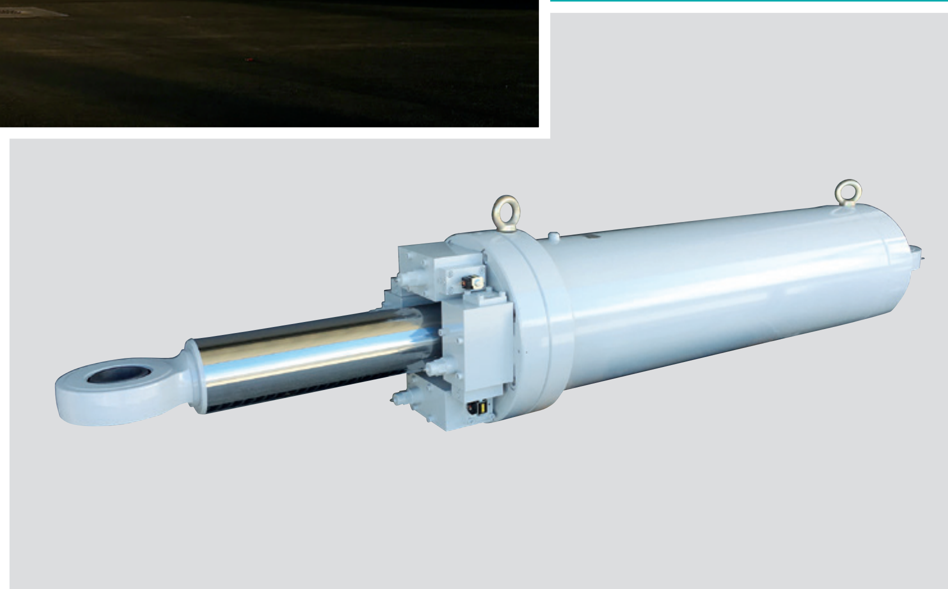

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CONTENTS

(**Cover Photograph**: Springs Plated with PREGIO-HCPS 〔see p.43〕, KMEX SA Plant 〔see p.49〕, Oil Damper System for Seismically Isolated Structures with Lock Mechanism 〔see p.79〕).

Foreword

Live with the Times

KOMAKINE Takashi*

While I tell myself on a daily basis that people who live alongside science and technology must continue learning, society demands technologies that everyone can use without studying. However, in order to at least benefit from such technologies, understanding and getting used to advancement are necessary. 157 years ago in 1864 when the Ikedaya Incident took place at the end of the Edo Period in Japan, the U.S., which was in its third year after the transcontinental telegraph system was completed, was in the middle of the Civil War. This year, Maxwell formulated a mathematical theoretical formula regarding electromagnetic waves in the U.K. In the beginning of the 1900s, Marconi succeeded with an Atlantic wireless transmission. In Japan, Dr. Uichi Torigata, who is from Odate of Akita Prefecture, carried out successful two-way wireless telephone communication in 1917. Today, 100 years later, we are enjoying the benefit of communication technologies, including mobile phones. In such a generation of technological development, the timing in which one lives their life greatly affects his/her technological life. I would like to reminisce how my life has taken its steps in this era of technologies by reviewing the technologies that I have learned and have been familiar with in chronological order.

50 years ago in 1968 when the pager service started in Japan, I remember that my late father, who was an engineer with Nippon Telegraph and Telephone Public Corporation (now NTT), showed me a sample pager when I was still in elementary school. In the following year, I obtained an amateur radio license and found a technical field to strive for. Although pagers came to an end in response to the demands of the times, technologies shifted to mobile phones/smartphones.

40 years ago in 1976, NEC released the one-board microcomputer TK-80, starting the era of personal computers. This enabled us to easily perform digital processing of signals with microcomputers. This was the year in which I started studying electronics at university. Following my graduation, I majored in computer science in graduate school and obtained one more field of technical specialty. The shift to high-performance and high-functioning personal computers accelerated, and the built-in microcomputer technology has been applied to a wide variety of electric products. The fusion of communication and information is supporting the era of IoT and the client-server system.

30 years ago, I had the opportunity to research human auditory functions in a research center in Kansai Science City, and I had the chance to be present in the forefront of speech recognition/speech synthesis technologies. These were the forerunners of technologies, such as machine translation, that have become commonly available now. This experience has always supported my research to follow.

25 years ago, I was part of research and development of the densification of magnetic recording devices in a prefectural research center in Akita, where I grew up. The volume of common regular hard disks for PCs was approximately 10GB back then, but it is not uncommon for them to exceed 1 TB now, thanks to the practical application of vertical magnetic recording. The wave measurement technology, with which I worked during this research, has become a great source of motivation for my research activities since then.

20 years ago in 1996, HONDA's autonomous bipedal robot "ASIMO®" was released. Development of robots, which had a hard time standing up until then, rapidly advanced after ASIMO®.

15 years ago, I finally turned my 20-year-long hobby into action and started enjoying motorcycle circuit runs with people who share kindred spirits in my area. The technological advancement of motorcycles surprises me. Standard implementation of ABS has been advancing, and ETC/navigation systems now come as standard equipment. While tightening of exhaust gas and noise regulations is accelerating, sport vehicles are being made lighter and with higher power/more electronic control. A recent topic is application of a robotics mechanism that doesn't fall even while stopping, and motorizing is also possible. However, these machines directly show the skills and sense of the driver, which is one of their attractions. It is (I hope) not possible that the direction of future advancement will only lean toward technologies.

Let's return to the main subject.

I have been inspired by a number of technologies that I have encountered in a mere half century and have made my living by responding to demands. Most of these encounters were by chance, but seeing it from another point of view, the technologies that I create may affect someone's fate and change society. History teaches us that technologies that were meant for good sometimes lead to negative legacies. I hope to strive to solve issues of the time so that the results are worth passing down to the future generations.

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Editorial

Becoming a Truly “Technologically Developed Country”

SUZUMORI Koichi*

1. Introduction

It seems as though the words that have praised the technological capabilities of our country, such as “technology-intensive nation”, “monozukuri nation”, “robot nation”, etc., have been somewhat fading in recent years. However, there are always ups and downs over the long course of history. With a slightly longer perspective, I still think Japan has the capabilities to remain the world’s top technologically advanced nation. I have high expectations as someone who has worked in engineering and technology for many years.

I specialize in robots and actuators with a base of mechanical engineering. Since I graduated graduate school, I have been involved with technological development from a number of different positions in industry, government, and academia, such as research and development in private companies, research management in a national project (micromachine), research education in university, and venture management.

As a researcher/engineer in such positions, I would like to share my expectations and opinions on how Japan can continue being an exceptional “technologically developed country”.

2. Let’s Become a True Pioneer

Many robot-related “leading technologies” have been exciting the media and society. There are too many of these technologies to list, including AI, IoT, automatic driving, drones, 3D printers, humanoids, MEMS, microrobots, soft robots, cleaning robots, and surgical robots.

The creation and turnover of technological booms have been moving very quickly in recent years. To take the exhibitions that I have attended in the past several years as examples, 2016 was all about AI. 2015 was all about drones, and I wondered where the 3D printers from 2014 had gone.

Many of these new trends start in the U.S. These booms were created by topics, such as AI and IoT being used for research by Google and universities in the U.S., drones being commercially utilized by Amazon, and 3D printers receiving a massive investment by the Obama Administration.

However, these technologies were already in Japan as well. With AI, for example, NHK Science & Technology Research Laboratories was already promoting deep learning research around 1980. With drones, Keyence had commercialized quadcopters around 1990. With 3D printers, Mitsui Engineering & Shipbuilding had developed laser beam lithography in the 1980s. In terms of MEMS, pioneering research was already being promoted many years ago mainly by Dr. Teru Hayashi of Tokyo Institute of Technology in the form of micromachines. NEC has also developed a number of micro capsules that enter the human body to provide medication and collect biological fluid.

However, these unfortunately did not become major technological trends. After some time, they received attention in Europe and the U.S., and technological development was restarted as if to follow the trend. For example, a number of cleaning robots were tested by multiple major domestic electronic manufacturers around 1990. When we look at the photos of the prototypes at the time, robots similar to the current Roomba by iRobot were already completed over 20 years ago. When you restart the development after Roomba starts selling, you have no choice but to focus on the development of peripheral technologies. It is not that you voluntarily pioneered the new technology area to “have a robot clean the house”, which is the core of the innovation.

Even if you promote research and development based on novel ideas in Japan, evaluation from others doesn’t go beyond “That’s interesting. It sounds like it has potential.” And this evaluation is sufficient for the researcher. I have seen many such cases. However, once this theme becomes a boom in Europe and the U.S., it is suddenly regarded as an authorized research field in Japan, triggering others to follow. Unfortunately, there are many such cases.

I think that this is caused by the fact that Japan lacks “confidence and pride” that are supported by the history that has established the current “natural science” with Copernicus, Newton, etc. However, with the exceptions of European countries and the U.S., Japan now has the largest number of Nobel laureates. I think it’s high time that we have the “confidence and pride” of being in the forefront of “human wisdom” pioneering and become true pioneers of science and technology.

* Professor, School of Engineering, Tokyo Institute of Technology

3. Research Simultaneously Sprout Worldwide

I have a very "disappointing experience".

When I was in my late 20s, I launched a research project called "medical micro manipulator" (M3). Fig. 1 is the drawing that I drew then. It was for a small robot to enter a body to perform minimally invasive medical procedures or accurately perform delicate and precise surgery.[1)]

Now, it sounds like an obsolete idea. However, back in 1986 when this project was launched, the general public (including myself) had not known the concept of micromachines or surgical robots. Thinking back, this was a research project that focused on the two trends of the following robotics development before others.

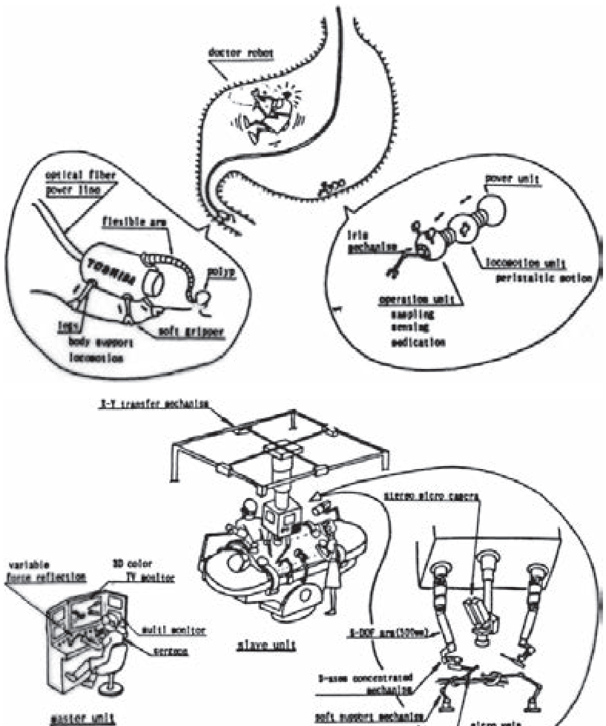

Fig. 1 My disappointing experience (medical micro manipulator; M^3)

The project obtained the approval to launch as an official research theme and I was the main person in the research. However, the project ultimately could not develop as hoped. We were completely beaten by the research and development of MEMS and surgical robots, which rapidly developed mainly in the U.S. immediately after our project launch.

I regret that one of the biggest reasons for this failure was that I had a hesitation deep within my mind that it might not be a good idea to seriously work on something no one else was doing (although the research had simultaneously started in the U.S.) or on a research theme that was far from the hot topics of robot research at the time. I think this is a result of a lack of the "confidence and pride" that I mentioned above. In other words, I did not have the self-awareness at the time that we were in the forefront of robot research and that I was the one leading it.

There is another reason. I had the optimistic mindset in which I thought "There must be no one else working on such a novel idea. I'll slowly work on this between the projects my superior gives me". However, in reality, someone else somewhere else in the world had thought of the same thing at the same time, and that someone had started taking action.

New technologies sprout at the same time in several different places in the world. I have actually encountered such an experience 3 times so far. Researchers with the similar awareness and skills in similar conditions come up with similar "amazing" ideas.

No matter how novel you think the idea may be, you should consider that someone somewhere has thought of the same thing at the same time. Whether or not you can achieve this depends on how boldly you can move to action.

4. Let's Overcome the "Nah, I'm just kidding" Way of Thinking

One of the biggest enemies of engineers, who should be the ones to create innovations, is the "Nah, I'm just kidding" way of thinking. This is often seen in idea-creating meetings and brainstorming. I believe this was one of the reasons for M3's failure.

Since negative statements are taboo in brainstorming, a number of ideas fly around the room. "It would be good to have a robot like this. What if we make it time travel like a cartoon character? Nah, I'm just kidding…" And people laugh and discussions grow bigger.

This is not the problem by itself. The problem is what happens next. You must take action based on the ideas that were created. We have to make this process function smoothly.

If there is even a small amount of the feeling "It's impossible anyway…" when we reach the execution stage, we can never create innovations. At the same time, we cannot create innovations solely by implementing "what we can do".

However, there are people in the world who look at seemingly impossible ideas and think "They are possible". Although it depends on the case, I feel as though these people often make small revisions to presuppositions for the argument and draw the path to achieve the essential goal. And these are the only people who are qualified to complete technologies. Even some subjective convictions sometimes end up working. The important thing is to believe that it is "possible" and take action.

5. Let's Positively Work with "Crazy Ideas"

Japan also has many examples of pioneering completely new "technological fields". Some of these examples are the gastroscope and WALKMAN.

The Gastroscope was a joint innovation by doctors of the University of Tokyo Hospital and Olympus engineers. I think it is impressive that they turned a "crazy" idea at the time, which was to see a world that people had never seen, into action. After this, Olympus continued developing fiber endoscope, electronic endoscope, and endoscopic surgery, leaving other companies far behind. How were they able to achieve such original technological development?

For one, it must be the passion and conviction of the doctors who led the development. Technological development requires leaders with "passion" and "confidence". Doctors at the University of Tokyo Hospital brilliantly played this role. Another reason must be the ambitious spirit of the engineers at the time. It does no good to plausibly list reasons to remain where you are by saying "The Japanese Pharmaceutical Affairs Act is strict…"

We can say that the WALKMAN was a result of the "crazy" idea of Mr. Morita and Mr. Ibuka being turned into action. I still remember the excitement of the stereo sound source that I heard for the first time walking outside when I was in university. I felt that a new world had opened up.

My laboratory recently developed a 20m-long robot arm (Fig. 2) [2]. When I suggest to students "Let's make a 20m giant arm", some students react positively and some react negatively. Talented students who react negatively would bring up textbook theories and formulas and explain why it cannot be done. This is indeed important, because working on something that cannot be done in principle is the same as alchemy. In many cases, however, they are voluntarily creating argument presuppositions and hypotheses and restricting their own possibilities. I think creation of innovations is about practicing ingenuity and overcoming such restrictions. Even with alchemy, if we go beyond chemical reactions and consider nuclear reactions…I will stop here, as it's not my specialty.

Fig. 2 20m-long robot arm (Taking on the "impossible" challenge)

6. Fusion of Various Fields Sharing Common Awareness for Issues

One method to create innovations is fusion of various fields. Innovations may come from fusion of two pieces of "knowledge", which previously had no common ground.

In the field of actuators, which is my specialty, fusion of various fields is especially important. While my fundamental field is mechanical engineering, a mechanical engineering framework alone is no longer enough to create new actuators. New actuators are only possible through collaboration with material specialists and new mechanical materials. Application is also important. I was once involved with the development of a motor that functions in special environments between 10 [T] and -270 [˚C]. This project was driven by the passion of chemical researchers who needed this motor.

One of the key points in fusion of various fields is sharing common awareness for issues. This is actually difficult when members' backgrounds are different. If the fields differ, "ideas" naturally differ.

For example, the ideas toward "experiments" completely differ between the "physics type", such as electrical engineering and mechanical engineering, and the "chemical/bioengineering type", such as chemical engineering and bioengineering, even though they all belong to the engineering field.

This is a rough expression, so I'm sure it doesn't apply to all cases. However, in general, "physics type" experiments are about confirmation of logic. For example, you apply 1V to 1Ω resistance, and the current of 1A is observed. This is called an "experiment" of the "physics type".

This is different for the "chemical/bioengineering type". "What happens if we inject this substance to a cell? We don't know, so let's do it." This is an "experiment" in the field of the "chemical/bioengineering type". A chemistry specialist once told me that the "experiment" I perform on my robots is "verification", rather than an "experiment". Differences in the environments in which we grew up obstruct fusion of various fields in a deeper sense than we would expect.

We also should not listen to the field's specialists without questioning them. Regardless of how much explanation you may provide, specialists' opinions are often based on the conventional common sense of the field. The value of fusion of various fields is in taking a step outside of the conventional common sense in each field, so it is necessary to share common awareness for issues by holding sufficient discussions.

I have seen many cases in which people give up, saying "I asked a specialist, and he/she said it lacked common sense or that it was impossible". The significance of fusion of various fields is to go beyond this limit.

7. Human Exchanges based on Mutual Trust

Another form of fusion is exchanges of people with different positions and backgrounds. When I was involved with the management work of a national project for micromachines, I had opportunities to closely work with researchers/engineers from many different companies that were part of the project. Through these encounters, I was made acutely aware of how great the influence of corporate climate and superiors was. There were gentlemanlike companies, aggressive companies, companies that pursue research/technologies to the limit, etc. The attitudes of the superiors and subordinates in each company were exactly alike. I witnessed that people receive a great amount of influence and sometimes even restrictions from their organization and superiors without realizing it. In different environments, people's ideas differ and so does the way they promote work. It's necessary to sometimes change the environment or exchange ideas with different people to cultivate a broad perspective. When doing so, we must accept and respect others.

Our ideas and the way we promote work also differ greatly with different positions, such as private companies, universities, public organizations, and managers. In my experience with industry, government, and academia, I think those who do their job thoroughly do their job in all of their positions. However, I sometimes feel as though people lack understanding of each other.

Between industry, government, and academia, our ideas toward research and development and the way we promote work should clearly differ. Having a solid understanding of this enables industry-government-academia collaboration to function smoothly.

I think that the natural roles of "academia" in technological development are; 1) Pioneer completely new sprouting technologies and demonstrating their potential through theories and experiments and 2) Promote analyses/designs by utilizing special experimental technologies and theories, which "industry" does not possess, etc. Development that presupposes the wide scope of practical knowledge of the industry, such as to enhance the completion level close to the product level or to promote development exactly as the initial research plan with no deviation, is naturally impossible with "academia". Such industry-academia collaboration does not achieve a sense of satisfaction for either party. Furthermore, in my experience, it often leads to great results to actually send people from "industry" to "academia" instead of funding the research and holding meetings every few months.

I sometimes feel that "industry" should focus more on commercialization and practical application. Especially when we promoted basic research in research centers of major corporations, I sometimes was concerned that they might not really see the end of the project. In some cases, I would even feel as though these corporations position "research centers" like a court orchestra of aristocrats, and I feel as though the resources are being wasted. However, it is not appropriate for me to complain from the sideline.

Dr. Yoshinori Ohsumi of Tokyo Institute of Technology, who was awarded a Nobel Prize last year, stated something along the lines of "They should spread research funds more liberally". Under the policies of "competition" and "concentration", the main distribution of research funding in the current "academia" is competitive funds. Due to this, there is a great difference between the budgets of researchers with massive research budgets and those who struggle to maintain the minimum research activities. My understanding of the gist of Dr. Ohsumi's statement was that Japan's overall academic activities would be better enhanced by spreading even 1 million yen per person without condition, instead of leading to such an extreme situation.

Some people may think "Universities have it too easy. They should introduce the elements of competition in private companies more. Spreading the funding is out of the question." This statement is acceptable because it comes from a Nobel laureate. If I say it, I may be in a big trouble.

However, from the field of "academia", I can fully understand Dr. Ohsumi's opinion. It is a fact that there are research projects that should receive funding with more weight, and they are important. However, if researchers voluntarily promote many different types of sprouting researches, the potential of some of these sprouts blooming big flowers in the future would also be great. I personally think it would lead to great contributions for the healthy development of academia and technology to trust the skills and good conscience of researchers in "academia" and to "spread" a certain amount of research funding to research other than those that were noticed by the "government" or some evaluators.

What are your thoughts on this matter? I think that it is necessary for us to at least accept that there are different views and trust and respect others. Only with these aspects, industry-government-academia collaboration functions smoothly. In that sense, I think fluid transfers/exchanges of human resources among industry, government, and academia are necessary to develop human resources that possess a wide scope of views with balance.

8. Let's Strive for True Globalization

It is often discussed how Japanese universities rank low in global university rankings.

Rankings that we often see use the evaluation criteria that give high scores to universities in English-speaking countries. For example, prestigious German universities also rank quite low in these rankings. However, this does not seem to be a big issue among people in Germany. Someone who has studied abroad in Germany once told me that he was asked why he was reading English articles and was told to read German articles.

On the other hand, the situation is different in Japan. The media don't hesitate to release articles, such as "High school students with more talent aim to attend universities in the U.S. instead of the University of Tokyo". These articles accelerate the poor reputation of "Japanese universities being no good".

However, my colleagues who are familiar with the actual situation of overseas research also say "We are not sure if high-ranking U.S. universities are really that much better than Japanese universities".

The danger is that we would lose the true strength by being overly affected by one-sided value. Our natural strength was that we provide "higher education in our native language". I do not think it's a good idea to simply regard this as "Galapagos". Japan's national isolation (It seems that this concept itself is also being questioned in the current historical science. "Values" change with the time.) also nurtured our original culture that we can proudly show the world. We must not lose sight of our natural strength and identity.

In that sense, I strongly regret that we had to stop the development of high-functioning and high-technology mobile phones by masochistically calling them "Galapagos". I think that it is in such times that we can pave the road by promoting activities with truly "global" perspectives from a wide variety of positions, such as product/technological development, standardization, research and development, and management.

9. In Closing

Thanks to our predecessors' efforts, Japan has become one of the top technological nations and economic nations in the world. I have shared some of my opinions in the hopes that Japan will further develop as a truly technologically developed country in the future.

Let's strive to become a truly technologically developed country from each of our own positions with a sense of challenge and a humble, sincere attitude without being overly swayed by the trends of society.

*「WALKMAN」 and its logo are registered trademarks of Sony Corporation in Japan and the United States,and are registered trademarks or trademarks of Sony Corporation in other countries or territories.

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Essay

Report of Residence in PT. KYBI

TANAKA Yoshihiro

1. Introduction

I worked in PT. Kayaba Indonesia (hereafter referred to as PT. KYBI) for 4 years and 10 months from January 2011 to October 2015 as a technical advisor.

I had always hoped to work abroad and my wish came true. However, there were ups and downs during my residency there. In this report, I will explain part of my life in KYBI.

2. Relocation

In early April 2010, I was busy visiting my superiors and colleagues at work telling them the date of my wedding ceremony which was going to be held in six months' time. However, one week after I gave them the wedding notice, my boss assigned me to work in PT. KYBI. Although I was a little baffled by the situation of having a newly-married life and a new life overseas at the same time, I accepted the relocation. In this way, I moved to Indonesia in January, 2011 (Photo 1).

Photo 1 View from my apartment

3. About Indonesia

The official name of Indonesia is the Republic of Indonesia, and the country consists of about 17,500 islands. Its area stretches for about 1,900 km north and south across the equator and about 5,100 km east and west, and it's about 5 times as large as Japan. Although the official language is Indonesian, there are some unique languages due to the different dialects spoken in each region.

During my expatriate life, I was somewhat confident with my Indonesian. However, I could not understand the conversations in regional languages between locals.

The official religions are Islam, Hinduism, Christianity and Chinese Confucianism. More than 90% of Indonesians are said to be Muslims and many of their education, culture and laws are based on the teachings of Islam. For example, in 2015, a law enforcing sales of alcohol, which is banned among Muslims, only in commercial complexes for foreigners or stores above a certain floor space threshold was established. It was aimed at reddressing the situation in which young Muslims can easily access alcohol out of curiosity. Actually, whether the law is effective or not is uncertain, as you can ask "Bir ada kah? (Do you have beer?)" and the staff will say "Ada (yes)" and then will grab one from behind the counter even in shops which are not allowed to sell alcohol.

Until a decade ago, cars were only used by some wealthy individuals or foreigners. In the last 10 years or so, income has rapidly increased and the so-called middle class has started to own cars. However, the road infrastructure hasn't improved to cover the increased number of cars. Almost everywhere in major cities including Daerah Khusus Ibukota Jakarta (hereafter referred to as Jakarta) struggled with huge traffic jams. Huge numbers of motorbikes also cut across the traffic and eventually made it not even worth it to drive. Roads were clogged by cars (Photo 2). The city was seemingly in a negative spiral.

It usually took me 1.5 hours and sometimes over 3 hours to commute just under 30 km by car through a motorway from my home in Jakarta to the MM2100 Industrial Complex (Bekasi Prefecture) where PT. KYBI is located. This experience made me a lot more patient with traffic jams during holidays in Japan.

Photo 2 Traffic jam during commuting

It is said that Indonesia is a pro-Japan country. In fact, people around me always offered empathetic help when I came across any trouble during work or in my private life. I think this is partly a result of efforts made by Japanese companies that have provided employment and benefits to Indonesia for over 40 years. Do you know there used to be Japanese soldiers who stayed behind in Indonesia after the war? During World War II, Indonesia was occupied by the Imperial Japanese army. Before that, it was governed by the Netherlands as the Dutch East Indies. When Japan was defeated and the war ended, the Netherlands took its governance again. Some of the soldiers from the Imperial Japanese army stayed behind in Indonesia and fought for Indonesia's independence in the war against Dutch forces in order to realize the promise made with Indonesian people during WWII. In August 2014 Sakari Ono, the last Japanese soldier who stayed behind, died. The news of his death made headlines in local newspapers and TVs, and I was able to watch his funeral. Emblazoned with an Indonesian flag, the coffin of Ono was carried to the hero's graveyard for burial, led by the national army. This fact is not written anywhere in Japanese history textbooks. However, he was a Japanese soldier who stayed behind and played a major role in Indonesian history. Indonesians might see Japanese people as dear friends who supported the country's independence with their loyalty.

4. Work in PT. KYBI

In PT. KYBI, I was appointed as a technical advisor for products related to shock absorbers for four-wheeled vehicles.

I was responsible for giving instructions to local staff mainly in departments including quality assurance, production, production engineering, maintenance and production management on the method of working and dealing with defects, and communicating with the Japanese office to pass on instructions. Although I didn't belong to any organization, I was intimately involved in part procurement, target costing, and safety and health divisions. It was rather difficult for me to directly work in other departments in a foreign country, as I had been engaged in production engineering only since I joined the company. Of course, I attended a series of lectures and learned Indonesian before moving there. However, there wasn't much I could do with such little knowledge, and I hadn't been able to provide good advice to local staff when they asked for help.

In particular, I had trouble with quality-related work. For example, staff members contacted me on my day off or in the middle of the night sometimes saying, "the performance of products is out of standards. We need to ship them today. What should we do?" When I started working in PT. KYBI, I was just giving any instructions I could think of regardless of their usefulness. Now, I am able to collect necessary information and give appropriate instructions on how to deal with any problem. If a flawed product left the factory by mistake, the client would contact me directly to make claims, and I would have to visit them to report by myself. I probably gave too many instructions and directions from the sense of unsettlement and urgency. I was annoyed by local staff who didn't carry things out as I told them, and I sometimes spoke in a rough tone. I began to feel that this was not a job I should take on. However one day, I saw a phrase in a local Japanese newspaper: "Don't panic, rush or expect too much. Don't get bored and give up."

These are the words of Terutake Kikuchi, General Manager of "Kikugawa," the first Japanese restaurant in Jakarta, which he advocated to his Japanese customers in 1969. This has now become a proverb in the Japanese community in Indonesia. In this country, troubles that we have never had in Japan happen one after another. It is impossible to make people who have different languages and cultures understand what you say immediately. Kikuchi said the most important thing when working in Indonesia is not to get bored, give up, and move on together with locals. I suddenly felt better after reading this article. I started to think I can move forward step by step without pushing myself too much. Although it was difficult for me not to panic and rush when there was a flaw, I think I managed to maintain my patience.

I greatly appreciate that many people from Japan visited our company during my stay in Indonesia. As aforementioned, I was in charge of divisions outside of my field and I lacked abilities needed to cover all the duties. Therefore, I requested support from professionals in each area. Acquiring a visa for entering Indonesia was difficult. Many of those who took a business trip here had acquired a business visa before travelling. However, this visa only allowed meetings and interviews. Although visitors were allowed to enter the factory, they were unable to engage in any business operations. If they wanted to be involved in operations, they required a working visa and a residence permit like us expatriates. We didn't try to go through the application process much, since it took around two months to prepare documents. Visitors were unable to touch actual products and demonstrate how to operate them. Because of that, I believe many of them had difficulty in communicating with local staff using words, gestures, and illustrations. As a technical advisor, assisting communications between these visitors and local staff was also an important responsibility of mine.

Based on what had been indicated by visiting experts, I had to give clear, detailed direction as to what local staff should do and what kind of output was required. At the same time, it was necessary to listen to what local staff required and what they had questions about and to pass that on to the visitors. If I failed to do these things, most techniques and methods that were taught wouldn't have been passed on before the period of the support program came to an end. I therefore had always held meetings before and after work during the support program in order to promote mutual understanding among colleagues. As a result, not only did the local staff learn a lot, but I did as well.

Photo 3 PT. KYBI main entrance

5. Food

Although the cooking methods and taste are not exactly the same, some Indonesian dishes are similar to what we eat in Japan.

Typical examples are: Nasi goreng (cha-han or fried rice), Mi goreng (yakisoba or fried noodle), Ayam goreng (tori no kara-age or deep fried chicken), and Sate ayam (yakitori or char-grilled chicken on skewers). To me, they were more delicious than Japanese dishes. Having said that, the above four dishes were the only Indonesian food I would pay to eat. No other dishes appealed to my palate.

Most Indonesian dishes were either spicy or sweet. I even sensed an odor in white rice. We had a monthly lunch event at our staff canteen. I feel sorry saying this but I just couldn't enjoy the food there. Every day, I bought Japanese food in a Japanese supermarket or similar ingredients and cooked for myself. Japanese food ingredients in Indonesia cost 2 to 3 times more than those in Japan. However, better the purse starve than the body. When I ate out with Japanese expatriates or visitors, I always had Japanese or Western food and rarely went to Indonesian restaurants.

In contrast, my wife often went to Indonesian restaurants with her friends. As my daughter was usually with my wife, she became fond of a rice cracker called Kerupuk. They also asked me if they could try various snacks from street vendors. I was strictly against the idea because if they had fallen ill it would have had a great impact on me.

As you know, Indonesia is a tropical country. Fresh tropical fruits were delicious and cheap. Prices of fruits were less than a third of Japanese prices even in large supermarkets. In a market, they were five times cheaper. Our typical breakfast fruit platter was comprised of papaya, dragon fruit and mango. In the late rainy season, we would often eat mangosteen, the queen of fruits. We will never be able to have breakfast with these fruits again in Japan unless I work in Southeast Asia again. I never tried durian, the king of fruits because of its strong smell.

Photo 4 Traditional Indonesian food

6. Weekends and public holidays

Like Japan, most companies in Indonesia have a five workday per week system. In PT. KYBI, we were basically off on weekends and public holidays. Many Japanese expatriates go to play golf on their days off. I was no exception and I played golf three to four times a month. Although I played many times, I was not very good at it. My skills didn't improve probably because I always thought, "I had a poor score today but I might play better next week," and I never really practiced.

As I had accompanying family members, we would go to large-scale shopping malls and restaurants near our home. As you know from the traffic situation mentioned above, almost all expatriates and their families hired a private driver. We paid our driver about 30,000 yen monthly by ourselves, but I thought it was rather reasonable considering the risk of having an accident in an overseas country.

Every day, our driver would come to the waiting station of our apartment and drove to the entrance to pick us up when we gave him a call. We rode in the back seat and got off at the entrance of wherever we wanted to go. The driver waited in the parking and picked us up at the entrance to drive home. We felt as if we were celebrities on TV. On the other hand, when I returned to Japan, it took me a long time before I had the driving feeling completely back.

Public holidays are based on religion except for New Year's Day and Independence Day, including those of Islam, Christianity and Chinese Confucianism. Many Indonesians around me did not work on public holidays. I had to consider this not only for PT. KYBI staff but also drivers and maids.

The biggest national holiday in Indonesia is Lebaran, a festival after fasting in Islam. Muslims fast during Ramadan, the ninth month of the Islamic calendar and the first two days of the following month are the festival days. Most companies and government services take a total of around 9 to 12 days off before and after the festival, making it the only long holiday in Indonesia.

It is basically like having the New Year and Bon festival in Japan at the same time, and most people return home to see their family. All supermarkets, shopping malls and restaurants are closed, and people told me that we would not have enough food if we stayed in Jakarta during the holiday.

As you may have expected, the mass exodus of travelers heading to their hometowns on the first day of Lebaran was beyond my imagination. Cars and motorbikes filled the entire length of roads and were stuck for hours, and horns resounded throughout the city. In an effort to reduce traffic as much as possible, road maintenance and improvement works occur all over the place every year before Lebaran. However, the speed of construction works had not caught up with the traffic as the number of people using cars and motorbikes had been increasing year by year.

Although many expatriates visit Japan during this holiday, our family travelled to Bali every year (Photo 5). Bali is one of the world's top resort destinations. As most people are Hindus, they spend time independent of Lebaran. Beyond that, the Lebaran holiday of PT. KYBI starts earlier and finishes later than the general holiday period. We could therefore travel and spend our holiday comfortably without experiencing major traffic jams. As the cycle of the Islamic calendar is two weeks shorter than the Western calendar, Lebaran comes 2 weeks earlier every year. While I worked in Indonesia, Lebaran happened to fall on the middle of the dry season and the weather was always nice. Thanks to this, we were able to enjoy walking around the beach, mountains and the city.

If we were to travel to the same place for the same length of time from Japan, it would cost a lot of money. However, domestic flights were reasonable and there were promotional prices for working visa holders in hotels which were much lower than those for other visitors. Needless to say, we had the advantages of various good conditions for these holidays, which we would never have again. We took our first daughter there three times, but never the second daughter who was born just before we returned to Japan. I don't know how I will make an excuse or make up for this when she is old enough to understand things and complain that we didn't take her there.

Photo 5 View from the hotel lobby in Bali

7. Return

In October, 2015, I returned to Japan and started working again in Gifu North Plant. I requested to return there as I wanted to learn skills in the mother plant, although I gained valuable experience and acquired a lot of knowledge in Indonesia. I am proud of myself for having gained more than a little capability of managing staff, items and time and giving directions to local staff toward achieving goals.

However, I felt that my technical abilities were not adequate towards the end of the program. One of the reasons for this was that it was becoming increasingly difficult to pass on the latest methods and the idea of process in the mother plant. In my early days of working in Indonesia, I explained what I had actually seen and experienced. Later, I started telling local staff what I hadn't experienced but only heard. I was often moving forward without fully understanding what was going on. I then began to think that I would like to return to my old workplace, the Production Engineering Dept., and improve my skills there. I appreciated when the then branch manager in PT. KYBI told me that he would like me to stay longer. I felt bad about telling him my wish to return to Japan as he supported me so much. Eventually, he understood my wish and accepted it.

I am currently engaged in the development of a new line in the Production Engineering Dept., Gifu North Plant. I would like to make efforts to compensate for my inadequate technical skills during the program in Indonesia.

