efficiency by modifying the CV.

To improve mechanical efficiency by modifying the CV spool, it is necessary to enlarge the maximum valve opening area during the full stroke of the CV spool, in order to reduce the pressure loss generated when the hydraulic fluid passes through it. However, enlarging the maximum opening area without changing the stroke will likely cause an abrupt opening, leading to poor operability of the actual machine. In order to avoid an abrupt opening and ensure the opening characteristics in the subtle steering zone equivalent to conventional counterparts, the maximum stroke of the CV spool is increased by about 20 % and the maximum opening area is enlarged by about 45 %.

Fig. 9 shows the CV opening characteristics diagram of the new and conventional products.

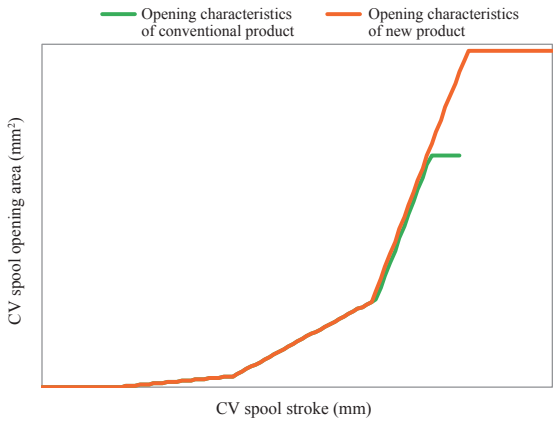


Fig. 9 CV opening characteristics diagram

5.3 Efficiency performance of new product

The efficiency diagram of the new product (MAG-170VP-4000H Series) to which the mechanical efficiency improvement plan was applied is shown in Fig. 10. Fig. 11 compares the efficiency with conventional products.

Compared to conventional products, the new product has been proven to have higher mechanical efficiency by about 9.0 % in the frequently-used normal travelling zone (indicated by arrows), which is equivalent to about 11.4 % reduction of pump output power.

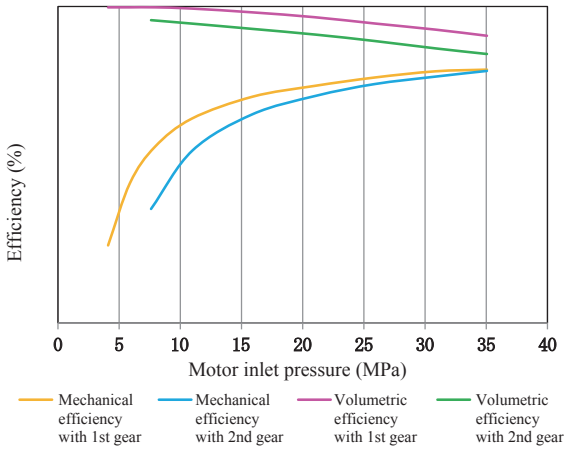


Fig. 10 Efficiency diagram of new product

Fig. 12 shows motor output power during normal travelling and pump output power under the same conditions.

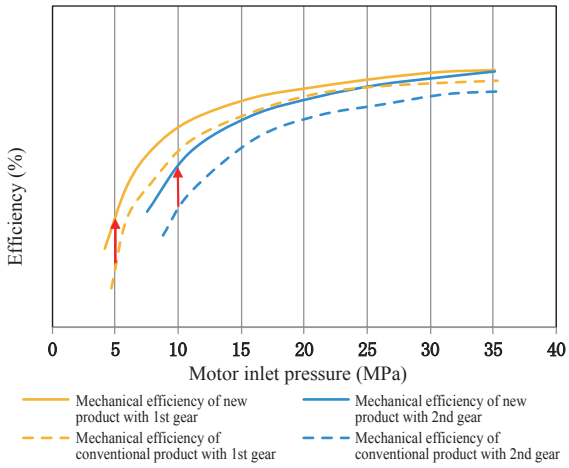


Fig. 11 Efficiency comparison diagram

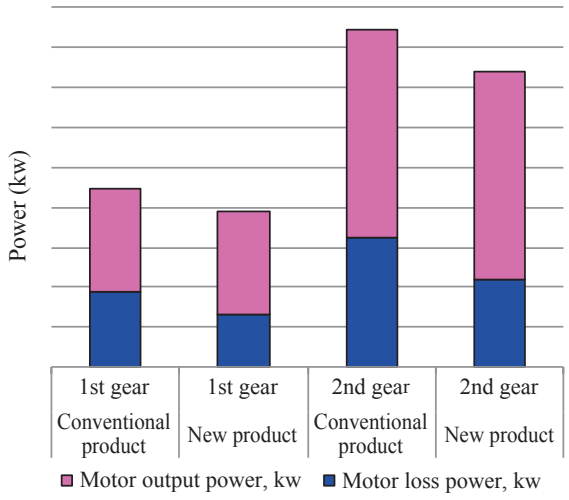


Fig. 12 Comparison of pump output power

6 Reduction Gear Unit Design

6.1 Output enhancement

To meet the higher output requirements for the new product, conventional products have been improved in several points. Some of them are described below:

(1) Gear strength

To reduce the number of components (thereby keeping costs at the conventional level), the number of gears on the 2nd stage in the planetary reduction gear unit has been changed from 4 to 3.

When the number of gears is reduced, the input load on each gear increases by 33.3 %. Moreover, if the development goal of higher output by 5 % is achieved, the input load on each gear would increase by 39.7 %. Gear strength cannot be secured without increasing the gear module.

To achieve the same outer diameter and reduction gear ratio as those of conventional products, it is necessary to review the gear specifications including tooth profile,

pressure angle, rack shift and face width. Optimizing the gear specifications has made it possible to maintain the dimensions of the conventional product and to enhance the output. If the new product is operated according to the conventional product specifications (output torque and output speed), the reduction gear achieves an about 1.4 times longer life than conventional products.

(2) Gear shaft rigidity

If the gears have a larger face width for theoretically higher strength, the tooth surface may be damaged (for example, pitting) unless proper engagement is attained. To secure proper engagement, not only the crowning in the tooth trace direction of the gears but also the shaft rigidity are critical factors.

The lower number of gears and the 5 % higher output lead to a higher input load on the shaft by 39.7 %. To raise shaft rigidity and secure face durability, an integrated structure of the flange (motor case) and holder (gear shaft) has been introduced. In addition, another plate has been installed and the fastening method has been changed. These improvements have resulted in shaft rigidity with which proper engagement can be attained (tooth face strength ensured) in spite of the smaller shaft diameter compared to conventional products. Fig. 13 shows the structural profile of the 2nd stage of the planetary gear unit using this structure.

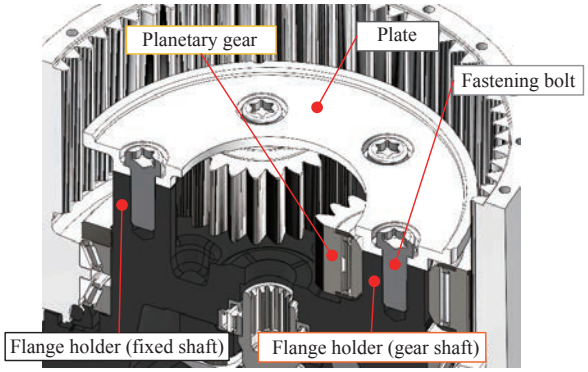


Fig. 13 Structural profile of 2nd stage of planetary gear

(3) Gear bearing

As the input load on the shaft increases by 39.7 %, it is indispensable to use a bearing with high load carrying capacity. However, a high load carrying capacity bearing would be larger than the existing and would not fit within the specified product dimensions. Then, special needle crowning and plastic cages have been used to ensure conventional durability even with high-output specifications.

6.2 Sprocket bearing design

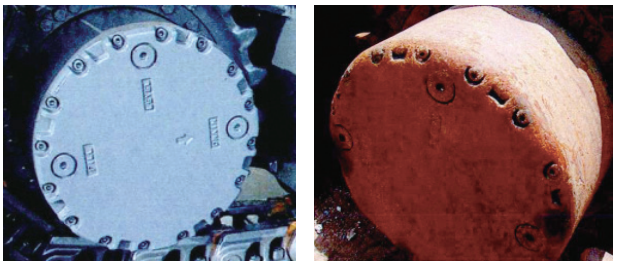
Since the flange holder structure has been used to ensure the required gear strength and shaft rigidity after output enhancement, the sprocket bearing needs to have a smaller cross section. Then, a tapered roller bearing with a low-profile cross section is used. Fig. 14 show the low-profile tapered roller bearing.

Fig. 14 Low-profile tapered roller bearing

Compared to conventional angular contact ball bearings, this tapered roller bearing provides 2.8 times higher rigidity for radial displacement and 1.3 times higher rigidity for axial displacement. The higher rigidity helps ensure proper gear engagement against any external input load variations and suppress displacement of the floating seal section, thereby improving the seal performance.

6.3 Strengthening the reduction gear unit

Today's excavators are more and more frequently used in even more severe environments due to diversified operating environments as mentioned at the beginning of this article. It is more often for their traction motors to be damaged on the external surface and fastening bolts. Fig. 15 gives pictures of the reduction gear cover.



(1) Reduction gear cover of new unit

(2) Reduction gear cover of unit in service

Fig. 15 Reduction gear cover of units in the field

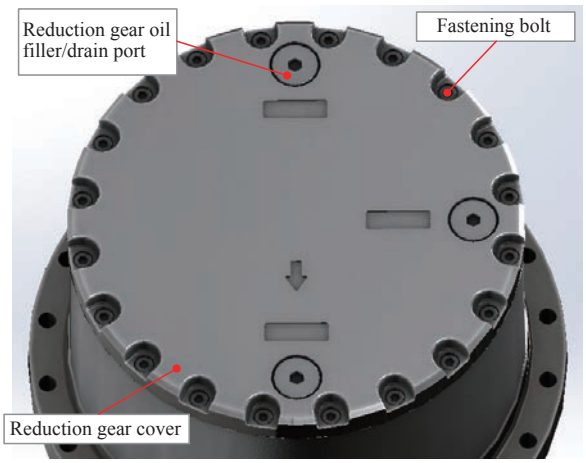


Fig. 16 Appearance of reduction gear cover

To make it harder for the reduction gear to have oil leakage even under such harsh environments, the cover has been redesigned to be thicker at its outer perimeter and to physically protect the fastening bolts. In addition, the number of fastening bolts has been increased from 16 to 20 in order to enhance strength.

The appearance of the reduction gear cover of the new product is shown in Fig. 16.

7 Future Outlook

The new product achieves, in the frequently used normal travelling zone, higher mechanical efficiency by about 9 % and lower pump output power by 11.4 % from conventional products.

Probably, the need for energy saving is increasingly rising. By making use of the expertise with which we have developed and produced a variety of hydraulic pumps and motors, we would like to develop products that can quickly meet even more demanding needs and continue providing high-performance, high-quality products to constantly satisfy market needs.

The new product has already been started to be produced in volume and delivered to customers.

The new product is packed with a great deal of expertise on design techniques and production engineering. Finally we would like to cordially thank all those concerned who extended substantial support and cooperation in the technical development.

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Product Introduction

Development of Furniture Overturning Prevention Damper

UNE Masaya

1 Introduction

It is predicted that mega earthquakes such as the Tokyo inland earthquake or Nankai Trough earthquake will occur in the near future with a high probability. To be prepared for these earthquakes, many buildings in Japan have been made quake-proof. However, not many people have actually taken measures to prevent furniture overturning although they recognize the danger of furniture fall. People are reluctant to do so because they believe that such measures will "damage furniture and walls" or "just be ineffective".

According to a survey conducted by the Tokyo Fire Department [1)], it has been reported that 30 to 50 percent of the causes of injuries during large earthquakes in recent years are overturning, falling or movement of furniture. To prevent injuries and secondary damage related to furniture, it is very important to take appropriate furniture overturning/movement prevention measures.

General furniture overturning prevention devices can be roughly divided into two types. One is fixtures that secure furniture to the wall with L-shaped angle brackets, chains or belts. The other is tension rods, including pole-types that are installed between the top of furniture and the ceiling so as to prop the furniture. However, it is already known that these furniture overturning prevention devices are not very effective during a large earthquake of seismic intensity upper 6 or higher. Furthermore, when furniture is securely installed to the floor or wall with anchor bolts, the installation and removal will entail high costs.

So, KYB has launched an internal project to develop a furniture overturning prevention device by making use of its own expertise on damping systems, which is one of our core technologies. This article introduces the newly developed furniture overturning prevention damper.

2 Product Specifications

2.1 Overview of product

This product is designed so that two dampers are installed onto a single piece of furniture as shown in Photo 1. The dampers are set on the top panel of the furniture in positions near the back corners and installed in a slanting position between the ceiling and furniture so as to prevent the furniture from falling over. Normally the dampers are secured (installed) by the repulsion of their internal spring. If the furniture starts overturning during an earthquake, the dampers will shrink with a damping force exerted by its hydraulic system, preventing the furniture from overturning.

Photo 1 Appearance of furniture overturning prevention damper

2.2 Furniture overturning prevention mechanism

This product is constructed so that the internal spring exerts a repulsion force alone during the stand-still and expansion phases and exerts both a repulsion force and hydraulic damping force during the contraction phase. How the product prevents furniture overturning is shown in Fig. 1.

During standstill, the dampers can secure the furniture with a relatively small repulsion force of around 60 N to 140 N, (the repulsion depends on how much the dampers installed are contracted). If the furniture starts overturning during a quake, the dampers will exert a damping force in the direction of contraction to prevent the furniture from falling over. When the furniture starts moving back to its original position, the dampers will quickly expand themselves with their repulsion to help the furniture move back.

Unlike the existing pole-type, this damper type tension rod has a pin-type rotary joint between the damper axis and pedestal. The pedestal can follow the inclination of the furniture and will never slide on the top surface of the furniture, contributing to the stable behavior of the product.

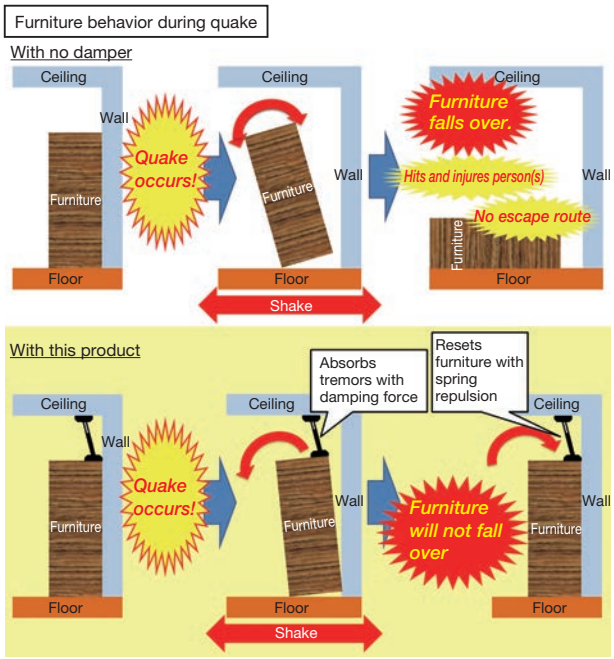

Fig. 1 Furniture overturning prevention mechanism

2.3 Product components

The product components are shown in Fig. 2. Since the product is installed in a slanting position, the pedestal sheet uses a material with a high coefficient of friction. The damper can be made into contact with the angle control bracket to allow easy installation at an appropriate angle (about 17 degrees from the vertical position).

The damper is kept contracted with the contraction band to assist installation. When the damper is set between the top surface of the furniture and the ceiling board, the band can be cut to cause the damper to expand with its repulsion, thereby automatically installing the damper. (The contraction band should be removed after installation).

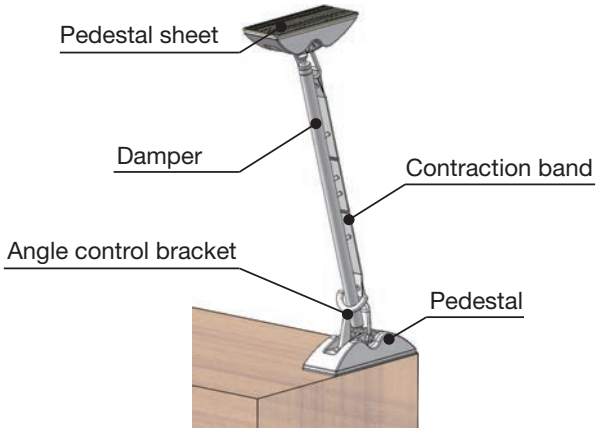

Fig. 2 Parts structure

2.4 Effective setting condition

2.4.1 Product lineup

Table 1 lists the product models for different height clearance ranges. The height clearance means the vertical clearance between the top surface of a piece of furniture and the ceiling (Fig. 3).

Table 1 Product models for different height clearance ranges

Model	Height clearance [cm]
PD16-43	43 – 50
PD16-50	50 – 60
PD16-60	60 – 74

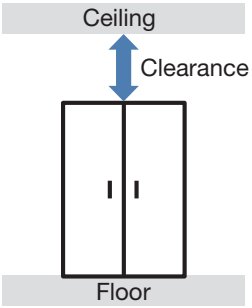

Fig. 3 Height clearance

2.4.2 Clearance range between furniture and wall

This product can only be used for furniture installed against a wall. The clearance between the furniture and the wall must be less than 3 cm, which is within the damper stroke (Fig. 4).

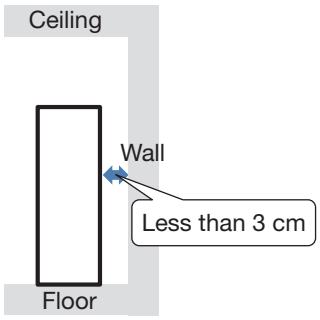

Fig. 4 Clearance between furniture and wall

2.4.3 Compatible ceilings

The product should be installed against a ceiling consisting of light gauge steel or wood ceiling joists and facing plates such as gypsum boards.

The target ceiling must have screws or nails fixing the facing plates (e.g., gypsum boards) either exposed or hidden behind any ceiling cloth, and must not be apparently dented when pressed with a finger at the position against which the damper pedestals are to be installed.

The product cannot be used for a lining board ceiling, system ceiling (with facing plates just placed on the frame), structurally weak ceiling, or non-horizontal ceiling.

2.4.4 Compatible furniture

The product can be applied to furniture that has sufficient strength, has a horizontal top surface and is stably installed.

The product cannot be used for unstable furniture such as rollaway-types.

2.4.5 Acceptable Floors

Wooden floors, tatami mats and any other types of floors are acceptable. For a slippery floor surface such as wood or tile, non-slip sheets for sideslip prevention provided with the product may be installed under the bottom of the

furniture at both front corners to prevent a decrease in damping effect (Fig. 5).

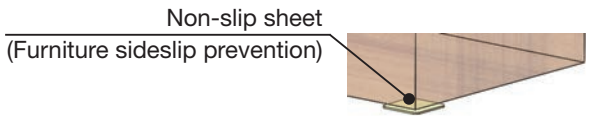

Fig. 5 Non-slip sheet

2.5 Damper specifications

The dampers for this product are based on stay dampers generally used in automobile applications. The dampers are designed to be installed with their piston rod up (ceiling side) so that the damping force is applied only in the direction of contraction. Fig. 6 is a sketch of the internal structure of the dampers. While automobile stay dampers generally deliver repulsion with internal nitrogen gas, this product uses a metal spring instead of nitrogen gas. The reason is that the use of nitrogen gas would inevitably lead to lower gas pressure (lower repulsion) as service time goes by.

Unlike automobile stay dampers, these dampers have a cylindrical stopper on the piston rod to ensure that the piston has a sliding motion within the hydraulic fluid. With the stopper, the damping force will always be generated regardless of the position of the piston rod as long as it is within the stroke range.

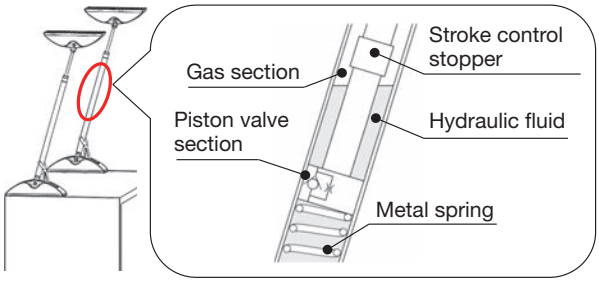

Fig. 6 Internal structure of damper

To determine the damping force, the damper was subjected to a 3-axis shaking table test at several damping force levels. Then, a damping force value with which the highest rank of the official evaluation described in section 3.1 is expected to be obtained was selected.

3 Performance Evaluation

3.1 Official evaluation

3.1.1 Official evaluation criteria

Performance evaluation of the product was carried out by an independent agency called General Incorporated Foundation (hereinafter "GIF") Japan Testing Center for Construction Materials according to "Overturning Prevention Device Performance Test and Evaluation Criteria"[2]. A piece of commonly used furniture (height 180cm, width 90cm, depth 40cm, weight 100kg or more) was used for the test. The shaking table was agitated with a seismic wave of intensity upper 6 observed by the Kobe Meteorological Observatory of the Japan Meteorological Agency during the Southern Hyogo Prefecture Earthquake (hereinafter "JMA Kobe wave") and the motion behavior of the furniture was measured and evaluated.

The evaluation result is expressed by the number of stars (☆). As the number of stars increases as in single (☆), double (☆☆) and triple (☆☆☆), the rank becomes higher. The top ranked dampers (with a triple star marking (☆☆☆)) are rated as "being able to minimize the tremor of the target specimen and prevent the overturning against a seismic motion equivalent to a seismic intensity upper 6".

Fig. 7 shows a graph of the rating criteria for performance evaluation. When the effective acceleration and maximum displacement of the top section of the furniture are plotted as shown in the figure, the red line, which is the straight line connecting the reference point of "effective acceleration 400 gal and maximum displacement 30mm" with the point of "effective acceleration 800 gal and maximum displacement 0mm", and the origin point can form a triangle. Measurements that fall within this triangle are rated as a triple star mark (☆☆☆).

The triple star ranked overturning prevention devices also must be visually identified to mostly stabilize the motion behavior of the specimen and have no deformations, damage or deviation.

3.1.2 Official evaluation results

In the test, specimens were shaken three times in a row. Of the three results, the one with most unstable behavior was selected for evaluation. In this evaluation test, a piece of furniture with a mass of 122kg was used.

As a result, the product was within the top-ranked triple star (☆☆☆) area as shown in Fig. 7. The furniture slightly moved, but mostly remained in the original position after shaking.

The performance certificate for the product was applied for at the GIF Japan Testing Center for Construction Materials and is pending at this moment (as of January 2018).

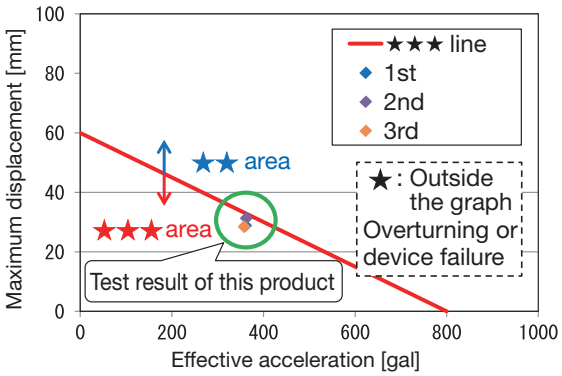

Fig. 7 Performance evaluation criteria and test results

3.2 Tests on different shaking tables

3.2.1 Evaluation using various seismic waves

Using several seismic waves of earthquakes that actu-

ally occurred (Table 2), the furniture overturning prevention performance was determined. Photo 2 shows how the 3-axis shaking table test was conducted.

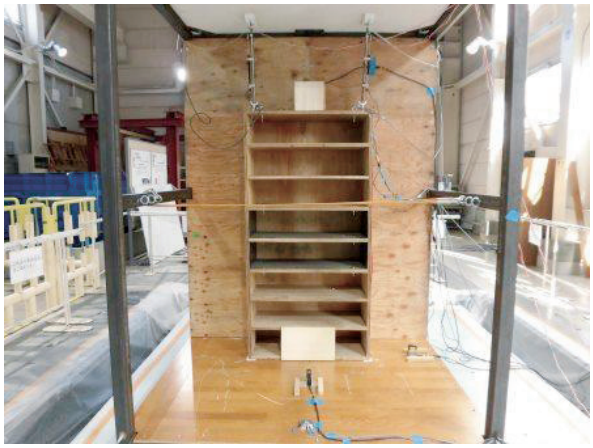

Photo 2 3-axis shaking table test

On the shaking table, a room and a piece of furniture equivalent to those used in the official evaluation test in section 3.1 were installed. Non-slip sheets were placed between the floor and the bottom of the furniture (two locations at both front corners) to prevent sideslip.