8. In Closing

I would like to express my appreciation to the branch manager, who gave me directions even though I was helpless, colleagues, people who visited us all the way from Japan and provided support, and everyone in PT. KYBI who always encouraged me to move forward, for your support over the 4 years and 10 months. I couldn't have carried out my duties overseas without their help.

Author

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Essay

Report of Residence in America and Mexico

OKUMURA Tetsuya

1. Introduction

I worked in America and Mexico for 8 years from February 2008 to January 2016.

I lived in America for 5 years and 8 months during the transition period of the company from the former KYB Manufacturing North America (hereafter referred to as KMNA) to the present KYB Americas Corporation (hereafter referred to as KAC), and in Mexico for 2 years and 3 months for the establishment of KYB Mexico S.A. de C.V. (hereafter referred to as KMEX).

I started living there with my wife, my daughter and my dog. My daughter spent 5 years in Indiana from when she was a second grade junior high school student until she graduated high school, and she returned to Japan to go to university. I will introduce some of the valuable experiences I had with my family through our life in these countries.

2. KYB Manufacturing North America (KMNA)

When I started living in America in 2008, property values dropped sharply due to the subprime mortgage crisis. It was the time of the so-called Lehman shock. KMNA had been struggling with continued deficits and the managing conditions were falling. This was worsened by the persisting downward trend in sales, and sales dropped to half of what they were before the Lehman shock in some months. The number of employees and expatriates decreased every year, local banks enforced forcible collection of outstanding loans, and American banks denied new loans, which made our financing difficult. Only the main bank of KYB accepted the increase of borrowing facility limit. All transactions including checks were transferred to this bank and the company was able to secure funding. We had the worst financial results in fiscal 2008 when the company was going through this uncertain period, as impairment loss on fixed assets was also applied.

Although the company was in these tough situations in fiscal 2008, sales gradually increased through a radical cost reduction and achieved a profit in 2009, the following fiscal year.

3. KYB Americas Corporation (KAC)

In October 2011, KMNA took over KYB America LLC, a sales company in Chicago. This merged the production and sales companies and the new company was called KYB Americas Corporation. As the accounting section was consolidated in Indiana, we scrambled for recruitment of new staff and transition activities in Chicago.

In 2012, we acquired the land and building of the Daily Journal newspaper company which was adjacent to our plant and moved the office there. Only the development and accounting sections were relocated at first, and we still shared half the building with the newspaper with only a wall being used as a divider for a while after the acquisition. Most back-office sections have now moved to the new building and it has now become the headquarters of the Americas (Photo 1).

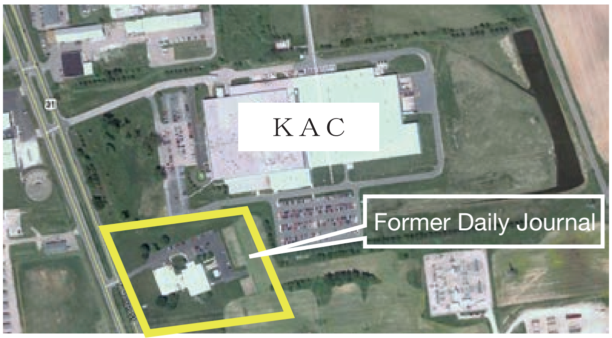

Photo 1 KAC and the former Daily Journal site

4. Natural environment of America

Indiana, where KAC is located, is in the Midwestern part of America. Being in the continental climate with low humidity, it is comfortable in the shade even in temperatures over 35 degrees C in summer. Thunderstorms with heavy rain occur occasionally, which could pose a threat even if you hear the thunder in the distance as there are no obstructions around. Trees on the company site were struck by lightning a few times while I worked there. We had a flood in the summer of 2008, five months after I started working in KAC. Roads were closed everywhere and the company parking was inundated with some cars being underwater. In April 2013, toward the end of my work contract in America, hailstones as big as golf balls fell around the company, damaging a staff member's car. Although Indiana is also known to have relatively frequent tornados and I often heard alarms, I was lucky to never encounter one.

In most winters, the temperatures dropped under –10 degrees C. The region is in a frigid climate and it could drop to under –20 degrees C on the coldest days. You would rather feel physical pain than the cold when you are outdoors. You need to drive carefully when commuting in the winter as snow stays on the ground a few times a year. It is particularly dangerous when freezing rain became ice on the ground as roads become slippery like an ice skate rink.

Even under this harsh natural environment, I was able to live safely without having any accidents thanks to the help of the local people (Photo 2).

Photo 2 Frozen plants in the garden after freezing rain

5. KYB Mexico S.A. de C.V. (KMEX)

KMEX was established in October 2012 in an industrial complex in Silao, Guanajuato. The area of the industrial complex is 200,000 ha. As it is close to the airport, freight railway runs across the complex. More than 100 companies, half of which are Japanese, own plants or warehouses there.

Guanajuato is in the middle of Mexico and has the sixth largest population in the country. Its major industry is manufacturing of automobiles and leather products. Mazda and Honda have been operating their plants there and Toyota will join in 2019. Plants of Nissan and JATCO, our clients, are located in the neighboring Aguascalientes.

During the construction of the plant, we rented a room in the administration building in the industrial complex and used it as a temporary office. Accounting processes were commissioned to the accounting department of a group company in Mexico City, the capital of Mexico. Before I started working in Mexico, I travelled from Indiana to Mexico City to check the books and prepare report materials.

In October 2013, I started working in Mexico. A temporary visa was issued at the Consulate of Mexico in Indiana and an official visa was issued at the immigration office in Mexico City. I was therefore able to complete the relocation process without returning to Japan.

In March 2014, we moved from the temporary office to the new plant and started preparation for the production of pumps for Continuously Variable Transmission (CVT). As the office was still under construction, we placed our desks in a temporary room (Photo 3).

Photo 3 KMEX office under construction

At the end of May 2014, we held the opening ceremony of the CVT pump plant with our clients, the governor, the city mayor and our business partners as guests. The government decided the order of the ceremony and the governor participated with many guards on that day. After he made a speech, he headed back on a helicopter from behind the plant. At lunch time, employees and expatriates sang Sukiyaki and

Photo 4 Opening ceremony of the CVT pump plant (right: Mayor of Guanajuato)


CIUDAD

Japón, principal socio comercial

Generará KYB 278 empleos

Photo 5 Newspaper article on the following day of the opening ceremony of the CVT pump plant

Cielito Lindo (Mexican songs known in Japan). Although we worked hard on the preparation, it was worth the effort and we had a unique opening ceremony (Photo 4 and 5).

In December 2014, our company consolidated manufacturing and sales departments by transferring aftermarket operations of group sales companies in Mexico and Panama to KMEX. For this reason, I travelled to Mexico City more often to have meetings with group sales companies, lawyers, etc.

Mexico City is located a little more than 380 km southeast of (and about 4.5-hour drive from) Leon City, where expatriates live. As it is at an altitude of 2,300 meters above sea level, some visitors from Japan develop altitude sickness.

On a different note, many expressways in Mexico limit the speed only to 110 km/h, and you often see people driving very fast. Despite that, people are walking and using bicycles on the same expressways, which poses various risks. It is obvious that many accidents occur including some severe ones which cause road closures. I once got caught in a big traffic jam when a small aircraft crashed into the expressway a few kilometers in front of me while I was driving home from a business trip. I might have been involved in the accident if I hadn't stopped for a break earlier.

In December 2014, the construction of the Shock Absorber (SA) plant began (Photo 6 and 7). The total site area of KMEX is 13,4000 m2 and a quarter of that is used for the CVT pump plant, half for the SA plant and the other quarter is grassed and used for an open house for company events.

Photo 6 Ground-breaking ceremony (kuwaire) of the SA plant

Photo 7 SA plant under construction

6. World Heritage

Guanajuato City is near Silao City, where KMEX is located, and is the capital and a World Heritage Site. It is a historical city lined with colorful buildings, which can be seen in KYB's promotion video (Photo 8). Guanajuato City was developed by the Spanish in the mid-16th century and was the world's leading silver producer in the late 18th century. The remains of silver mining tunnels are used for streets leading to Guanajuato. They look very elegant but it feels as if you are driving in a maze. Silver brought wealth to Mexico and cultivated a cultural city with the representative large theatre in Mexico, Teatro Juarez (Photo 9), and produced people with liberal ideas who led the independence movement.

Students can be seen as the University of Guanajuato is in the city, and tourists can also be found.

Photo 8 Guanajuato City

Photo 9 Teatro Juarez

7. Life in Mexico

Leon is the largest city in Guanajuato with a population of about 1.4 million, which has flourished as a leather producer. It is located at an altitude of 1,800 meters above sea level. Japanese expatriates from our company live there, and many other Japanese companies operate in the city. We socialized with families from other

Photo 10 Typical Mexican food "Tacos"

companies and shared living information.

You can have variety of good food including Mexican (Photo 10), Spanish, French, and Korean restaurants as well as Japanese restaurants and supermarkets. However, you need to be careful not to get food poisoning in local restaurants.

Guanajuato was a relatively safe city compared to other cities in Mexico while I worked there. I feel disappointed and worried about the recent news of the decline in the safety of the city. I was careful not to leave anything behind in the car when I was away from it as theft cases were reported frequently when I was there. I think it would be even harder to live there now because you have to pay attention even more.

In general, Mexicans are optimistic, cheerful, merry, friendly and helpful, and they enjoy every moment but don't think about the future much. Once I was invited to a colleague's wedding. They had a ceremony in the evening at a church and then we moved to the reception hall. They drank tequila, ate and danced till dawn. In the company's Christmas parties, they danced from beginning to end to lively music which is unique to Mexico.

As both Americans and Mexicans place high priority on time with family, most workers finish work and go home before the regular time.

Mexicans enjoy life. They are religious and it is very unusual for people to commit suicide. After returning to Japan, I hear news of suicide almost every day. This makes me think seriously about Japanese people's views of life.

8. In Closing

I would like to express my appreciation to local staff and Japanese expatriates who worked together in KAC and KMEX for their continuous support which helped me complete my 8-year work stint in America and Mexico. In both locations, we had very good teamwork. We shared both happy and hard times at work and enjoyed golf on the weekends to relieve our stress. Eight years passed in a blink of an eye.

It was a valuable experience in my work and also life for me and my family.

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Technology Explanation

Response Characteristics of Water Hydraulic Proportional Control Valves*

YOSHIDA Futoshi

Abstract

Water hydraulic proportional control valves using "tap water" as the working fluid are suitable for systems that require high levels of environmental friendliness and safety as they use "tap water" as the working fluid. There is a high level of expectation for applications in the fields of food processing machinery and semiconductor manufacturing equipment in particular. In the previous report, the authors defined the transfer functions of three components of the water hydraulic proportional control valve, namely the compensation circuit, the solenoid, and the pilot valve, and examined the effects of design parameters on valve performance using experimental and analytical methods. These water hydraulic proportional control valves use tap water, which has poor lubricating properties, as the working fluid, and the hydrostatic bearings and damping orifices that make up their mechanical features function to prevent friction and wear in the spool, and stable operation of the spool itself. The structure of the hydrostatic bearings also consist of a meter-in circuit that is effective for spool operation response, while the damping orifices consist of a meter-out circuit that is effective for damping characteristics of the spool; their functions are used as required depending on the purpose of the valve. This report focuses on the open loop transfer function represented by the solenoid and the pilot valve sections that have a major impact on the characteristics of the entire valve, examines the effect of hydrostatic bearing and damping orifice geometric parameters, and verifies analytically the step response characteristics that these parameters have on the entire valve.

1 Introduction

Water hydraulic proportional control valves are suitable for systems that require high levels of hygiene and safety as they use "tap water" as the working fluid. Their application scope is vast, including food, beverage, semiconductors, medicine, pharmaceuticals, cosmetics, chemicals, natural energy, and underwater work equipment.

Realization of systems with high levels of hygiene and detergency is anticipated, especially with automation of meat/seafood processing, which has conventionally been manually performed.

In the previous report, I defined the transfer functions of three components of this valve, namely the compensation circuit, the solenoid, and the pilot valve, and examined the effects of design parameters on valve performance by using experimental and analytical methods for each element [1)-5)]. This valve uses tap water, which has poor lubricating properties, as the working fluid. In this structure, the hydrostatic bearings support both ends of the spool to prevent wear and friction, and the fluid that comes through the hydrostatic bearings is guided to the pressure chambers on both ends of the spool, generating damping force to stabilize the spool operation. Due to their positions in response to spool operation, the structure of the hydrostatic bearing orifices consists of a meter-in circuit, and the structure of the damping orifices consists of a meter-out circuit. A meter-in circuit is effective for spool operation response, while the meter-out circuit is effective for damping characteristics of the spool; their functions are used as required depending on the purpose. While these dimensions must be set at the optimal values to stabilize the valve, no sufficient theoretical study had been conducted so they were empirically determined.

This report focuses on the open loop transfer functions represented by the solenoid and the pilot valve sections that have a major impact on the characteristics of the entire valve, examines the effect of the geometric parameters, and verifies the characteristics of the entire valve from the perspective of response characteristics. Specifically, the dimension difference between the equivalent throttle diameter D'_b of the hydrostatic bearing orifices and damping orifices diameter D_n is defined as $C_r = D_n / D'_b$ to analytically study: (1) the impact of C_r changes on T_L, which is the time constant of the first-order lag system for the pilot valve, (2) impact of C_r changes on ζ, which is the damping coefficient of the second-order lag system including solenoid and pilot valve sections, and (3) impact of C_r on the step response of the open loop transfer function, including the compensation circuit of the entire valve [6)].

* Presented in the Scandinavian international conference of fluid power (SICFP2013), Linkoping, Sweden (June, 2013)

2 Overview of Water Hydraulic Proportional Control Valves

The structural characteristics and control method of water hydraulic proportional control valves are as follows:

2.1 Structure

Fig. 1 shows the structure of water hydraulic proportional valves. Table 1 shows the main specifications. Since they use tap water with low viscosity as the working fluid, it is difficult to form a water film in the gap of the sliding part. Due to this, hydrostatic bearings are used to support both ends of the spool of this valve. The spool displaces without coming in contact with the sleeve with the aim of reducing the wear and friction from sliding.

There are damping orifices between the pressure chambers on both ends of the spool and the return line. This structure creates damping force for the spool operations, thus stabilizing the valve operations.

The spool is oriented with the solenoid's thrust and spring force. While general solenoid valves are structured so that both ends of the spool are supported by a solenoid and a compression spring, this valve uses a tension spring. Using a tension spring creates a free edge on one side of the spool, so hydrostatic bearings can more efficiently function in response to the reduction of moment and lateral force.

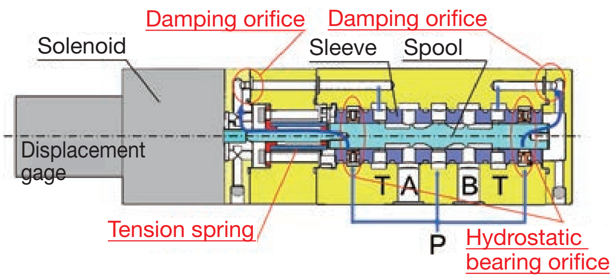

Fig. 1 Structure

Table 1 Main specifications

Item	Specifications
Rated flow	20L/min
Used pressure range	3.5 - 14MPa
Used temperature range	2 - 50°C
Working fluid	Tap water

2.2 Functions of the Hydrostatic Bearing Orifices and Damping Orifices

Fig. 2 shows the schematic positional relation of the spool, hydrostatic bearing orifices, and damping orifices. The function of the hydrostatic bearing orifices is to support the spool within the sleeve without coming in contact with it in order to prevent wear/friction, so the design dimensions are determined by the load capacity to support the spool [1]. The fluid that passes the hydrostatic bearing orifices is guided to the pressure chamber on the spool edge. When this passes the damping orifices, the damping force is created. Therefore, the design dimensions of the damping orifices depend on the design dimensions of the hydrostatic bearing orifices and are not determined in a definite manner.

As the hydrostatic bearing orifices' function to support the spool without coming in contact with it and the positional relation with the spool suggests, the hydrostatic bearing orifices function as the meter-in circuit against the spool operation and are effective against the fast response of the spool operation. On the other hand, the damping orifices function as the meter-out circuit against the spool operation and have the damping effect on the spool operation. Whether the meter-in function or meter-out function works more effectively against spool operation is determined by the relative relation of the two orifices. In other words, if the hydrostatic bearing orifices are relatively smaller than the damping orifices, the meter-in effect would be stronger. On the other hand, if the damping orifices are relatively and sufficiently larger than the hydrostatic bearing orifices, the meter-out effect would be stronger. If they are the same, it is assumed that the meter-in and meter-out effects are combined to effect the spool operation.

In general, water viscosity is extremely small at approximately 1/30 of oil, so it is assumed that the orifice diameter must be extremely small in order to create sufficient damping force. From a practical perspective, reduction of the orifice diameter creates a concern for contamination. Due to this, hardly any quantitative studies on its effect have been performed. With regard to this aspect, this report targets these valves and studies the frictional coefficient, which is required to calculate the damping force of the damping orifices, by comparing with oil.

First, the relationship between the orifice diameter D and the Reynolds number R_e is calculated by using orifice dimensions and the actual measurement value of the flow volume [2]. For example, if the orifice diameter is φ0.6, the water's Reynolds number is approximately 9,000, creating a turbulent flow. On the other hand, oil's Reynolds number is approximately 300, creating a laminar flow. This indicates that the flow conditions differ between water and oil, despite the same orifice diameter. Next, Fig. 3 shows the relationship between Reynolds number R_e and frictional coefficient λ. Since oil creates a laminar flow, $\lambda = 64/R_e$ is applied based on the Hagen-Poiseuille equation, resulting in the frictional coefficient of $\lambda_{Oil} = 0.22$. On the other hand, due to the fact water creates a turbulent flow, $\lambda = 0.3164/R_e^{0.25}$ is applied based on the Blasius equation, resulting in the frictional coefficient of $\lambda_{Water} = 0.033$. Based on this, we know that the frictional coefficient of water is approximately 1/6 of that of oil.

Based on the above results, Fig. 4 shows the comparison of the damping forces between water and oil, which are calculated by using the general orifice diameter. This result shows that the orifice diameter for water needs to be approximately half of that for oil in order for water to gain the same level of damping force as oil. From the mass

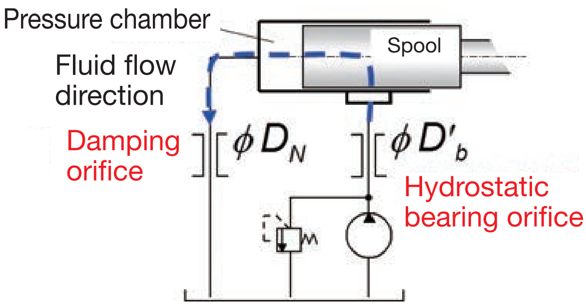

Fig. 2 Positions of hydrostatic bearing orifices and damping orifices in relation to the spool

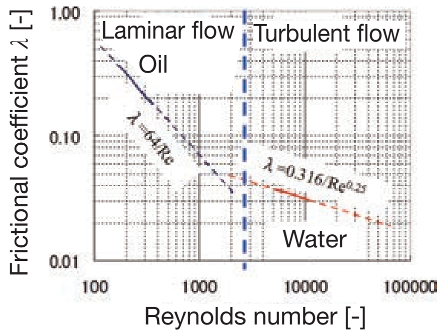

Fig. 3 Relationship between Reynolds number R_e and Frictional coefficient λ

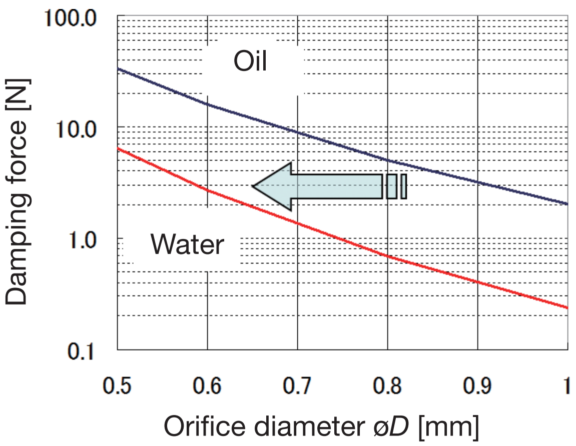

Fig. 4 Relationship between orifice diameter and damping force

production perspective, reducing the orifice diameter makes improvement of the hole drilling precision and contamination measures even more difficult. Due to this, in order to gain damping force in water pressure systems, reducing the damping orifice diameter is not sufficient. It is appropriate to use circuit configurations by integrating meter-in and meter-out effects, such as those mentioned in this report.

2.3 Control Method

Fig. 5 shows the block diagram for the system within the valve. This valve can be divided into the elements of the compensation circuit, solenoid, and valve. The transfer function for each is represented by $C(s)$, $S(s)$, and $P(s)$. The spool displacement is detected by the displacement gauge of the operation transformer, and the displacement is provided as feedback; the PI control compensation circuit operates the valve control.

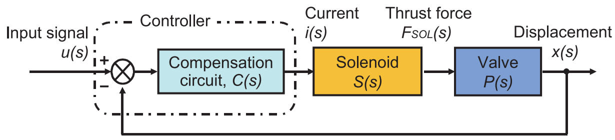

Fig. 5 Block diagram

3 Transfer Function

Fig. 6 shows the parameter definition diagram for the analysis model.

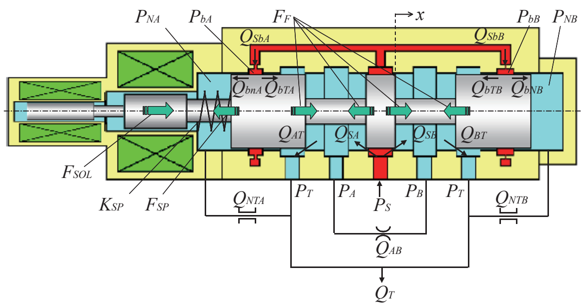

Fig. 6 Parameter definition

As previously mentioned, this valve can be considered to consist of the 3 elements of the compensation circuit, solenoid, and pilot valve sections. The compensation circuit is defined as formula (1) as a general PI controller.

$$C(s)=k_P\left(1+\frac{1}{T_I\, s}\right) \tag{1}$$

In the previous report, it was experimentally confirmed that solenoid transfer function $S(s)$ can be approached in a first-order lag standard form, and it is defined with the transfer function in formula (2). Fig. 7 shows the experiment result of the thrust frequency characteristic of the solenoid alone and the analysis result comparison for the transfer function in formula (2).

$$S(s)=\frac{K_{SOL}}{\tau_{SOL}\, s+1} \tag{2}$$

Transfer function $P(s)$ for the pilot valve section can be calculated as the first-order lag system transfer function in formula (3) by performing Laplace transformation on the linearized mathematical models of the pressure/flow volume in each section near the experimental points. Parameters in formula (3) are defined by formulas (4) through (19). C_r in formula (15) is the diameter ratio between the damping orifices and hydrostatic bearing

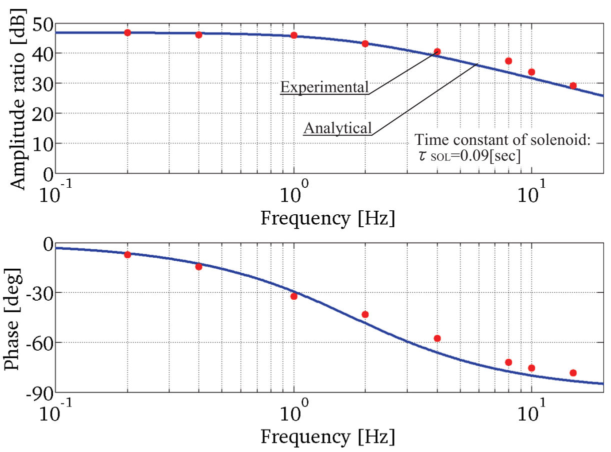

Fig. 7 Solenoid thrust frequency characteristics

orifice. Since there are 4 hydrostatic bearings located in the circumferential direction of the spool, these are represented by equivalent diameter D_b', which is defined in formula (14), as one orifice. The ratio is $C_r = D_N / D'_b$. The flow from the hydrostatic bearing orifices was determined as laminar flow based on the Reynolds number R_e calculated from the measured flow volume and the geometrics, and the orifices were modeled in formula (12) as choke orifices. With frictional coefficient λ, which determines the damping force of damping orifices, the Blasius equation was applied due to the turbulent flow, as previously mentioned. It was modeled in formula (19).

Among the 3 elements defined above, the transfer characteristics consisting of the solenoid and pilot valve without a compensation circuit are represented in the second-order lag system in formula (20) as the open loop transfer function $V(s)$, which is in the block diagram in Fig. 8. The damping coefficient ζ, natural frequency ω, and proportionality constant K are defined in formulas (21) through (23). Furthermore, as shown in Fig. 5, the closed loop transfer function $V_{SYS}(s)$ for the feedback control of the valve system, including the compensation circuit, is the third-order lag system shown in formula (24).

$$P(s) = \frac{x(s)}{F_{SOL}(s)} = \frac{K_L}{T_L s + 1} \tag{3}$$

$$T_L = \frac{\Gamma - \xi}{K_{SP} + \beta} \tag{4}$$

$$K_L = \frac{1}{K_{SP} + \beta} \tag{5}$$

$$\Gamma = (L_{bn} + L_{bT}) \frac{2\pi \cdot D_{SPL} \cdot \mu}{\delta} \tag{6}$$

$$\xi = \frac{2A^2{}_{SPL}}{\alpha \cdot \alpha_{bN}} \tag{7}$$

$$\beta = 8 \cdot C \cdot L_W \cdot (P_S - P_L)\cot(\theta) \tag{8}$$

$$\alpha_N = \frac{\pi^2 2^5 D_b{}^5}{16 \rho L_{NT} Q_{NT0} \cdot \lambda} C_r{}^5 \tag{9}$$

$$\alpha = \frac{\alpha_{bN}}{\alpha_{bN} + \alpha_{bT} - \alpha_b} - \frac{\alpha_N}{\alpha_{bN}} - 1 \tag{10}$$

$$\alpha_{bN} = \frac{\pi \cdot D_{SPL} \cdot \delta^3}{12 \cdot \mu \cdot L_{bN}} \tag{11}$$

$$\alpha_b = \frac{\pi \cdot D_b{}^4}{32 \cdot \mu \cdot L_b} \tag{12}$$

$$\alpha_{bT} = \frac{\pi \cdot D_{SPL} \cdot \delta^3}{12 \cdot \mu \cdot L_{bT}} \tag{13}$$

$$D'_b = 2D_b \tag{14}$$

$$C_r = \frac{D_N}{D'_b} \tag{15}$$

$$D_N = 2C_r D_b \tag{16}$$

$$w = \frac{4Q_{NT0}}{\pi \cdot 2^2 D_b{}^2} \frac{1}{C_r{}^2} \tag{17}$$

$$\lambda = 0.3164 \cdot \left(2\frac{wD_b}{\nu}\right)^{-0.25} C_r{}^{-0.25} \tag{18}$$

$$R_e = \frac{2wD_b}{\nu} C_r \tag{19}$$

$$V(s) = \frac{K\omega^2}{s^2 + 2\varsigma\omega s + \omega^2} \tag{20}$$

$$\omega = \sqrt{\frac{1}{T_L \cdot \tau_{SOL}}} \tag{21}$$

$$\varsigma = \frac{1}{2}\left(\frac{1}{\tau_{SOL}\ \omega} + \tau_{SOL}\ \omega\right) \tag{22}$$

$$K = \frac{K_{SOL}}{K_{SP} + \beta} \tag{23}$$

$$V_{SYS}(s) = \frac{k_p K\omega^2 \left(s + \frac{1}{T_I}\right)}{s^3 + 2\varsigma\omega s^2 + (1 + k_p K)\omega^2 s + \frac{k_p K\omega^2}{T_I}} \tag{24}$$

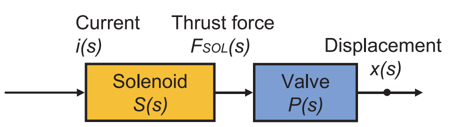

Fig. 8 Block diagram for the solenoid and pilot valve without the compensation circuit

4 Result and Consideration

It is important to learn the relationship between the transfer characteristics of the open loop transfer function, which is described in Fig. 8, and the equivalent diameter ratio C_r for the damping orifices and hydrostatic bearing orifices before studying the characteristics of the entire valve.

Below are studies on the relationship between the time constant T_L of the pilot valve section's first-order lag system transfer function $P(s)$ in formula (3) and the damping coefficient ζ of the second-order lag system transfer function $V(s)$ of the solenoid and pilot valve section in formula (20) in relation to the changes of C_r, which is defined with the equivalent throttle diameter ratio of the damping orifices and hydrostatic bearing orifices. Fig. 8 shows the relationship between C_r, damping coefficient ζ, and time constant T_L.

4.1 Impact of C_r on Transfer Function $P(s)$ in the Pilot Valve Section

When $C_r > 1$, it means that the damping orifice diameter is relatively larger than the hydrostatic bearing orifice diameter. On the other hand, when $C_r < 1$, it means that the diameter is relatively smaller than the hydrostatic bearing orifice diameter.

Based on the above, the following can be said regarding the relationship between the pilot valve section's transfer function time constant T_L and C_r:

① The smaller C_r is, the larger the time constant T_L value is, delaying the pilot valve section response. This means that the damping orifices have a meter-out effect on the spool operation.

② The larger C_r is, the smaller the time constant T_L value is, accelerating the pilot valve section response. This means that the meter-in effect of the hydrostatic bearing orifices is larger than the meter-out effect of the damping orifices.

③ The overall trend is that time constant T_L inversely decreases against the increase of C_r. The meter-out effect against spool operation also rapidly decreases, and we can say that the effects of damping orifices are almost nonexistent when $C_r > 1.2$.

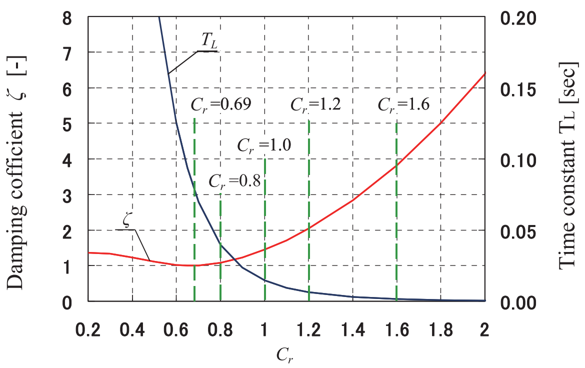

Fig. 9 Relationship between C_r, damping coefficient ζ, and time constant T_L

4.2 Impact of C_r on Transfer Function $V(s)$ Represented by the Product of the Pilot Valve Section and the Solenoid

In the same manner, the below can be said regarding the relationship between the C_r and the damping coefficient ζ of the open loop transfer function $V(s)$ represented by the product of the pilot valve section and the solenoid in formula (4) in Fig. 9:

① Regardless of the C_r value, it is always positive. Therefore, in principle, the transfer characteristics of the solenoid and the pilot valve section excluding the compensation circuit are stable.

② When $C_r = 0.69$, the damping coefficient ζ becomes the minimum value of 1. The response critical damping prevents overshoots in the transient response.

③ When $\zeta > 1$, it leads to overdamping, delaying the response.

④ Damping coefficient ζ exponentially increases along with C_r increase, accelerating overdamping.

4.3 Impact of C_r on the Open Loop Transfer Function's Step Response Characteristics excluding the Compensation Circuit

Fig. 10 shows the impact of C_r on the open loop transfer function's step response characteristics. This is when C_r is between 0.69 and 1.6.

The smaller the C_r is, the larger the time constant T_L of transfer function $P(s)$ becomes, indicating the trend to accelerate the rise.

The larger the C_r is, the smaller the time constant T_L of transfer function $P(s)$ becomes, accelerating the rise. However, increased damping coefficient ζ of transfer function $V(s)$ causes overdamping, which means that this is not necessarily a good response. When C_r is 1 or greater, not much difference in the stabilization time is observed.

Due to the above relationship, the pilot valve section response is delayed due to the meter-out effect of the damping orifices when C_r is small, and the response is delayed due to overdamping caused by the increased damping coefficient ζ when C_r is large. Due to this, it is considered that the appropriate value for C_r is between 0.69 and 1.6.

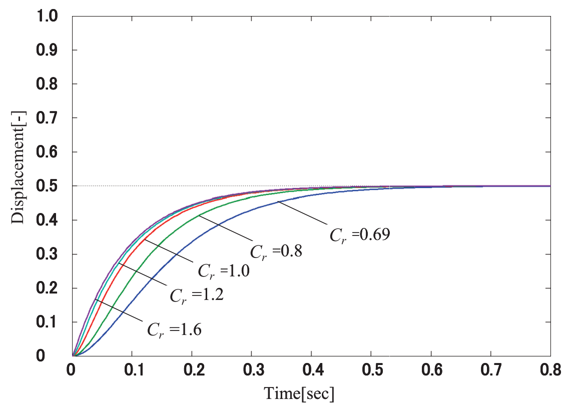

Fig. 10 Impact of C_r on the open loop transfer function's step response characteristics

4.4 Impact of C_r on the Valve's Overall Step Response Characteristics

The above result indicated that there is an appropriate range for C_r. It also indicated that the transfer characteristics, which are calculated from the solenoid's thrust property and the geometric construction of the pilot valve section, are always stable. This section considers the entire valve's response characteristics, including the compensation circuit.

This valve generally composes a feedback control system including a compensation circuit, and the closed loop transfer function indicates third-order transfer characteristics, according to formula (25).

Fig. 11 shows the impact of C_r on the step response of the closed loop transfer function. Based on this result, the compensation circuit's impact is studied from the perspective of step response characteristics of this valve. In this study, C_r is between 0.69 and 1.6, the proportional gain K_P of the compensation circuit is 1.9, and the integral time T_I is 0.1sec. When C_r is 0.69, the rise is slow with damped oscillation and slow convergence. The trend shows that as C_r grows from 0.69 to 1, the rise as well as the convergence accelerate. Furthermore, when comparing C_r 1.2 and 1.6, the rise is faster with C_r = 1.6 but it rapidly attenuates. The stabilization time is longer than that of C_r = 1.2. It is assumed that the fast rise is largely affected by the time constant T_L, and the damping effect rapidly functions after the point of inflection as it reaches the target, due to the effect of damping coefficient ζ.

In the same manner, Fig. 12 and Fig. 13 show the impact of C_r with different proportional gain and integral time. However, the proportional gain K_P is 4 and the integral time T_I is 0.1sec in Fig. 12, and the proportional gain K_P is 1.9 and the integral time T_I is 0.05 in Fig. 13. These results show that the smaller the C_r is, the slower the rise is, regardless of the proportional gain and integral time, and it comes to convergence with damped oscillation. The trend shows that when the C_r is too large, the rise is fast, but the stabilization time is prolonged.

In general, the faster the rise is, the more likely overshoots are to occur. However, this trend is not observed with this valve. As Fig. 10 indicated, the rise speed is due to the time constant T_L of the pilot valve section's transfer function $P(s)$, and the property while the value is approaching the steady-state value until convergence is due to the damping coefficient ζ of transfer function $V(s)$, combining the solenoid and pilot valve section.

Due to the above result and the perspectives of rise speed and damping force, etc., it is considered that the appropriate value for C_r is between 0.69 and 1.6. The proportional gain and the integral time for the compensation circuit should be determined from both aspects of valve safety and response, and the appropriate value needs to be set within a certain range.