Table 2 Description of seismic waves

Seismic wave	Intensity	Description
JMA Kobe	6 upper	The seismic wave observed by Kobe Meteorological Observatory during the Southern Hyogo Prefecture Earthquake in 1995
JMA Kobe NS 130%	Equivalent to 7	The JMA Kobe wave multiplied by 1.3 only in the NS direction (front-back direction of the furniture)
K-NET Sendai	6 lower	The seismic wave observed by Sendai City K-NET Note 1) during the Great East Japan Earthquake in 2011
KiK-net Mashiki foreshock	7	The seismic wave observed by Mashiki-machi KiK-net Note 2) during the foreshock of the 2016 Kumamoto earthquakes
KiK-net Mashiki main shock	7	The seismic wave observed by Mashiki-machi KiK-net Note 2) during the main shock of the 2016 Kumamoto earthquakes

Note 1) A nationwide network of strong-motion seismographs operated by National Research Institute for Earth Science and Disaster Resilience

Note 2) A network of strong-motion seismographs installed on the ground surface operated by National Research Institute for Earth Science and Disaster Resilience

In the test, the furniture did not fall over, even with a seismic wave equivalent to the seismic intensity 7 (JMA Kobe NS 130%) as shown in Table 3. For the test with the foreshock and main shock of the Kumamoto Earthquakes KiK-net Mashiki, the furniture rocked more heavily with the foreshock than with the main shock. This was probably because the seismic wave of the foreshock had a higher maximum vertical acceleration, thereby floating the furniture before being additionally applied with the longitudinal and lateral accelerations.

Table 3 Test result by seismic wave

Waveform	Result
JMA Kobe	Furniture rocked very little and remained stable.
JMA Kobe NS 130%	Furniture rocked very little and remained stable.
K-NET Sendai	Furniture rocked very little and remained stable.
KiK-net Mashiki foreshock	Furniture rocked to some extent, but did not fall over.
KiK-net Mashiki main shock	Furniture rocked slightly, but generally remained stable.

3.2.2 Evaluation with simulated ceiling

The ceiling used for the official evaluation test in section 3.1 had sufficient strength for the testing condition. For this test, ceilings of general wooden houses and office buildings were simulated. Photo 3 shows the simulated general wooden house ceiling and Photo 4 the simulated

Photo 3 Simulated general wooden house ceiling

Photo 4 Simulated office building ceiling

office building ceiling. The JMA Kobe wave was selected as the seismic wave to be applied. The furniture and the room components installed on the shaking table, except the ceiling, were equivalent to those used in the official evaluation test in section 3.1.

In the test, neither the simulated general wooden house ceiling nor the simulated office building ceiling was damaged as indicated in Table 4. As the ceiling deforms, the furniture rocked more largely but did not fall over. Recently constructed buildings probably have ceilings stronger than the simulated ceiling. Therefore, furniture in such buildings are likely to show even less effects.

Table 4 Test result by ceiling type

Ceiling	Result
Simulated for general wooden house	Furniture rocked to some extent, but did not fall over. The ceiling was not damaged.
Simulated for office building	Furniture rocked to some extent, but did not fall over. The ceiling was not damaged.

3.3 Ceiling strength evaluation

The relationship between the damping force of the dampers during an earthquake and the ceiling strength was identified. As shown in Photo 5, a test jig simulating the pedestal of this product was used to apply a compressive load to the ceiling sample with steel furring, and the static breaking load was measured. The jig was pressed against the ceiling sample at the most disadvantageous position in terms of strength. The ceiling joist interval was selected using the examples of steel furring included in the "Gypsum Board Handbook" [3] issued by the general incorporated association (hereinafter GIA) Gypsum Board Association of Japan as a guide.

The static breaking load measurement was about 1300 N. Under the test condition for the official evaluation in section 3.1, the relevant damper showed a maximum damping force measurement of about 800 N. Therefore, the ceiling will not be damaged. However, dampers may behave differently depending on the furniture weight or seismic wave. It is also necessary to pay attention to ceiling damage or the gypsum board condition.

Photo 5 Measurement of static breaking load on ceiling

4 Installation Status

Trial installation of the new product for monitoring purpose was launched in March 2016. 209 sets (418 pieces) of the dampers have been installed inside or outside KYB so far. In each installation location the product was installed by several individuals. It was found that most of them were able to install the product with no difficulty according to the instruction manual. Photo 6 shows the product installed at KYB Kumagaya Plant.

Photo 6 Product installed at KYB Kumagaya Plant for monitoring purpose

5 In Closing

KYB successfully developed furniture overturning prevention dampers resistant to the seismic intensity 7 by making use of the company's proprietary damping technology, which is one of our core technologies. The product aimed at corporate clients started to be sold by KYB-YS Co., Ltd. in October 2017. Currently KYB-YS Co., Ltd. is promoting activities for order intake, cost reduction, performance improvement and lineup enhancement.

Finally, on this occasion, I would like to deeply thank all those who extended guidance and support in this development project.

References

1) Tokyo Fire Department: Furniture Tip Over, Fall and Movement Prevention Handbook, (2015 edition).
2) (GIF) Japan Testing Center for Construction Materials: Overturning Prevention Device Performance Test and Evaluation Criteria, (April 2008).
3) (GIA) Gypsum Board Association of Japan: Gypsum Board Handbook, (2016 edition).

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Product Introduction

Development of New Controller for Impulse Test Stand

YOSHIMURA Yuki

1 Introduction

Recently, news about accidents attributable to industrial fatigue breakdowns or false inspections that compromise product safety have attracted publicity. One thing indispensable to fundamentally ensure product safety is fatigue testing machines of Kayaba System Machinery Co., Ltd. (hereinafter "KSM"). Most of existing fatigue tests are carried out using endurance testing equipment that applies a stationary wave load to specimens, such as material tester. Now the demand for fatigue tests using an even more accurate, realistic test waveform has risen with diversified product/testing needs. Among these is an impulse test stand that applies pressure loading to specimens such as hydraulic hoses.

KSM offers impulse test stands that can accept a variety of specimens using a dedicated controller. These impulse test stands have earned a reputation in the market, particularly for the reproducibility of the JIS waveform Note 1). This article introduces the latest model of impulse controllers.

Note 1) A test waveform with sharp peaks used for hydraulic-pressure impulse tests on hoses specified by the former JIS K6330-8.

2 What is the impulse test stand?

Fig. 1 shows the general configuration of KSM impulse test stands. The hydraulic pressure is generated by a special cylinder called a "boost cylinder" with a built-in pressurizer on its end. The boost cylinder is used to compress the fluid within the specimen, generating any given pressure.

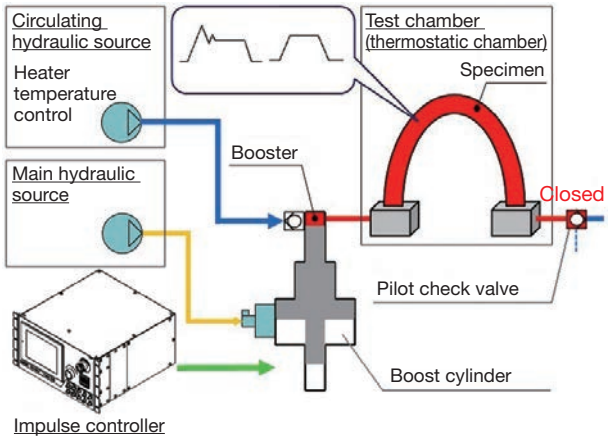

Fig. 1 Configuration of impulse test stand

The test stand mainly consists of a main hydraulic source that drives the boost cylinder, a circulating hydraulic source that circulates the service fluid, and a test chamber in which specimens are installed for testing. Another component of the test stand to control the boost cylinder and reproduce a specified pressure waveform for specimens is the controller for impulse testing, which is the development target.

3 Background of Development

Controllers used for KSM impulse fatigue test stands include the old 2107 model (hereinafter "old model") shown in Photo 1. Since many years have passed since the development, this old model is now difficult to manufacture because some of the components are out of production.

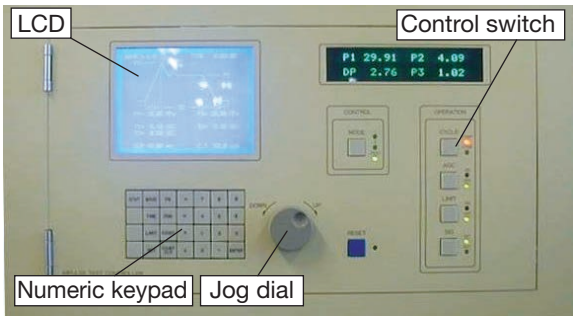

Photo 1 Appearance of old model

Also, the old model cannot satisfy customized specifications without changing its internal ROM. It has become difficult for the old model to meet customer testing needs that have diversified with various factors, including maintenance of the development environment, quality and cost issues. KYB has thus decided to develop Model 3100 (hereinafter "new model") using a general-purpose programmable logic controller (hereinafter "PLC"), which has recently produced a substantially higher performance, to implement the control requirements.

4 Concept and Outline of New Model

When developing the new model, the functionality, operability and customizability of the old model were improved. Moreover, the waveform reproducibility of the old model, which was still highly rated, was further enhanced to achieve a high-standard performance that cannot be caught up with by any competitor. The new model has the same size and external interfaces as those of the old model to support full backward compatibility, thereby enabling users to only replace/update the controller without changing the test stand itself. Photo 2 shows the appearance of the new model.

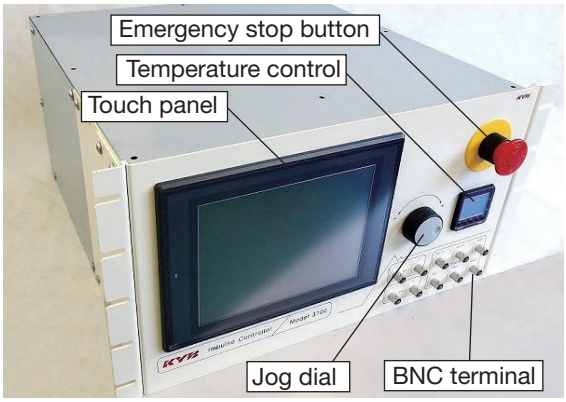

Photo 2 Appearance of new model

A large-sized touch panel LCD is mounted on the front panel, achieving comfortable operability and customizability. Test parameters can be set by direct input of numeric values or by just turning the jog dial. The jog dial can also be used for intuitive control to adjust the neutral position of the boost cylinder. BNC terminals for connecting the temperature control or various measuring instruments are put together on the front panel. Almost all operating actions and connections with measuring devices can be collectively operated on the front panel.

5 Internal Structure

Hardware includes analog amplifier circuits as a minimum component, which is modularized by function. They can be optimally designed by selecting a combination of necessary boards and PLC units for the actual scale of the test stand (Photo 3). This structure makes it possible to replace the hardware in units on site if a failure occurs, contributing to shorter recovery.

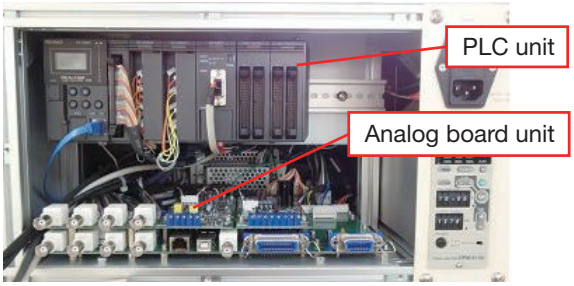

Photo 3 Internal structure

6 Control Software

The main control section is based on the PLC. It uses not only the ladder language [Note 2)], but also a description called "script" that is similar to the BASIC or C Language, making it possible to achieve complex control processing such as cylinder displacement control and specimen pressure control.

Unlike the old model, the new controller accomplishes all control processing tasks by calculation on the PLC, except the final physical controls including the servo valve drive and pressure amplifiers. Thus this is a fully-software-controlled controller. That is why the extended control functions, including error correction control to be described later except PID control [Note 3)], were successfully implemented. The new design also allows easy additional customization such as modifications suited to each specific test stand or programming for customer-specific testing. Furthermore, the control of peripheral equipment including hydraulic sources, which was carried out by a separate PLC, is now integrated into the controller. This new integral model only requires a smaller space for the control board than the old model, contributing to resource conservation and power saving as well.

Note 2) A programming language mainly used in PLCs that represents a program with a graphical diagram like a ladder using symbols representing electric relay circuit devices.

Note 3) Stands for proportional-integral-derivative control. This is one of the traditional feedback control mechanisms and implements control with three elements: output proportional to an error value as the difference between an actual value and a desired setpoint (P), output proportional to the integral of the error values (I), and output proportional to the differentiation of the error values (D).

7 Reproduction of JIS Waveform

Reproduction of the JIS waveform is one of the requirements for impulse test stands. An expandable specimen

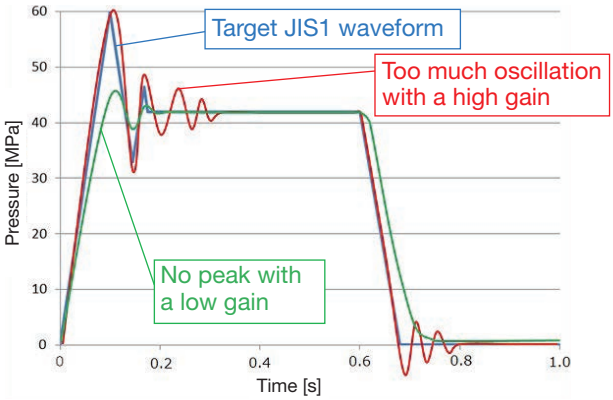

Fig. 2 Reproduction of JIS waveform 1 by PID control

filled with compressive fluid is subjected to an impulse test to verify the high-accuracy quick control of the internal pressure with a pressure waveform called the JIS1 waveform, consisting of a prominent peak and its subsequent flat section as indicated by the blue line in Fig. 2. In reality, it is quite difficult for the regular PID control alone to reproduce the exactly same waveform as the JIS1 waveform due to the specimen's pressure responsivity attributable to its own properties.

8 Error Correction Control

A new control mechanism called error correction control has been developed and implemented in the new model. In this error correction control, the error between the target and response waveforms of each wave is stored as time-series data and is superimposed on the target waveform of the following wave in the feedforward manner [Note 4)] so that the response waveform is closest to the original target as much as possible. This procedure is repeated over and over again. Fig. 3 shows a flow of the error correction control for the JIS1 waveform.

Note 4) A control system that preliminarily measures data such as disturbance to the control system and determines in advance the control amount with the data taken into account.

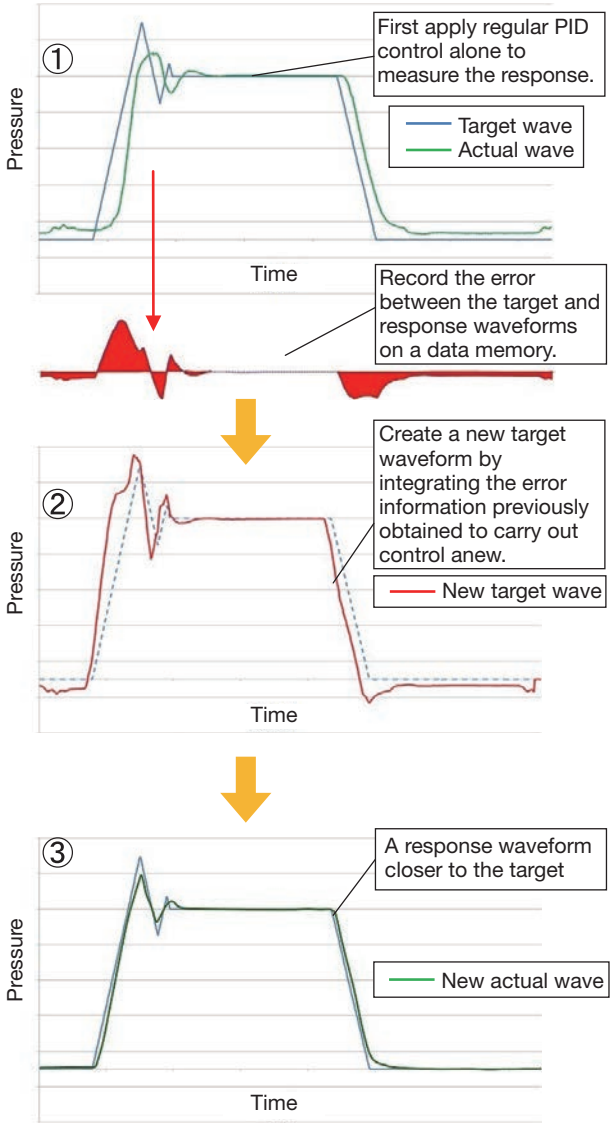

Fig. 3 Error correction control

It is essential for this impulse test with the JIS1 waveform that measurement values for the highest pressure peak coincide with the target value stably. Another control mechanism to keep only the peak value at a constant level independent of those obtained by PID or error correction control has also been conducted separately, achieving stable generation of the peak value.

Also, the error correction control automatically adjusts the correction gain according to the degree of coincidence of the peak values. The controller is designed to temporarily stop the correction processing when waveforms coincide with each other to a certain extent, helping achieve stable operation.

For the old model, many analog quantities had to be adjusted by trial and error to obtain a coincidence of waveforms. Now the new model can almost automatically reproduce accurate pressure waveforms with error correction control. Once parameter settings are entered on the test screen, just turning on the error correction will enable correction processing unless the specimen's characteristics are considerably changed.

Fig. 4 Test screen

9 Results of Measurement in Actual Machines

Using an impulse test stand of the specifications shown in Table 1 with the new and old controllers, waveform measurement was carried out under the same test conditions for comparison of response waveforms. The results are shown in Fig. 5.

For the old model, the actual waveform is off the target in some sections, including the 2nd peak and the trailing edge. The new model diagram shows that the actual waveform coincides exactly with the target waveform throughout the entire zone.

For the new model, the controller automatically adjusts the waveform itself. A waveform with only a slight error

as shown in the graph above can be obtained regardless of whoever carried out the setting. The new model has the great advantage of being able to ensure stable test quality.

Table 1 Test stand specifications and test conditions

Max. specimen volume	6000cm^3
Specimen expansion	9cm^3 MAX
Max. dynamic pressure	25MPa
Max. static pressure	30MPa
Specimen	Hydraulic hose
Fluid	Automatic transmission fluid Note 5)
Test conditions	Peak pressure: 30 MPa Test frequency: 1 cycle/sec.

Note 5) A kind of gear oil used to lubricate gears or operate valves and torque converters of vehicles equipped with reduction gears

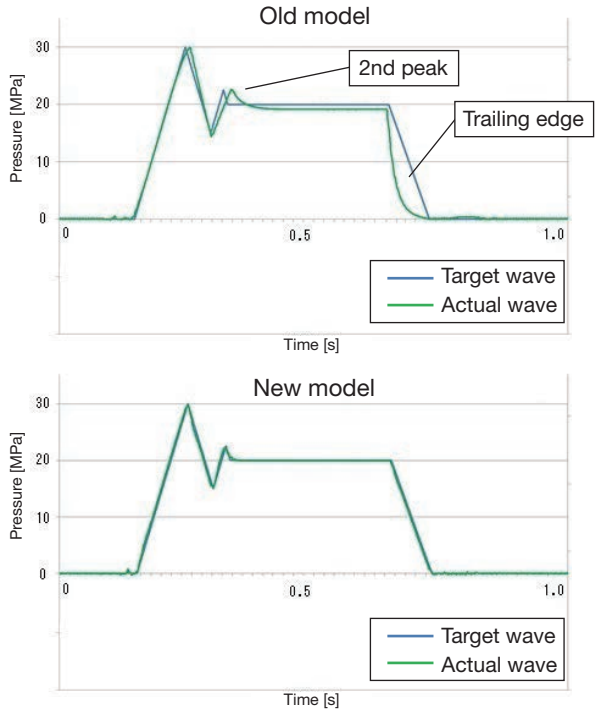

Fig. 5 Comparison of waveforms for actual machines

10 Future Outlook

This development project has demonstrated that fatigue test stands can be sufficiently controlled by a PLC-based controller. We will apply this technology to various other testing machines. The error correction control proposed in this development project can be applied not only to impulse test stands but also to other testing machines. For example, it has already been confirmed that a shock absorber (SA) testing machine with its displacement control integrated with the error correction control shows improved results of velocity waveform in testing (Fig. 6).

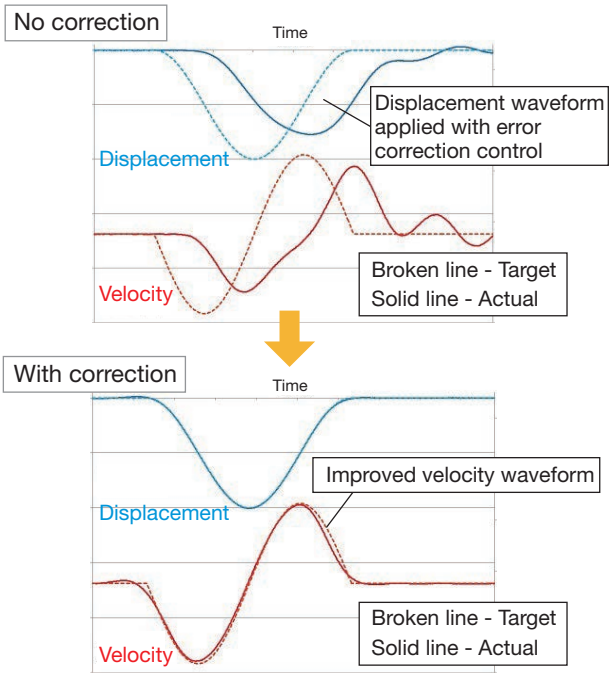

Fig. 6 Improvement of velocity waveform of SA testing machine

11 In Closing

The new model has gained a good reputation with customers in field tests. We have already received many inquiries. We can expect the technology to grow in future by exploring new markets, making use of the customizability.

Finally, I would like to deeply thank the related KSM departments, all the related partner companies and all those who extended cooperation in the field tests for the development.

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Product Introduction

Semi-Active Suspension, Extending the Limits

Alexander Alonso Torres

1 Introduction

The avalanche of SUVs and the arrival of autonomous driving are pushing vehicle manufacturers to improve ride-comfort compromise during last years. Semi-active suspension is a very powerful tool that increases considerably vehicle behavior comparing with a standard one. Although there are some limits, studying each application carefully these can be extended.

In the last years KYB has developed a semi-active suspension system, and it's now entering into the market as TIER1, as a complete system shock absorber & software supplier. During the development KYB has manage to solve some limitations related to lack of robustness and noise. This will be the case study for this article.

2 Semi-Active System Architecture

Semi-Active System architecture is built by four level sensors, three G-sensors, an ECU ("Electronic Control Unit") and one actuator on each shock absorber.

Working principle of the system is defined in three steps following the general rule Sense > Define > Act. The level sensors measure wheel – body relative displacement for each wheel and the G-sensors located on the car body, two of them on the front axle and the third one on the rear are in charge of measuring the vertical accelerations. These measured signals from sensors added to many other information available directly from the CAN Bus (such as vehicle speed, steer wheel movement, longitudinal and lateral acceleration, braking status, others…) are treated as input for the ECU control strategy. Each 2ms software control strategy analyses vehicle status by reading input signals. If needed the ECU transmits an output current command to each shock absorber actuator in order to increase each damping force and correct/adapt vehicle dynamics deviation. See Fig. 1.

From shock absorber point of view, the standard technology has been combined with a fast response electro valve. The aim is to adapt the damping force – piston speed system to a damping force – piston speed – command current dependent system. See Fig. 2.

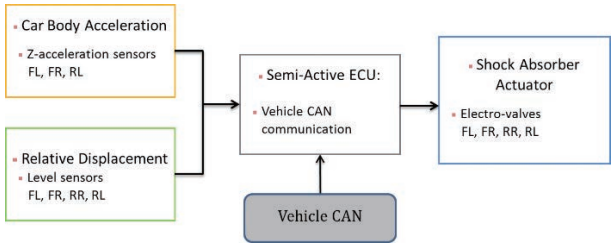

Fig. 1 System Architecture

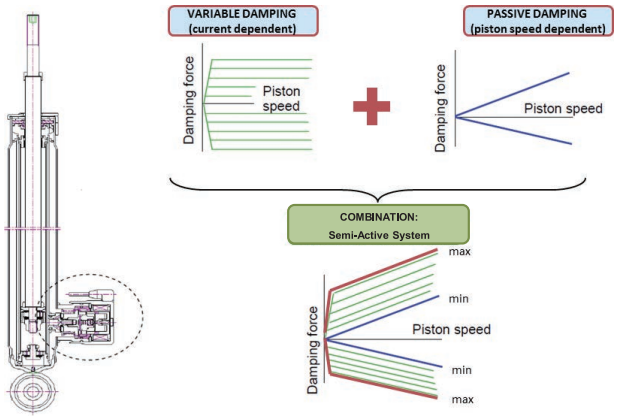

Fig. 2 Damping force, piston speed and command current dependent system

3 Semi-Active Control Strategy

During driving life, Semi-Active system will need to manage many different situations. By mixing vehicle

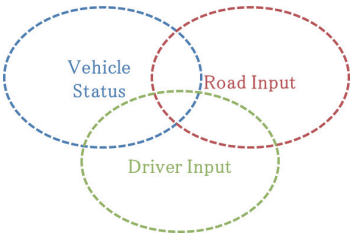

Fig. 3 Vehicle driving live situations

status with driver and road inputs, all these life situations are collected and Semi-Active control strategy must be able to cover all of them. See Fig. 3.

For the purpose of this study pure driver input live situations have been discarded. So from now on, we will focus just on road input cases. See Fig. 4.

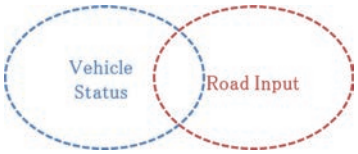

Fig. 4 Vehicle driving live situations simplified

Vehicle behavior must accomplish three main targets (Fig.5) and each of them is ensured by some functions or tools as described in Fig. 6.