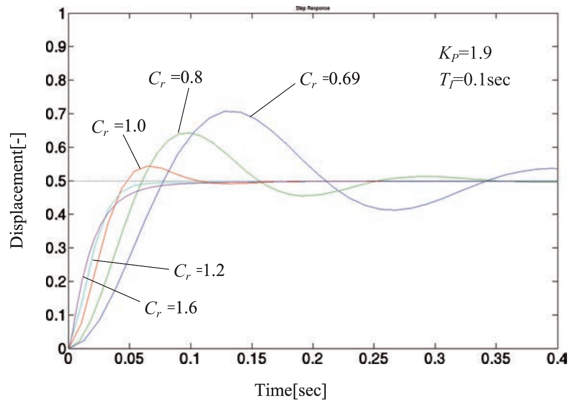

Fig. 11 Impact of C_r on the step response characteristics (K_P = 1.9, T_I = 0.1sec)

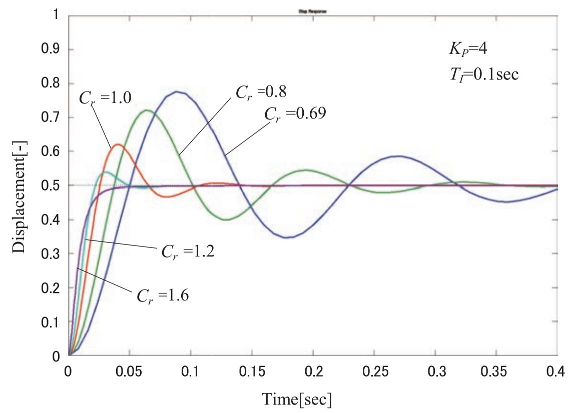

Fig. 12 Impact of C_r on the step response characteristics (K_P = 4, T_I = 0.1sec)

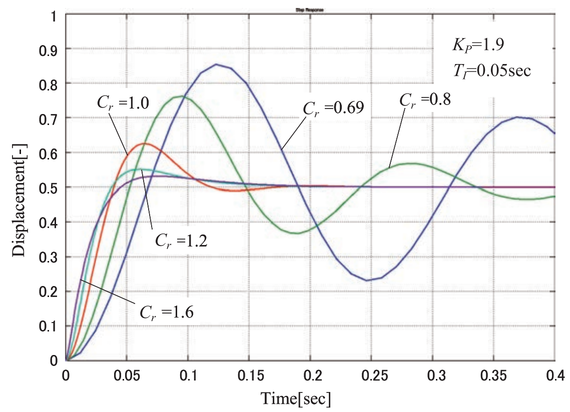

Fig. 13 Impact of C_r on the step response characteristics (K_P = 1.9, T_I = 0.05sec)

5 Experimental Verification

The analytical verification up to the previous chapter has clarified that C_r is optimal when between 0.69 and 1.6 based on the quick step response launch characteristic, damping characteristic, etc. This was experimentally verified.

5.1 Experiment Method

Fig. 14 shows the summary of the experiment device for the step response characteristics. The procedure was as follows: The valve's neutral point is adjusted with the stop valve closed. While inputting 50% input signal to the controller as the equilibrium point in the experiment, the load pressure difference P_L between ports A and B is adjusted to 7MPa while opening the stop valve. After adjusting the load pressure, the input signal is switched to 0. The input signal is input to the valve as a step waveform of 0 -> 50%. The input signal u and spool displacement x are recorded by the measuring instrument in chronological order. The provided pressure Ps is 14MPa, and water temperature is 25 +/- 5˚C.

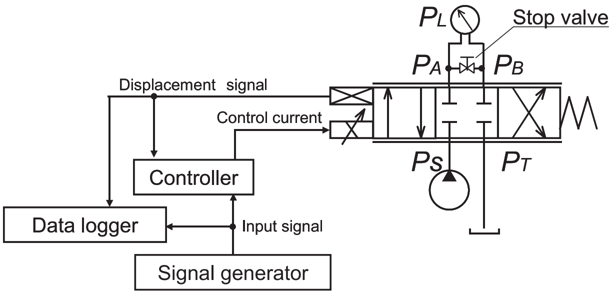

Fig. 14 Summary of the experiment device for the step response characteristics

5.2 Experiment Result

Fig. 15 shows an example of the experiment result for the effect of C_r on the step response characteristics. However, the compensation circuit parameter was adjusted to further clearly demonstrate the effect of C_r, and the spool displacement was normalized by excluding the stationary error. When C_r is 0.9, it proportionally rises in approximately 50m sec before reaching the steady-state value. When C_r is 2, the rise is faster than when C_r is 0.9, but the slope reduces after the point of inflection when it reaches approximately 95% of the target before reaching the target. This is assumed to be caused by the fast rise when C_r is large due to the small time constant T_L as well as the overdamping effect from the large damping coefficient following this point of inflection. This result indicated the same tendency as the analysis result that the rise is slow when C_r is small and that the rise is fast when C_r is large, but the stabilization time is increased due to the overdamping effect.

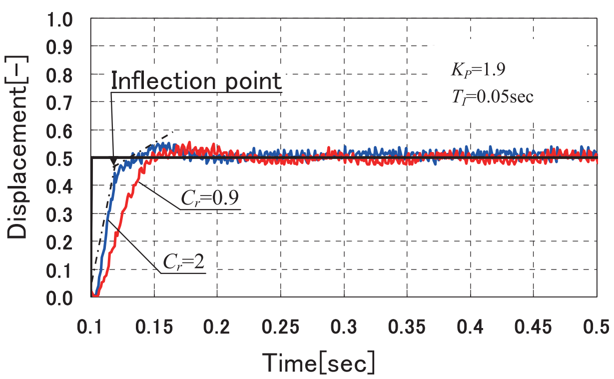

Fig. 15 Experiment result for the effect of C_r on the step response characteristics(K_P=1.9, T_I=0.05sec)

6 Concluding Remarks

① When C_r is small, the pilot valve section response is delayed due to the meter-out effect of the damping orifices. When C_r is large, the response is delayed due to the overdamping caused by the increased damping coefficient ζ. Due to this, the appropriate value of C_r is between 0.69 and 1.6.

② In terms of step response characteristics, the convergence until the target value is slow due to the slow rise when C_r is too small. On the other hand, when C_r is too large, the rise will be fast, but it leads to overdamping; the convergence until the target value is delayed. The result showed the tendency that the rise is fast and the convergence is also fast when C_r is within a certain range.

③ The findings above were also clarified in the experiment result.

Symbol

Designation	Denotation	Unit
A_{SPL}	Spool Cross-sectional area	[m^2]
D_b'	Equivalent orifice diameter	[Pa]
D_{SPL}	Spool diameter	[m]
D_n	Damping orifice diameter	[m]
F_F	Flow force	[N]
F_{SOL}	Solenoid thrust	[N]
K_{SP}	Spring constant	[N/m]
K_{SOL}	Constant of solenoid thrust	[N/A]
L_W	Control orifice width	[m]
L_{bn}, L_{bT} L_{NT}	Annular clearance lengh	[m]
P	Supply pressure	[Pa]
Q	Flow rate	[m^3/s]
ζ	Damping coefficient	[-]
λ	Friction facter	[-]
θ	Jet angle	[degree]
δ	Radial clearance	[m]
μ	Viscosity	[Pa s]
v	Kinetic viscosity	[m^2/s]
ρ	Working fluid density	[kg/m^3]
k_P	Proportional gain	[-]
T_I	Integral time	[sec]
τ_{SOL}	Time constant	[sec]
β	Coefficient of flow force	[N/m]
Γ	Coefficient of viscosity	[Ns/m]
C	Flow constant	[-]
C_r	Ratio of orifice diameter	[-]

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Essay

Setting out to Become a Professional Engineer, Japan

TAKAMATSU Shinichi

1. Introduction

Have you ever heard of the qualification known as "professional engineer, Japan (P.E.Jp : *gijutsu-shi*)"? I'm sure there are many people who have not heard of or are not familiar with this qualification. Generally, the word "*shi*" comes from meanings, such as "samurai" and "person who excels at academics and morals who should be respected", and it is often used as a suffix for occupations, etc. with specialized characteristics. "P.E.Jp" is also one of the special qualifications that are true to this meaning.

That being said, I also had not even heard of this qualification immediately before deciding to take the examination. Opportunities enabled me to acquire the qualification a few years ago, so I would like to introduce the contents of the qualification and the background before I obtained the qualification through this report.

2. Professional Engineer, Japan

The professional engineer qualification is for "workers who have expert knowledge, skills or experience", such as certified public accountants and physicians, according to Article 14 of the Labor Standards Act (Table 1). Furthermore, "professional engineer" is defined as "a person who conducts business on matters, which require advanced and adaptive expertise in science and technology using the name of professional engineer" according to the Professional Engineer Act. Due to the fact that only those who have passed the professional engineer examinations, which are national examinations, and have completed the registration can call themselves "professional engineers", we can say the title of "professional engineer, Japan" is for highly-skilled engineers whose capabilities have been certified by the government. Since doctors formulate theories and professional engineers apply them to industry, doctors and professional engineers are often expressed as two wheels of technology. Knowing this relationship would probably help you to understand the positioning of professional engineers.

It was 1958, when the high economic growth period was starting, that the certification system for professional engineers started. Since engineering skills have always been specialized skills, it has never been easy for those who aren't involved with technology to assess the skills. Japan had not had a system to demonstrate the practical skills of engineers until then. Due to this, selection of business operators to perform practical tasks came with risks for the side which wished to utilize science and technology. This was holding the national economy back. Due to such a background, they launched a certification system for professional engineers as a structure to appoint engineers with experience and practical skills to important posts. This significance still remains today, and it seems as though many companies provide incentives or payment amounting to that of Ph. D holders when they obtain the qualification [1] as the engineer qualification of the highest authority [2].

Table 1 Qualifications for workers who have expert knowledge, skills or experience according to Article 14 of the Labor Standards Act

	Qualification name	Difficulty		Qualification name	Difficulty
A	Certified public accountant	Extremely difficult	G	Certified tax accountant	Difficult
B	Physician	Extremely difficult	H	Pharmacist	Difficult
C	Dentist	Difficult	I	Certified social insurance consultant	Difficult
D	Veterinarian	Difficult	J	Real estate appraiser	Difficult
E	Attorney at law	Extremely difficult	K	Professional Engineer, Japan	Extremely difficult
F	Class-1 architect	Difficult	L	Patent attorney	Extremely difficult

3. Professional Engineer Examinations

As Fig. 1 indicates, there are several ways to become a professional engineer. While the first stage examination is said to be a difficult examination, it is sometimes exempt, depending on the curriculum. On the other hand, the second stage examination cannot be avoided. This examination is said to be extremely difficult to pass, with both difficult eligibility requirements and difficult

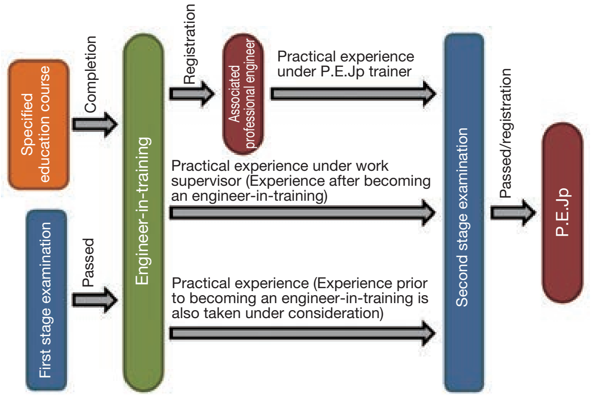

Fig. 1 Structure of professional engineer, Japan examinations

examination contents. For reference, I have included the difficulty level of each qualification, which is taken from the material [1], in Table 1. If you are familiar with some of these qualifications, you can probably easily imagine the difficulty level of the second stage examination.

First of all, the second stage examination for professional engineers normally requires that you have at least 7 years of specialized work experience to take the examination. This alone greatly reduces the number of qualified people for the examination.

Examinees select the preferred categories from the total of 21 technical categories (Table 2), and they further select the subjects according to their own specialty to prepare for the written examination. For example, the list of subjects to select from is shown in Table 3 for the mechanical engineering category, which I took. Among these, I selected mechanical dynamics/control.

The written examination tests your specialized knowledge regarding the overall engineering in the selected category, in addition to questions in which you have to discuss engineering for as long as 4 hours. You are tested on your advanced technical knowledge, capabilities to identify issues, capabilities to adjust contradicting elements, capabilities to formulate theories,

Table 2 Elective categories for professional engineer, Japan

1	Mechanical Engineering	8	Mining	15	Industrial Engineering
2	Marine & Ocean	9	Civil Engineering	16	Information Engineering
3	Aerospace	10	Water Supply & Sewerage	17	Applied Science
4	Electrical & Electronics Engineering	11	Environmental Engineering	18	Biotechnology & Bioengineering
5	Chemistry	12	Agriculture	19	Environment
6	Textiles	13	Forest	20	Nuclear & Radiation
7	Metals	14	Fisheries	21	Comprehensive Technical Management

Table 3 Elective subjects in the mechanical engineering category

Engineering category/ elective subject		Elective subject description
1 Mechanical engineering category		
1-1	Mechanical design	Machine element, tribology, design engineering, study of design information, and other mechanical design-related matters
1-2	Material mechanics	Structural analysis/design, fracture mechanics, mechanical materials, and other material mechanics-related matters
1-3	Mechanical dynamics/control	Motion/vibration, measurement/control, structural dynamic analysis/control, and other mechanical dynamics/control-related matters
1-4	Power energy	Internal-combustion engine, hydraulic turbine, boiler, generator, steam turbine, gas turbine, wind power generation, photovoltaic power generation, fuel cell, and other power energy-related matters
1-5	Thermal engineering	Heating/cooling, thermal transfer (including electric heat, convection current, and reproduction), combustion, heat exchanger, freezer, heating and cooling equipment, thermal storage machinery, and other thermal engineering-related matters
1-6	Fluid engineering	Fluid engineering, fluid machinery (including air blowers), chemical machinery, hydraulic equipment, and other fluid engineering-related matters
1-7	Process/factory automation and construction machinery	Process approach, processors, production systems (factory automation, etc.), their components, factory facility plans, industrial machinery, and other process/factory automation and industrial machinery-related matters
1-8	Transportation/hoisting and conveying machinery and construction machinery	Rolling stock, automobile, hoisting and conveying machinery, construction machinery, systems related to the above, other transportation/hoisting and conveying machinery, construction machinery, and matters related to their relevant systems
1-9	Robot	Industrial robot, locomotive robot, construction robot, robot-related equipment, and other robot-related matters
1-10	Information/ precision equipment	Information/precision equipment, optical instruments, electronic application equipment, operation monitoring control devices, other information/precision equipment, and matters regarding relevant systems

capabilities to explain, etc.

Furthermore, when you pass the written examination, you must take the oral examination, which is the final examination. The interviewers, who are expert professional engineers, determine your competence as an engineer.

In the second stage examination in 2015, the number of examinees was 24,878, the average age of examinees was 43.3 years old, and the passing rate was 14.7% [3]. This is considered to be the most difficult national examination among engineering-related examinations.

4. Motivation behind Taking the Examination

So far, I have briefly explained the professional engineer qualification and its examination system based on general theories. From here, I would like to resume the story from the aspect of why I aimed to obtain this qualification by going back to my personal perspective.

When I decided to take the examination, my oldest son was starting to learn word after word. Children grow so quickly, and they copy their parents' words and learn new things one after another. One day, seeing my son's growth like this made me think of something. It was that "My son is learning about the world from every move I make, but I'm living my life without much growth". I thought that this attitude was unfavorable as a parent, who should be a role model for their children.

Encountering the unknown and learning from failures are key factors in enriching one's life. I want my children to have many such experiences. In order to do so, it is important to voluntarily be interested in many things and have the habit of voluntarily taking action. It would be difficult to teach a child to obtain this habit, but I thought it might become a natural lifestyle for my children if I, as a parent, naturally practice this on a daily basis.

So, I decided that I would like to always be hungry for challenges and pursuits. I always try to be rid of adult-like hesitance and follow my curiosity. Whether it's something serious or something silly, I always try it if I'm interested, no matter what. And one day, I thought about obtaining a qualification. And I thought it would be more fun to aim for something difficult, if I'm going to obtain a qualification anyway. And the "professional engineer" qualification caught my attention for being reputably extremely difficult.

5. Examination Preparation

Once I decided to take the examination, I first took the first stage examination. This requires university-level engineering knowledge, but I will omit the details because I passed this by skimming through the textbook.

The main examination starts with the second stage examination, which I took in the following year. I submitted my application, and I decided to start studying approximately 1 month before the test. I began researching on the internet.

According to my research, the average experience for most people seemed to be finally passing the second stage examination after studying every day for several years. Some even said that they spent thousands of hours of studying before passing the examination.

I was aware that I was quite behind, but I didn't want to give up and waste the application fee. Despite its reputation for being extremely difficult, I hadn't even known about the qualification until the previous year. I underestimated that the reputation made it sound more difficult than it actually was.

On the other hand, passing the examination in this situation would feel great. I decided to pass the test by formulating a strategy to significantly enhance my studying efficiency.

However, how can I come up with such a convenient strategy? I had no idea, but I had nothing to lose. I decided to start with analyzing past exam questions.

These contents slightly deviate from the main purpose of this report, but I would like to introduce this because I came to an interesting result.

5.1 Exam Questions Area Prediction Model

I looked at exam questions for the past 5 years that I obtained from the official website of the Institute of Professional Engineers, Japan. I couldn't solve any of the essay questions, which are regarded as difficult. However, I realized that there is a certain tendency concerning the contents of the exam questions. For example, in case of an essay question discussing nonlinear springs or a jump phenomenon, we can categorize this as a common technology by regarding this as vibration of nonlinear systems. When we consider these small areas, it seems that we can categorize the essay questions from the past 5 years into 13 areas, which are shown in Table 4. I thought studying this question appearance tendency and predicting the exam question areas for 2014 would help me study efficiently, so I decided to prepare a prediction model.

Needless to say, the exam question appearance frequency differs for each area. When you consider this frequency as the expectation value, it becomes a prediction model P_R based on the exam question appearance rate. However, such an easy model is not interesting. Therefore, I read deeper into the psychology of the examination preparers who would think "This area was in last year's examination, so let's not include it this year". I decided to formulate another model. This is the model shown in Fig. 2, using the Marcov process.

Taking the nonlinear system vibration area as an example, this area is included in the examination every year except for 2011. From the phenomenon aspect of stochastically shifting this into the 2 states of being included in the examination and being excluded from the examination, the probability of this being excluded from the examination in the year after it was included would be 0.33, and the probability of it being included in the examination in the year after it was included would be 1.00. The characteristics of the state of the next point being stochastically determined based on the state of one point is called the "Markov property", and a series of these characteristics is called the "Markov process". I formulated the Markov model P_M by calculating the Markov process state transition probability for all areas.

I came up with 2 models, but I was unable to perform sufficient precision verification due to lack of data. Because of this, I used the integrated model P_I, which equally integrated the 2 models, as the exam question area appearance prediction model as shown in formula (1).

$$P_I = (P_R + P_M) / 2 \qquad (1)$$

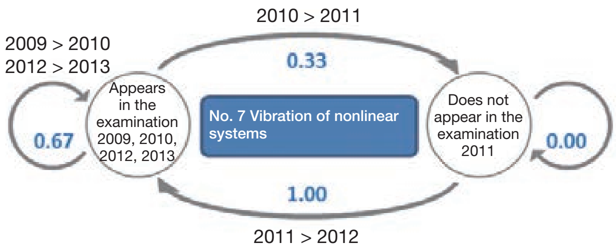

Fig. 2 Markov process

5.2 Priority Study Area Decision Model

Once the exam question area prediction was completed, I started to get excited. The upcoming examination aside, the result of abstracting and numerically analyzing the examination preparation was more interesting. In order to further advance this model, I decided to prioritize the study areas next.

You would think that simply prioritizing and studying the areas with higher exam question appearance frequency would be effective, but that may require a

Table 4 Area information for the past 5 years, including exam question appearance tendency

No.	Question area	Past questions					Actual examination	Probability model	Markov model	Integrated model	Study time	Study priority	Total study time
n		'09	'10	'11	'12	'13	'14	P_R	P_M	P_I	T	F	
1	Frequency domain inherent question	✓	✓		✓	✓		0.80	0.66	0.73	4	0.183	4
2	Vibration measure		✓	✓	✓	✓	✓	0.80	1.00	0.90	6	0.150	10
3	FF/FB control	✓		✓	✓			0.60	1.00	0.80	6	0.133	16
4	Vibrating excitation mechanism			✓			✓	0.20	0.33	0.27	2	0.133	18
5	Rotary machine vibration		✓	✓			✓	0.40	0.50	0.45	4	0.113	22
6	Mode analysis	✓		✓	✓			0.60	1.00	0.80	8	0.100	30
7	Nonlinear vibration	✓	✓		✓	✓		0.80	0.66	0.73	8	0.091	38
8	System stability		✓			✓	✓	0.40	0.00	0.20	4	0.050	42
9	PID control					✓		0.20	—	0.20	6	0.033	48
10	Coupled vibration				✓			0.20	0.33	0.27	10	0.027	58
11	Piping system vibration	✓	✓					0.40	0.00	0.20	8	0.025	66
12	Cases and measures					✓	✓	0.20	—	0.20	8	0.025	74
13	Bearing vibration property	✓						0.20	0.00	0.10	10	0.010	84
14	Transfer function	Exam question did not appear in the past examinations					✓	—	—	—	—	—	—

massive amount of time to study areas that I do not know well. On the other hand, studying areas that I was already familiar with would take little time. The significance of being able to efficiently study would be great, even if the exam question appearance rate is relatively low. Due to this, I decided to incorporate into the model the idea that studying my favorable areas would contribute to the enhancement of study efficiency.

Table 4 also shows the exam question area prediction result, the study time T for each area, etc. in addition to the past exam question areas. This study time T shows values, which are the number of hours spent on studying until I can score over 60% estimated in a subjective manner. Then, I calculated the study priority level F from formula (2) based on the exam question area prediction model P_I and the study time T.

$$F=P_I/T \tag{2}$$

Areas with higher study priority level F are areas which have high exam question appearance rates and short study time while simultaneously being areas where I can aim for scores over 60%. Therefore, all I needed to do was to start studying the areas with a higher value of the study priority level F first.

5.3 Passing Rate Estimation Model

As you can see, the model I developed by blindly grasping in the dark showed great applicability. However, there was more room to improve. This was deciding the areas not to study.

If I had to ultimately study all of the areas, there was no point in determining the priority. If I spread too wide, I wouldn't be able to sufficiently respond to areas other than the essay questions. If my objective is to pass the examination, studying all areas is worse than just being wasteful, as it requires the resources of time and concentration. Therefore, I decided not to spend any time on areas with low study priority level F. However, how many areas could I afford not to study? In order to make this determination, I then performed the passing rate estimation according to the progress of each area to study.

I'd like to simplify and explain the examination format to help you understand the passing rate estimation. There are 6 essay questions in the professional engineer second stage examination. You select 3 exam questions out of them and answer them. In addition, it has been disclosed that the passing criterion is that the average score of the 3 exam questions is over 60%. With this examination format in mind, I made the following passing rate estimation.

Based on the trend of past exam questions, it is assumed that the 6 exam questions would be from the total of 13 areas without overlapping. There are 1,716 combination patterns, based on ${}_{13}C_6$. We can expect that one of these patterns would be the essay questions in the examination, but the exam question appearance rate is biased for the 6 areas constituting the combination. Due to this, the incidence rate of each combination is not consistent. Therefore, I calculated the incidence rate of each combination by considering the exam question appearance rate.

First of all, the 1,716 combination patterns are expressed as C_i by using the suffix i ($1 \leqq i \leqq 1{,}716$). Combination C_i consists of 6 areas with different exam question appearance rates of P_I. This is expressed as formula (3) as a set of exam question appearance rates P_{In}. The suffix n here means a serial number ($1 \leqq n \leqq 13$) for each area.

$$C_i = \{x \mid x \in \{P_{In}\}, P_I \text{ included in the } i\text{th combination}\} \tag{3}$$

By considering the exam question appearance rate P_{In} of each area as the weight and adding all of the exam question appearance rates P_{In} of 6 areas in the combination C_i, the weight W_i for each combination is calculated (formula (4)).

$$W_i = \prod_{n=1}^{6} C_i \tag{4}$$

There are 1,716 patterns of this combination weight Wi, and adding all of them amounts to the weight of the overall examination. Due to this, the C_i incident rate R_i is calculated by subtracting the weight of the overall examination from the weight W_i of each combination, as shown in formula (5).

$$R_i = W_i / \sum W_i \tag{5}$$

The above calculation determined R_i, which are the incident rates for 1,716 combination patterns for the 6 areas included in the examination in 2014. I can only pass the examination when one of these combinations is included in the examination if the appeared combination C_i includes at least 3 areas in which I can score over 60%. (Areas that I cannot score 60% are assumed to be 0 points.) Therefore, I expressed R_i as shown in Fig. 3, which is the incident rate of the combinations C_i in which I can expect to pass if I studied according to the order of the study priority level F. I am also including the passing rate, which was calculated by adding the appearance rate R_i.

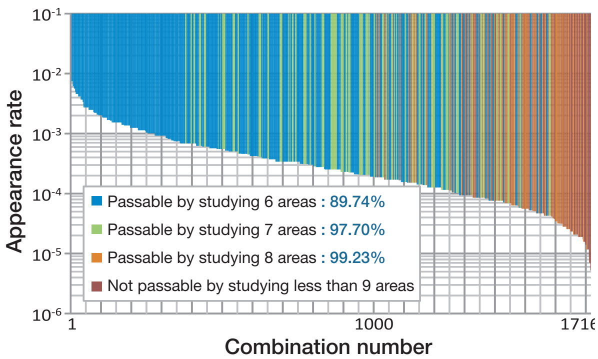

Fig. 3 Passing rate by study progress

The figure shows incident rate R_i in the vertical axis and all 1,716 combinations in the horizontal axis so that incident rates R_i are in descending order. This figure shows that I can pass the test as long as I study 6 or 7 areas in the order of higher priority level F for approximately the top 1,000 patterns with the higher incident rate R_i. In addition, while studying 7 areas would present the 97.70% passing rate for the written examination, studying of 8 areas would present 99.23%, only presenting a minute difference. Therefore, I can determine that studying areas beyond the 8th area is a waste of time and that it is appropriate to continue studying 7 areas. In addition, as Table 4 shows, the total number of hours required for studying 7 areas is approximately 38 hours.

You can say that I scientifically made an educated guess based on the data. This unexpectedly enabled me to reduce the amount of studying required for the written part, which is considered to be the key point in the second stage examination for the professional engineer examination, by half. If the preparation for the written part only requires 38 hours, securing the time and maintaining concentration would be easy. I would be able to secure sufficient time to study for categories other than the written part. Determining the essence of matters and coming up with a format that we can apply to reality is the duty of professional engineers. I can say that this model was created by this spirit, although somewhat ironically.

The development of this mathematical model, which I formulated out of mere curiosity, was completed even with the added touch of the passing rate when presenting the studying strategy. Mad scientist-like villain characters in comic books often say something like “Hehehe…the chance of you beating me is only XX%!”, and I expect that the design philosophy behind these calculation models is similar to my model. I’m extremely happy about being able to see a glimpse of their philosophy.

6. From Studying to the Result Announcement

All I had to do then was study. I decided to study for approximately 4 hours every day. After about 2 weeks, I was done with the study and even struggled with the time on my hands until the examination day.

On the day of the written examination, I selected 3 subjects from the areas that I had studied, as I had expected, for the essay part. I received the passing notification at a later date. As Table 4 shows, there was one question from an area which did not exist in the past examinations. However, this had no effect on my prediction that as long as you study 7 areas, the probability of at least 3 of them being included in the examination was extremely high. As far as I can tell from completing the experiment verification of N=1, it seems as though the established model satisfied the expected functions and worked.

The remaining part of the examination is the oral examination, which was to be held in the following year. The passing rate seems to be about 60%, but this part is more troublesome than the written part because you cannot formulate a clear preparation method. The examination guidelines say that this part is checking your experience, application capabilities, engineer ethics, understanding toward the professional engineer system, etc. However, the examination day came while I still had no idea exactly how I was supposed to prepare.

In the end, no special question was asked. Questions were about the professional engineer system and engineer ethics as well as regarding my motivation to take the examination and skills. The examination ended without me being able to offer any especially impressive answers, and I wasn’t confident about the result. As far as I researched on the internet, it seems as though all the other examinees had similar impressions. Therefore, the passing criteria for the oral examination is still a mystery.

I was nervous on the day of the announcement, as one would expect. However, I was happy to learn that I had passed in the end. Back in 2014 when I took the examination, the passing examinees were disclosed in the official gazette. When I saw my name in the official gazette, it stimulated my sense of belonging as a member of this country. I remember being motivated to make efforts for the society.

7. Looking back on Obtaining the Qualification

As I have already explained, my examination preparation period was much shorter than the average time spent by others who passed the examination. One of the reasons for this achievement was that I formulated a strategy without studying at random and succeeded. However, I think the bigger contribution was the fact that my work experience in KYB supported my technical capabilities.

Professional engineer examinations don’t simply test knowledge. They test your technical capabilities that you cannot acquire in a short period of time. You can strategically reduce the amount of studying, but it is impossible to reduce the difficulty level of the exam questions. I don’t think I could have passed the examination if I only had a small amount of work experience. In other words, my experience that I have accumulated through work as a mechanical engineer has refined my expertise and, with regards to the mechanical engineering category, even made obtaining the professional engineer qualification easy despite the fact that it is considered to be extremely difficult. In fact, I briefly looked at past questions for the computer science category, which is not my field, after I passed the examination. I couldn’t even understand the meaning of the question, which made me realize just how difficult professional engineer examinations are. This experience was also a good opportunity for me to be impressed by the quality of work in KYB.

Based on this experience, it seems as though the professional engineer qualification is something that middle-ranking engineers can naturally obtain. While this is generally considered to be a highly difficult qualification, it is not true in a sense. This is because we engineers are isolated from the general public especially in technology. If one spends more than 7 years in the specialized field and spends the time using his/her brain to develop technology, this would amount to as many as 5,600 hours of studies, even at 4 hours a day and 200 days per week. I think it’s natural that one should have suitable expertise.

This is the reason why I recommend fellow engineers with experience to take these examinations to measure your own expertise. If you pass, it should give you a sense of pride for the experience you have accumulated. If you fail, it would give you an opportunity to notice what you lack and study again with humbleness.

Being a professional engineer has other perks. Since I obtained the qualification, I have been encountering new experiences and situations, such as conversations developing when I exchange business cards with people, being inquired to co-write an engineering book, and being requested to write articles for books like this. Gathering with other engineers from various fields but with kindred spirits is especially guild-like, and it often gives me important inspirations to exchange with other industries. Having the professional engineer qualification doesn't drastically change anything, but I feel as though the opportunities and situations such as the above are priceless rewards.

8. In Closing

Upon aiming to obtain the professional engineer qualification, I was able to extract a logical strategy by formulating a numerical model for the boring territory of examination preparation in all seriousness. Even with this kind of math, which was partly for fun, it still brought me joy to think, uncover unexpected discoveries, and get excited. The course of developing this model was far more enjoyable than the examinations themselves. Although the main topic for this report was the professional engineer qualification, I hoped to share my experience as an example that even a boring thing can be fun if you work with seriousness while knowing that it will become useful. I would be happy if you could use my experience for reference in the future.

I will stop here, as it will significantly deviate from the main topic. However, the approach of creating models for various matters to comprehend the framework is effective not only in this example but also in all types of thought experiments. Therefore, the approach is effective both to deepen consideration and to fulfill curiosity. Personally, I would like to recommend not only taking on the challenge for the professional engineer qualification but also of learning this idea itself. If you are interested, I would recommend that you research the key phrase of "Fermi estimate[4]", as it is a similar concept.

While I was glad to obtain the professional engineer qualification, this was neither a goal nor a passing point for me but rather one of the many efforts with the aim of making challenges and pursuits into habits. Although there is no end to these efforts, there is no limit to interests in the world and challenges that I want to take. I think it is up to your frame of mind whether or not to enjoy life, as the alleged death poem by Shinsaku Takasugi reads;

"What makes a world with no interest interesting is your mind".

If this is the case, I would like to take after the spirit of the samurai and continuously grow as a professional engineer worthy of its name and as a father without forgetting the perspective of freely enjoying (*asobi*) with science.

Finally, the word "*asobi*" comes from Buddhism. Its original meaning apparently is quite serious, leading to enlightenment. With this in mind, I would like to conclude my report by sharing a quote that recently moved me.

- Quote -

I feel as though the mindset to "enjoy research" is related to this "*asobi*". Enjoying does not mean choosing an easy way or being satisfied with immature ideas. If you are to pioneer a new world that no one knows, you need the strength to take a step into the wasteland. In order to enjoy research, you must have the spirit to enjoy free pursuits supported by great expertise and deep knowledge. This is the true pleasure of research[5].

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Technology Introduction

Development of Automotive Semi-Active Damper Control

KUDO Tomoyuki

1 Introduction

The number of vehicles with semi-active dampers is still growing, and even some small vehicles use them, as seen in the example of Alfa Romeo MiTo, etc. In such a situation, the needs greatly differ for each manufacturer, vehicle rank, and vehicle type, as different manufacturers focus on different aspects, such as vehicle performance, cost, stable driving performance, comfort, etc.

We need control technologies that we can prepare in anticipation for these various needs. KYB's initiatives toward such needs include the development of semi-active damper control for magnetorheological fluid dampers, semi-active damper control for proportional solenoid dampers, etc. These control technologies provide both sprung mass control and unsprung mass control. In this control development, we have added more variations to these control technologies with the aim of responding to various needs. Specifically, this project developed control technologies that can further expand the adjustment range of vehicle performance by changing the number of sensors while providing both sprung mass control and unsprung mass control. This report introduces these technologies.

2 Sensors for Semi-active Damper

Firstly, I would like to explain the sensors for semi-active damper installed on vehicles. Our semi-active damper control requires 7 sensors for the semi-active damper control. The breakdown of these sensors includes 3 accelerator sensors that detect the vertical direction of sprung mass and 4 suspension stroke sensors, which are positioned as shown in Fig. 1. In this sensor configuration, sprung mass oscillation is detected through the accelerator sensors, and unsprung mass oscillation is detected through the stroke sensors. We have decided to remove the stroke sensors, which are more expensive than accelerator sensors and have more installation restrictions by changing the number of sensors from 7 sensors.

To develop semi-active damper control with a different number of sensors, we have changed the sensor installation positions according to the number of sensors. Reducing stroke sensors means that the unsprung mass oscillation information that had previously been obtained can no longer be obtained. Due to this, we must enable unsprung mass oscillation detection through sensor position changes.

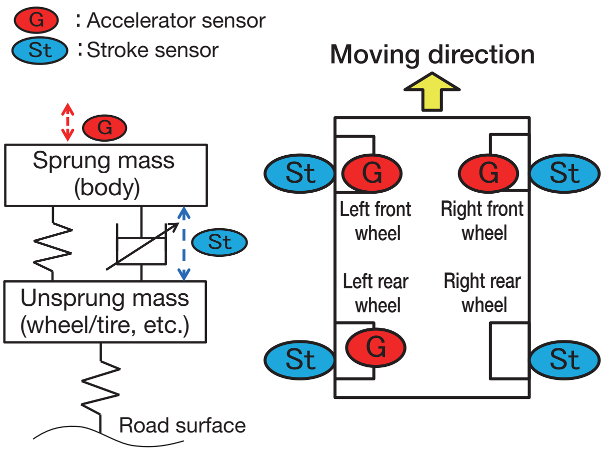

Fig. 1 Position diagram for 7 sensors

In this project, we developed the semi-active damper control with 5 sensors and the semi-active damper control with 3 sensors as semi-active damper control by reducing the number of sensors. Fig. 2 shows the arrangement plan for 5 sensors, and Fig. 3 shows the arrangement plan for 3 sensors.

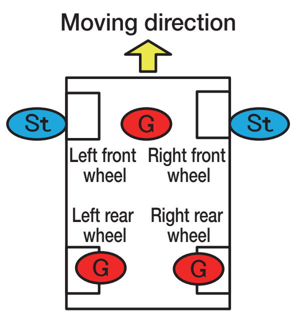

Fig. 2 Position diagram for 5 sensors

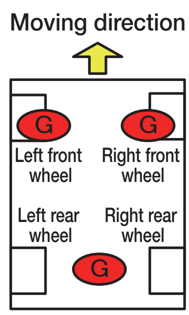

Fig. 3 Position diagram for 3 sensors

With 5 sensors, we removed the stroke sensors on the rear wheel side and placed an accelerator sensor over each rear wheel. The objective of this change was to thoroughly control the oscillation of the front wheels, which are the first wheels to capture the road surface input, so the information from the front wheels was prioritized. In other words, the unsprung mass oscillation for the front wheels is detected with stroke sensors to control the oscillation. On the other hand, unsprung mass oscillation on the rear wheels must be detected somehow in place of the removed stroke sensors. Therefore, the unsprung mass oscillation components, which are communicated to sprung mass, are extracted from the accelerator sensor placed over each rear wheel, enabling the detection of unsprung mass oscillation of the right rear wheel and left rear wheel. In addition, extraction of the unsprung mass oscillation components will be explained later.

With 3 sensors, we removed all of the stroke sensors. An accelerator sensor was placed over each front wheel in order to make the unsprung mass oscillation for the right front wheel and the left front wheel detectable. The reason that 2 sensors were placed on the front wheel side is because we focused on the front wheels, which are the first wheels to capture the road surface input, as with 5 sensors. In terms of the rear wheels, the unsprung mass oscillation obtained from the accelerator sensor between the rear wheels is distributed evenly to the right and left wheels.

3 Semi-active Damper Control in Response to the Number of Sensors

Next, I would like to explain the control for each number of used sensors (7, 5, and 3). In this development, we differentiated not only the control for each number of sensors but also two types of control, one focusing on comfort and the other on stable driving performance, by changing the control itself in addition to gain tuning. In other words, we developed control according to the number of sensors/vehicle performance, such as "comfort-oriented control with 3 sensors" and "stable driving performance-oriented control with 5 sensors" (Table 1). Table 1 shows the control of parts that especially contributed to the reduction of sensors and expansion of the performance adjustment range. In addition, I will omit the explanations regarding controls that are not affected by the number of sensors in this report. These controls include the steering control using steering wheel angles, vehicle velocity, horizontal acceleration, etc. and the control performed solely through gain tuning.

First, I would like to explain the control when the number of sensors is 7. When there are 7 sensors, not only the sprung mass oscillation but also the unsprung mass oscillation of

Table 1 Control in accordance with the number of sensors and vehicle performance

Number of sensors	Comfort-oriented control	Stable driving performance-oriented control
7	Comfort control Thrust absorption control Unsprung mass control	Road surface follow-up control Thrust absorption control
5	Differentiation of technologies for 7 sensors and 3 sensors	Differentiation of technologies for 7 sensors and 3 sensors
3	Thrust absorption control Unsprung mass control	Thrust absorption control

each wheel can be detected. Due to this, even more detailed control can be implemented. We were especially able to increase the performance range for comfort-orientation as well as stable driving performance-orientation through the comfort control, the objective of which is to maintain the sprung mass flat during each unsprung mass oscillation cycle, and the road surface follow-up control, the objective of which is to follow the road surface rolling.

Fig. 4 shows the image diagram for sprung mass movements when comfort control is being performed. Comfort control uses skyhook control, which is used in common suspension control. This not only controls the extension/compression ratio of the damper's damping force against the sprung mass velocity in every unsprung mass oscillation cycle but also ensures that the damping force does not suddenly change when controlling the extension/compression ratio. This control improves comfort.

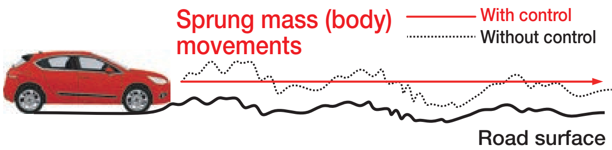

Fig. 4 Comfort control image diagram

Fig. 5 shows the image diagram for spring mass movements when road follow-up control is being performed. The road follow-up control controls the low-frequency damper velocity in every unsprung mass oscillation cycle. "Low-frequency damper velocity" here refers to the 1-2 Hz low frequency components that are extracted from the damper velocity, which is detected by the stroke sensors, through filtering. This enables the vehicle to follow vast rolling of road surfaces, improving the stable driving performance.

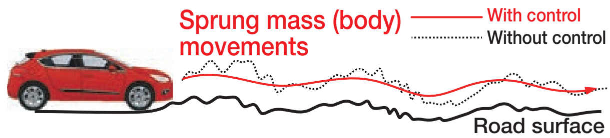

Fig. 5 Road surface follow-up control image diagram

Fig. 6 shows the image diagram for unsprung mass movements when unsprung mass control is being performed. Unsprung mass control increases the damping force according to the unsprung mass oscillation level. This enables the damping force to be reduced on road surfaces with minor unevenness, contributing to the improvement of comfort.

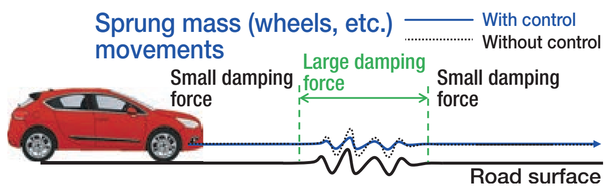

Fig. 6 Unsprung mass control image diagram

With 5 sensors, the sensor placement for the front wheels for oscillation detection is the same as that of 7 sensors. The sensor placement for the rear wheels is the same as that for the front wheels when the number of sensors is 3. Therefore, the control with 7 sensors and control with 3 sensors are used differently for the front wheels and the rear wheels. Due to this, I will omit the explanation.

When there are 3 sensors, we cannot obtain the information from stroke sensors, which we can obtain from 7 sensors. Due to this, we calculated alternative values by using accelerator sensors that detect the sprung mass oscillation to implement unsprung mass control. The unsprung mass oscillation components in addition to sprung mass oscillation information are superimposed on the accelerator sensors for sprung mass. Due to this, we have extracted only the unsprung mass oscillation components from the accelerator sensor values to only detect how much oscillation the unsprung mass had (unsprung mass oscillation level) (Fig. 7). As Fig. 7 shows, the oscillation level, which is calculated from the damper velocity that has been differentiated with the values detected by the stroke sensors, and the oscillation level, which is calculated from the sprung mass acceleration detected by accelerator sensors, draw almost the same waveforms. Due to this, we can say that the unsprung mass oscillation level can also be detected from sprung mass acceleration. Then, we implemented the control to increase the damper's damping force according to the detected unsprung mass oscillation level (unsprung mass control).

However, the detection accuracy is less than the detection of unsprung mass oscillation from stroke sensors. Due to this, we did not implement control for every unsprung mass oscillation cycle, which we did for 7 sensors. In addition, since the minimum damping force is enhanced for stable driving performance-oriented control, we did not implement the unsprung mass control.

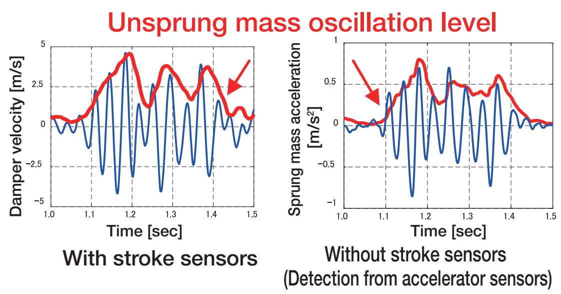

Fig. 7 Unsprung mass oscillation detection

The thrust absorption control, which is implemented in both control specifications, controls the distortion of the damping force waveform caused by valve cracking within the damper. The test result of this thrust absorption control for the damper alone is shown in Fig. 8.

This shows that the distortion of the damping force waveform within the green frame is reduced through the thrust absorption control. Although the distortion reduction seems small on the waveform, the reduction of this distortion absorbs the thrust feel during actual vehicle evaluation, improving the comfort.

Next, Fig. 9 shows the actual vehicle test result when thrust absorption control is implemented.

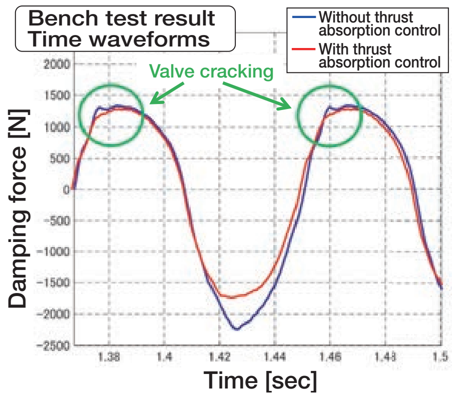

Fig. 8 Bench test result for thrust absorption control for the damper alone

The timing in which the damping force waveform distorts due to valve cracking is slightly after the positive/negative switch of the damper velocity. Upon this, the greater the damping force is, the more sudden the damping force change is. Therefore, considering the damper response delay, the current command is lowered around the damper velocity of 0. This can reduce the sudden change in the damping force, absorbing the thrust feel and improving the comfort.

In addition, as Fig. 9 shows, there is correlation between the movements of the sprung mass acceleration (accelerator sensor detection) and damper velocity (stroke volume derivative). Due to this, the thrust absorption control was implemented with the sprung mass acceleration when the stroke sensors were reduced.

In addition, current commands without thrust absorption control are difficult to identify due to noises, but they are close to consistent.

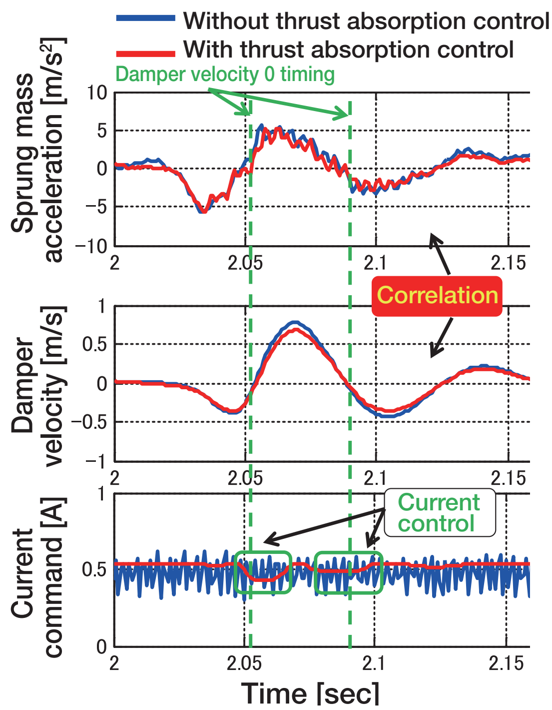

Fig. 9 Actual vehicle test result for thrust absorption control

4 Sensory Evaluation with an Actual Vehicle

We performed a sensory evaluation based on the internal evaluation criteria by installing the control, which was mentioned in the previous chapter, on an actual vehicle. Prior to performing the evaluation, we picked up items that contribute more to comfort and stable driving performance among the actual vehicle sensory evaluation items, as shown below. Each item was scored for the comfort and stable driving performance.

Comfort score: “Flat feel” + “Harshness*”

Stable driving performance score: “Grounded feel” + “Yaw/roll feel”

*Refer to Glossary “Harshness” on P. 34

In addition, the evaluation was conducted with the control of comfort-oriented specifications with 3 sensors as the standard. The sum of the comfort score and stable driving performance score is used as the definition of vehicle performance.

Fig. 10 shows the sensory evaluation result using an actual vehicle. “Standard vehicle” in Fig. 10 refers to the commercial vehicle, which was used in this control development. The control is provided through the standard semi-active damper and control algorithm (manufactured by another manufacturer/7 sensors). This vehicle was used for the internal evaluation to obtain the reference values and is therefore included in the figure. In addition, the standard vehicle also comes with 2 modes of comfort-oriented control and stable driving performance-oriented control.

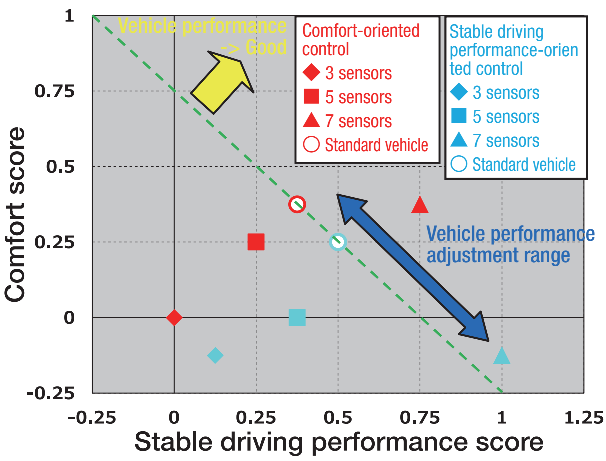

Fig. 10 Actual vehicle sensory evaluation result

The green broken line in Fig. 10 is a line that connects the scores for comfort-oriented control and stable driving performance-oriented control of the standard vehicle.

Generally, when turning is performed solely with control gain, the comfort and stable driving performance contradict each other. Due to this, the vehicle performance would change as if to move over the green broken line in case of the standard vehicle.

On the other hand, by tuning both the control algorithm itself and the control gain, the tuning flexibility increases. With less contradictions, this method realizes vehicle performance that especially focuses on comfort and stable driving performance. While it is unclear whether or not the standard vehicle’s tuning is solely through the control gain, our scores for both comfort-oriented control and stable driving performance-oriented control were on the right side of the green broken line connecting the 2 scores of the standard vehicle, both cases using 7 sensors. This demonstrated that the vehicle performance is tuned at a high level.

In terms of stable driving performance-oriented control with 7 sensors, the road follow-up control (indicated in Table 1) is highly effective. We were able to tune the stable driving performance to the level in which the comfort deterioration from poor road rolling conditions was acceptable. Due to this, the comfort score was lower than that with 5 sensors, but we were ultimately able to greatly change the adjustment range of the vehicle performance.

5 In Closing

We have been able to change the vehicle properties focusing on stable driving and focusing on comfort with each number of sensors. We were able to achieve suitable control for each number of sensors as well as a wide range of vehicle performance adjustments.

Also with 3 sensors and 5 sensors, we think it is necessary to work on the development of even better control by comparing with vehicles that are controlled with the same numbers of sensors.

This report introduced our efforts to change the number of sensors for semi-active damper control, but we will also continue developing the technology to provide the control of both sprung mass and unsprung mass without newly adding sensors for semi-active damper control.

Finally, I would like to express my sincere gratitude for everyone in the relevant departments who have provided support in this development.

Author

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Glossary

“Harshness”

Included in “Development of Automotive Semi-Active Damper Control” P. 30

KYB TECHNICAL REVIEW editor YONEZAWA Kazuhiko

1 What is “Harshness”?

“Harshness” refers to when an impact noise and vibration are created when a vehicle goes over uneven surfaces, such as joints in paved roads, steps, or protrusions.

In terms of a physical sense, the body would feel the vibration from the seat, floor, or steering wheel from the strong shock (Fig. 1) on the tires from the road surface in the vertical direction or front-back direction being transmitted to the vehicle body through the suspension.

This phenomenon became an issue along with the spreading of radial tires, which have less envelope characteristics [Note 1)] compared to bias tires.

Harshness is also related to rigidity of the front-back direction and vertical direction of the suspension. The greater the rigidity is, more severe the harshness becomes.

Note 1) Property in which the tire tread surface wraps around a protrusion to absorb the force from the protrusion when the tire goes over it.

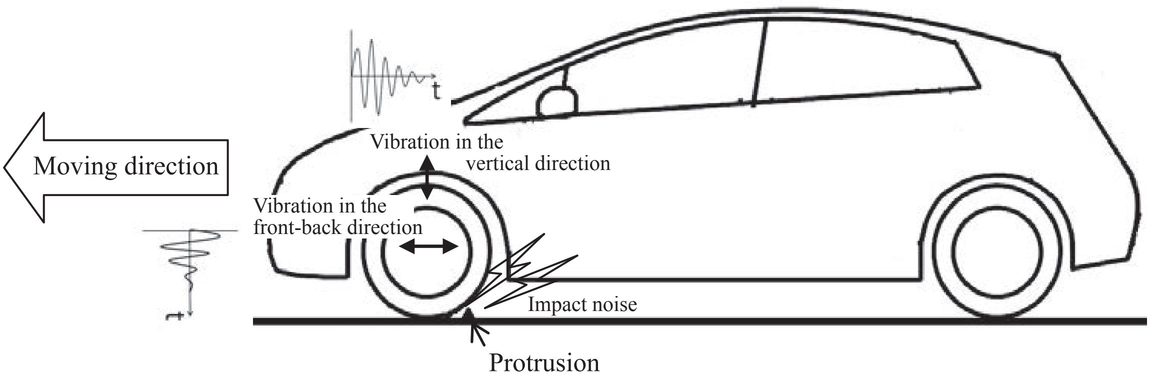

Fig. 1 Impact noise and vibration transmitted to the vehicle body when going over a protrusion

Technology Introduction

Development of Die Casting Analysis Techniques

YOKONO Kouta

1 Introduction

The gear case for KYB'S electric power steering (hereinafter referred to as "EPS") for vehicles and the component called "body" for the vane pump for hydraulic power steering (hereinafter referred to as "HPS") are manufactured using the die casting method (Fig. 1).

EPS uses the torque, which is generated by the electric motor in the vehicle steering operation, as power assistance. The vane pump for HPS is necessary in safe driving by enabling steering operations with few operations and quickly responding to avoid danger, etc. by using hydraulic power.

Casting faults, such as shrinkage cavities, in these die casted components can lead to rust from water seeping and working fluid leakage, causing operation failure.

If casting faults occur in the prototype stage, we must respond to the fault through additional prototypes. Therefore, the mold modifications and prototypes require budget and time.

In this report, I would like to introduce our efforts to improve the fault prevention accuracy level of die casting simulation with the aim of reducing the development lead time as well as their application examples.

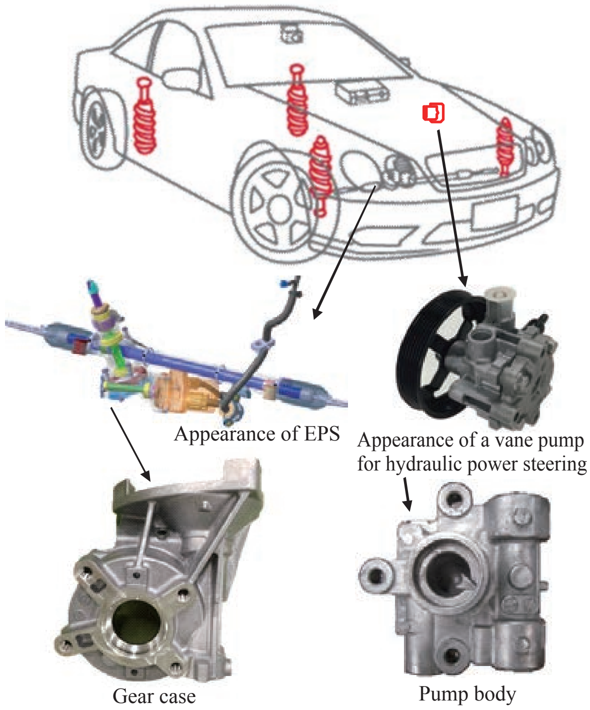

Fig. 1 Example of KYB's die-casting components

2 Casting Faults and Measures

Casting faults include gas entrainment, flow lines, and shrinkage cavities (Fig. 2).

In gas entrainment, air that is entrained when molten metal is injected into the mold is left inside the product as bubbles. The countermeasure against gas entrainment is to create passages for the molten metal that are less prone to entraining air.

Flow lines are surface faults, in which molten metal solidifies before completely fusing, creating wrinkle-shaped cavities. The countermeasure for these faults is to prevent the molten metal temperature from dropping.

Shrinkage cavities refer to gaps created within the product due to solidification shrinkage of the molten metal. They are mainly seen at the center of thick parts or parts that solidify last. Countermeasures for shrinkage cavities include directional solidification by enhancing

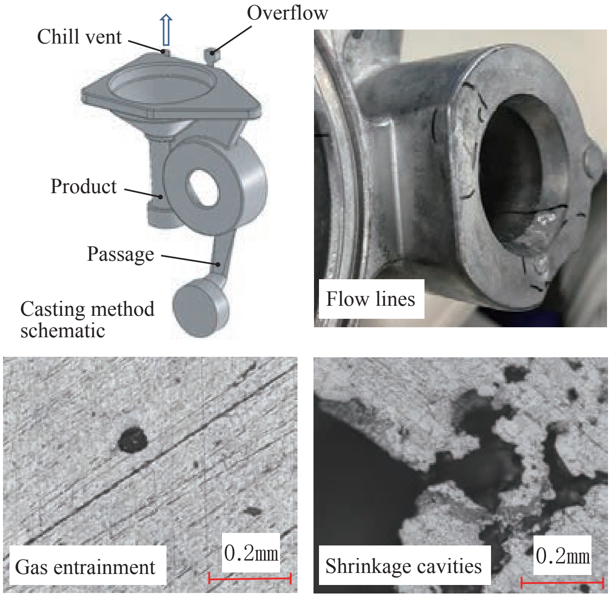

Fig. 2 Casting method and casting faults

the cooling of thick parts, supplementing molten metal through local pressure.

These faults deteriorate products' mechanical properties. If faults surface after machining, they can cause leakage. However, shrinkage cavities and gas entrainment in products cannot be avoided in die casting due to the production process. Therefore, we prevent outflow of faulty units through visual inspections and leak tests. In addition, in case of high defect rates, we had been changing the mold or injection conditions based on past experiences to address the issues. However, these measures had issues, such as prolonged lead time in mold modification and multiple modifications.

3 Improving the Simulation Prevention Accuracy Level

For the simulation software, we used the commercial analysis software for casting (ADSTEFAN[Note 1]). In order to utilize the simulation, the existence and locations of the faults must match between the actual product and the simulation. With the actual casting faults, we used an X-ray CT scan to confirm the gap distribution and observed the cross-section of each part, thus categorizing them into 2 fault types of "shrinkage cavities" and "gas entrainment". The simulation software comes with physical property values, such as specific heat and thermal conductivity, as default. However, directly using these values does not enable us to accurately predict fault occurrence. Therefore, we decided to improve the prediction accuracy with the following procedure.

Note 1) Registered Trademark of Hitachi Industry & Control Solutions, Ltd.

3.1 Improving the Temperature Distribution Prediction Accuracy

Reproducing the actual product's mold temperature through simulation is necessary in order to predict faults in fluidity and solidification analysis. In order to do so, the temperature distribution prediction accuracy of the simulation must be improved.

Casting models consist of elements, such as molten metal, mold, and water-cooling tubes for the mold (Fig. 3). In order to improve the temperature distribution prediction accuracy, we must comprehend the physical property values unique to each element, such as specific heat and density, as well as heat transfer coefficients between elements. With physical property values unique to each element, we measured the specific heat, density, thermal conductivity, and viscosity and reflected the actual measurement values on the simulation.

Since we were unable to measure the heat transfer coefficients, we measured the mold temperature with thermography and made adjustments so that the measured temperature could be reproduced in the simulation.

With the default physical property values, there was as much as +100˚C and over temperature differences. By adjusting the heat transfer coefficients with the actual measured physical property values, we were able to maintain the temperature difference with the actual product under 20˚C maximum (Fig. 4). In addition, we were also able to maintain the temperature difference with the actual products of different models under 20˚C maximum without re-adjusting the physical property values, as long as the materials and process were the same.

3.2 Improvement of Fault Prediction Accuracy

We evaluated the gas entrainment with the "maximum air pressure", which displays the gas pressure from the start of injection to completion. Based on the idea that gas entrainment occurs when the pressure of the entrained air

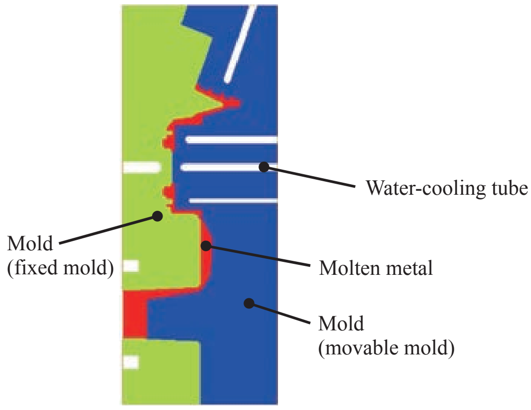

Fig. 3 Schematic of a casting model

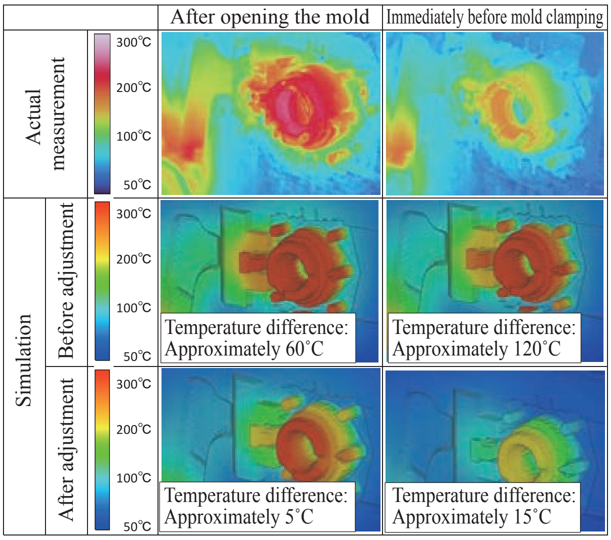

Fig. 4 Calibration result of mold temperature distribution

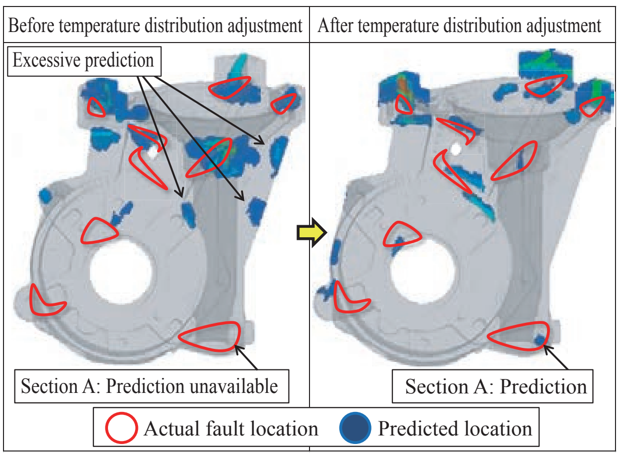

Fig. 5 Gas entrainment prediction result

becomes high, we only displayed areas with a certain gas pressure or above. As a result, we were unable to predict Section A in the default condition, and faults were excessively predicted in other areas. By shifting the physical property values and temperature distribution closer to the actual values, we were able to predict Section A and reduce the excessive prediction areas. Due to this, we were able to improve the gas entrainment prediction accuracy (Fig. 5).

The locations of the flow lines in an actual product matched the locations of the flow lines where the “air contact time” of the molten metal is long and the temperature is low where the molten metal meets when the filling process is completed (Fig. 6).

For the prediction method of shrinkage cavities, we used the “soundness of degree” which considers the solidification shrinkage of molten metal and the shift of the molten metal caused by solidification shrinkage. Soundness is represented in terms of ratio, and the smaller the value is, the greater the shrinkage cavity risk is. As with gas entrainment, we were able to improve the prediction accuracy by shifting the physical property values and temperature distribution closer to the actual values (Fig. 7). In addition, we were also able to match the locations of shrinkage cavities with the “solid phase rate”, in which unsolidified areas within solidified product were identified (Fig. 8). We learned that soundness can also reproduce the local pressure [Note 2)] effect and that unsolidified areas can predict the shrinkage cavity range with good accuracy.

Note 2) Method to supplement the molten metal that shrinks from solidification by directly applying pressure to part of the mold during the solidification process.

4 Simulation Application Examples

4.1 Measure for Gear Case Shrinkage Cavities

We studied the gear case in which a fault in Section A was found in order to determine the cause and to take countermeasure for the fault (Fig. 9). The observation result showed that Section A mainly had shrinkage cavities. Therefore, we considered the measure through simulation prior to conducting the casting experiment.

We responded to shrinkage cavities by enhancing the mold cooling process. We added water-cooling tubes where additional cooling is possible from the structural perspective of the mold. The simulation demonstrated that the mold temperature reduced and the unsolidified part

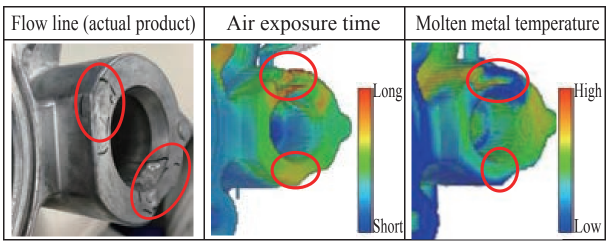

Fig. 6 Flow line prediction result

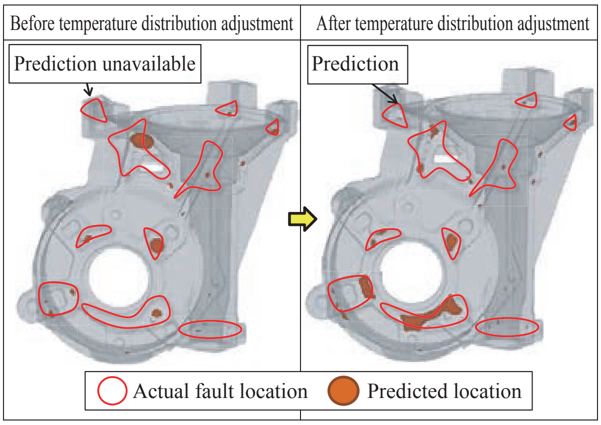

Fig. 7 Shrinkage cavity prediction result (Soundness)

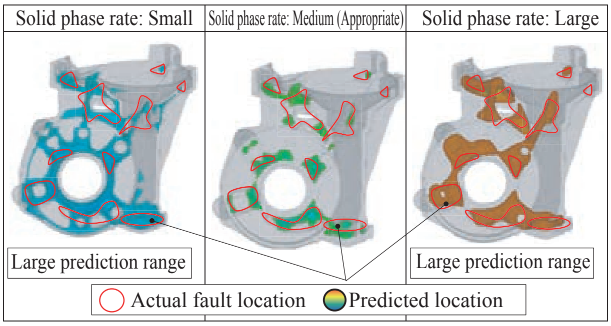

Fig. 8 Shrinkage cavity prediction result (Unsolidified area)

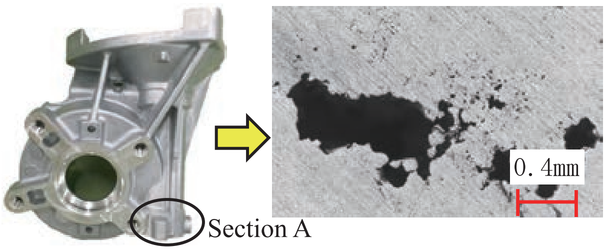

Fig. 9 Fault in Section A of a gear case

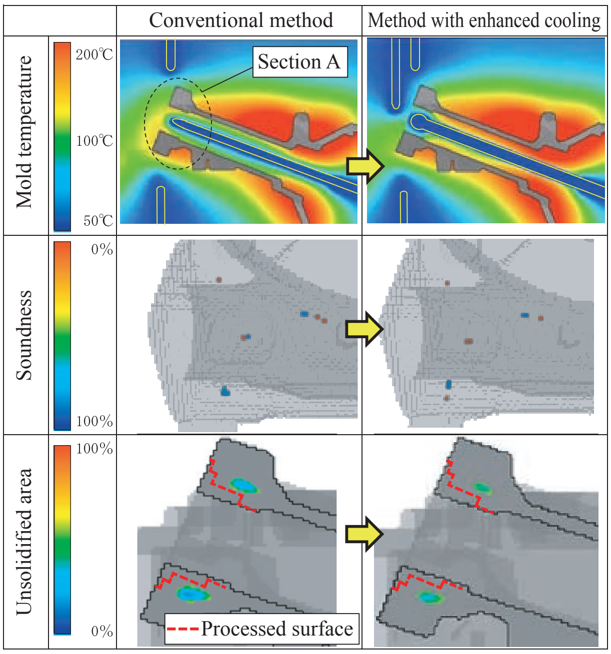

Fig. 10 Difference in shrinkage cavity distribution due to enhanced cooling

was made smaller with the same soundness (Fig. 10). Based on this result, we determined that the risk of the shrinkage cavities being exposed on the processed surface after the machining process and leading to leakage would be reduced, although the shrinkage cavities cannot be completely removed.

As a result of the casting experiment, we were able to reduce the extent of shrinkage cavities and significantly reduce the leakage defect rate.

4.2 Flow Line Measure

Flow lines were seen in a similar-shaped component in the past when considering the casting method for a new model. It was highly likely that flow lines would occur in the same place, so we took measures when considering the casting method through simulation.

The simulation result presented that the locations of the flow lines were where the molten metal met from both sides of the mold hole and that the molten metal temperature was lower where it met.

As a countermeasure, we created an overflow in the gap where the molten metal meets so that the overflow is the last section to be filled, thus guiding the reduced-temperature molten metal into the overflow.

As a result, no flow line occurred in the section from casting, allowing us to launch the mold without modification. This led to the reduction of development lead time (Fig. 11).

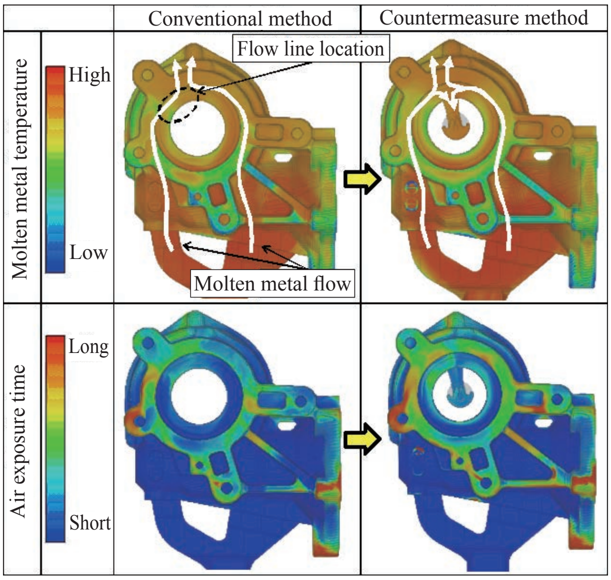

Fig. 11 Flow line measure through overflow addition

5 In Closing

It took a long time for the simulation results to reproduce actual faults, but they reached the usable level in this development. However, there are still aspects that cannot be fully predicted, and we must further improve the simulation accuracy. Due to this, we consider that it is important to accumulate internal know-how by increasing the number of case studies.