Fig. 5 Vehicle behavior targets

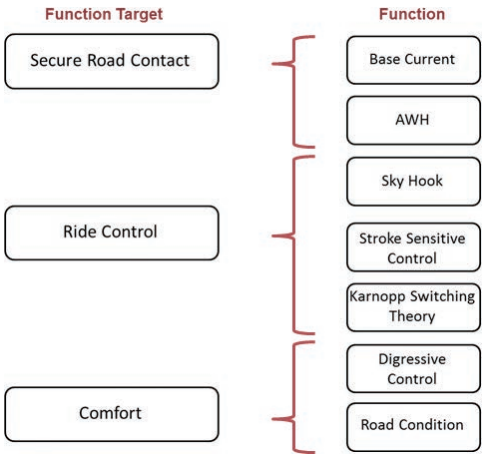

Fig. 6 Sw strategy functions for road inputs

For safety reasons highest priority target is to secure road contact. For this, a base minimum damping has to be set. This is handled by "Base Current" function and basically it applies a current command depending on vehicle speed.

To provide robustness to base damping in case of abrupt bumps and wheel hopping, "Anti Wheel Hop" function increases the command current during a period of time. This function detects wheel hoping case and adds a step of current to fix it. See Fig. 7.

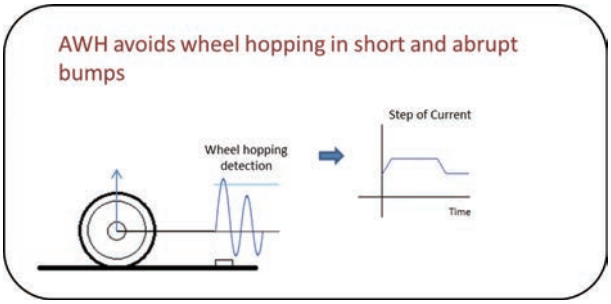

Fig. 7 Anti Wheel Hop Function description

Once minimum safety conditions have been stablished, control strategy is set to manage ride control. "Sky Hook" theoretical function has been chosen for this purpose. See Fig. 8.

Fig. 8 SkyHook functionality

As described in system architecture description, Semi-Active system has three G-sensors distributed in vehicle body in charge of measuring bounce, pitch and roll body rates. See Fig. 9.

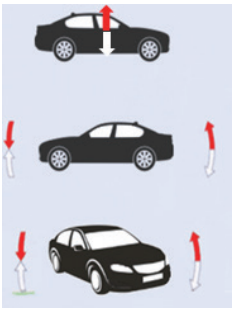

Fig. 9 Modal Speeds: Bounce, Pitch and Roll

After calculations using bounce, pitch and roll rates, vehicle speed signal and vehicle tuning parameters, Sky Hook function provides a continuous damping command to the system (Fig.10).

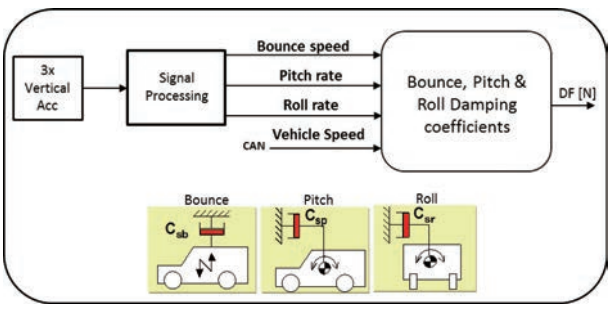

Fig. 10 SkyHook function DF calculation

In order to increase ride control efficiency at end stroke, the "Stroke Sensitive Control" function gain multiplies Sky Hook damping force command. See Fig. 11.

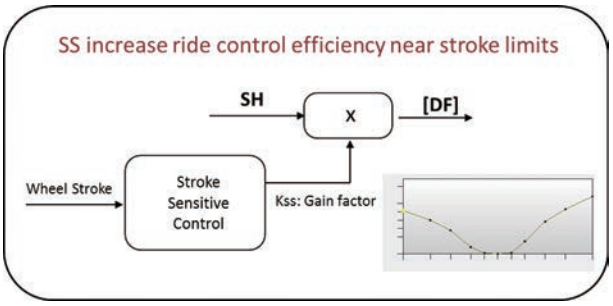

Fig. 11 Stroke Sensitive Function DF

Until this point, a continuous damping command has been provided to achieve ride control. In order to warranty vehicle flat behavior, the wheel and body relation movement sense has to be taken into account. For this purpose, software designer needs to consider the "Karnopp Switching Theory". See Fig. 12.

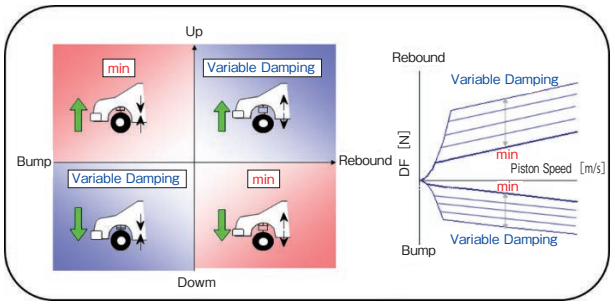

Fig. 12 Karnopp Switching Theory Description

Body and wheel vertical displacement combination can be split in four different cases: body up and wheel in compression or rebound, body down and wheel in compression or rebound.

For cases 1 and 4, Semi-Active control strategy sets minimum damping force in order to recover the reference position as soon as possible, while during cases 2 and 3 it is allowed to adjust the damping according to the damping command defined until now.

Taking a look to following road input example (speed breaker), a clear effect of "Karnopp" function can be seen. See Fig. 13.

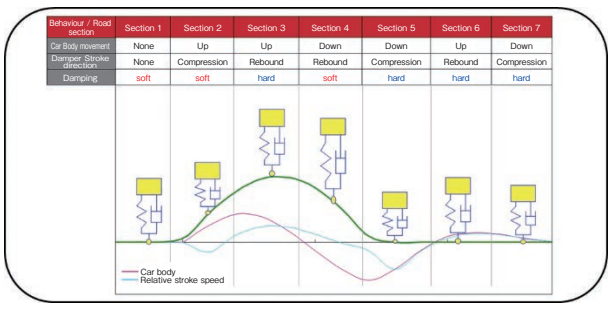

Fig. 13 Karnopp Switching Example

Once having managed body control, it's time to take a look to comfort and increase the filtering. "Digressive Control" is responsible to decrease variable damping in case of impacts throw aggressive road inputs. See Fig. 14.

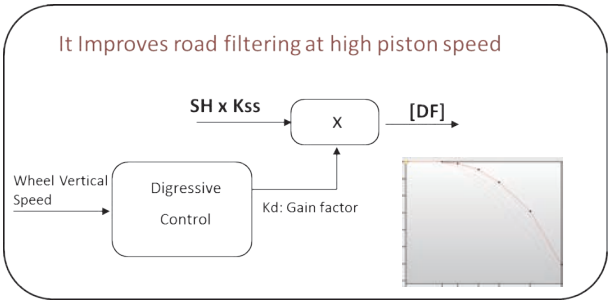

Fig. 14 Digressive Control Function DF calculation

This simple function is very efficient in case of single input, but for continues road inputs, what usually it's call "rough road", Semi-Active control strategy uses a last function called "Road Condition". See Fig. 15.

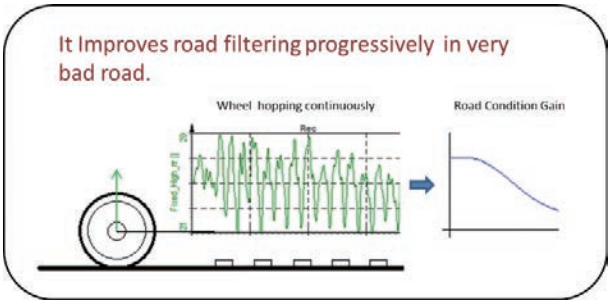

Fig. 15 Road Condition Function Description

If continuous wheel hopping happens, the function adapts requested variable damping progressively until having the desired filtering.

4 Theoretical Strategy Limitation

Highest limitation of semi active suspension is the non-possibility to predict road inputs. Nowadays autonomous driving technology is providing many different solutions of preview systems, but even combining some of them, they are not robust enough to work properly 100% of driving time. This means that Semi-Active system must cover robustly all live situations by itself. To be considered that no preview systems have been taken into account during this case study.

As the spring properties can't be adapted, and time consumption for movement stabilization is needed. an optimization by "Karnopp Switching" function has to be done by applying a minimum damping in some maneuver steps.

Let's imagine a worst case, comfort oriented vehicle, with short stroke shock absorbers and the lack of damping in some steps according to semi active suspension func-

tionality, this implies a high risk of impact noise and lack of body control in aggressive road inputs, for instance, speed breakers or down steps.

Fig. 16, shows a real case study measurement, where some rebound end of stroke impacts can be seen just in the last down steps.

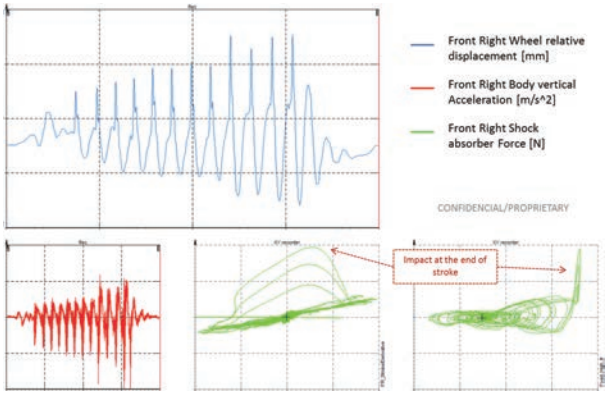

Fig. 16 Down Steps track, with rebound end of stroke impact noise example

During this test the last 4 steps of 70mm height have been enough to trigger rebound end of stroke impact noise. This fact is very clear in downstairs right graphic, force vs displacement, where some force peaks appear just at the end of rebound stroke (positive).

5 Studied Solutions

In order to solve the issue, two different solutions have been tested. First one, based on a passive solution, a HRS

Photo 1 HRS

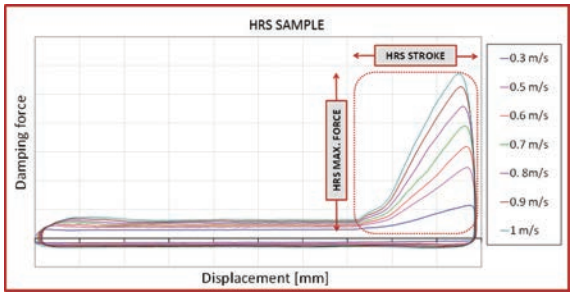

Fig. 17 HRS Damping force characteristics

("Hydraulic rebound stopper") system have been used. See Photo 1 and Fig. 17.

Basically, using a deformed inner tube and a plastic segment located in piston rod, a new chamber is created in rebound side, and it is increasing damping force according to piston speed and rebound stroke.

This is a fantastic solution to improve shock absorber efficiency at the end of rebound stroke because it absorbs a great quantity of energy, fast and progressively.

On the other hand, the implementation of this system has an important cost impact on shock absorber price.

The second solution tested, has followed same HRS philosophy, but in this case, it has been implemented modifying software control strategy. So, a new function has been implemented, and called DHS ("Double Hydraulic Stopper"). See Fig. 18.

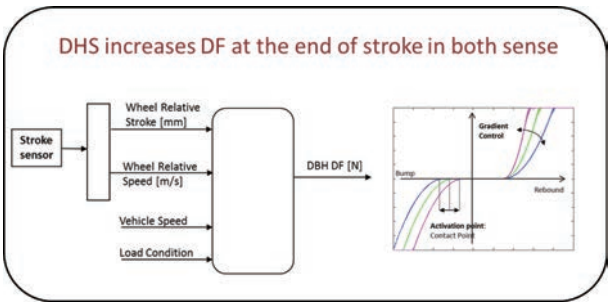

Fig. 18 DHS function DF calculation

The function adapts the damping command (activation point and gradient) according to vehicle speed and load condition.

DHS function avoids end of stroke impact noise and provides robustness to ride control in aggressive road inputs as speed breakers or down steps. See Fig. 19.

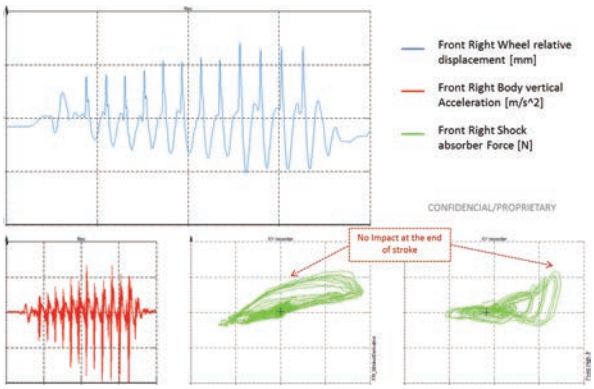

Fig. 19 Down Steps track, without rebound end of stroke impact noise

6 Summary

KYB provided two different solutions to solve impact noise and lack of ride control in aggressive road inputs as speed breakers. Finally the customer decided to go on

with DHS software solution. See Fig. 20.

By intelligent combination of theoretical strategy and experimental function, KYB has managed to improve noise filtering and avoid extra cost to our Customer. Studied solution has been implemented in mass production software strategy.

KYB is now extending the limits of the system in order to enhance even more the body control and comfort level as expected from such an intelligent technology, KYB's Semi-Active Suspension.

We believe that providing solutions to specific requirements as in this project we also led to build up our know-how and expertise on E/E (Electrical/Electronics) system development. We would like to take advantage of this experience to continue adding value to electronic controlled system which seems to be the future.

Last but far from least, I'd like to express my sincere appreciation to my colleagues great cooperation during this project development.

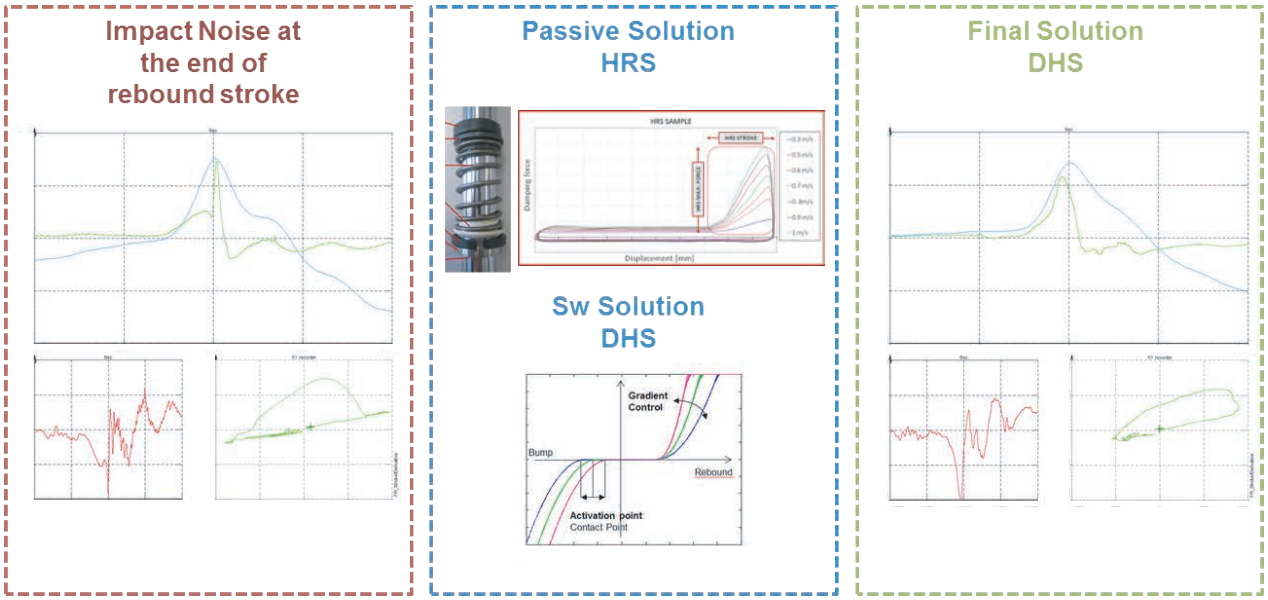

Fig. 20 Summary

Author

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Join the company in 2012.
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Product Introduction

Development of Inverted Front Fork for Small- and Mid-sized Motorcycle

MIYAUCHI Yoshihiko, OZAKI Kosuke

1 Introduction

People's income in the Association of Southeast Asian Nations (hereinafter "ASEAN") region has tremendously increased in recent years. The higher income certainly affects the local motorcycle market. The market has seen a change in the popular category of motorcycle bodies and required motorcycle performance.

The front fork (hereinafter "FF") that connects the body to the wheels contributes to motorcycle stability with its control of vibration input from the road surface, vehicle position control and its presence as a component to provide vehicle strength. The circumstances of the FF have been affected by the higher income of the ASEAN population too. Against the conventional cost-centered product concept, appearance and performance have gained more and more attention.

2 Aim of Development

The conventional popular motorcycles in the ASEAN region were mopeds [Note 1)] and scooters (Photo 1) with an engine displacement of not more than 150cc. The rising income in the region raised the demand for larger-displacement motorcycles. Various motorcycle racing competitions typified by the Asia Road Racing Championship (Photo 2) have also become popular in these countries. With these situations, components for small and mid-sized motorcycles, that are differentiated from conventional products and make customers feel even higher added value, are in demand. As a product group to satisfy the market needs, a new inverted front fork with high salability has been developed.

Photo 1 Example of scooter: Mio Z [Note 2)]
(Source: Yamaha Motor Co., Ltd. Website)

Photo 2 Asia Road Racing Championship
(Source; Yamaha Motor Co., Ltd. Website)

Photo 3 Example of moped: Jupiter MX King150 [Note 2)]
(Source: Yamaha Motor Co., Ltd. Website)

Note 1) The term "moped" used in this article refers to a manual variable speed motorcycle in the shape shown in Photo 3. (In general, the moped often refers to a motorized two-wheeled vehicle with pedals).

Note 2) Mio Z and Jupiter MX King150 are trademarks of Yamaha Motor Co., Ltd.

3 Overview of Development

None of the production sites of KYB Group in the ASEAN region has a track record of producing inverted FFs or offers inverted FFs of a size suitable for small and mid-sized motorcycles. It was then decided to develop an

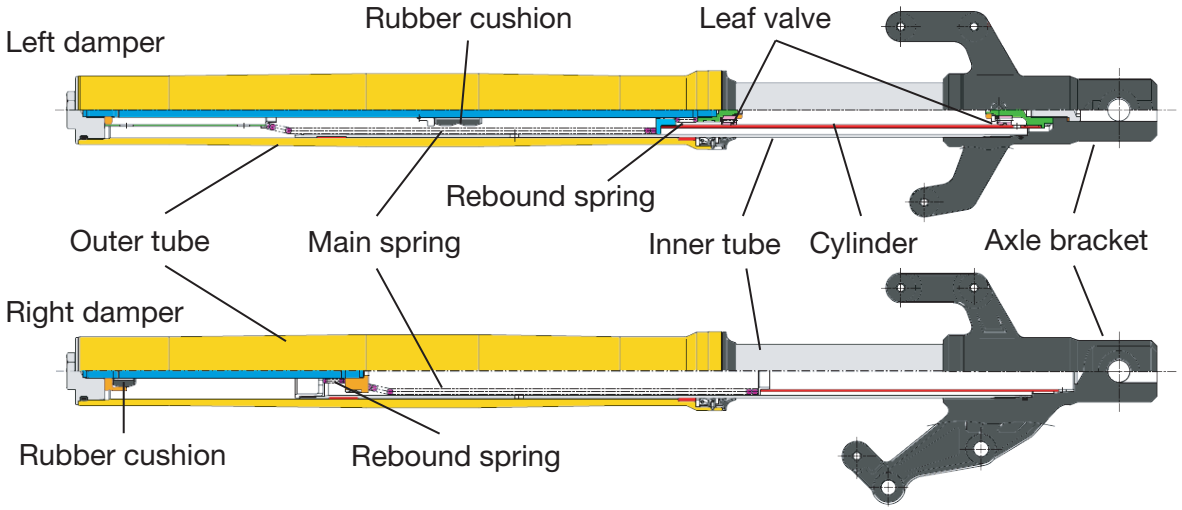

Fig. 1 Structure of ø37 inverted FF

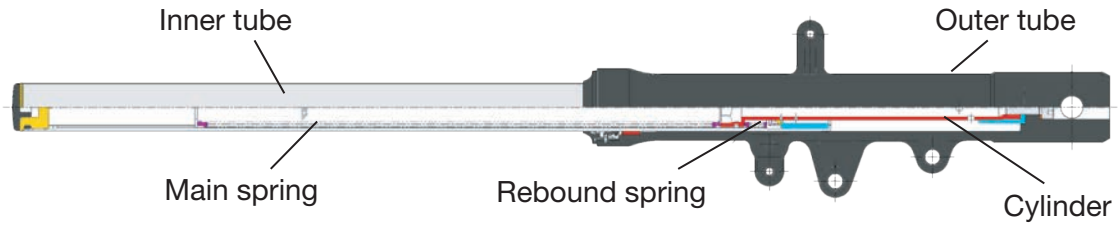

Fig. 2 Example of standard FF

inverted FF with an inner tube diameter of ø37, which was considered to be the best-balanced product for toward the 150cc to 300cc class.

The structure of the newly developed inverted FF is shown in Fig. 1 and the following section:

3.1 Basic structure

The newly developed FF is of inverted telescopic type [Note 3)]. The inverted type has its outer tube up and its inner tube down. Another type in which the outer and inner tubes are arranged on opposite sides is called an standard FF (Fig. 2).

In general, the FF is mounted on the body with the two dampers sandwiching the front wheel. These right and left dampers are joined with an axle and upper and lower brackets. The dampers serve as shock absorbers with their built-in damping force generator and coil spring.

Note 3) The term telescopic type refers to a mechanical structure consisting of several tubes of different diameters to be able to freely expand or contract in the longitudinal direction.

3.2 Specifications of components

3.2.1 Damping force generator

The new inverted FF uses a cartridge type damping force generator that can generate a damping force with its piston assembly containing a leaf valve so as to provide good responsivity even suited to sports driving.

While the ordinary inverted FF has a damping force generator in both dampers, this cartridge type has a damping force generator only in the left damper as it can deliver a sufficiently high damping force with a single generator. As a result, cost reduction can be achieved.

3.2.2 Springs

The new FF has the following spring elements:

① Metal coil springs
② Rubber cushions
③ Air springs

The new FF uses two kinds of metal coil springs. One is a main spring that generates a spring force in the direction of expanding the dampers over the stroke. The other is a rebound spring that is only used to alleviate the shock after the dampers fully expand.

The rubber cushions can alleviate the knocked-up feel during bottom hitting [Note 4)].

The air springs utilize the pressure increase in the enclosed chambers of the dampers when the air is compressed. They mainly contribute to the feel of "go further" in the end of the stroke.

Note 4) The bottom hitting refers to a phenomenon in which the inner tube bumps into the bottom of the outer tube during the full stroke of the FF applied with a strong compressive load by the tires when the motorcycle runs over a step for instance.

3.2.3 Outer tube

The outer tube of the inverted FF uses a tubelized aluminum alloy pipe. The production method for the outer tube was selected by giving considerations to local avail-

ability.

The tube is surface-treated with colored anodized aluminum to possible local work specifications.

3.2.4 Inner tube

The inner tube is one of the important parts that decides the strength and performance of the FF. The relationship between the displacement and inner tube diameter of a motorcycle with an inverted FF is shown in Fig. 3.

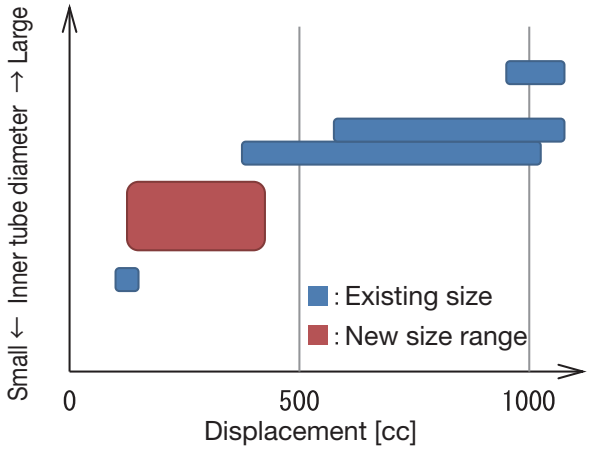

Fig. 3 Inverted FF inner tube size

4 FF Rigidity

The contribution of FFs to motorcycle stability was mentioned in the beginning of the article. Small and mid-sized motorcycles have used an erecting FF with an inner tube sized from ø33 to ø41. In developing this new inverted FF for those motorcycles, it was easily imagined that stability would be substantially affected.

First of all, it should be noted that the inverted FF is clamped to the vehicle body with its outer tube and the erecting FF is clamped to the vehicle body with an inner tube that is different in size from the outer tube. This generally means that the inverted FF has high rigidity and the erecting FF has low rigidity. A high-rigidity FF will help stabilize the motorcycle position during braking, high-speed running or turning. Even during quick steering such as slalom riding, the rider can cut the handle with excellent responsiveness.