We will continue utilizing the developed fault prediction methods and make efforts to reduce the development lead time and improve productivity through theoretical considerations of casting methods. Finally, I would like to express my sincere gratitude for relevant parties and everyone who provided guidance and support.

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Technology Introduction

Development of PREGIO-HCPS (High-brightness Chemical Plating System)

OKAJIMA Noriyuki

1 Introduction

Metal is used in many key components that make up the products by KYB Motorcycle Suspension Co., Ltd. (hereinafter referred to as “KMS”). The surface treatment includes paint, alumite (anodic oxide coating), decorative chrome plating, etc. Each has advantages and disadvantages, and new surface treatment technologies that can be applied to KMS products were being anticipated. Therefore, we focused on silver mirror plating, which is characterized for its visual properties, to promote the development.

The development of silver mirror plating in KMS was started as technology to replace the decorative chrome plating, which is used in shock absorber components for motorcycles (aluminum outer tubes). Decorative chrome plating was outsourced to an affiliated company, and we had been troubled with high defect rate and high cost caused by the complex processes and the number of processes. Pin holes, which are representative defects, are caused by cavities. The chrome plating process enlarges pin holes, making them more visible (Fig. 1). This was causing the defect rate to increase.

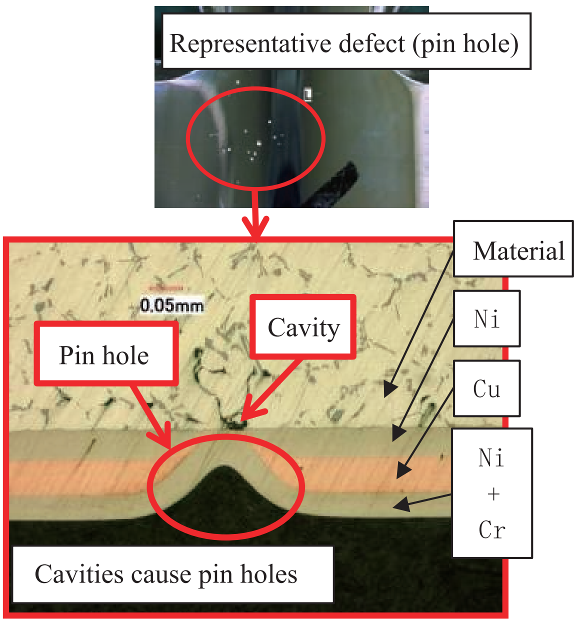

Fig. 1 Plating defect

There are 2 reasons that silver mirror plating was focused on as replacement technology for decorative chrome plating.

One is that silver mirror plating utilizes the painting technology. If we can cover faults, such as cavities, with a coating film, we may be able to reduce defects.

The second reason is that we could assimilate the appearance to chrome plating by coloring the coating film. We utilized the color variations and high brightness, which are the main characteristics of silver mirror plating. In order to fully utilize these characteristics, we shifted the direction away from mere development of technology to replace decorative chrome plating. We decided to establish new surface treatment technology with great added value and named this silver mirror plating technology “PREGIO-HCPS (High-brightness Chemical Plating System)”. PREGIO means “values” or “merit” in Italian.

2 Overview

Silver mirror plating is an application of the silver mirror reaction of the silver plating technology. This is existing technology used for resin materials as surface treatment to enclose a silver film, which is formed through a chemical reaction in a spray method, with undercoat and topcoat (Fig. 2).

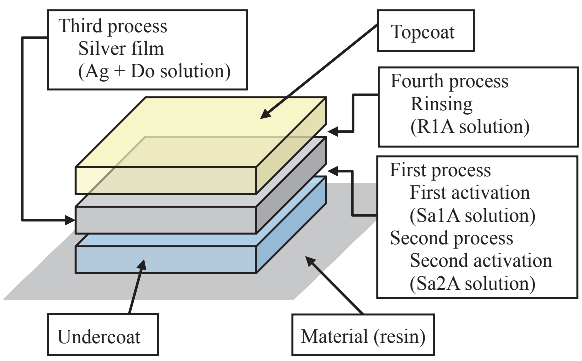

Fig. 2 Silver mirror plating structure

The silver mirror reaction is a chemical reaction in which ammoniacal silver nitrate solution is reduced by various reducing agents, extracting silver. This technology was discovered in the first half of the 19th century and has been used for many years. It is called the "silver mirror reaction" due to the fact that it is now industrially used as a manufacturing method for mirrors. The advantage of silver is that the reflectance of visible light is 98%, being the highest among metals. The disadvantages are that it is the second most expensive metal after gold and that it easily undergoes chemical reactions. Our affiliated manufacturer applied the silver salt processing know-how that they obtained through their work with photographic printing paper to silver mirror plating and developed silver mirror plating technology that can control chemical changes, such as **whitening, yellowing, and whitening unique to silver mirror plating** (refer to Glossary "Coating Defect" on P. 44), that had been considered the weakness of silver mirror plating.

There are 4 processes to form a silver film (Fig. 3).

Resin material
↓
Undercoat
↓
Baking
↓
Silver film:
Pure water wash
↓
First process
(First activation: Tin is added as a catalyst)
↓
Pure water wash
↓
Second process
(Second activation: Silver nitrate is reduced by tin to form silver nuclei)
↓
Pure water wash
↓
Third process
(Silver mirror reaction: Silver film is formed)
↓
Pure water wash
↓
Fourth process
(Rinsing process: Stabilize silver, which is prone to corrosion reactions, to control the reaction)
↓
Pure water wash
↓
Baking
↓
Topcoat
↓
Baking

Fig. 3 Silver mirror plating process

3 Target

The existing silver mirror plating was intended for indoor use, and plated materials were limited to resin. Due to this, the undercoat did not adhere to metal materials. Therefore, we decided to develop surface treatment technology that can respond to the coating quality standards that are applied to current articles by targeting metal material components of KMS with the cooperation of the manufacturer.

4 Preparation Test

We knew that the undercoat adhered to resin. Due to the fact that KMS components are coated components (resin coating), we thought we can make silver mirror plating on metal materials possible as long as the undercoat adheres to the coating.

First, we studied the undercoat's adherence with cathodic electrodeposition for rear cushion unit springs and with clear electrostatic spraying for aluminum outer tubes.

On the other hand, clear coating as basecoat can be used for aluminum and iron coating production lines in KMS. It had been used in the aluminum coating production line and demonstrated great adherence.

4.1 Result of the Square Grid Adherence Test

① Components with cathodic electrodeposition: Good

② Components with clear electrostatic spraying: Exfoliation occurred between the clear coating and the undercoat (Photo 1).

As a result of the investigation for the cause conducted by the affiliated manufacturer, it was presented that the cause was the overcuring of the clear coating and that clear coating was not suitable for the basecoat.

Clear coating for aluminum outer tubes is two-part curing acrylic silicon resin coating. Silicon resin doesn't have great adherence with other coating resin materials. The poor adherence becomes more prominent as the coating film's curing develops. Two-part curing coating has 2 agents of the coating material and curing agent. By injecting the curing agent into the coating material, the coating film cures. The curing develops along with baking heat and time, and this characteristic emphasized the poor adherence of silicon resin.

Due to this, we were unable to use the clear coating for aluminum outer tubes, which had been used in the past. We needed to develop new basecoat.

Photo 1 Exfoliation (aluminum material)

5 Development of Basecoat

To do this, we requested the affiliated manufacturer to select new basecoat, and they selected high temperature baking type acrylic resin coating and low temperature baking type polyester resin coating. Among coating materials by the affiliated manufacturer, these coating materials are primer materials that especially excel at the adherence to the base material. We decided to evaluate the advantages to make the selection.

5.1 Results of the Square Grid Adherence Test and Corrosion Resistance Test

(1) High temperature baking type acrylic resin coating

We manufactured testing plates (hereinafter referred to as “TPs”) and confirmed the adherence with square grid adherence tests. There was exfoliation between the basecoat and the undercoat, but the corrosion resistance performance was good.

According to the affiliated manufacturer, the cause of the exfoliation was overcuring of the high temperature baking type acrylic resin coating.

(2) Low temperature baking type polyester resin coating

When we manufactured TPs, foaming occurred (Photo 2). Due to this, we were unable to confirm the adherence, and the corrosion resistance was also poor.

According to the affiliated manufacturer, the foaming was caused by part of the solution within the low temperature baking type polyester resin coating vaporizing while the topcoat was being baked.

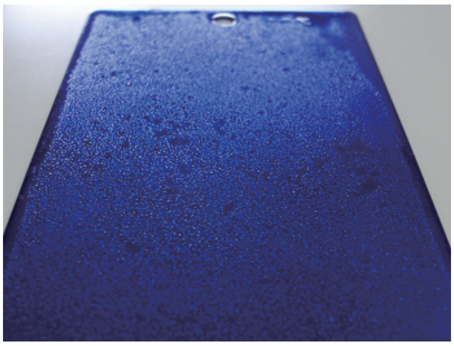

Photo 2 Foaming

Due to the above results, we selected high temperature baking type acrylic resin coating. This is because it was difficult to improve the corrosion resistance of the low temperature baking type coating in terms of coating material design and we decided that it was easier to respond to the defect, which is considered to be caused by the overcuring of high temperature baking type coating with good corrosion resistance.

5.2 Measures against Defects and Their Results

In order to prevent the overcuring of the basecoat and ensure good adherence with the undercoat, it is advantageous to set the baking temperature for the basecoat lower than that of the undercoat so that curing of the undercoat and curing of the basecoat can complete at the same time when the undercoat is being baked. Furthermore, in order to prevent the basecoat and the undercoat from being affected by the baking temperature while the topcoat is being baked, it is desirable to have the same baking temperature for the undercoat and the topcoat.

As a result, the basecoat curing method was changed from the heat-curing method using high temperature baking to the two-part curing method. Since two-part curing coating materials are cured by adding curing agents, the basecoat baking temperature can be set lower than that of the undercoat baking temperature. It was considered that it would also work better with the undercoat, which uses the same curing method. As a result of manufacturing TPs, no foaming was found, and adherence performance was secured through the grid adherence tests. Due to the above, silver mirror plating on metal materials was made possible by enclosing basecoat (cathodic electrodeposition or modified high temperature baking type acrylic resin coating) between the metal material and undercoat.

6 Evaluation according to the Coating Quality Standards and Measures

To evaluate according to the coating quality standards, we removed the re-coating performance test from the evaluation items. The objective of this test is to re-coat the same coating material over the baked coating film to confirm the adherence performance when the second coat is baked. We omitted this part because silver mirror plating uses Color Clear for the topcoat, meaning that re-coating deepens the color and changes the appearance. Since appearance changes affect product values, we decided that we cannot re-coat the coating material.

6.1 Evaluation Result according to the Coating Quality Standards

The coating standards were not satisfied for the weather resistance and flexibility (Photos 3 and 4).

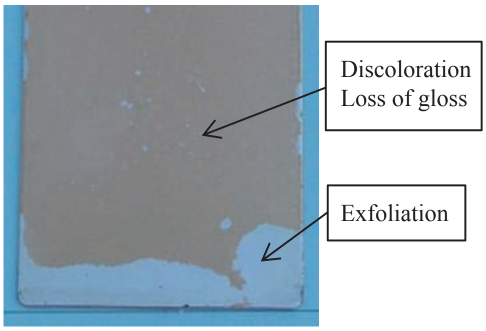

Photo 3 Weather resistance test result

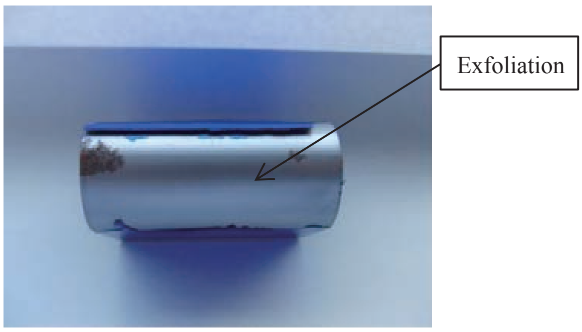

Photo 4 Flexibility test result

6.2 Measures against Defects and Their Results

(1) Defect description for the weather resistance test Note 1)

The topcoat for silver mirror plating is more prone to discoloration and whitening compared to common colored coating. Common colored coating films reflect part of incident light, such as UV rays, on the coating film surface, so the coating film deteriorates due to the incident light. On the other hand, the topcoat for silver mirror plating uses Color Clear, which is colored but allows incident light to penetrate. The incident light that passes the coating film is reflected on the silver film, and it passes the topcoat again, meaning that the topcoat is affected by both the incident light and the reflecting light, accelerating the coating film deterioration (Fig. 4).

Note 1) The test sample is set in a sunshine carbon arc-type weatherometer (JIS B 7753), and the test is conducted for the specified duration of time. The sample passes the test if no cracking or abnormality in the shine/color, etc. is found in the visual evaluation.

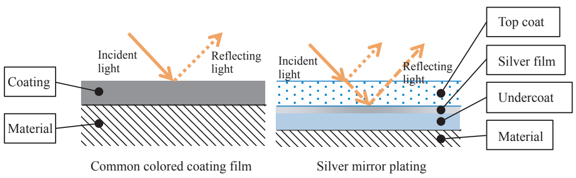

Fig. 4 Difference in light reflections

(2) Defect description for the flexibility test Note 2)

This was caused by the fact that the coating film thickness between the basecoat and the topcoat is approximately 50 μm, which is thicker than common coating films.

Note 2) The test sample is set on a bend test device (JIS K 5600-5-1) so that the tested surface would be on the outside when it's bent. The surface is bent 180 degrees over a period of approximately 1 second. The sample passes the test if no cracking or exfoliation is seen in the coating film.

(3) Measures

In order to satisfy the coating standards, the affiliated manufacturer has promoted efforts to improve the performance by repeating studies and tests for various additives for the basecoat, undercoat, and topcoat. In order to confirm the extent of the improvement for this performance, we decided to evaluate the actual values of two basecoat materials.

(4) Result

We were able to confirm that the performance was clearly improved in terms of weather resistance and flexibility, which did not satisfy the coating standards in the previous evaluation. However, we were unable to satisfy the target coating standards (Photos 5 and 6). The coating standards were satisfied with other evaluation items.

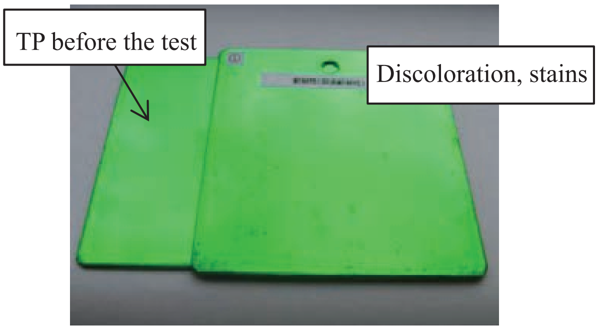

Photo 5 Weather resistance test result

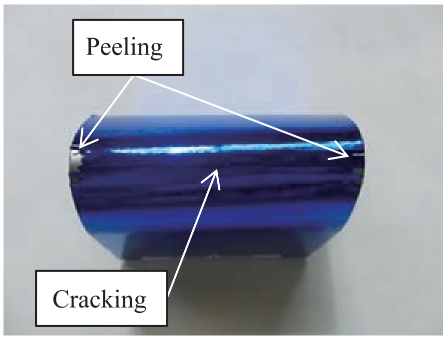

Photo 6 Flexibility test result

7 Conclusion

Our affiliated manufacturer has developed stabilization technology to overcome the 3 major defects of silver (whitening unique to silver mirror plating, yellowing, and adherence defect), undercoat required to form the silver film, and the topcoat to protect and brighten the silver film. Enclosing the basecoat that was developed in this project between the metal material and the undercoat in addition to the above technologies enabled us to use silver mirror plating on metal materials. This in turn has enabled us to establish a new surface treatment technology system and its basic technology to respond to outdoor environments in which KMS products are used (Fig. 5 and 6).

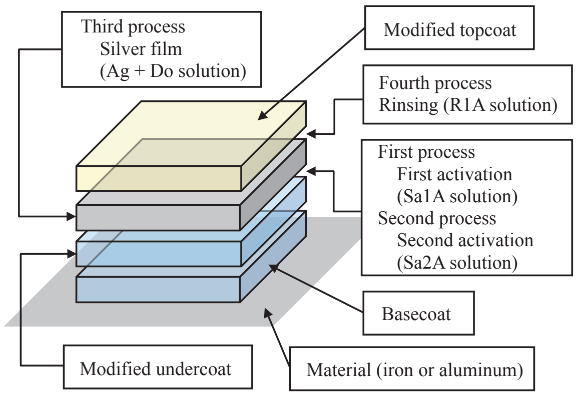

Fig. 5 Structure of PREGIO-HCPS

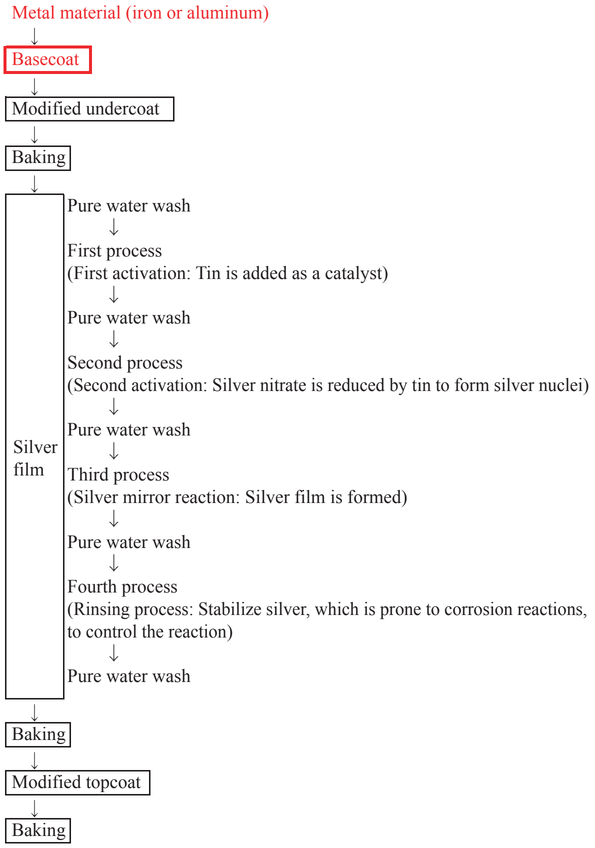

Fig. 6 Process of PREGIO-HCPS

8 In Closing

Although the silver mirror plating technology has existed for a long time, its use is limited. We hear that multiple companies have attempted developing this but gave up without achieving the result.

While part of the performance was not achieved in this development, we were able to achieve good results. I believe this is largely because the affiliated manufacturer and KMS collaborated with each other.

In the future, we intend to consider the sales channels by using the above evaluation results as the actual values of PREGIO-HCPS.

Photo 7 Spring treated with PREGIO-HCPS

*「PREGIO-HCPS (logo)」 are registered trademarks of KYB Corporation in Japan and other country.

Author

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Joined the company in 1992.
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Glossary

“Coating Defect”

Included in “Development of PREGIO-HCPS (High-brightness Chemical Plating System)” P. 38

KYB TECHNICAL REVIEW editor AKAHORI Masahiro

1 Representative examples of coating defects

There are various defects involved with paint processes.

I would like to briefly explain the description of each defect for those included in this report as well as representative ones.

1. Whitening

Defect in which the coating film surface becomes cloudy and loses gloss in the drying process as if it has been covered with dew.

2. Yellowing

Defect in which the surface finish has pale yellow to brown discoloration instead of the original paint color.

3. Whitening unique to silver mirror plating

Whitening defect that is unique to silver mirror plating

4. Peeling, exfoliation, and adherence defect

Symptom in which the coating film is peeled due to contamination, etc. This occurs on material surfaces or between layers (Fig. 1).

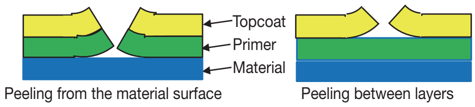


Fig. 1 Peeling

5. Foaming

Defect in which small bubbles and holes are formed in the course of coating film curing and drying (Fig. 2).

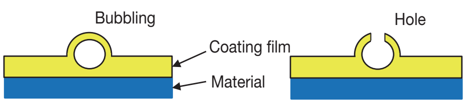


Fig. 2 Foaming

6. Loss of gloss

Defect in which the coating film’s natural gloss is not found after drying. Defect in which the surface loses gloss within a short period of time.

7. Fracturing, cracking

Defect in which there is a tear in the coating film. This includes defects in which the crack reaches the material, defects in which the crack does not reach the material, defects in which shallow cracks cross each other on the coating film surface, etc.

8. Discoloration

Defect in which one or a combination of the brightness, hue, or saturation of the coating film is changed to make another color.

9. Stain

Defect in which there are small spots or unevenness of the color on the coating film surface.

10. Dripping

When painting a vertical surface or angled surface, the paint runs down, making some areas have thick coating film and resulting in an uneven surface (Fig. 3).

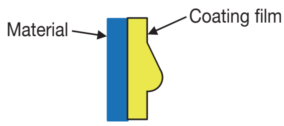


Fig. 3 Dripping

11. Transparency

Defect in which the material or primer surface can be seen through the coating film, resulting in a different color than the coating film’s original color.

12. Uneven color

Defect in which the coating film’s color is partially uneven.

13. Seeding

Defect in which foreign substances adhere to the finish, creating protrusions. This is caused by foreign substances being mixed into stored paint or adhering to the material surface (Fig. 4).

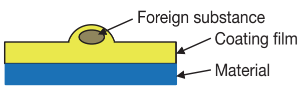


Fig. 4 Seeding

14. Cissing

Defect in which paint does not adhere evenly, partially creating dips in the coating film. This is caused by uneven surface tensions between the primer surface and the paint, etc. (Fig. 5).

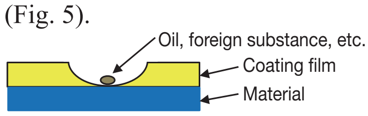


Fig. 5 Cissing

Technology Introduction

Development of High Damping Force Piston Valve for Extra Low Velocity

KIMISHIMA Kazuyuki

1 Introduction

In recent years, the rigidity of suspension frames and vehicle bodies of newly developed vehicles made by automobile manufacturers has been increasing. Tires/wheels are also being made larger, lower, and flatter. These shifts have been increasing the rigidity of vehicles in general.

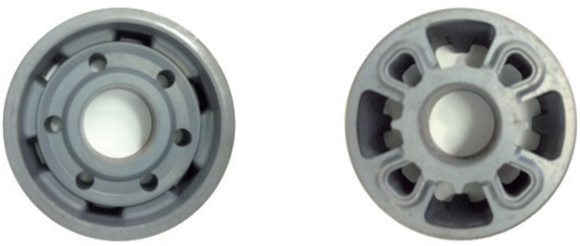
Along with such changes, fine oscillation that used to be absorbed by tires, etc. and did not used to be transmitted to shock absorbers (hereinafter referred to as "SA") have begun being transmitted to SAs. SAs are forced to move in a more detailed and delicate manner in response to the same input from the road surface.

If the above oscillation cannot be controlled, the oscillation is transmitted from the SA to the body through the upper mount, etc. and ultimately leads to discomfort for users. Therefore, securing of the damping force in micro-low velocity and low amplitude as well as high damping force responsiveness in SAs are anticipated more than ever.

In response to such demands, we have developed a piston valve with improved damping force responsiveness, and details were introduced in KYB TECHNICAL REVIEW No. 51 [1].

In this valve, we modified the inner seat surface shape from the original shape (Fig. 1 (a)) (Fig. 1 (b)), which is a key component, and significantly improved the damping force responsiveness. Not only that, but the leaf valve can now be opened at lower velocity. By further reducing the damping force valve orifices, the damping force for extra low velocity can also be improved (Fig. 2).

In this report, I would like to introduce the development of piston valves that can further improve the damping force for extra low velocity for the valves with improved damping force responsiveness, which was in the previous report.



(a) Conventional valve [Circular seat surface]

(b) Piston valve with improved damping force responsiveness [Independent seat surface]

Fig. 1 Inner seat surface form within the piston

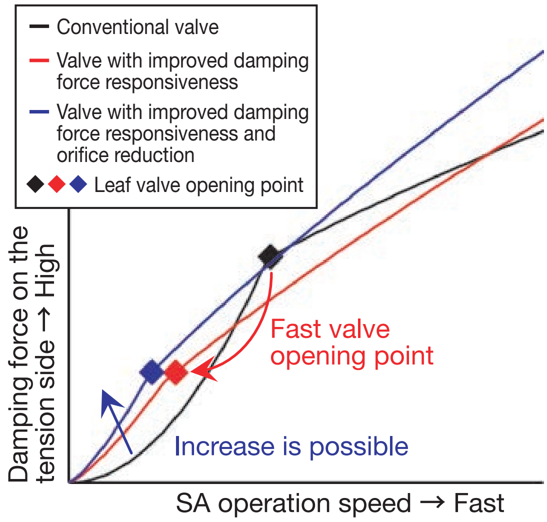


Fig. 2 Comparison image for damping force – velocity characteristics between the conventional valve and the valve with improved damping force responsiveness

2 Development Background

Fig. 3 shows the positioning image of the feeling on actual vehicles in response to SA operation strokes and operation frequency. Stable driving performance can also be described as the responsiveness/tracking performance mainly in response to steering, and texture can also be described as the blocking sense against fine numbing input from the road surface; comfort can also be described as sprung mass damping performance.

While stable driving performance and texture have different domains in Fig. 3, they are both positioned in the same micro-low velocity area when you focus on the operation speed of SAs. This indicates that damping force for extra low velocity greatly affects stable driving performance and texture. We can also say that the damping force in the medium/high velocity area greatly affects comfort.

Through the application of the valve with improved damping force responsiveness, the stable driving performance and texture significantly improved compared to the existing valves. However, automobile manufacturers have further performance improvement demands.

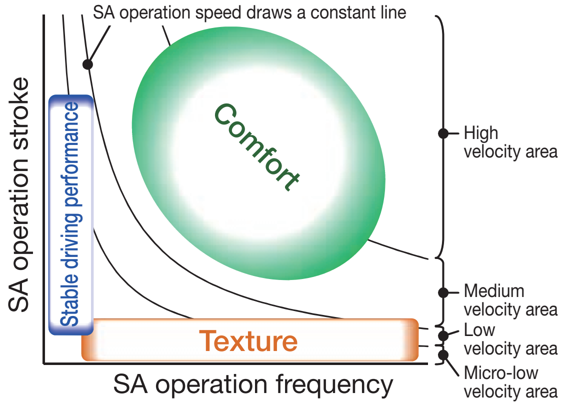


Fig. 3 Impact on the feeling on actual vehicles in response to SA operation

Furthermore, we were unable to only reduce the damping force in the medium/high velocity area due to the characteristics, so comfort still had room for improvement.

In general, ① stable driving performance/texture and ② comfort have a trade-off relationship. SA's damping force tuning means to search for a balance point (greater compromising point) for both ① and ② performance aspects in accordance with the vehicle (weight, suspension system, geometry, etc.) and grade (vehicle characteristics).

Since it was difficult to maintain or improve the ② comfort and further improve ① stable driving performance/texture with damping force tuning alone, we began developing a damping force valve that balances ① stable driving performance/texture and ② comfort at a higher level (Fig. 4).

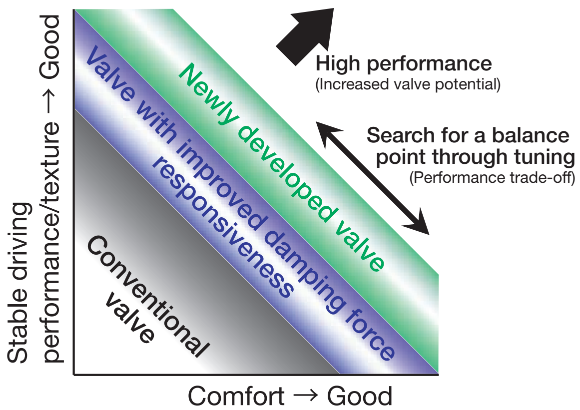


Fig.4 Development direction image for the newly developed valve

3 Development of a New Piston Valve

3.1 Objective of the Development

As previously mentioned, securing of the damping force for extra low velocity by SAs (≈ shift to linear characteristics) contributes to the improvement of stable driving performance/texture. It is considered that control of medium/high velocity area damping force by SAs (≈ shift to saturation characteristics) is effective in improving comfort. There was no valve that simultaneously balanced both of the above characteristics among KYB's existing valves (Table 1).

Table 1 Characteristics of the conventional valve and the newly developed valve

	Damping force in the micro-low velocity area	Damping force in the medium/high velocity area
Conventional valve 1	Low (orifice characteristics)	High (linear characteristics)
Conventional valve 2	Low (orifice characteristics)	Medium (weak saturation characteristics)
Conventional valve 3	Low (orifice characteristics)	Low (super saturation characteristics)
Valve with improved damping force responsiveness	High (linear characteristics)	High (linear characteristics)
Newly developed valve (Objective)	High (linear characteristics)	Low – medium (saturation – weak saturation characteristics)

① Possesses the same level of damping force for extra low velocity as the valve with improved damping force responsiveness.

② Able to control medium/high velocity area damping force and further improve the damping force for extra low velocity without compromising comfort.

③ Possesses the tuning capabilities that can make various changes to the damping force breakpoint, slope, etc. according to the vehicle.

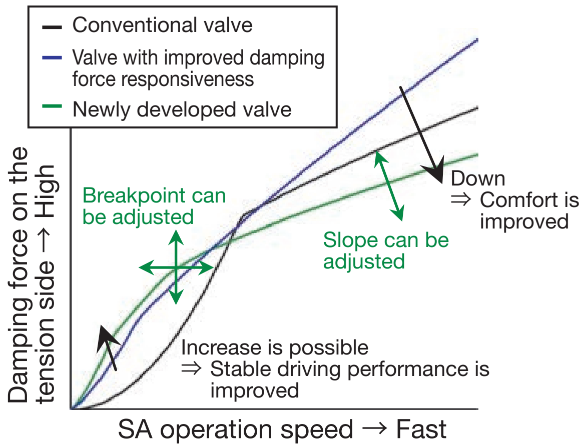


Fig. 5 Image for damping force – velocity characteristics for the newly developed valve

3.2 Design of the Piston Form

In order to shift the damping force for extra low velocity to linear characteristics, separation of the piston seat surface form (as shown in Fig. 1 (b)) is effective. This is due to the fact that the damping force – velocity characteristics become more linear because local opening of the leaf valve is promoted with the pressure applied to the leaf valve in a spot-like manner when the SA operates, causing it to shift from orifice characteristics to valve characteristics at an early stage.

In addition, to shift the medium/high velocity area damping force to saturation characteristics, circularization and enlargement of the valve seat surface is effective. This is due to the fact that they both enlarge the leaf valve opening area, which means that the valve pressure difference is less prone to increasing in response to the increase of operation fluid flow, thus controlling the increase of the damping force.

In order to simultaneously achieve the shift to linear characteristics in the micro-low velocity area and the shift to saturation characteristics in the medium/high velocity area, we designed the inner seat surface form within the piston to have dual seat surfaces, including the independent seat surface and circular seat surface, as shown in Fig. 6.

We also designed the structure so that it can respond to preloads of various load positions and sizes by installing a number of valve supports on the inside of the piston's circular seat surface, aiming to secure a wide scope of damping force tuning characteristics. I will explain the mechanism at a later point.

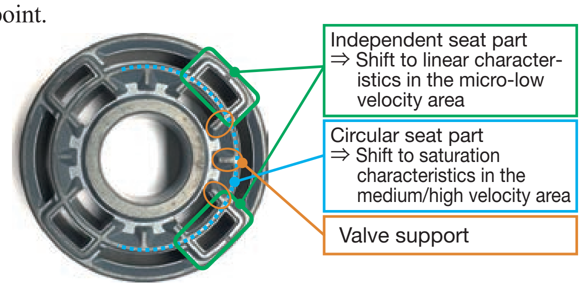
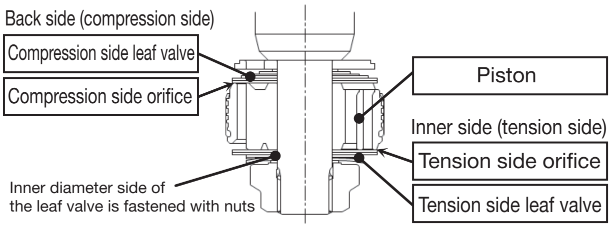


Fig. 6 Inner seat surface form within the piston of the newly developed valve

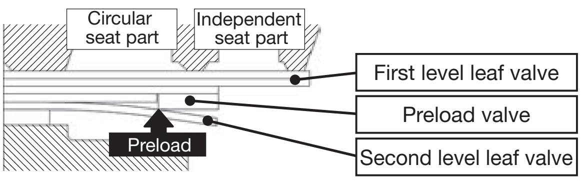
3.3 Structure of the Piston Valve

The cross-section structure of the new piston valve is shown in Fig. 7 (a). The overall structure uses the conventional method of nut fastening to fix the inner diameter side of the laminated leaf valve, but its uniqueness is in the fact that the lamination structure of the leaf valve on the tension side is a two-level structure to match the dual seat surface of the piston (Fig. 7 (b)).

By installing valve supports on the inside of the piston's circular seat surface (Fig. 6), the volume and position of the preload valve, which is installed in between the first level leaf valve and the second level leaf valve, can be freely adjusted. We aimed to achieve the desired damping force – velocity characteristics by controlling the valve opening point of the circular seat part.



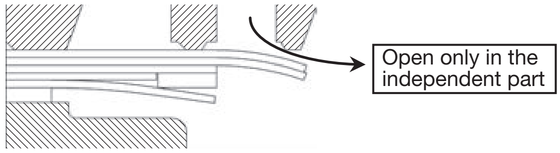
(a) Overall structure/components



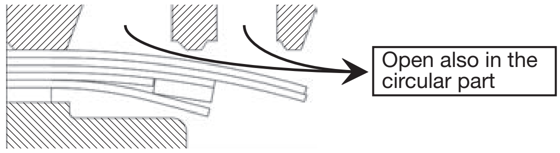
(b) Inner structure details

Fig. 7 Structure of the newly developed valve

Fig. 8 shows a model of the leaf valve opening conditions when the SA is extended. When the SA's operation speed is slow, only the independent seat section opens, only opening the first level leaf valve. The diameter of the first level leaf valve is enlarged as much as possible, and the pressure load is applied in a spot-like manner. Due to this, the leaf valve starts opening in the early stage of SA operation. This allows the valve to make the orifices smaller than the conventional valves, enabling the increase of damping force for extra low velocity.



(a) Micro-low velocity/low velocity area



(b) Medium/high velocity area

Fig. 8 Tension side valve operation model

When the SA operation speed gradually accelerates, the circular seat part that contacts the second level valve opens, suddenly increasing the open area. This controls the increase of the pressure difference against the operation speed, thus controlling the damping force in the medium/high velocity area.

The opening point of the circular seat part can be freely controlled according to the size and diameter of the load from the preload valve. The uniqueness after the opening point is in the fact that adjustments can be made according to the rigidity of the second level leaf valve.

With the summary of the above information, Fig. 9 shows the objective of adjusting the damping force for each tuning element.

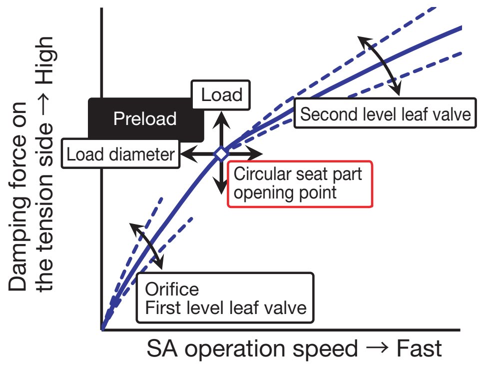


Fig. 9 Objective of each tuning element

3.4 Confirmation of the Damping Force – Velocity Characteristics

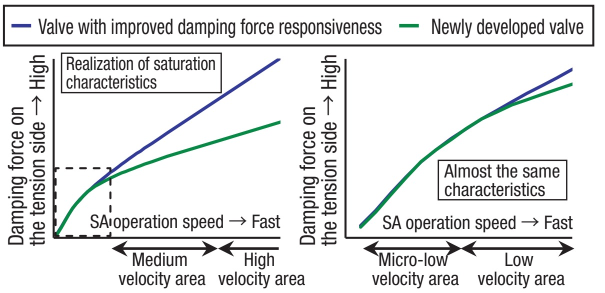
3.4.1 Comparison with the Valve with Improved Damping Force Responsiveness

We used the representative-sized SA (cylinder diameter: ø35, rod diameter: ø22). Fig. 10 shows the comparison result of the damping force – velocity characteristics on the tension side. The damping force in the micro-low velocity area – low velocity area almost has the same characteristics as the valve with improved damping force responsiveness. It also controlled the damping force in the medium/high velocity area, so we were able to achieve the objective.

3.4.2 Confirmation of the Extent of Tuning Freedom

Fig. 11 (a) through (e) show the impact of each of the new valve's tuning elements on the damping force - velocity characteristics and confirmation of the cover range.

(a) Due to the orifice area change, a sufficient scope of damping force variables is achieved in the micro-low velocity



(a) Entire velocity area (b) Micro-low velocity/low velocity area (Enlarged image of the broken line part in the left figure)

Fig. 10 Comparison of damping force – velocity characteristics

area. In addition, even if the damping force in the micro-low velocity area is significantly improved through the effect to control the damping force in the medium/high velocity area, the damping force changes in this area is controlled to be relatively small. We consider that this is achieving a good balance with comfort.

(b) By changing the rigidity of the first level leaf valve, adjustment of the damping force volume in all velocity areas is made possible. The fact that the damping force starts to change in the micro-low velocity area also indicates that the leaf valve starts to open at an extremely early point.

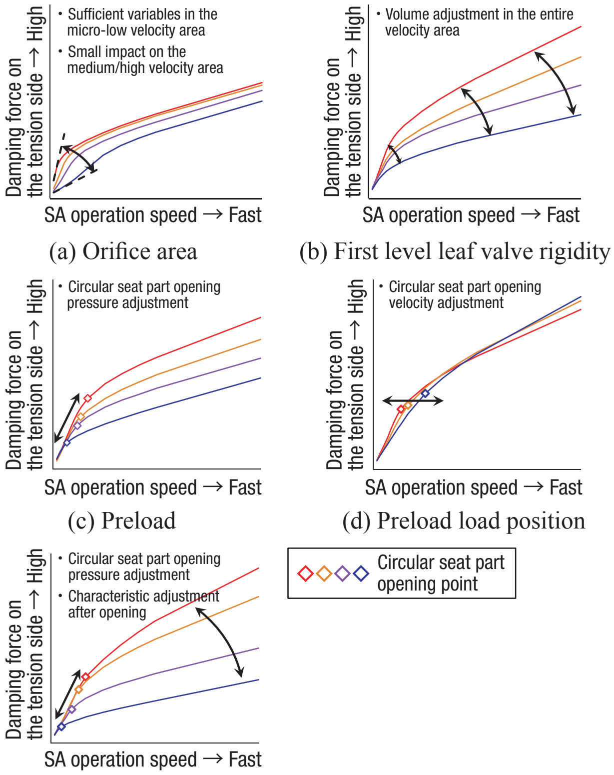
(c) By adjusting the load of the preload by selecting the preload valve level, the opening pressure in the circular seat part can be changed. At the velocity near the opening point, the damping force goes up and down in an offsetting manner.

(d) Adjustment of the load diameter for the load of the preload through selection of the preload valve outer diameter enables fine tuning of the opening speed for the circular seat part.

(e) Changes to the second level leaf valve rigidity enables adjustment of the opening pressure of the circular seat part as well as the damping force slope after the opening point.

4 Utilization Status

The mass production of this newly developed piston valve started in December of last year, and the trend still shows that it is going to be utilized in a wide variety of vehicles. We are promoting its application development. As with the recent piston valve with modified damping force responsiveness, we intend to promote this valve's deployment as our new main valve by positioning it as a value-adding valve that is distinctly different from common valves. We expect that both the number of vehicles in which this valve is used and production volume will increase.



(a) Orifice area (b) First level leaf valve rigidity (c) Preload (d) Preload load position (e) Second level leaf valve rigidity

Fig. 11 Impact/effect of each tuning element on the damping force – velocity characteristics

5 In Closing

We have developed a new item to overcome the weaknesses of the recently developed valve by focusing on the improvement of the damping force for extra low velocity and control of the damping force in the medium/high velocity area. Thanks to this, we can achieve a balance of stable driving performance and comfort at a higher level and provide end-users with comfortable vehicles.

Finally, I would like to express my sincere gratitude for everyone involved who has provided us with guidance and cooperation in the course of this development.

Reference

1) "Development of Valve with Improved Damping Force Responsiveness," KIMISHIMA, YAMANAKA, YAMAMOTO, KYB TECHNICAL REVIEW. No. 51 (Oct. 2015).

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Introduction

Launch of KMEX SA Plant

KUSAKABE Makoto

1 Introduction

The automobile market in the Americas continues to be active, and customers continue to move south. The advancement of automobile-related companies in Mexico is especially remarkable. KYB has also been successful in our sales expansion activities in the region, requiring us to strengthen our production capabilities. After considering the supply system for the overall production plants in the Americas (KAC/KMEX/KMB) while also considering customer trends, we have decided to establish a shock absorber (SA) plant in KMEX to enhance our production system (Fig. 1).

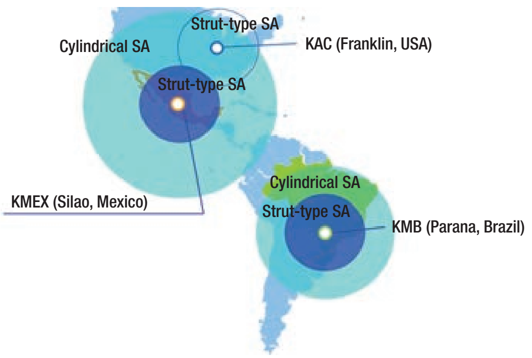

Fig. 1 KYB's production strategy in the Americas

In order to provide high quality SA at low cost, we have made a number of considerations for the entire production process from component procurement to shipment in the plant construction stage.

In this report, I would like to introduce the following initiatives:

① Phased investments according to product launch in order to control investments (plant/process/machine)

② Internalization of processes to be promoted from the beginning of the launch

③ Establishment of production lines with good transportation efficiency that are rectified with process sequence positioning, which can be a model line for future production lines.

④ Establishment of processes that do not create or bring in contamination with the aim of achieving high quality

2 Overview of plant

KMEX was established in October of 2012, and the CVT plant started its operations in October of 2014. The SA plant will be the second plant here.

KMEX is located within the Silao industrial park, which is 350km from Mexico's main city, Mexico City. KMEX is approximately 5km from Del Bajío International Airport in León.

Fig. 2 Location of KMEX (from Google Maps)

Photo 1 Exterior view of KMEX SA Plant

3 Implemented Initiatives

3.1 Phased Investment to Control Investments

We formulated a plan to make phased capital investments according to product launches (Fig. 3).

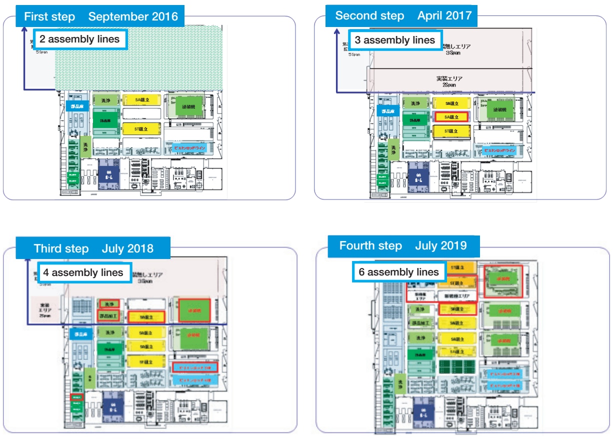

Fig. 3 Plan of factory layout (Phased investments)

Since the production volume was small in the beginning, we launched the SAI production line for cylindrical SA, which flows both aftermarket products and OEM products, in May of 2016 as the first step. We also began delivering aftermarket products (Fig. 4).

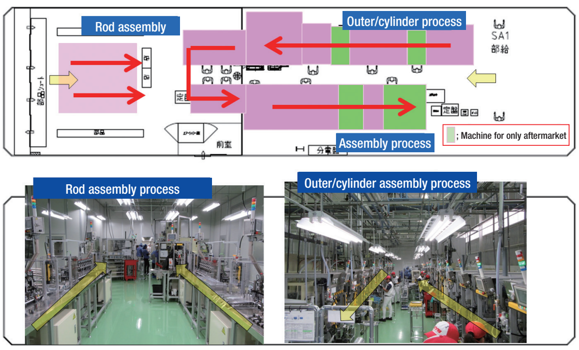

Fig. 4 SA production line #1 overview

We launched the STI production line for strut-type SA in September of 2016 as well and began delivering OEM products along with the cylindrical SA.

In the future, we plan to add SA production line #2 and exclusively use SA production line #1 for OEM and SA production line #2 for aftermarket products, with the aim of streamlining our production.

3.2 Initiatives to Internalize Processes

(1) Tube cutting process (outer/cylinder)

Operation was launched in May of 2016 with the aim of reducing the variable expenses and inventory by promoting local procurement of materials and introducing tube cutting process.

We will add processes in a phased manner in response to demands (Photo 2).

Photo 2 Tube cutting process

(2) Piston rod process

We launched the process according to the following concepts, with the aim of achieving the global standard (Photo 3):

- Establish the production line according to the demands to control the investments, and procure the machines in the optimal manner from the aspects of quality/cost/performance.
- Important machines are to be procured from Japan.
- Machine specifications are to allow production of small lots as small as 40 in order to respond to aftermarket products.

Photo 3 Piston rod process

3.3 Rectified Layout

We have established the plant layout in accordance with the KYB Production Standards so that products flow in a certain direction from the component warehouse → assembly area → completed product store area (Fig. 5).

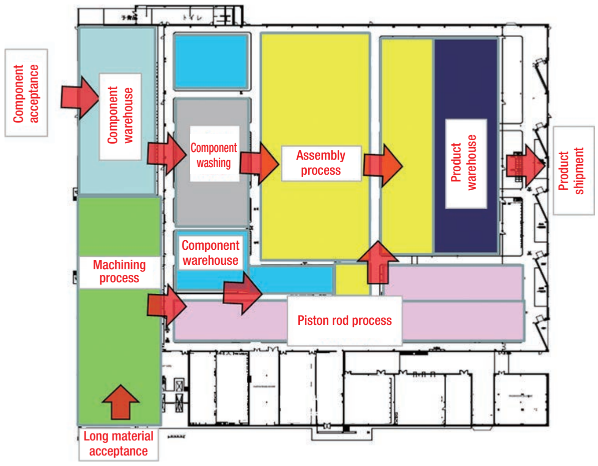

Fig. 5 Overall plant layout

3.4 Contamination Measure (Plant – Process – Machine)

(1) Preventing mutual contamination between plants

- Once a worker enters the plant, he/she can perform the day's work without leaving the plant.
- Pressurize the connecting passageways (Photo 4) between plants so that workers can remove contamination with an air shower (Photo 5) so that contamination is not brought into the plant.
- Introduce special shoes for the plant so that contamination is not brought into the plant from outside.

We promoted the initiative in accordance with the above concepts.

Photo 4 Connecting passageway

Photo 5 Air shower

(2) Contamination Measure within the Plant

By cleansing components before bringing them into the assembly room, we prevent contamination within the assembly room.

Internal component preparation and valve and rod assemblies are performed in the assembly room (Fig. 6).

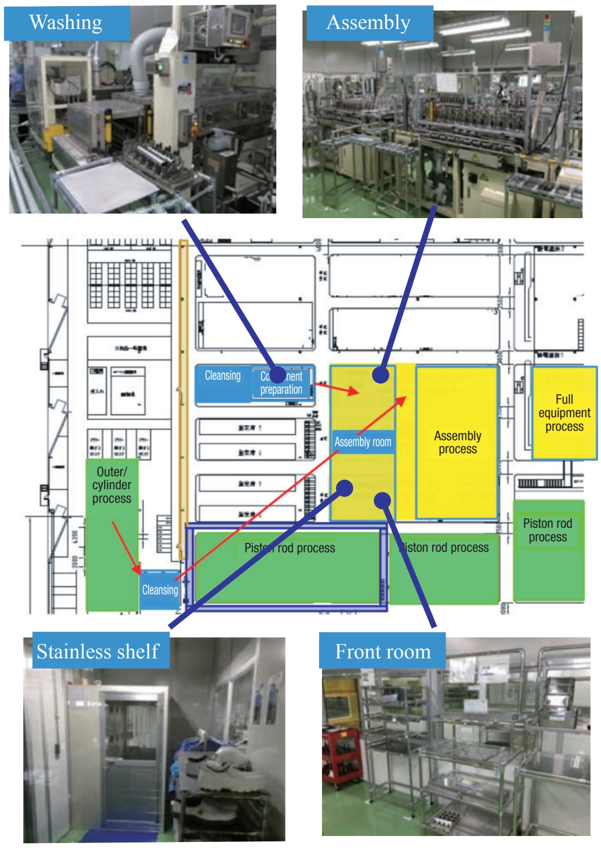

Fig. 6 Contamination measure within the plant

4 Launch of Production Line

(1) Prior confirmation in Japan

Since this was the first SA production line launch in KMEX, we manufactured accessories, such as component feeding chutes and work benches, when we made adjustments to the machines in Japan. We confirmed the following items in the environment that allowed us to perform operation in the same manner as KMEX (Photo 6):

Photo 6 Launch of production line in Japan

・There is no unsafe point/operation.
・Operator can work as per the planned standard work.
・Target cycle time is achieved.
・Required documents have been prepared. (Condition table, etc.)

In the final phase of the machine adjustment, we identified issues through the production trial, in which operations were actually appointed by assuming mass production (Photo 7).

Photo 7 Verification of standard work

(2) Evaluation of launching production line in KMEX

We launched the production line by confirming each item that was evaluated in Japan along with local staff from the machine setup stage to evaluation completion (Photo 8).

Photo 8 Production trial

After passing the internal review in KMEX, we started the production as per the following schedule (Photo 9):
・Launch of production for aftermarket products
From May, 2016
・Launch of production for OEM products
From September, 2016

Photo 9 Internal review in KMEX

5 In Closing

We were able to safely complete the launch of aftermarket products and OEM products by enhancing the progress through utilization of periodical meetings with KMEX.

New launch of many aftermarket products and OEM products are scheduled in the future, so we will launch the production lines as per the schedule by thoroughly evaluating the production lines and products to avoid defects.

Finally, I would like to express my sincere gratitude for everyone who has provided support for this initiative.

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Technology Introduction

Methods for Improving Productivity and Quality for Machining EPS Dampers

ITO Susumu, KOUKETSU Hisato

1 Introduction

In response to the new order of electric power steering (hereinafter referred to as "EPS"), we started positioning dampers (Fig. 1) as the core technology/core component in 2007, developed damper machining, and started internalizing production in order to achieve a high quality steering feel. In order to improve the performance, we have been expanding the scope of production internalization with the aims of improving precision and reducing cost in accordance with the internalization policy for core components. We would like to introduce our activities toward productivity improvement and quality improvement through utilization of the existing facilities.

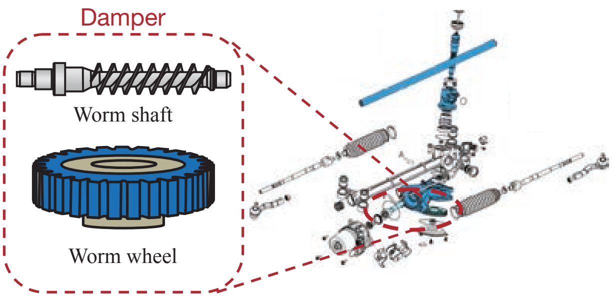

Fig. 1 Internally machined EPS components

2 Overview

2.1 Product Overview

Worm dampers (hereinafter referred to as "dampers"), in which a worm shaft (hereinafter referred to as "worm") and worm wheel (hereinafter referred to as "wheel") are integrated, possess an important function to assist vehicles by transmitting the motor torque to the wheel shaft via the worm to create torque according to the reduction rate (Fig. 2). Since the wheel is on the steering shaft, the engagement precision is easily communicated to the driver's hands. Therefore, this is an important component that largely affects the 3 aspects of quietness, high responsivity, and accuracy, which are required in steering.

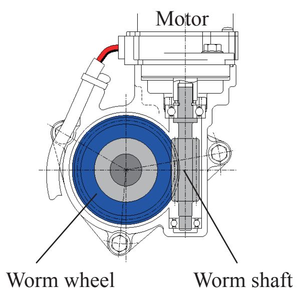

Fig. 2 Worm damper

2.2 Overview of the Damper Machining Lines

Damper machining production lines consist of the worm machining process, which involves turning, gear cutting, grinding, and cleaning, and the wheel machining process, which involves gear cutting, flash removal, cleaning, and matching (Table 1).

Table 1 Process overview

Worm machining

Process name	Process contents
(1) Turning	Outer diameter rough machining
(2) Whirling	Rough gear cutting
(3) Grinding	Outer diameter polishing
(4) Thread grinding	Thread polishing
(5) Brushing	Improvement of the surface roughness of the tooth surface
(6) Cleaning	Contamination removal
(7) Inspection	Visual inspection and engagement test

Wheel machining

Process name	Process contents
(1) Hobbing machine	Gear cutting
(2) Chamfering machine	Flash removal
(3) Cleaning	Contamination removal
(4) Storage	Dimensions are stabilized by storing for a certain period of time
(5) Inspection 1	Visual inspection and engagement test
(6) Inspection 2	Matching

3 Issue and Target

3.1 Productivity-related Issue and Target

We needed to control the investment and enhance the production capabilities in stages in order to reduce the cost in anticipation for production increase in the future (Fig. 3).

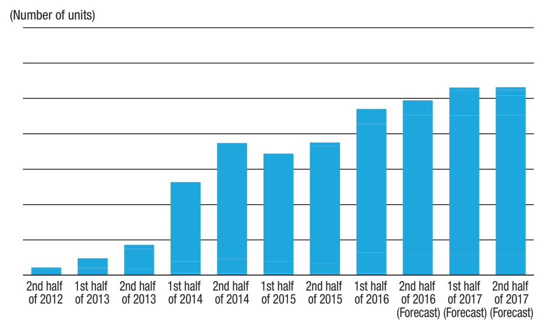

Fig. 3 Production results and forecast for internally manufactured dampers

In order to improve the overall production capabilities by establishing 2 production lines consisting of a "various kinds and small quantity" production line and a "high productivity" production line by using the existing production line from 2012 as the benchmark (hereinafter referred to as "B.M."), we decided to set the target below and promote our efforts (Table 2).

Table 2 Production capabilities of damper production lines

Item	Benchmark (October 2012)	Production line #1 target	Production line #2 target
Concept		"Various kinds and small quantity" production line	"High productivity" production line
CT	B•M	31% reduction	44% reduction
Operation rate	B•M	Same	26% increase
Production capabilities	B•M	45% increase	124% increase

3.2 Quality-related Issue and Target

In order to provide high quality products in terms of noises and feelings, we needed to improve the quality of the engagement error per gear, which represents the changes of the distance between shafts when the worm and wheel are pressed together to turn (Fig. 4).

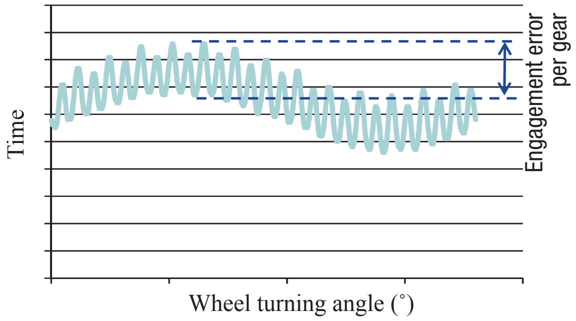

Fig. 4 Changes in the distance between shafts

In operation inspections, dampers with an engagement error with higher severity per gear have greater steering force fluctuations against the steering angle, as shown in the red lines. The smaller the severity of the error is, the smaller the fluctuations are, as shown in the black lines (Fig. 5).

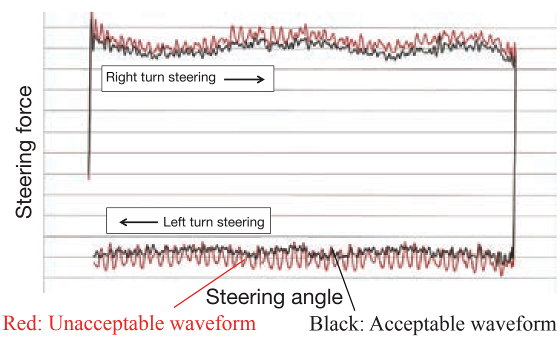

Fig. 5 Operation resistance test data for finished gear products

We decided to promote our improvement efforts by aiming to reduce the defects by 50% compared to the B.M.

4 Implemented Initiatives

4.1 Productivity Improvement

We needed to reduce the machine time (hereinafter referred to as "MT"), which is an obstacle in realizing high productivity production lines (Fig. 6). Below are examples.

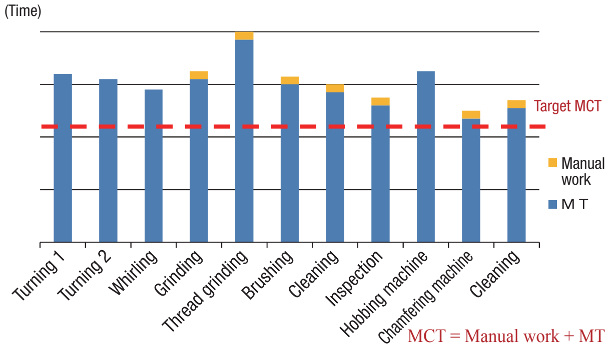

Fig. 6 Manual work + MT for each process

4.1.1 Machine Time Improvement

(1) Thread grinding process improvement

This is the process in which the grinding finish is given to the gear-cut part, which was turned by the whirling machine.

We reviewed the dress cycle in order to complete the machining process within the target MT. The conventional method was as follows: Dressing was done without angling the grindstone or dresser. The dressed grindstone turned in the angle that engages with the worm to grind. It then returned to the no angle position to repeat the process. It took time to turn the grindstone during each cycle, so the manufacturer and KYB focused on this aspect. We

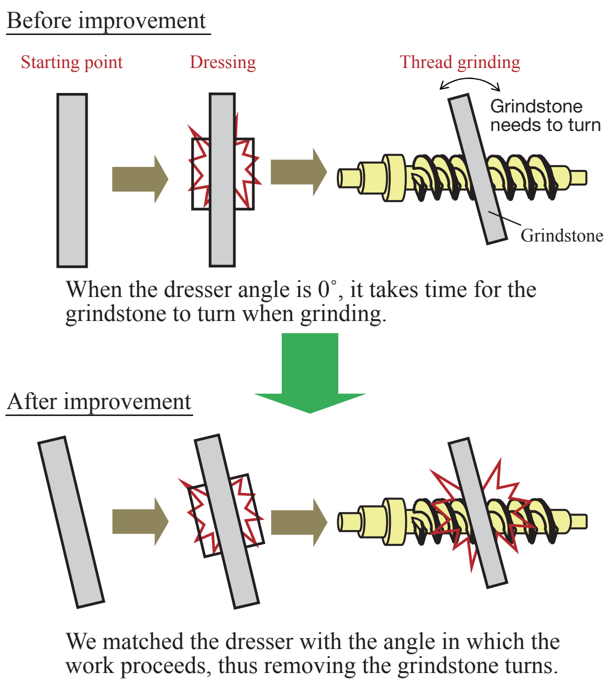

Fig. 7 Turning of the grindstone for thread grinder

aggregated the high productivity production line into one model so that the dressing process could be done with the dresser and the grindstone kept at an angle, and we stopped the turning of the grindstone during each cycle to reduce the MT (Fig. 7).

(2) Brushing process improvement

This is the process to remove the flash on the teeth and improve the surface roughness of the tooth surface after the thread grinding process.

We attempted to reduce the MT by increasing the conditions, but the standard for the surface roughness of the tooth surface was not achieved. With 2 separate processes, the surface roughness is achieved, but the MT is not achieved, thus requiring equipment investment. We had been using a one-shaft brush unit in this process, so we designed and manufactured a two-shaft brush unit. This enabled us to achieve the quality as well as the MT (Table 3, Fig. 8).

Table 3 Brushing matrix

	Number of brush turns	Brush grinding move	MT	Quality (surface roughness)	Cost	Effect
Current condition	B•M	B•M	B•M	○	○	—
Changed condition 1	1.5 times	2.0 times	0.67 times	×	○	×
Process the changed condition 1 twice	1.5 times	2.0 times	1.34 times	○	×	×
Use of 2 brush shafts	1.5 times	2.0 times	0.67 times	○	△	○

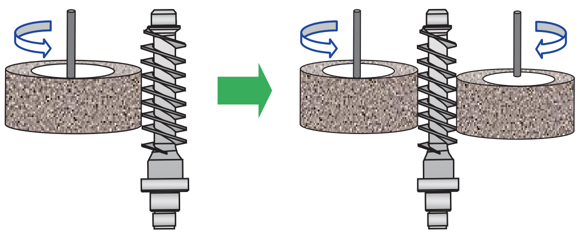

Fig. 8 2-shaft brush unit for brushing

4.1.2 Changeover improvement

In order to establish a "various kinds and small quantity" production line, we needed to improve the changeover (Fig. 9). Below are examples.

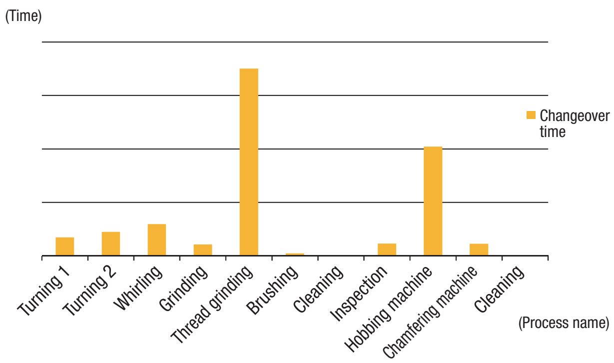

Fig. 9 Changeover time for each process

(1) Thread grinder drive method change

Originally, we used a 3-claw chuck to clamp the work for the thread grinder. It took a long time to control the run out when changing over this 3-claw chuck. When the run out is big, the engagement error per gear becomes more severe, and this was producing defects.

Due to this, we switched from the chuck method to the carry method. Since all models are supported by both centers, we can complete the changeover simply by switching the carry for each model (Photo 2).

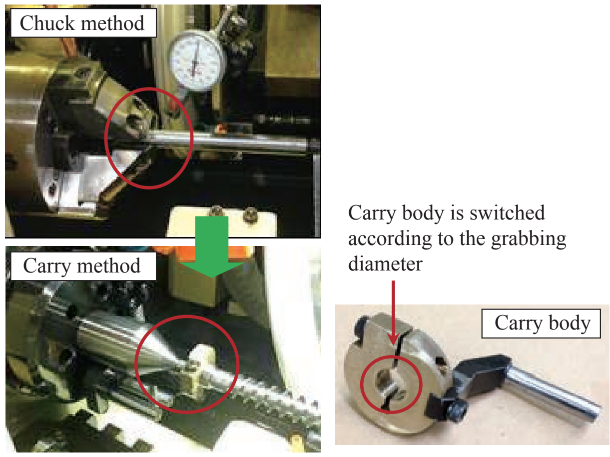

Photo 2 Thread machine driving method

(2) Removing the changeover process for the thread grinder dresser

Since only one dresser can be installed on the thread grinder, we had to switch the dresser to change over to models with different modules. The switching process took 30 minutes, as we had to secure the process precision. We removed this switching process by introducing a mechanism to incorporate 3 dressers (Fig. 10). This also removed the run out of the dressers from switching, leading to quality improvement.

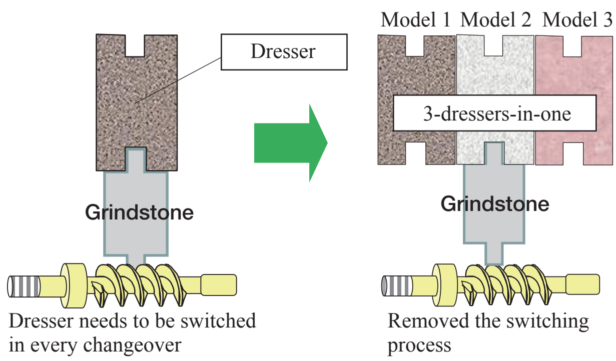

Fig. 10 3-dressers-in-one device for the thread grinder

4.2 Quality Improvement

We changed the material of the tightening nut to change the friction of the contact against the other surface in the quenching process when tightening the hob cutter of the hobbing machine, which is used in the wheel gear cutting process, onto the arbor. This enabled us to easily control cutter run out, enabling us to reduce the engagement error per gear.

Before the improvement, we were using a commercial nut. With this nut, the contact surface would come to a stop during the tightening process due to friction, and the contact surface couldn't bear the external force motion, causing it to momentarily slip over the other surface, which resulted in run out. Due to such issues, we kept having to make adjustments.

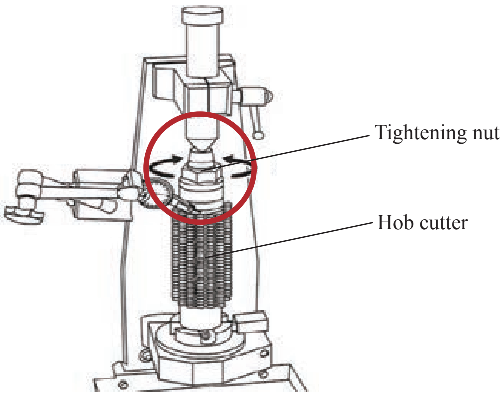

Fig. 11 Detailed diagram for hob cutter installation

5 Result

5.1 Productivity Improvement Result

The CT, operation rate, etc. for the "various kinds and small quantity" production line and "high productivity" production line have changed as follows (Table 4).

Table 4 Result of productivity improvement efforts

Item	Benchmark (October 2012)	Production line #1 target	Production line #1 result
Concept		"Various kinds and small quantity" production line	"Various kinds and small quantity" production line
CT	B•M	31% reduction	31% reduction
Operation rate	B•M	Same	10% increase
Production capabilities	B•M	45% increase	50% increase

Item	Benchmark (October 2012)	Production line #2 target	Production line #2 result
Concept		"High productivity" production line	"High productivity" production line
CT	B•M	44% reduction	42% reduction
Operation rate	B•M	26% increase	16% increase
Production capabilities	B•M	124% increase	97% increase

5.2 Quality Improvement Result

We were able to reduce the engagement error per gear by 98% by changing the tightening nut material, centering the thread grinder, and removing the dresser changeover.

6 In Closing

We focused on the non-machining time in order to secure the productivity capabilities through CT reduction and changeover time reduction. We presented our proposal when the new facility was being established and were able to achieve the effects that exceeded the conventional method.

As the next step, we hope to reduce the required number of human resources through automation.

Finally, I would like to express my sincere gratitude for everyone involved in this project who has provided support.

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Technology Introduction

Construction of a PPM Pump Flange Machining Line

OKUSHIMA Kouichiro, OKAMOTO Kazuya

1 Introduction

One of the PPM Note 1) products manufactured in KYB Sagami Plant is the “piston pump” (Photo 1). This piston pump is a component used in hydraulic excavators. One of the components for this pump is the “pump flange” (Photo 2), and this pump flange is a core component in the pump. The pump flange contains a semicircular part called the “cradle” Note 2). This is an important part that catches the bearing for the component that controls the pump flow volume.

KYB used to internally manufacture this pump flange, but we loaned the equipment to a supplier for them to manufacture the component in order to respond to the sudden increase in production volume. However, we decided to internally manufacture the pump flange due to the fact that it is a core component, and we have newly established the pump flange machining line.

Note 1) Abbreviation for “piston pump motor”.

Note 2) Refers to the semicircular part that acts as a bearing.

Photo 1 Piston pump

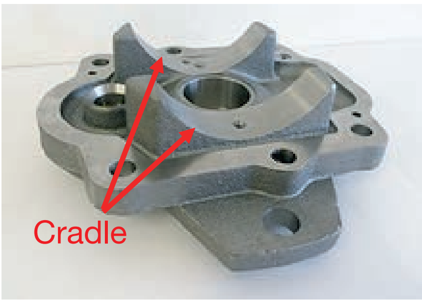


Photo 2 Pump flange
(The semicircular part is called the “cradle”)

2 Overview of Pump Flange Machining

2.1 Characteristics of Pump Flange Machining

① Various kinds and small quantity
(7 casted materials, 16 machined shapes)
② Products with different sizes are produced in one production line.
③ One line has different fluctuations in production volume.
④ It involves the cradle, which is difficult to machine.

2.2 Basic Pump Flange Machining Processes

① Reference level is machined with a lathe.
② Holes are drilled with a machining center.
③ Flash is removed from the machined parts.
④ Unit is washed in a washer.
⑤ Inspection is performed.
⑥ Rust prevention oil is applied.

3 Objective

Establish a pump flange machining line that can respond to “various kinds and small quantity” production.

4 Target

① Operation rate: 85.0% or above
② Line complaint: 0
③ Production start timing: May, 2016

5 Requirements

① Machining line that can respond to production volume fluctuations.
② Establishment of new machining technology that goes beyond the conventional machining method.
③ Line that incorporates a system that does not allow outflow of faulty units to later processes.

6 Implemented Initiatives

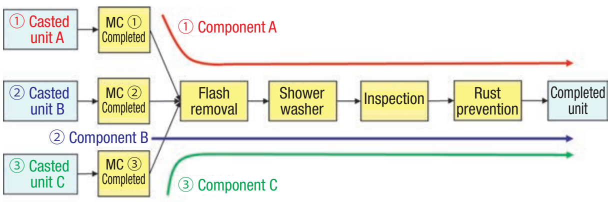
6.1 Responding to Production Ratio Fluctuations

6.1.1 Line Establishment through Process Aggregation

The conventional line was a divided process line in which machining was completed by using a lathe and a machining center. The line machined products with different sizes, and switchover could not be performed often despite the production ratio fluctuations. Due to this, we had a large volume of inventory while promoting the production activities.

We established this line so that it can respond to "various kinds and small quantity" production as a process-aggregated line, in which machining is completed with one machining center unit and in which items with different part numbers were processed at the same time. Fig. 1 shows the flow of mixed-flow production utilizing process aggregation.

Machining of casted unit A in (1) is completed by the machining center (1), and the unit is completed after the flash removal, washing, inspection, and rust prevention processes. By considering this as one flow, the units move through flow (2) and flow (3) to complete the processes for (1), (2), and (3) as one cycle.