However, it may be inconvenient in some cases to use the inverted FF on a vehicle that uses an erecting FF because of its quick responsiveness. The rider may feel too responsive, or even unstable compared to the existing erecting FF. This difference in rider feel was the most difficult part of the development. Some measures to integrate the inverted FF, which has inherently different properties from the erecting FF, into the vehicle were needed.

Then, a new attempt was made to create a 3-dimensional (3D) model of FFs and determine the rigidity through the finite element method (FEM) analysis. The analysis model is shown in Fig. 4.

Different rigidity levels of the erecting and inverted FFs were derived from the analysis and compared with each other. The component profile affecting the rigidity was changed in different ways to achieve integration. As a result, the inverted FF has been successfully adjusted to have a rigidity level suitable for small and mid-sized motorcycles on an analysis basis.

Actually, the determined rigidity was verified with sensory evaluation using an actual motorcycle equipped with a prototyped FF. The sensory evaluation will be described in the following section.

On the other hand, the decrease in the higher rigidity of the inverted FF means lower strength. The analysis has verified that the absolute strength of the FF and the strength balance between the vehicle body and the FF have no problem. In this way the specifications have been reviewed with few redos by using the FEM analysis.

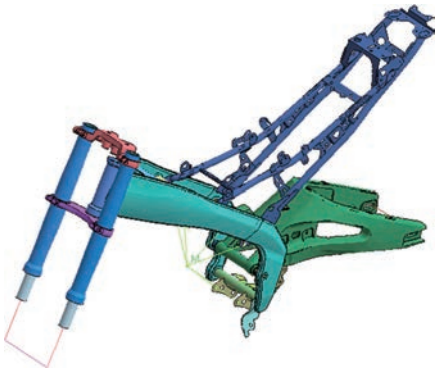

Fig. 4 FEM analysis model

5 Sensory Evaluation by Actual Vehicle

In addition to the analysis-based integration of the inverted FF described in the previous section, a prototyped FF was mounted on an actual vehicle to carry out sensory evaluation by the vehicle according to customer evaluation criteria. Several items including vehicle stability and riding comfort were evaluated.

The rigidity stated in the previous section is a property related to vehicle stability and particularly affects the steering feel upon quick steering during slalom riding as well as the vehicle stability during acceleration, braking or cornering. Since the shape determination through analysis resulted in the accurate adjustment of the rigidity, the prototyped FF was able to be smoothly set in the actual vehicle for sensory evaluation.

6 Cost Reduction and Local Procurement

We actually visited the site to work on determining a cost reduction solution in collaboration with local staff at the site. We discussed possible local manufacturing methods and component availability, and determined an

optimal design with these points taken into account. Finally, we achieved almost 100% local procurement, leading to cost reduction.

7 Product Situation and Future Outlook

The newly developed product started to be manufactured in volume in March 2017 and is being applied to other vehicle models for sales expansion. This standard inverted FF for small and mid-sized motorcycles is also planned to be developed as one of the company's key products. Production is expected to increase and the product will probably be used in more and more motorcycle models.

8 In Closing

The recent market of small and mid-sized motorcycles of less than 400cc has dramatically changed. European motorcycle manufacturers, who have mainly manufactured large-displacement motorcycles for developed countries, are now entering the small and mid-sized motorcycle market as well. These motorcycles use inverted FFs of a size equivalent to that aimed by KYB with its motorcycle suspensions. The market of motorcycles of this displacement range is currently overheated with the additional participation by European manufacturers. We cannot take our eyes off the market situation.

We are proud that the newly developed product has been used in the motorcycle model shown in Photo 4. We will make further efforts to have a stronger presence in the market.

Photo 4 YZF-R15 [Note 5)] equipped with ø37 inverted FF
(Source: Yamaha Motor Co., Ltd. Website)

Note 5) YZF-R15 is the trademark of Yamaha Motor Co., Ltd.

Finally, we would like to cordially thank all those in the related departments who extended support in product development.

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Introduction

Journal of Asia Cross Country Rally

TANAKA Kazuhiro

1 Introduction

The Asia Cross Country Rally (hereinafter "AXCR") is South East Asia's largest four-/two-wheel rally raid race certified by the International Automobile Federation (FIA) and the International Motorcycling Federation (FIM). Starting from the Kingdom of Thailand, participants drive through its neighboring countries. The 2017 AXCR marked 22 years of history. This is a formal international competition of this kind that is geographically closest to Japan and can be expected for the country to deliver a tremendous advertisement effect in the Asian region. Many Japanese teams with business strategies enter the rally, including those based on Japanese automobile manufacturers or four-wheel drive (4WD) vehicle related companies. Particularly in recent years, AXCR has seen a fierce battle for championships by international cars for emerging countries manufactured by various automobile makers. The participating teams have substantially raised their racing level in their rally vehicles with dramatically improved performance. From Japan, a lot of private teams also participate in the rally probably because AXCR takes place during the summer holiday season in Japan and the costs incurred for participation is reasonable.

The rally course is immensely rich in variety, ranging from labyrinth-like jungle, steep mountainous areas, high-speed gravel-surfaced roads with solid red soil, tarmac winding roads, rocks and mogul sections like trial competitions, to grass tracks including wading. AXCR also features variable road conditions as it takes place in the rainy season. Rainfall may loosen the hard red clay soil to form a slippery mud road surface or change any hollows and mountain streams into sumps or rivers. These conditions may be difficult for even racing vehicles to pass through (Photo 1).

Recent AXCR is arranged to have a total mileage of around 2,000 km and is scheduled so that racers can run on the whole course in six days. The 2017 AXCR had a total mileage of about 2,144 km, of which the road section (hereinafter "RS") was about 972 km and the special stage (hereinafter "SS") about 1,172 km. On the day with the longest mileage of about 420 km, about 250 km was time attack racing. To compare, this would be like driving from Tokyo to Nagoya on general roads in a day of which the section between Kanagawa and Shizuoka Prefectures is a competition.

Photo 1 Bad road surface due to rainfall

2 Position of Cross Country Rallies

Motorsports of four-wheel cars can be roughly classified into three types: racing, rallying and trials.

Racing is a competition where multiple motor vehicles run simultaneously on a closed course such as a circuit to compete with each other. The most famous being the top-ranked Formula 1 (F1).

Rallying consists of the RS rallying that racers have to accurately drive each segment of a course in a specified time and the SS rallying that racers compete against the time of running over a specified section of a course. In either type, each team starts the rally at fixed intervals. Multiple RS and SS rallies are usually set and the RS penalty time is added to the SS running time to determine rankings. Rallying also features two contestants: a driver and co-driver who navigates. The famous rallies include the World Rally Championship (WRC) and the Dakar Rally.

Trials refer to time trials in which each vehicle runs on a specified section of a course to finish as quickly and accurately as possible. Examples of these trials include

Gymkhana, Dirt Trial and Drag Racing.

In addition, many other motorsport activities exist: Eco Run to struggle for fuel efficiency and drift championship for competition with vehicle position and speed during drifting.

Rallying can be divided into two types: Sprint Rally, typified by the WRC (Photo 2) and Rally Raid, typified by the Dakar Rally (Photo 3). A major difference between the two is that Sprint Rally has a pre-run process called reconnaissance or recce that allows drivers to run on the stages of the course before competition and create their own pace notes on the course information, based on which they tackle the time attack racing. In either type teams run on a specified section to compete with each other for the running time over the section based on the distance information, as well as branch and obstacle information indicated on competition maps called "route notes" (Photo 4) supplied by the organizer.

Photo 2 Sprint Rally (Japanese Rally Championship)

Photo 3 Rally Raid (AXCR)

For Rally Raid in turn, the target stages of the course for both RS and SS are not allowed to be scanned prior to race. Drivers have to compete with each other on the stages they run for the first time. In this way Rally Raid requires them to always try to identify the proper course by using the route notes during SS time attack racing. For complex routes with a high degree of difficulty, it is quite difficult to completely avoid time lost due to course error

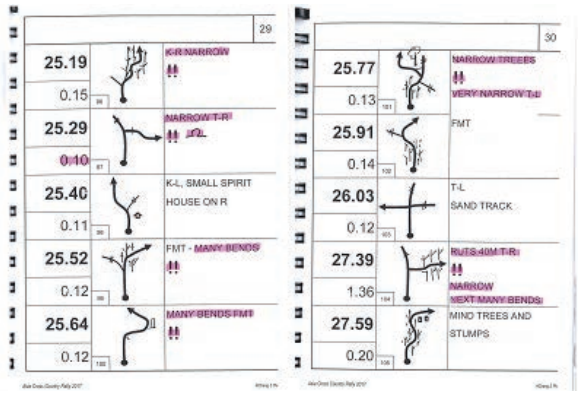

Photo 4 Route notes

or a penalty time charged by not-passing a check point, greatly affecting the running time.

Another difference is that Sprint Rally is conducted on properly maintained general or forest roads while Rally Raid is more like an adventurous endurance race in which drivers rather run a long distance off-road course under natural conditions.

Furthermore, Sprint Rally racers can improve their driving accuracy by accumulating experiences on the same course as they run over and over again without changing their camp location where the operation headquarters are established. For Rally Raid, they relocate their camp almost every day to move ahead toward the destination. Competitors repeat their great movement over several days and almost never run on the same course.

Drivers running on their first-ever course need to instantly determine the situation from their own driving feel & empirical value, actual visual information and navigational information provided by their co-driver, and must be adaptable to properly control the vehicle and drive faster. Co-drivers must be able to identify where they are by reading the route notes, give the driver proper route instructions, control the rally progress time of their own vehicle, obtain and develop the latest information about the general rally progress provided by the organizer, and manage the driver's mental control. Co-drivers are thus required to have management skills in addition to navigation capability. During competition, the driver and co-driver have to overcome many different difficulties, including accidents and troubles through teamwork, trying to finish the rally. The relationship of trust between the two parties is very important and substantially affects the rally result.

3 Trend of Dampers for Rally Raid

Among international rally raids, AXCR has a relatively short total mileage, thereby imposing a lighter burden to racing vehicles. These vehicles are invested with less money for manufacturing accordingly and likely to be

finished by modifying limited parts. Therefore the suspension finishing substantially affects the rally results in many cases. AXCR may be a rally highly dependent on the damper performance.

Basically, participating teams can freely select damper modifications within a specified range, for example, changing the installation position, installing additional dampers and extending the damper length, although there are some limitations on usable dampers according to the regulations related to entry into each rally raid. Furthermore, the teams are allowed to almost freely determine the installation of a damping force control or vehicle level adjuster, the addition of a separate reservoir, provision of other additional functions as well as the material, size and form of dampers. The damper specifications can be set with a high degree of freedom (Photo 5).

Noticeable prohibitions include electronic or mechanical devices that allow competitors to voluntarily change the damping force or vehicle level during racing.

Photo 5 2017 AXCR Spec. damper for Team-JAOS

For off-road driving, the most effective means to ensure that racing vehicles can run through a whole bad road course is to extend the suspension stroke. The current predominant dampers are designed to have a long stroke by taking into account the angle of oscillation of the drive shaft and flexibility of the suspension link. In addition, many vehicles use a double damper setup with sub dampers added (twin shock type) for higher damper reliability against the input from the road surface during the rally as well as for additional damper functions. However, this double damper setup involves constraints related to possible interference with the suspension arm since the setup is installed in limited space within the tire house. On the other hand, a single damper setup (single shock type) only involves low limitation on the interference (Photo 6). It has advantages of lower damper cost, lower weight, fabrication in shorter time at lower cost, simpler maintenance, and lower number of spare parts to be carried.

The use of wide tread arms of a length different from the genuine product is possible depending on the modification regulations related to the entry. With these arms, some vehicles have a damper setup to substantially extend

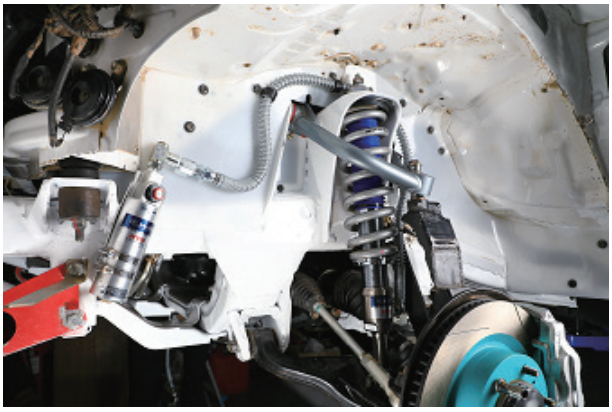

Photo 6 Single shock type (front suspension for Team-JAOS)

the suspension stroke so that the maximum possible stroke for the wheel shaft can be attained within the specifications. This configuration can achieve a certain long tire stroke that cannot be implemented with the genuine arm, providing a great advantage of improved running on bad roads.