* "MC" is short for "machining center".

Fig. 1 Mixed-flow production flow using process aggregation

6.1.2 Responding to Mixed-Flow Production

Since this is a mixed-flow production line in which different part numbers are processed at the same time, we took measures to prevent mistakes in various places.

In order to prevent work piece mistakes in the beginning of the line, we attach an order instruction form to pair with one work piece. This form remains attached to the work piece until the work piece is completed (Photo 3).

Next, before the machining center, the QR code Note 3) (Photo 4) on the production instruction form and the program are checked against each other in order to prevent a program selection mistake. If the check result differs, the alarm goes off to prevent machining. Furthermore, the equipment number and the part number are engraved in the machining center process to prevent mistakes between the work piece and the production instruction form, thus making it obvious for workers at first glance which equipment was used and what the part number is (Photo 5).

Note 3) "QR code" is a registered trademark of DENSO WAVE.

Photo 3 Production appearance

Photo 4 Production instruction form with a QR code

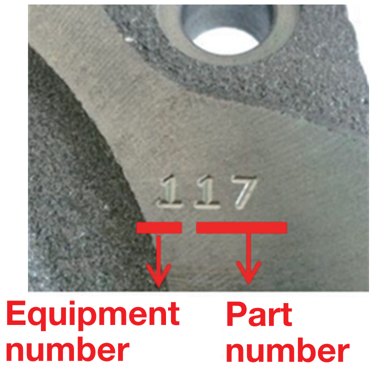


Photo 5 Engraving

6.1.3 Production Method That Can Respond to Production Ratio Fluctuations

Since there is a wide scope of pump flanges, they can simultaneously have different production ratio fluctuations. Since different part numbers can be machined by each machining center, we can freely select production methods, such as lot preparation Note 4) and pattern production Note 5). By promoting lot preparation for products with larger production volume and pattern production for products with less production volume, we can respond to production ratio changes by switching them (Fig. 2).

Note 4) Production method in which the machining timing is determined for each model.

Note 5) Production method with standardized production sequence.

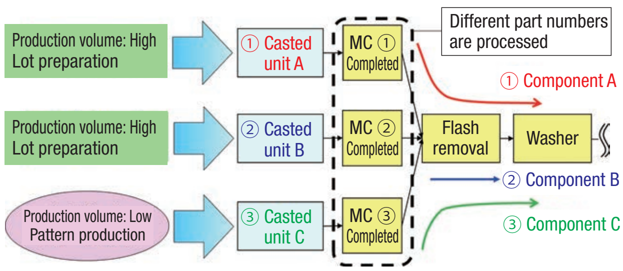


Fig. 2 Production method

6.1.4 Measures to Improve the Switchover Capabilities

In the conventional method, a jig was used for each casted unit. Due to this, manual clamp jigs had to be switched for different work piece thicknesses. Since manual tools were used in this switching process, it took time.

In this initiative, we utilized the toggle mechanism using a hydraulic clamp for the clamp jig. Due to this, the clamp stroke expanded, enabling us to respond to various unit types by using one clamp jig (Fig. 3). Furthermore, now that the clamp jigs can be switched in one step without using tools, jig switchovers can be minimized, reducing the time.

Moreover, we considered standardizing sub-jigs by using work piece overlays in order to reduce the number of switchovers and reduced the number of jigs to reduce the number of switchovers (Photo 6).

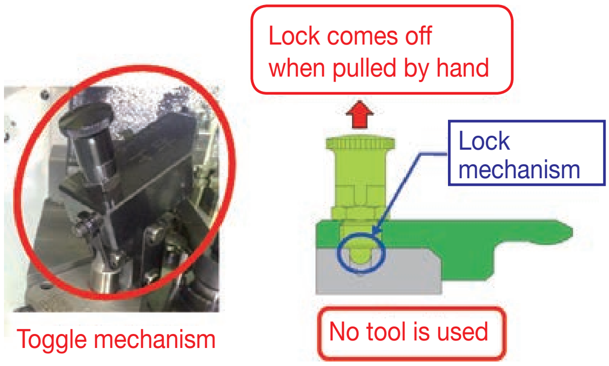


Fig. 3 Hydraulic clamp

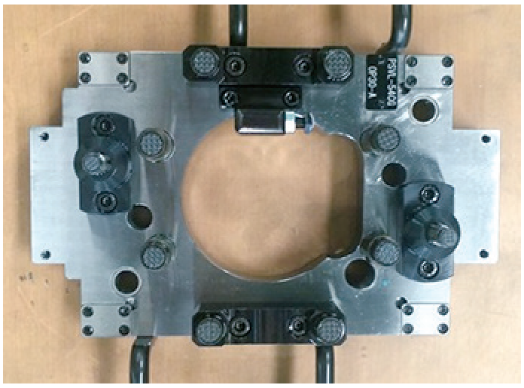


Photo 6 Standardized sub-jig

6.2 New Machining Technology for Cradles

6.2.1 Establishment of High-speed/High-precision Machining Technology

In the conventional machining method, 2 work pieces facing each other were set as a pair on the lathe to turn-machine the semicircular shape of the cradle part (Fig. 4). Since 2 work pieces were attached to the jig in this method, the weight was heavy. This caused the chuck clamping force to be reduced, making it easy for the work pieces to come off. Due to this, we could not improve the machining conditions.

Since this new line is a self-completion line using one machining center, machining technology at the machining center was required. The common method to machine cradle-like semicircular shapes one by one is to perform contouring machine [Note 6)] that moves in a circular manner. However, this requires machining time. Therefore, we used boring machining [Note 7)] that moves in a linear manner in order to achieve high-speed machining (Fig. 5).

Tool rigidity is also important to realize high-precision machining. We responded to this issue by enlarging the tool diameter to enhance the rigidity by considering the tool deflection so that chattering is not caused by the interrupted turning of the semicircular shape and also by considering the interference with the jig. This enabled us to achieve the high-speed/high-precision machining.

Note 6) Outline machining that uses NC table control.

Note 7) Precision hole machining method.

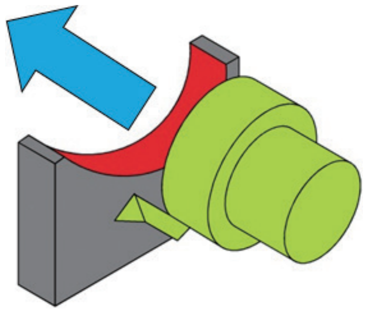


Fig. 5 Boring process

6.2.2 Establishment of Measuring Technology

In the conventional measuring method of the cradle part, we were only able to take measurements when 2 work pieces were chucked within the unit immediately after lathe machining. We used to take measurements by using a cylinder gauge (as shown in Fig. 6) and managing the measurements, but measurement of large-diameter units was difficult, requiring expertise.

In this initiative, we developed a semicircular measuring instrument to measure the cradle part (Photo 7). In this

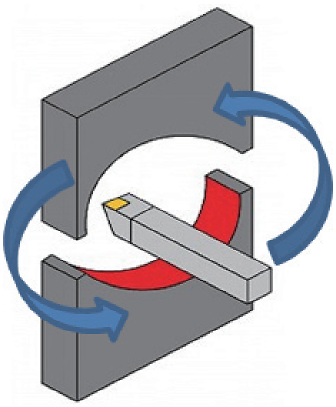


Fig. 4 Conventional processing method

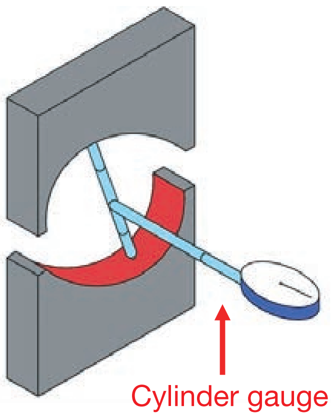


Fig. 6 Conventional measuring method

method, the master ring gauge is used as the standard to compare and measure the work piece and the master. Since the machined diameter can be calculated based on the obtained radius of curvature, this method has enabled us to measure each work piece.

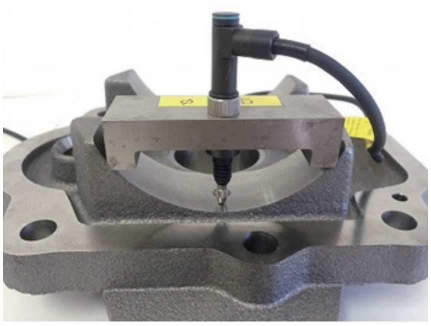


Photo 7 Developed measuring instrument

6.3 Measure against Faulty Unit Outflow

In the conventional method, a worker would look at the standard, search for the location to be measured, and manually write the measurement result in the measurement form. Since the order of measurement could change depending on the worker, we were unable to establish a standard work piece procedure for measurement.

In this initiative, we introduced the inspection support system (Photo 8), which was developed by KYB's Production Technology R&D Center, in order to be able to measure work pieces that are randomly manufactured in mixed-flow production and to establish a standard work piece procedure for measurement. With this line, each work piece is produced with the production instruction form attached to it. This production instruction form has a QR code printed on it. When the part number information is read from the QR code, the screen is switched for each part number, initiating the measurement.

This work pieces with all 16 models, enabling 3 machining centers to simultaneously respond to the production of 3 different models.

In order to remove the work time variations and to establish the standard work procedure, each measurement location is displayed one after another, helping the workers understand where to measure. In addition, by standardizing the measuring method, we can now control work variations. Furthermore, we matched the measuring instrument number on the screen and the actual goods number to prevent workers from being confused. In this system, the measurement results from the measuring instrument are communicated wirelessly, allowing the worker to measure the next part only if the result is within the tolerance.

Photo 8 Inspection support system

7 Result

All of the targets were achieved.
① Operation rate: 86.0%
② Line complaint: 0 (As of December, 2016)
③ Production start timing: May, 2016

8 Summary and Future Tasks

By establishing this line, we were able to establish high-speed/high-precision technology for cradle machining by machining centers. We were able to establish a process-aggregated line that can respond to the "various kinds and small quantity" production.

In the future, we will deploy and develop the initiatives to other lines by using this technology as the base.

9 In Closing

We would like to express our appreciation to relevant divisions who have provided us with cooperation in the establishment of this pump flange machining line as well as everyone who has provided us with guidance and support.

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Technology Introduction

Make Fabrication of Manifold In-House for Commercial Aircraft

KIDA Shigehito

1 Introduction

The Aircraft Components Div. has been expanding sales among private companies. As part of such sales among private companies, we received an order for the valve module used in the flight control system, which is installed in commercial aircraft (business jet aircraft).

However, the setup capabilities are low in the fabrication method of a similar manifold, which is manufactured with the existing facilities, forcing us to promote large lot production. Due to this, the lead time (hereinafter referred to as “L/T”) is prolonged. It would be difficult to respond to a production increase in the future.

Because of this, we decided to internally fabricate the manifold, which is a component. I would like to introduce the newly established special fabrication line with great setup capabilities that can accommodate small lot production (lot: 1 unit).

2 Overview of Manifold Fabrication

2.1 Characteristics of Manifold Fabrication

The manifold, which is a component in a valve module, must be carved out of a rod (Photo 1).

While it is possible to fabricate this with a machining center alone, the precision requirements for the hole diameter and positions are strict due to the fact that the component must be lightweight and have a complex profile and many holes.

Photo 1 Valve module

2.2 Basic Fabrication Parts of the Manifold

Below are the basic fabrication parts of the manifold. There are multiple fabrication angles, and we must consider the movement range of the equipment and dimension requirement precision when determining the processes (Fig. 1).

① Profile fabrication
② Hole drilling fabrication
③ Port fabrication
④ Solenoid installation part fabrication
⑤ Main valve hole fabrication

Fig. 1 Fabricated part

3 Objective

Consider the issues with the existing facilities and establish a fabrication line with great setup capabilities that can accommodate small single-lot production (lot: 1 unit).

4 Objectives

① Operation rate: 85.0% or above
② Setup loss: Within 5 min.
③ Fabrication L/T: 30% reduction

5 Requirements

① Automate manual work, reduce the work time, and remove setup mistakes.
② Fabrication line that can accommodate small single-lot production (lot: 1 unit).

6 Implemented Initiatives

6.1 Fabrication Facilities

To select the fabrication facilities, we focused on space conservation and versatility. We also selected a high-speed and high-torque main spindle so that we can use it with various materials. Furthermore, in consideration of reducing setup time, we selected facilities that can permanently install the required number of tools.

6.2 Automatic Measuring Device within Equipment

By using an automatic measurement device, we can automate manual work.

To select the measuring device within the equipment, we focused on the measurement precision and versatility with the existing facilities. We also considered the work measurement parts to select the stylus with the optimal length (Photo 2).

Photo 2 Automatic measuring device within equipment

6.3 Consideration of Fabrication Processes

In general, fabrication processes can be roughly divided into the process division-type process and process aggregation-type process.

6.3.1 Process Division Type

In the process division-type (Fig. 2), a line is established by appointing facilities for each process to fabricate the units. Due to this, the machine time (hereinafter referred to as "MT") for each facility is reduced, reducing the L/T. On the other hand, the number of setups increases due to the increased number of facilities, reducing the operation rate. In order to secure high productivity, we need to enhance the setup capabilities.

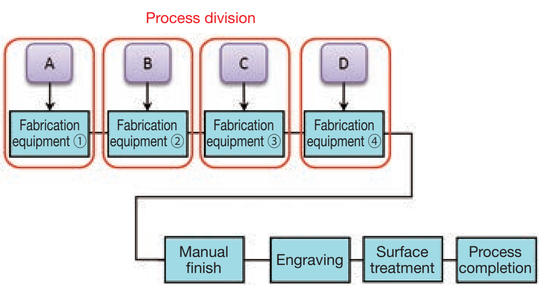

Fig. 2 Process division type

6.3.2 Process Aggregation Type

Since the process aggregation type (Fig. 3) aggregates various fabrication processes (A, B, C, and D), we can establish a line with a small number of facilities. However, it increases the MT for each facility, resulting in longer L/T. In addition, process aggregation often uses multiple-shaft-control fabrication equipment, meaning that it is difficult to maintain the quality from age-related deterioration, etc.

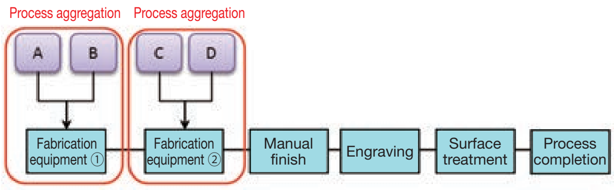

Fig. 3 Process aggregation type

6.3.3 Production System

Large lot production has work-in-process in each process, and it causes stagnation in each process (Fig. 4).

Single-lot production removes work-in-process in each process, resulting in reduced inventory (Fig. 5).

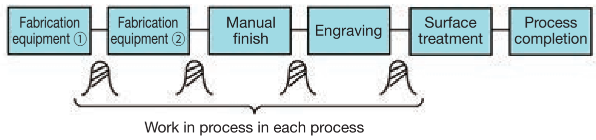

Fig. 4 Large lot production

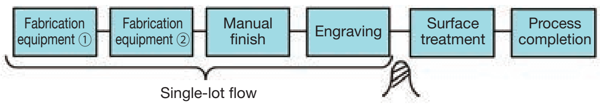

Fig. 5 Single-lot production

With the new line, it is easy to maintain the quality during a long course of production. We also utilized the single-lot production system so that we can reduce inventory and shorten the L/T, and we selected the process division-type fabrication process.

6.4 Improvement of Setup Capabilities

In general, setup work involves the following items. In order to promote small-lot production, great setup capabilities are required.

① Installation of fabrication tools
② Installation of jigs
③ Confirmation of the zero position (hereinafter referred to as "zero positioning")
④ Setting of the fabrication program

6.4.1 Fabrication Tools

By identifying the required tools beforehand and selecting the facilities that can permanently install those, we were able to abolish the installation and removal of the tools that had been done every setup change. We also prepared tool lists for tool part numbers, tool names, part numbers of products for which the tools are used, etc. in order to simplify tool management.

By standardizing the tools used through this initiative, we reduced tool inventory.

6.4.2 Fabrication jigs

In order to standardize jigs and simplify installation, we utilized one-step clamp-type jigs (Photo 3).

As for production jigs, we standardized the installation work by standardizing the base shape when the jigs were being designed. As an error-proofing system to prevent installation mistakes caused by the standardized base shape, we chamfered the base corners and installed blocks for discrimination.

Through this method, we removed tool collision risks caused by jig installation mistakes.

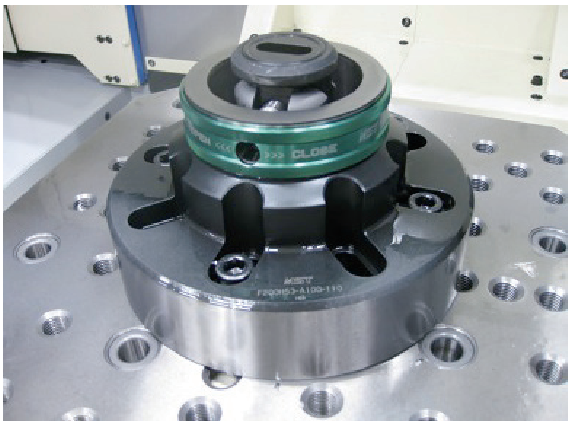

Photo 3 Fabrication jig

6.4.3 Zero Positioning

Zero positioning work, which is promoted to maintain the fabrication precision, must be performed every setup. This was manually performed by workers. Due to this, there were variations caused by workers' skill level differences, and there were more risks of measurement mistakes, requiring a lot of time. This was one of the causes for the reduction of productivity.

By utilizing an automatic measuring device within the equipment, we can measure outer diameters, etc. By automatically inputting them into the fabrication facility, we automated the zero positioning work at the time of setup.

Through this initiative, we were able to significantly reduce manual work and completely removed work mistakes (Fig. 6).

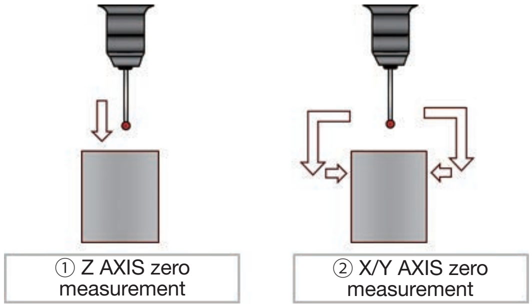

Fig. 6 Zero measurement

6.4.4 Fabrication Program Setting

Since the material is rods, their forms are very similar. Due to this, there are extremely high risks of facility collisions and defects caused by material installation mistakes and fabrication program setting mistakes.

Therefore, we developed a special program using an automatic measuring device within the equipment and custom macro.

By performing automatic product discrimination based on the material or jig shape difference for each product, the fabrication program can be automatically called. Due to this, operation is possible without workers having to reset the fabrication program, which used to be required every setup (Fig. 7).

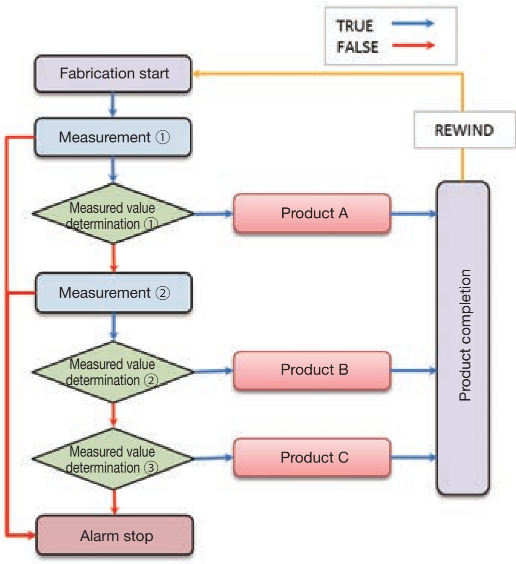

Fig. 7 Automatic discrimination program flow

6.5 L/T Reduction

Since the manifold is one of the major components, it is required to have product traceability through serial number (hereinafter referred to as "S/N") labeling (Photo 4).

Photo 4 S/N labeling

Since S/N are consecutive numbers, a special machining facility with the count-up function is required. Although we considered modifying the existing facility to control the investment amount, the existing facility also receives mixed-flow from other lines and often has general work for high-mix low-volume production. Since its setup capabilities are also low, the production is large lot production, meaning that the L/T is long.

In order to perform the engraving work within the line to reduce the L/T without investing in a special machining facility in the new line, we developed a special program using custom macro (Fig. 8).

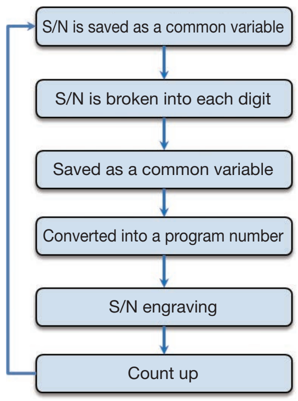

Fig. 8 Engraving program flow

With this program, we were able to engrave consecutive S/N numbers without using a special machining facility, and we were able to not only reduce the L/T but also save space and control the investment amount (Fig. 9).

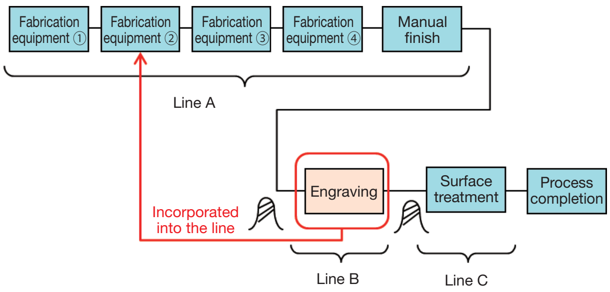

Fig. 9 Process flow

7 Result

① Operation rate: 86.4%
② Setup loss: 0 min.
③ Fabrication L/T: 35% reduction

8 Summary and Future Tasks

With this new line, we were able to establish a fabrication line with great setup capabilities that can accommodate small lot fabrication.

In the future, we will deploy and develop this initiative to other lines by using this technology as the base.

9 In Closing

I would like to express my appreciation to relevant divisions that have provided us with cooperation in the establishment of this line as well as everyone who has provided us with guidance and support.

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Product Introduction

Development of Piston Pumps for Compact-Excavators

TAKEI Gen, SAKAI Yuki

1 Introduction

Excavators are generally classified by body mass. As Fig. 1 shows, those under 6t are called "mini excavators", those between 6t and 9t are called "compact excavators", and those 10t and over are called "medium/large excavators".

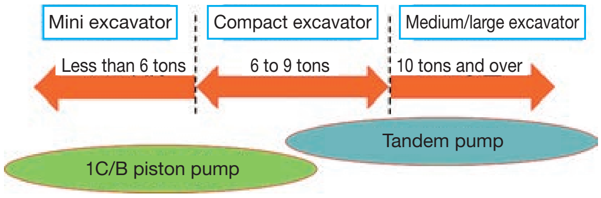


Fig. 1 Excavator classes and used pumps

The installed pump differs for each class, and "1C/B2 flow pump" (hereinafter referred to as "1C/B pump"), which is shown in the upper image of Fig. 2, is used for mini excavators. "C/B" in "1C/B pump" is short for "Cylinder Block". In the rotary part which consists of a C/B, piston, etc., the C/B rotates to allow the piston to move in and out, changing the cylinder capacity and collecting/discharging oil. Although one pump is used in this type of pump, the C/B discharge ports are divided into the inner ones and outer ones (inner ones: blue, outer ones: red), as shown in the lower image of Fig. 2. This division allows 2 discharge types. This structure enables us to shorten the overall length and achieves a compact size and low cost, but we cannot control the discharge flow volume of the 2 ports separately.

Next, in medium/large excavators, we use a "tandem pump" as shown in the upper image of Fig. 3. This system consists of 2 pumps, so the overall length is increased. C/B discharge ports are not divided as shown in the lower image of Fig. 3, and the size is larger and the cost is higher compared to 1C/B pumps. However, they can control the discharge flow volume for each port and have many functions, including a number of added functions.

In compact excavators in between these types, the pump used differs for each mother machine manufacturer, and both types are used.

These developed products are 1C/B piston pumps for compact excavators, but we installed the added functions of tandem pumps on the 1C/B pumps and strived to develop low-cost and high-functioning 1C/B pumps with

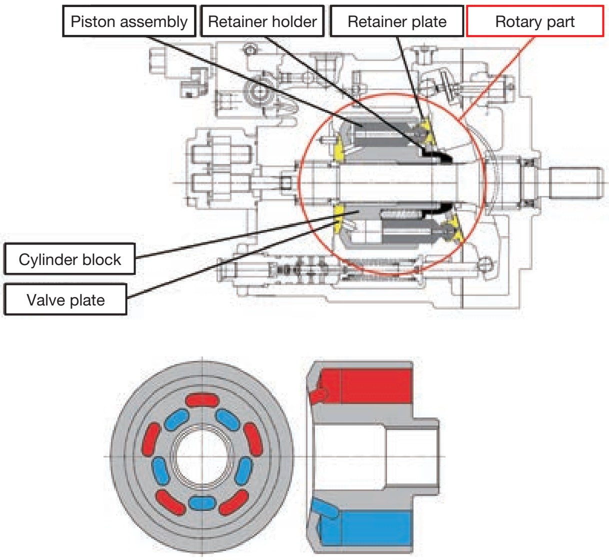


Fig. 2 (Upper image) 1C/B pump, (Lower image) C/B details

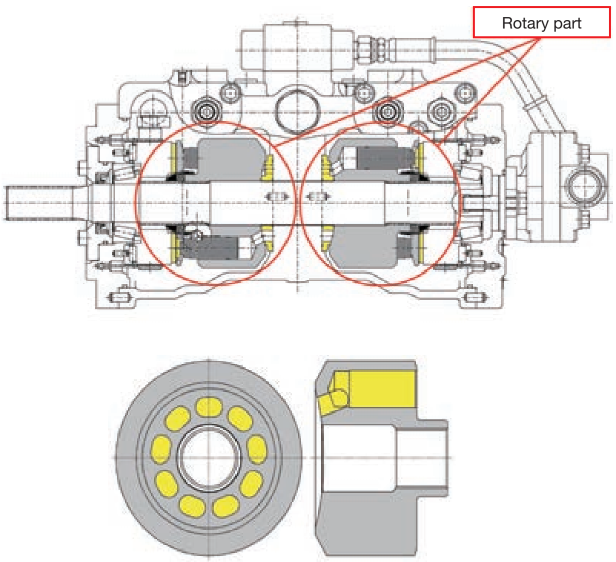


Fig. 3 (Upper image) Tandem pump, (Lower image) C/B details

the aims of expanding the application scope of 1C/B pumps and replacing the tandem pumps.

2 Product Summary

2.1 Lineup

The newly developed 1C/B pumps include PSVL-84, which is a single flow load sensing (hereinafter referred to as "L/S") pump, and PSVD2-42, which is a split flow open pump, and PSVL2-42, which is a split flow L/S pump. Fig. 4 shows PSVL2-42.

In this development, we simultaneously promoted the development of the above 3 models. In order to improve the development efficiency and reduce the cost, standardization of the rotary part was one of the development requirements. By using the C/B with two discharge ports, which was mentioned in the previous chapter, the single flow integrates 2 flows within the pump to discharge from one location (there is no functional difference from a single pump), and the split flow discharges the 2 flows from 2 locations as P1 and P2.

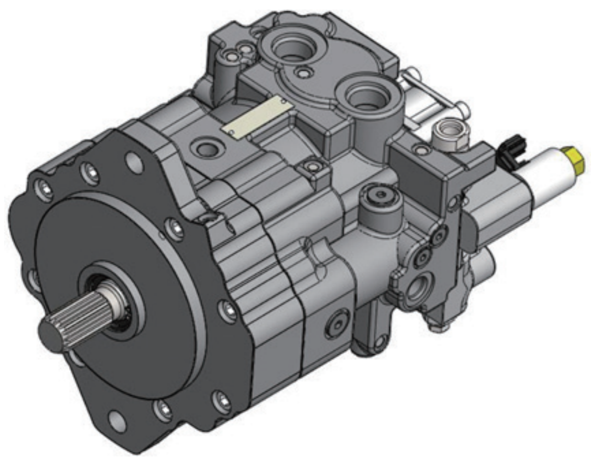


Fig. 4 PSVL2-42

Fig. 5 shows part of the product lineup for pumps used in KYB excavators. The yellow ones are the developed products, and the blue parts in the lower half of the image are the split flow open pump. The green parts in the upper half are the L/S pump (both split flow and single flow). We were able to add pumps for almost all excavators up to the 9t class to the product lineup.

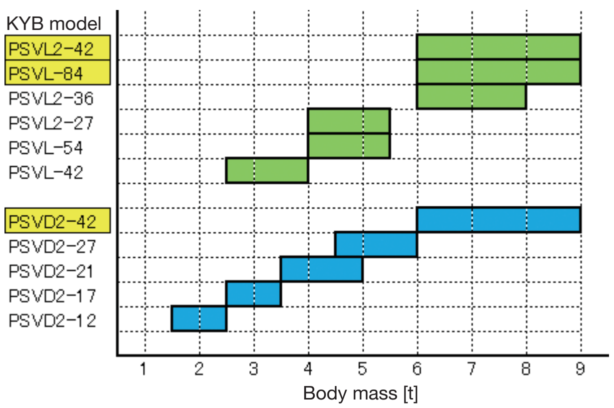


Fig. 5 Pump product lineup for excavators

As Table 1 shows, by mass producing these products, we were able to set up the product lineup for all of the hydraulic equipment installed on 6-9t excavators. By offering hydraulic equipment for excavators as systems, we can offer them as total solutions that include tuning and maintenance.

Table 1 List of hydraulic systems for excavators

	Open	Load sensing (LS)	
	Split	Split	Single
Pump	PSVD2-42	PSVL2-42	PSVL-84
Control valve	KVMM-80	KVSX-18	KVMX-18
Traveling motor	MAG-50		
Turning motor	MSG-44		

2.2 Product Specifications

Specifications of the developed products are shown in Table 2. The maximum pressure and the rotational speed were set to values that can respond to the demands of all customers. The maximum value for displacement volume is 42.3 + 42.3 cm3/rev so that the actuator's operation speed can be maintained even if the engine rotational speed is reduced to conserve energy for excavators. In addition, the minimum value is 36.0 + 36.0 cm3/rev in order to respond to as wide a scope of classes as possible.

Table 2 Product specifications

Displacement volume [cm^3/rev]	• Split flow: 36.0+36.0～42.3+42.3 • Single flow: 72.0～84.6
Maximum pressure [MPa]	32.0
Maximum rotational speed [rpm]	2200

2.3 Added Functions

As mentioned in the beginning, a number of added functions were incorporated into the 1C/B pump in these developed products. Table 3 shows a list of these functions.

Table 3 List of added functions

1	Horsepower control
2	Hydraulic pilot type variable horsepower control
3	Electronic type variable horsepower control
4	★Stand-by control
5	★Variable gain L/S control
6	★L/S dual level gain change control

* ★ are added functions only available for L/S pumps

2.3.1 Horsepower Control

Horsepower control is a basic function for pumps for excavators that prevents the pump absorbing horsepower from exceeding the maximum engine horsepower to prevent engine failure. As shown in Fig. 6, the discharge flow volume (swash plate angle) is changed according to the load pressure to control the pump absorbing horsepower.

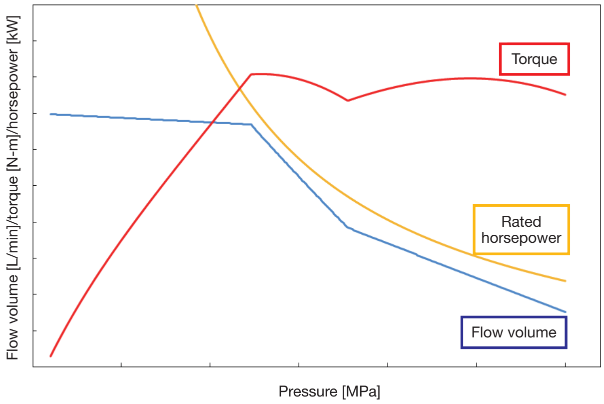


Fig. 6 Horsepower control characteristics diagram

2.3.2 Hydraulic Pilot Type Variable Horsepower Control

The hydraulic pilot type variable horsepower control is a function that can change the horsepower control absorbing horsepower with external pilot pressure.

Fig. 7 shows the characteristics of reduced horsepower control that reduces the absorbing horsepower with this function. The pump absorbing horsepower can be changed in 2 levels by switching the external signal pressure ON and OFF.

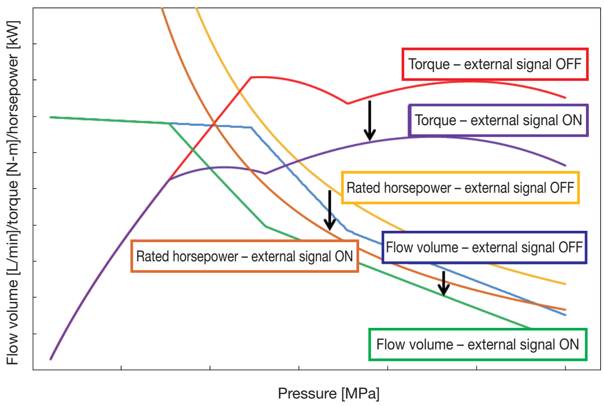


Fig. 7 Reduced horsepower control diagram

2.3.3 Electronic Type Variable Horsepower Control

Electronic type variable horsepower control uses electronic control for the above absorbing horsepower changes by using a proportional solenoid. While the external pilot type has 2 levels of ON and OFF, electronic control can change the pump absorbing horsepower without the restrictions of levels by changing the current value, improving the pump's versatility.

2.3.4 Stand-by Control

The stand-by control is a function that maintains the minimum pump absorbing horsepower by minimizing the pump discharge flow volume when the control valve is unloading (=when the excavator operator is not performing lever operations). This function controls unnecessary fuel consumption and contributes to energy conservation of excavators.

2.3.5 Variable Gain L/S Control

L/S control is an energy-conserving function that provides the operator's lever operation volume to the pump as feedback in a hydraulic manner to let the pump only discharge the necessary flow volume. In this L/S control, the function to change the gain between the "lever operation volume" and "discharge flow volume" is called the "gain changing function". The mainstream control nowadays is the gain change L/S control that reduces the gain when the engine rotational speed is reduced to prevent deteriorating operability.

Variable gain L/S control is a function to optimize the gain change volume according to the rotational speed. With regular gain change L/S control, for example, the discharge flow volume proportionally changes according to the rotational speed, as shown in the blue line in Fig. 8. When the engine rotational speed is reduced from A to B, it conserves energy, but the operation speed (discharge flow volume) at the same lever position also decreases. Variable gain L/S control changes this to the gain characteristics as indicated in red so that the same flow volume can be discharged with rotational speed B as A. In other words, this control can achieve the same actuator operation speed by changing the gain characteristics even if the rotational speed is reduced.

This function allows operators to reduce the engine rotational speed to as low as possible according to the work load, so this system enables fuel consumption reduction while working.