There are various ideas about damping force characteristics. It may be useful to take measures for two separate damping zones: a regular bad road zone for ordinary off-road running and a full bump zone involving jumping & landing in relation to large hollows. In regular bad road zones, importance is placed on the adhesion of tires and a low damping force is preferred. In full bump zones, a high damping force is needed. These are tradeoffs of damping forces during off-road running. Normal dampers have a speed-dependency structure and cannot resolve the tradeoffs. The two factors only have to be compromised with an aim of striking a balance between the two as far as possible, resulting in compromised damping force characteristics.

One of the recent potential solutions is to replace the rubber or urethane cushions installed between the vehicle body and suspension arms with hydraulic or pneumatic position-dependency damping force mechanisms that can alleviate only the input during full bump, although it depends on the regulations. In this case, the conventional speed-dependency damper structure remains to still ensure the characteristics suitable for the regular bad road zone. This solution resolves the tradeoffs stated above.

In terms of strength, it is difficult to find durability-oriented specifications similar to the damper design for mass-produced vehicles. Therefore, a robust design is preferred in which the worst possible input case during the actual rally and safety margin have been taken into account. The dampers can hardly be changed with new ones within the competition section in the same way that flat tires are changed. If the vehicle cannot reach any service point for repair, it may have to retire from the rally. A breakage of dampers that would immobilize the vehicle is not acceptable, so robustness takes precedence over weight. The resultant damper design is a large

damper, like those for trucks that have large outside diameters as well as large rod diameters.

The heat generated during running on long-distance bad roads decreases the damping force, leading to inferior steering performance and stability of the vehicle. The upsized dampers need more damper oil and installation of separate reservoir leads to measures against the generated heat, using even more oil. A large aluminum reservoir equipped with a radiating fin is introduced in some cases, with an expectation for a cooling effect from the wind during running (Photo 7).

Photo 7 Large aluminum reservoir

The rally raid damper market has products from many countries. Particularly, U.S. damper manufacturers introduce a lot of products to the market. The reason behind this fact is that off-road or desert races typified by Baja 1000 are brisk in the U.S. Off-road race goods, including customized parts are commercially viable to form an after-sales part market in the country.

4 Participating in AXCR

KYB supports a rally team named "Team-JAOS", mainly consisting of JAOS, a Japanese general 4WD after-sales parts manufacturer. The team had participated in AXCR as part of its forerunner "RV Park with JAOS" for two successive years since 2004. In 2015, JAOS eventually established its own independent team as a project to celebrate its 30th founding anniversary.

KYB's relationship with JAOS originated in around 1998 when KYB started to supply damper products for 4WD vehicles to be introduced into the customization market. KYB began supporting rally activities when JAOS participated in AXCR in 2004. This is its third year of participation in AXCR as an independent team. I have continuously provided technical support since its establishment.

4.1 2015 AXCR

In the 2015 AXCR when the team was established, I was given an opportunity to accompany the team to the site as both a damper engineer and mechanic. I was selected as a supplementary member to strengthen the foundation upon establishment of the team since my capability of designing/developing dampers and my experience in on-site technical support for the leading teams participating in the Dakar Rally were recognized.

In addition to being a supportive damper engineer, I was assigned with an important role as mechanic or team crew. That was a valuable experience I had never had before.

The general daily schedule started with a final inspection of the rally car in the morning, watching the start with my own eyes, arriving ahead at the merging area in the afternoon to carry out minor maintenance called remote service, and arriving ahead again at the camp in the evening to do major maintenance service for the next day (Photo 8) until midnight. This flow of activities is repeated every day during the competition period. I was required to do speedy, accurate work for days on end in outdoor sites with poor equipment under a higher-temperature, higher-humidity environment than in Japan. Particularly, the afternoon remote service was busy and the maximum maintenance menu had to be completed in a limited time as short as around five minutes. The maintenance menu included temporary repair of broken parts, inspection and oiling of applicable parts, wiping of windshield glass and number decals, and replenishment of drinking water and food. These tasks should be promptly prioritized and assigned to mechanics so that they can quickly complete their own work menu. I directly felt a one-of-a-kind atmosphere with much excitement and strain. The sense of finished work in securely sending off the car was a privilege that could be experienced only by mechanics.

Photo 8 Mechanics doing service work until midnight

I remember an impressive day on which a machine problem could not be smoothly resolved and mechanics continued working in the rain until midnight without taking dinner. Under the depressive atmosphere, a manager-ranked member brought us hot sandwiches and Coca-Cola bought in a convenience store as provisions. I felt the food most delicious during the competition period.

The rally car was a Toyota FJ Cruiser, modified from a demonstration car owned by JAOS. With its wide body of a width of about 1.9 m, the vehicle was actually difficult to steer in the jungle, but quite reliable as it showed pow-

erful running with a gasoline engine of large displacement (Photo 9) in steep mountainous areas.

Photo 9 First entry as Team-JAOS

4.2 2016 AXCR

In the 2016 AXCR, I was assigned to be team manager based on the previous years' experience as an on-site supporter, in addition to damper engineer & mechanic as before. The mission of team manager varied from determining the service crew activity schedule, identifying the maintenance points of the rally car, controlling the spare parts, procuring food and beverages, to money control. I strongly remember that I ran around here and there all the time while getting involved in damper or vehicle maintenance so that mechanics could focus on working stress-free. Partly because I was short of sleep, which was even worse than in the 2015 rally, I came back to my room and lay down on the bed to just take a rest for a while after a prize-giving ceremony party, but I fell asleep there. I eventually missed the following celebration party of the team. This is a still regrettable memory.

I was also impressed by border crossing from Thailand to Cambodia during movement in the competition. I left Thailand with departure processing and then walked about 50 meters to cross the border (Photo 10). Then I completed my entry formalities to Cambodia. The cross border walk was wonderful for me as a Japanese who lives in an island nation. I did not know why, but local people freely crossed the border without any processing, which was also strange to me.

Photo 10 Border on the Thailand side

For this rally, a new model of Toyota HILUX REVO, which had not yet been introduced to Japan at that time, was directly imported and finished as a rally vehicle in a short period. This tough vehicle with a ladder frame structure and high-rigidity chassis ran the whole distance without failure in spite of minimum reinforcement (Photo 11). The vehicle was modified in its many parts even during the short time. For example, the long body of a total length of about 5.3m was converted into a short deck for easier steering on the narrow rally field. The rear suspension was also relocated. The knowhow accumulated in this modification was put into use in the vehicle modification for the following 2017 AXCR. 2016 was the year in which we acquired important data.

Photo 11 2nd year with a stronger tie between JAOS and KYB

4.3 2017 AXCR

In the following 2017 AXCR, the collaboration between JAOS and KYB was further strengthened. As my technical support and on-site accompanying as a team member in the past two years' competitions were recognized, I was assigned with the leading role as a co-driver in addition to damper engineer. Against the package-type damper specifications in the previous two years that were based on the product concept for general customers, the objective in the 2017 AXCR was to pave the way for the development of a high-performance damper comparable to those made by leading overseas damper manufacturers.

An aim behind the objective was to evaluate a damper designed by an engineer in the actual rally himself by driving the actual vehicle and to directly feedback to Manufacturing. This was a very valuable opportunity for me, as an employed engineer. I spent a quite busy year playing both roles as a damper engineer and a competitor. I strove not only to design and manufacture a new high-performance damper but also to obtain a competition license, take training as a co-driver and improve my physical prowess. I did not forget spending with my family to compensate my absence from home during the

summer holidays as in the previous years. Thus I prepared for the rally as much as possible in both my public and private life.

All events during the competition were fresh and exciting to me, although I was nervous or confused in many scenes. It was also true that I spent hard days getting a harsh lesson on the rally raid almost every day (Photo 12). The rally environment was severer than I imagined. For example, the route setup was so difficult and more complicated than in previous years that even an experienced co-driver could miss the course. I also had to handle emergency repair of sporadic vehicle problems, heatstroke due to high temperatures, and fatigue from long-distance/time SSs. I felt acutely anew that a rally raid is a survivor rally for human beings and that a contestant needs to have not only experience, judgement, physical fitness, mental power, but also a wild hunch.

Photo 12 The author in the car as co-driver

The dampers endured the running over the total distance of about 2,000 km over six days under various adverse road conditions free from trouble or need for maintenance, demonstrating their strength, rigidity and endurance. In terms of characteristics, I fully experienced the strong and weak points myself and consequently obtained many hints for future improvement. In particular, the actual rally track was found to be different in many points from the trial track used during the development stage. Selecting a highly reproducible road surface will smoothly promote the development in my opinion. I was also convinced that any items to be improved should be addressed with the whole vehicle, not only with the dampers.

A simple idea of ensuring that rally cars can run faster, which is in fact common to all motorsports cars, is how long the driver can depress the accelerator. In rally raid races, it is ideal to run the whole course with no need for deceleration, as if there is nothing wrong no matter how irregular the road surface is.

Like the 2016 race, our team took part in the 2017 AXCR with a Toyota HILUX REVO. Based on the result in the previous year, the vehicle was improved in many areas, including a substantial change in arrangement of the rear suspensions. Despite being a hard race equivalent to, or even harder than the previous year, the vehicle had no obvious trouble, proving its toughness. The colored skeleton graphic body (Photo 13) was something new.

Photo 13 Colored skeleton graphic body

5 Automobile Situation and Rally Raid in Thailand

Thailand is an important country for Japanese manufacturers to establish overseas production sites. This is also the case with automobile related companies, including KYB. Like the base vehicle of the rally car used in the AXCR races, a number of locally produced cars run in the cities. It is also certain that cars imported from Japan are popular in Thailand. The proportion of Japanese cars throughout the country is quite high according to my impression.

Among these, pickup trucks, which are seldom seen in Japan, are rather popular in Thailand. They seem to be selected by Thais as general passenger cars, a method of transportation that can carry many people and cargo and run even on unpaved roads, although this may vary by city. Pickups are used, not only as regular trucks, but also as taxis or even police cars (Photo 14). For AXCR as well, many pickups are selected as racing cars probably because of advertisement strategies of automobile makers with a focus on the local market.

I had a lot of opportunities to visit local cities and rural villages in Thailand in supporting the rally. I had the

Photo 14 Police car (left) and taxi (right)

impression that roads in these areas are unpaved but maintained quite well, and the road improvement covers even deep in the mountains. I saw highway construction work in many places all over the nation, including towns and mountain villages. As I have heard that countries with a higher standard of road infrastructure development have a higher economic growth rate, Thailand seems to have achieved a steady economic growth.

The highway network development allows people to come and go actively, even in remote areas. In the SS rally section, I passed by several villagers riding on scooters in spite of being in a mountain area far from town (Photo 15). I also had the impression that the number of routes suitable for racing has unfortunately decreased inside Thailand when I considered safety during competition and the adventure characteristics of the rally raid. As more and more roads are improved, however, sprint rallies, instead of rally raids, may become popular in future in the country.

Photo 15 Local children coming to watch the rally

6 In Closing

Many people both inside and outside KYB extended cooperation and support to me in participating in the 2017 AXCR as a co-driver. I successfully entered the competition and finished the course in the end (Photo 16).

On this occasion, I would like to deeply thank all those concerned.

Photo 16 The team that finished 2017 AXCR (author on the right)

Author

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Joined the company in 2001.
Design Sect. No.3, Engineering Dept., Suspension Headquarters, Automotive Components Operations.
Engaged in development of commercial shock absorbers.

Editors Script

Scripts for KYB Technical Review are corrected by the editors prior to each issue. I, as an editorial member, checked the scripts for a whole day and noticed anew the variety of products and technologies covered by the authors.

Naturally, the scripts contained a lot of information I did not know, and some of them were too difficult for me to readily understand. In fact, every article has its own unique drama that has been concentrated into several pages after repeated reviews by the authors. The fact convinces me again that these articles are very valuable.

(YOSHIMURA Mitsuaki)

Over 20 years have passed since I got involved in engineering design. Recently I have felt difficulty, particularly in developing products beyond my own ready-made ideas. When I read the Technical Review, I sometimes happen to see an article that surprises me, saying to myself "I've never thought of it that way". Of course I do not fully understand the details of the technical information, but such articles could be read as that the authors dared to introduce an approach normally very difficult to be used according to my own common sense. I imagine that these articles were produced by the authors who gave it a try beyond common sense, stereotypes or ready-made ideas. I want to work on activities without denying any new hints, awareness or new ideas, so as to produce what is beyond the current status.

(AKATSUKA Koichiro)

The first job for me, as an editor, was a report on an expatriate experience in China where I had been stationed before too. I noticed in the report that the same country, China in this case, may be recognized by individuals as a totally different environment depending on their sense or area they stay in. That was a pleasant surprise.

This issue of KYB Technical Review includes a report on an expat experience in Thailand where I have only visited on a business trip. From the report, I have learned many things that one can figure out only through actually living there. That is interesting for the editorial members. As an editorial member of KYB Technical Review, I will continue keeping in mind to communicate the fun of the Review to readers.

(CHIGUCHI Shinichi)

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