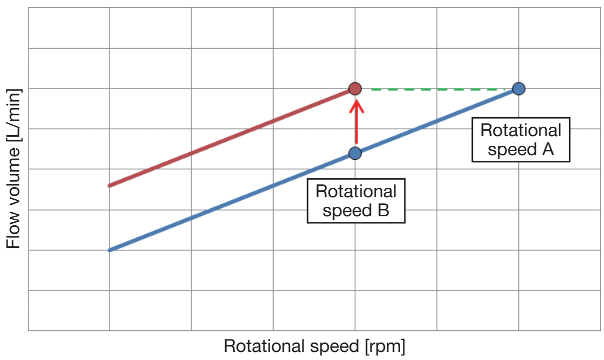


Fig. 8 Variable gain LS characteristics

2.3.6 L/S Dual Level Gain Change Control

In the aforementioned gain change L/S control, the basic control is linearly proportional control, such as that shown in the red line in Fig. 9. However, operators often operate with reduced engine rotational speed due to the recent energy-conservation preference. This has the issue that the operation speed is reduced.

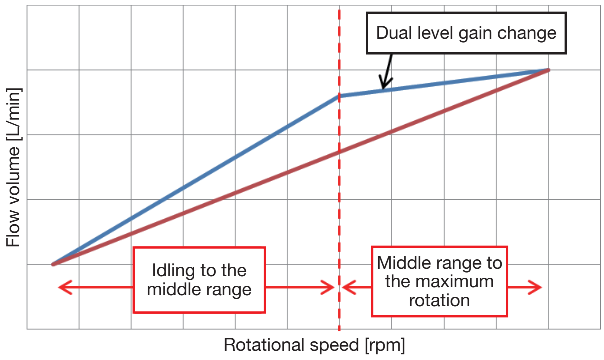


Fig. 9 Dual level gain change characteristics

In L/S dual level gain change control, the operator can set the gain change characteristics in two different levels, as shown in the blue line in Fig. 9. It controls the reduction of control flow volume between the maximum rotational speed and medium speed to secure the operation speed, and it increases the reduction of the control flow volume between the medium speed and idling to secure operability during low speed.

3 Rotary Part Design

These developed products use a spherical rotary part. This spherical rotary part is designed by making a valve plate (hereinafter referred to as "V/P") into a spherical shape as shown in Fig. 10 so that it makes spherical contact with the cylinder block. This spherical rotary part is generally said to be able to enhance the speed, increase the pressure, and stabilize the performance of pump specifications.

The rotary part is a core part of a piston pump, and its design determines the performance. Efficiency, quietness, and durability are the 3 most important aspects of pump performance, and design that balances these 3 aspects is required.

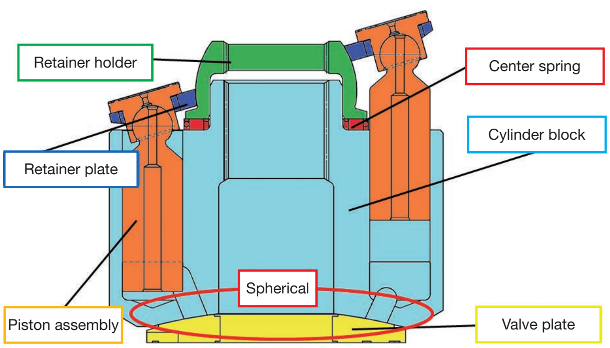


Fig. 10 Spherical rotary part cross-section

3.1 Spherical Clearance Design

We focused on the fact that the contact force on the outside of the V/P increases due to the distorted shaft caused by the hydraulic power when pressure load is applied. We differentiated the spherical radius (SR) of the V/P and that

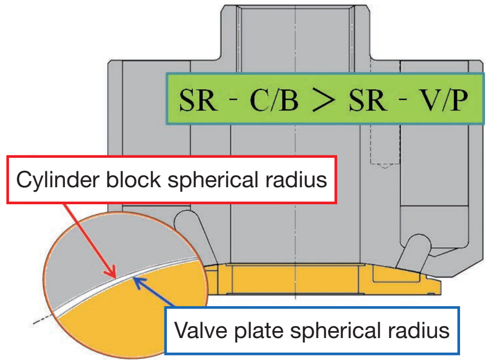


Fig. 11 Spherical radius difference

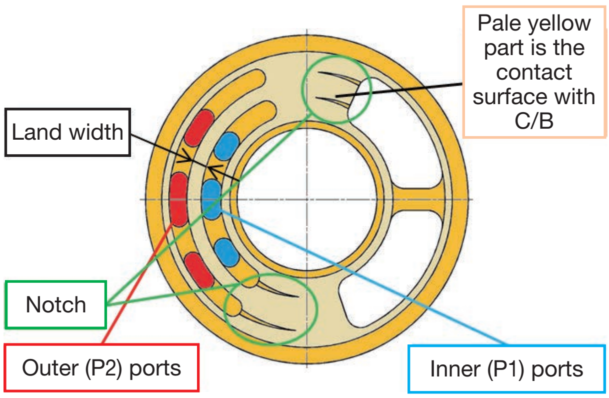


Fig. 12 Valve plate form

of the C/B (SR-V/P < SR-C/B) so that the distortion can be absorbed, as shown in Fig. 11. However, discharge must be divided into two in case of split flow. If the inner ones are P1 ports and the outer ones are P2 ports as shown in Fig. 12, the outer (P2) ports are prone to being affected by the clearance (CL). Leakage from the outer (P2) ports increases due to the clearance caused by the spherical radius difference.

Therefore, we performed a bench test in order to learn the correlation between the spherical radius difference and the outer (P2) port volume efficiency. We prepared 3 levels A, B, and C (CL-A < CL-B < CL-C) with different clearance and compared the port volume efficiency of each outer (P2) port. Refer to Fig. 13.

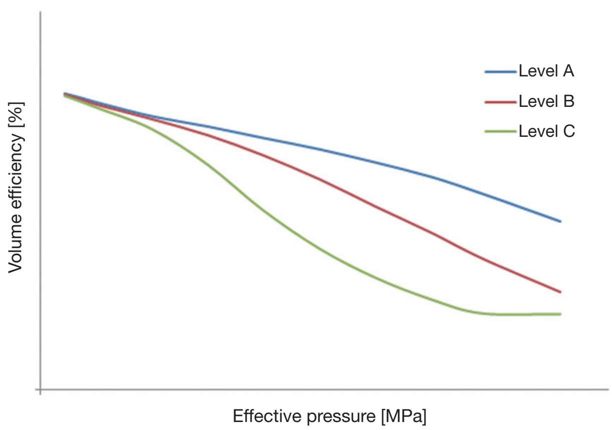


Fig. 13 Outer (P2) port volume efficiency test result

The test indicated that the greater the clearance is, the greater the volume efficiency reduction is. Level C has great reduction volume in the low pressure range (more leakage). Based on this result, we set the spherical clearance.

3.2 Optimization of the Hydraulic Balance

In order to satisfy performance, quietness, and durability, the optimal design of the hydraulic pressure balance that functions with the cylinder block is important. In order to streamline the design, we modeled the cylinder block, valve plate, piston assembly, and shaft as shown in Fig. 14 and established an analysis program that calculates the force on each part at arbitrary angles.

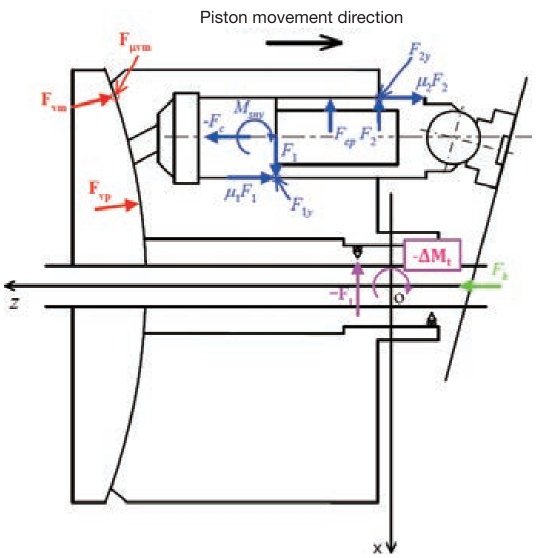


Fig. 14 Hydraulic balance calculation model

By entering the dimensions and pressure of each component, it calculates the pressure distribution, etc. between V/P and C/B as shown in Fig. 15. It outputs this data to calculate the pressing ratio (ratio of the entire load in the Z direction shown in Fig. 14) per pitch (angle obtained by dividing 360˚ by the number of pistons) and fluctuations of the moment balance (ΔMt) that indicates the C/B stability, as shown in Fig. 16.

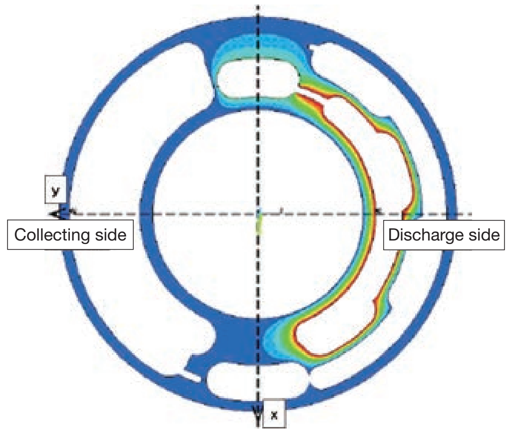
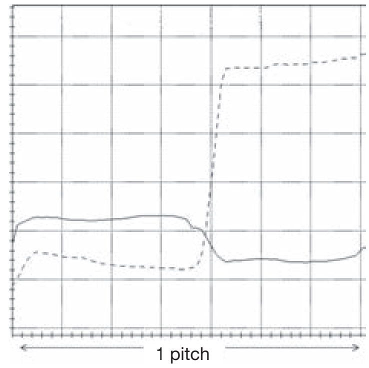
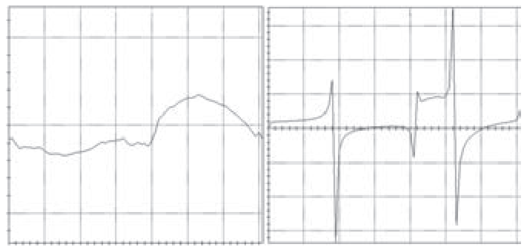


Fig. 15 Pressure distribution reference between V/P and C/B



(a) Pressing rati



Moment ratio

(b) Around the x shaft (c) Around the y shaft

Fig. 16 Output graph

By utilizing this analysis model, we performed performance and durability evaluations through bench tests by using the design values in which the pressing ratio and moment balance fluctuations are small and stable by changing the notch form in Fig. 12 to change the cylinder inner pressure patterns and changing the V/P land width to change the pressing ratio, etc., thus utilizing the design values that satisfy the performance, quietness, and durability.

4 Performance Result

Fig. 17 shows a graph that compares the overall efficiency of PSVL2-36, which is KYB's existing product,

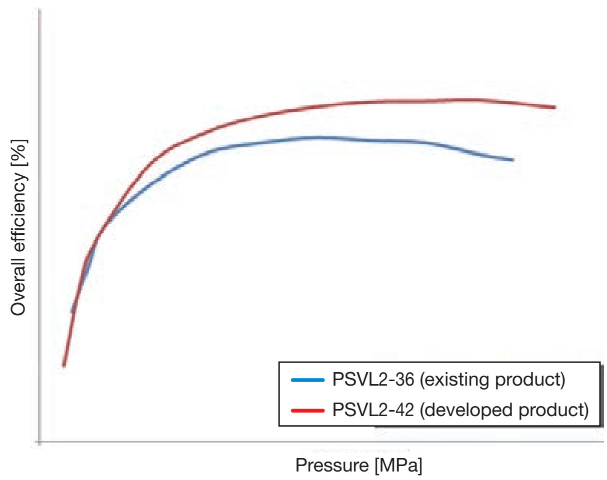


Fig. 17 Overall efficiency comparison

and PSVL2-42, which is this newly developed product. Based on the comparison according to KYB's evaluation points, the efficiency has been improved by approximately 4%, achieving the high efficiency goal through the optimization of the rotary part mentioned in Chapter 3.

As Fig. 18 shows, noise was also reduced by approximately 4 to 8 dB (A) compared to the existing product PSVL2-36, according to the measurement value taken 1m behind the pump. They have also passed all of the strict tests on durability conducted by KYB. We were able to develop products that satisfy all of the aspects of efficiency, quietness, and durability.

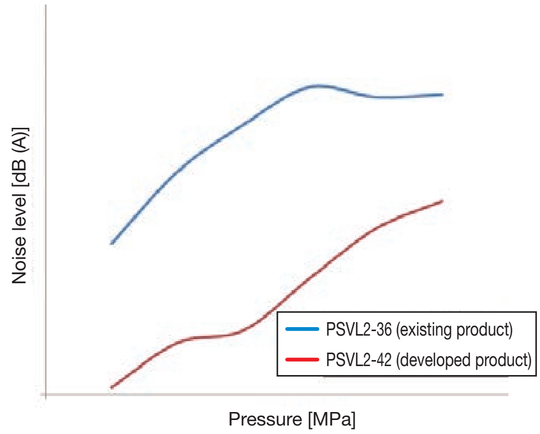


Fig. 18 Noise level comparison (1m behind the pump)

5 In Closing

We developed high-efficiency 1C/B piston pumps for compact excavators responding to energy conservation needs with added functions to expand the application scope. With the launch of these products, we were able to set up the product lineup of hydraulic systems for KYB's excavators up to the 9t class.

Finally, we would like to express our sincere gratitude for everyone involved in the development who has provided us with their great cooperation.

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Product Introduction

Development of High Power Output 2 pinion EPS

TSUTSUI Takaaki, MURASE Tomoyuki

1 Introduction

Electric power steering (hereinafter referred to as “EPS”) is currently utilized in many passenger cars, and the EPS installation rate has been increasing every year. The main reason for its utilization is improvement of vehicles’ fuel efficiency, but the steering feeling improvement and high output design are also contributing to its utilization increase. EPS systems using various methods according to vehicle characteristics for a wide scope of vehicles from compact vehicles to large vehicles have been developed and installed. We have developed 2 pinion EPS and started mass production of them in KYB Gifu North Plant (Fig. 1) in 2016. We would like to explain the characteristics of the 2 pinion EPS in the next section.

2 2 pinion EPS

KYB was the first manufacturer in the world to start mass production of 2 pinion EPS in 1989.

Since then, we have been mainly developing and mass-producing pinion types by adding 1 pinion EPS to the product lineup. The 1 pinion type has an assisting mechanism on the handle shaft. They are generally compactly structured with a small number of components. However, the area around the handle shaft is enlarged, resulting in mountability issues in some cases. In addition, due to the fact that all of the steering force from the driver and the assisting force from the motor is supported by one rack & pinion, the load on the rack & pinion grows greater if high output is required.

On the other hand, the 2 pinion type has 2 different shafts for the handle shaft and assisting shaft. The handle shaft consists of the torque sensor section, which detects the input torque from the driver, and the rack & pinion, which transmit the steering force. The assisting shaft consists of the worm reduction gear section, which decelerates motor rotation, and the rack & pinion, which transmit the assisting force. Due to this, we can make the handle shaft area size smaller than the 1 pinion type. Furthermore, the right/left position and the rotational phase for the assisting shaft can be freely set, achieving great mountability. By utilizing this flexibility along with high-output motor and high reduction ratio, we can establish high-output EPS over 10kN.

Another advantage is its direct and natural steering feeling, due to the fact that the handle shaft doesn’t have an assisting mechanism so that the assisting force is directly applied to the rack.

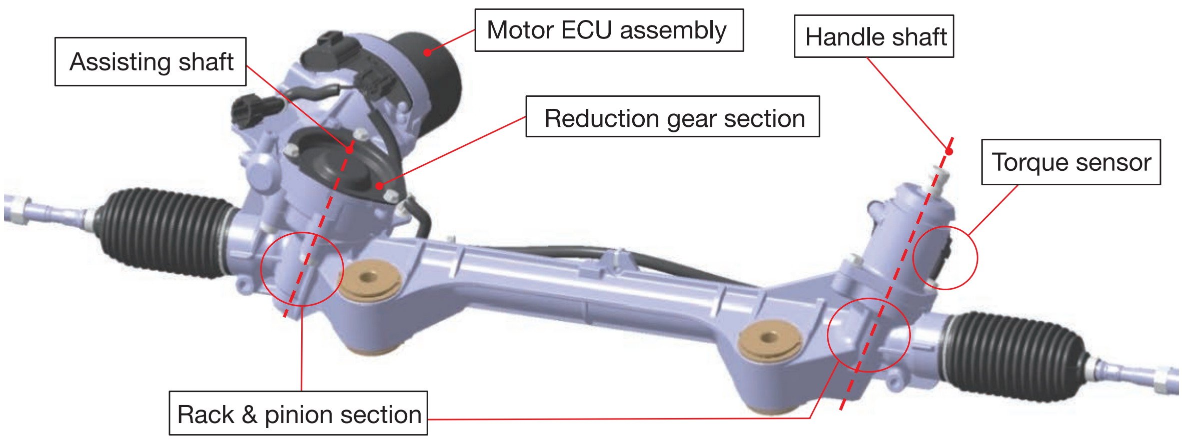

Fig. 1 2 pinion EPS

3 Product Introduction

It's been more than 25 years since KYB started mass producing 2 pinion EPS. Based on the wide scope of element technologies that we have accumulated in the course of this period, including utilization of brush-less motors, high output design, silence, improvement of steering feeling, and the addition of a wide variety of control specifications, we developed the system of this product by focusing on the following items:

① High output design
② Improvement of silence
③ Improvement of safety
④ Improvement of steering feeling

Key specifications of this developed product are shown in Table 1.

Table 1 Key specifications

Item	Specifications
Motor type	DC brush-less
Steering method	Rack & pinion
Theoretical thrust	9.6kN
R & P gear ratio	44.66mm/rev
Reduction gear ratio	1/15.5
Rack stroke	134.4mm
Rack diameter	ø28

3.1 High Output Design

High output design increases the load on the rack & pinion and reduction gear, so strength and durability improvement are required.

As a measure for the rack & pinion, we improved the durability by increasing the rack diameter. We also used a material with high abrasion resistance for the pressure pad seat, which is a sliding part that supports the rack.

Since there was not enough space between the reduction gear and peripheral vehicle components, the reduction gear had to be made compact. We were able to achieve this by maintaining a small reduction ratio. In order to achieve the contradicting requirements of a small reduction ratio and high output design, we needed to increase the motor torque, resulting in an increased load on the reduction gear. Therefore, we decided to use an injection-molding worm wheel using a new material (Photo 1) to respond to the strength and durability improvement. Furthermore, we optimized the reduction gear profile through FEM analysis to improve durability.

3.2 Improvement of Silence

Demands for EPS silence continue to increase along with the improvement of comfort in vehicle interiors, and we needed to reduce operation noise.

Photo 1 Injection-molding worm wheel

Fig. 2 shows the rack & pinion section and the stroke stopper section. With the rack & pinion section, we reviewed the specifications of the rack and the pressure pad that supports the rack to simultaneously achieve durability and silence. In addition, we placed a resin damper ring between the gear box, which is part of the stroke stopper section, and the inner joint assembly to reduce the impact noise from contact.

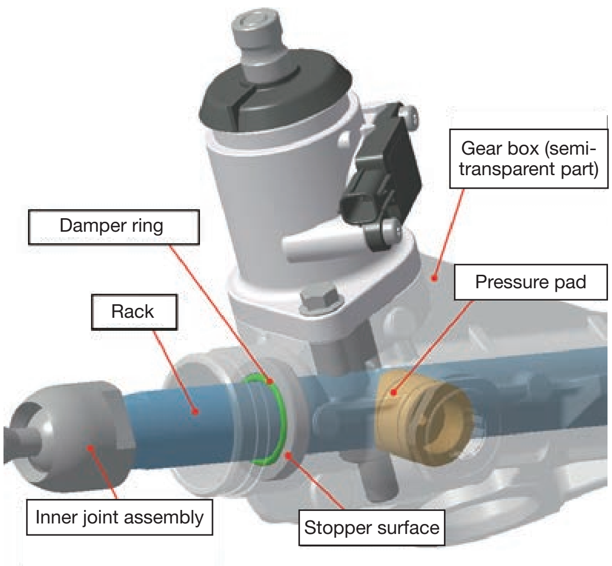

Fig. 2 Rack & pinion, stroke stopper section

Fig. 3 shows the worm reduction gear section. We stabilized the backlash from the worm and the worm wheel with the adjustment mechanism using a spring and coupling to reduce the reduction gear noise.

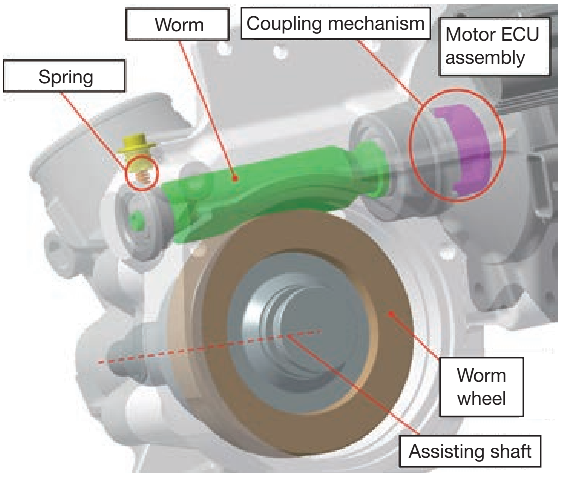

Fig. 3 Reduction gear backlash adjustment mechanism

3.3 Improvement of Safety

In recent years, there have been more demands for ISO26262 compliance as functional safety response, due to the heightened interest in safety.

ISO26262 is a functional safety standard for vehicles issued in November of 2011 as an international standard.

The EPS system is in charge of "turning", which is one of the 3 basic functions of vehicles, and the required safety level is extremely high. Due to this, system safety is positioned as the highest priority issue in development.

The ISO26262 standard provides the definition "Absence of unreasonable risk due to hazards caused by malfunctioning behavior of Electrical/Electronic systems", so the risk due to failures of electrical/electronic systems on vehicles must be reduced to a socially-acceptable level. Representative hazardous modes include self-steering, in which the handle moves regardless of the driver's intention, and steering lock, in which the handle does not move when the drive wants to steer.

The safety level required in electrical/electronic systems is defined by ASIL[Note 1)]. Each hazard caused by malfunctioning behavior of systems is assessed according to the 3 indexes shown in Table 2 and is categorized into 4 ASIL levels from "A" to "D" (Fig. 4). The development of the EPS system was required to achieve ASIL D, which is the strictest level.

In order to achieve functional safety, we are required to apply processes in accordance with the standard. Due to this, we newly established an internal development process in accordance with the standard and promoted the following activities based on the process:

① Failure mode analysis
② Refinement of safety requirements to the technical level
③ System design that satisfies the refined safety requirements
④ Development of safety mechanism that detects abnormalities and shifts to safe status
⑤ Verification of the system's safety requirement achievement level
⑥ Tests from perspectives required by the standard
⑦ Functional safety assessment

In addition, a safety mechanism to thoroughly detect system abnormalities that can cause hazards is also required. Due to this, we newly applied the redundant monitoring method used to enhance microcomputer monitoring mechanism to this system (Fig. 5).

Table 2 ASIL determining indexes

Index	Description
Severity	Extent of failures caused by malfunctioning (serious injury, minor injury, etc.)
Exposure	Frequency of the operation situation (situation in which the vehicle travels at high speed, etc.)
Controllability	Likeliness of being able to avoid the hazard (most drivers can avoid the hazard, etc.)

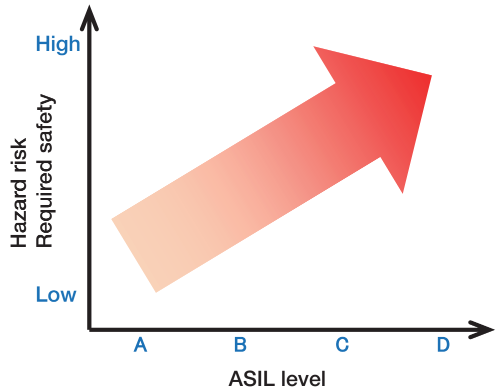

Fig. 4 ASIL levels, risk, and required safety

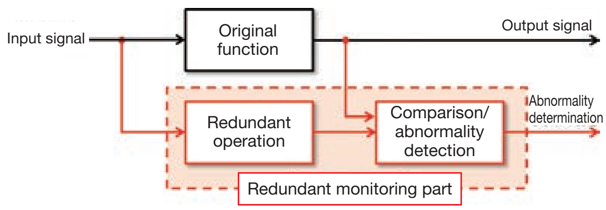

Fig. 5 Redundant monitoring block diagram summary

As a result, we confirmed in the functional safety assessment that the development was promoted by correctly applying the required development process and that the system satisfies the safety requirements by customers.

Note 1) Short for "Automotive Safety Integrity Level". This is a safety level standard for automobiles.

3.4 Improvement of Steering Feeling

The following control parameters were applied to this vehicle:

① Basic assisting control
② Phase compensation control

③ Damping control
④ Friction compensation control
⑤ Steering wheel return control

As a result, we were able to achieve the optimal steering feeling for the vehicle.

4 In Closing

We can say that the 2 pinion EPS is a product that can balance the performance required in EPS, such as high output, vehicle mountability, and steering feeling, at a high level. We expect that the demands will grow further in the future.

Through this development, the 2 pinion EPS has achieved high output design as well as improvement of silence, safety, and steering feeling. We would like to express our appreciation for everyone who has provided us with their cooperation in the course this development.

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Product Introduction

Development of New Stroke Sensing Cylinder for Middle-Sized Machine Control and Machine Guidance Excavator

TAKAHASHI Yusuke

1 Introduction

Information communication technologies (hereinafter referred to as "ICT") are now being utilized in various industries more than ever before. In recent years, movements to utilize ICT are becoming increasingly active in the construction equipment industry. Utilization of ICT is being promoted as comprehensive computerization called "i-construction" under the lead of the Ministry of Land, Infrastructure, Transport and Tourism.

In this report, I would like to introduce a cylinder with a stroke-sensing function (hereinafter referred to as "SSC") which aims to comprehend the equipment attitude of ICT construction equipment used in computerized construction technologies included in Fig. 1.

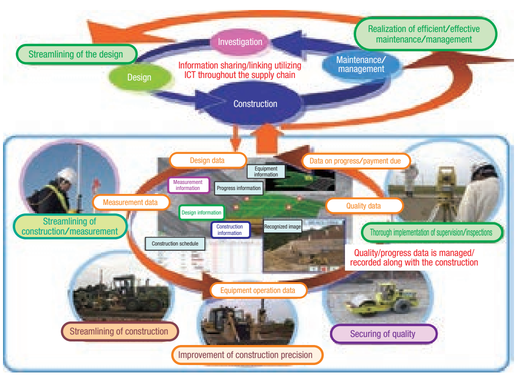

Fig. 1 Computerized construction image
Excerpt from the computerized construction promotion strategy by the Ministry of Land, Infrastructure, Transport and Tourism (2013)

Computerized construction is being promoted with the aims of improving productivity, resolving the lack of labor force, and improving the field safety in the construction industry, and its purpose is to optimize construction itself.

In computerized construction, measurement using the 3D measurement technology is performed by UAV (unmanned aerial vehicle), etc., and the obtained 3D data and the design data are both transmitted to ICT equipment. The ICT equipment performs the construction through machine control (semiautomatic operation) or machine guidance (operation support) based on this information. Ultimately, the construction is completed with an inspection using the construction information from the equipment and 3D measurement, so this method allows us to not only improve the construction efficiency compared to the conventional construction method but also omit prior measurement, inspection of the progress, etc. Due to this, we expect that construction periods can be significantly reduced. Support systems, such as tax incentives, for these technologies have been in effect since the certification of recommended general technology in 2013.

2 Development Background

In 2014, when we first started the development, add-on-type angle sensors were attached to various oscillation pins in most excavators that were compatible with computerized construction. However, due to the characteristic of excavators which operate the bucket in a 3-dimensional manner to perform construction, only the bucket cylinder near the construction surface had the problem of being damaged from coming in contact with the construction surface. This was restricting use.

Under such circumstances, the objective of this development was to incorporate the stroke sensing function within the cylinder to resolve this problem.

KYB also developed an SSC in 1987. This cylinder used the incremental method (relative position detection) to measure the cylinder's stroke fluctuation volume by in-

Fig. 2 ICT excavator ZX200X-5B made by Hitachi Construction Machinery

stalling nonmagnetic sections on the piston rod at regular intervals. In the new product development, we developed a new model for ICT construction equipment that utilizes absolute output (absolute position detection) and is standard-cylinder compatible in order to make an SSC that is easier to operate and has better precision.

This product is currently used on ICT excavator ZX200X-5B (Fig. 2) made by Hitachi Construction Machinery.

3 Product Specifications

3.1 Development Requirements

Since this cylinder was developed based on the assumption that it would be installed on the existing excavators, many aspects are the same as the current hydraulic cylinder KCH (KYB-Cylinder-High pressure) series.

The development requirement was that it would have additional high-precision position detection function while maintaining the same functions as the standard KCH. In addition, due to the fact that the hydraulic cylinder would be an electronic component incorporating a sensor, responding to the harsh usage environment of construction equipment was difficult for the sensor.

Furthermore, mass-productivity was also added as a development requirement in order to be able to produce them in the standard KCH mass production process of KYB.

(1) Development requirements

① Durability that can be used in the same manner as the standard KCH
② Installation compatibility with the standard KCH
③ Sufficient position detection precision and absolute position detection
④ Output characteristics according to the equipment specifications (CAN J1939)

(2) Mass production requirements

⑤ Structure that allows mixed-flow production in the standard KCH mass production process
⑥ Structure that can respond to size variations of the standard KCH

3.2 Basic Specifications

Basic specifications of the standard KCH are as follows:

① Maximum usage pressure: 35MPa (Maximum pressure in temporal increase: 40MPa)
② Fastest cylinder speed: 60m/min
③ Working fluid temperature range: -20˚C to 100˚C

3.3 Additional Specifications

Below are additional SSC specifications to the standard KCH.

① Stroke detection resolution: 0.1mm
② Stroke detection precision: +/- 1.5mm (Actual value: +/- 0.5mm)
③ Anti-vibration performance: 700m/s^2 maximum (70G) Note 1)
④ Anti-shock performance: 1,000m/s^2 maximum (100G) Note 1)
⑤ Ambient temperature range: -40 to 105˚C (When stroke is detected)
⑥ Protection level: IP69K
⑦ Electrical specifications: ISO standards, EN standards, and JASO standards compatible
⑧ EMC specifications: ISO standards, EN standards, and JASO standards compatible
⑨ CAN communication: SAE J1939
⑩ Power source: DC24V 1.5W or less

Note 1) Anti-vibration/anti-shock values are this product's specification values.

Fig. 3 Stroke sensing cylinder (developed product)

3.4 Stroke Detection Sensor

In this development, we focused on development period reduction and technical reliability for the stroke detection method. We selected the magnetostrictive type stroke sensor (Fig. 4) made by MTS Sensors Technology Corporation (hereinafter referred to as "MTS Sensors"), due to the fact that the sensor has been installed in other cylinders. By designing unique inner components for the sensor in response to the stroke sensor's integration into KCH, we have satisfied ① and ③ of the development requirements.

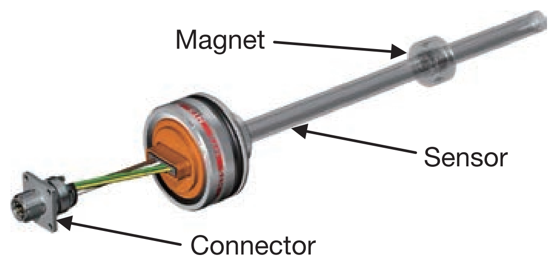

Fig. 4 Magnetostrictive type stroke sensor made by MTS Sensors

4 Development Issues

4.1 Basic Structure

In order to satisfy the previously-mentioned development requirements, the cylinder had to be in the form that allows the same mountability as the standard KCH and that the stroke sensor was attached with sufficient precision. In addition, sensor assembly including wiring needed to be completed in the standard KCH mass production process, which is horizontal assembly.

In order to resolve these issues, we adopted the new structures shown below.

(1) Newly adopted structures

① A structure that can be assembled in the standard KCH automatic assembly line by temporarily assembling the stroke sensor onto the piston rod ((g) and (i) in Fig. 5).

② Assembly is to be performed with the cylinder positioned horizontally, and the design involves cylinder bottom wiring holes to simplify the process ((a) and (l) in Fig. 5).

③ The collar was set to simplify the cylinder bottom process. The configuration allows press-fitting in the existing press-fit process, and the structure can improve workability and ease of assembly ((a) and (k) in Fig. 5).

④ The sensor is attached with set screws in 2 locations to prevent inner components from falling off due to vibrations and shock. A structure that prevents assembly mistakes and components from falling off even when they are loose by achieving the optimal design for the set screw length and groove depth ((i), (j), (n), and (o) in Fig. 5)

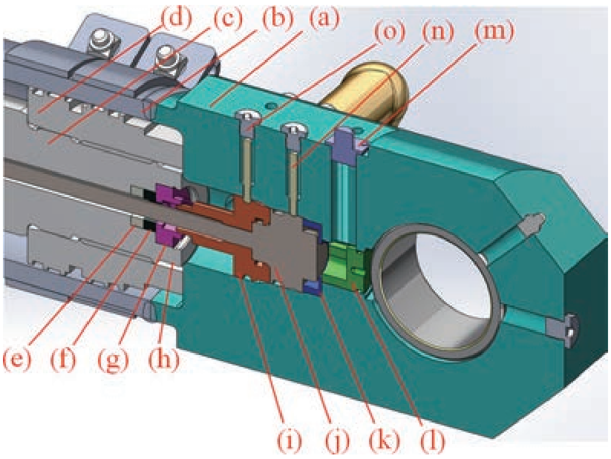

Fig. 5 Internal structure of the stroke sensing cylinder

(a) Cylinder bottom: Special design
(b) Cylinder tube: Standard product
(c) Piston rod: Additional deep hole process
(d) Piston: Standard product
(e) Spacer: Added to detect position
(f) Magnet: Added to detect position
(g) Magnet holder: Added to detect position and for assembly
(h) Snap ring: Added to fix (e) through (g)
(i) Sensor holder: Added to fix the sensor
(j) Sensor: Added to detect position
(k) Collar: Added to simplify the process of (a)
(l) Cover: Added to protect the back of the sensor
(m) Connector: Added for output
(n) Set screw: To fix the sensor/holder
(o) Plug: Added to protect the set screw

We developed this new SSC by combining these structures and the basic design of the standard KCH.

4.2 Anti-vibration/Anti-shock Performance

In this development, SSC was required to have the anti-vibration performance to install electronic components and acceleration specifications related to anti-shock performance, in addition to KCH specifications. In order to be able to use SSC in the same level of environment as the current KCH, SSC had to achieve the specifications that would not break in the environment in which customers had been using KCH.

In actual work, excavators are used for more than just excavation. Since they can perform various types of work by utilizing the flexible movements of the equipment body, they would sometimes perform smooth crane work and sometimes perform work involving strong shocks, such as fracturing work by using a special attachment.

There are some equipment bodies among the existing excavators, which are compatible with computerized construction, that restrict such harsh work. However, having restrictions on the above work with the installation of a stroke sensor would mean that excavators' functions are lost.

Unless they can withstand the maximum level of acceleration in actual work, SSC is not usable in the same manner as the standard cylinder.

We established certain criteria for these equipment body vibration environments based on KYB's past actual equipment test information and conducted the tests. As a result, we discovered the following facts in the prototype stage:

- Acceleration exceeding the acceleration generated by the cylinder is generated in the sensor depending on how the sensor is attached.
- The sensor's standard specifications cannot satisfy KYB's durability tests, resulting in damage in the sensor itself.

To respond to the above issues, we took vibration measures not only through optimization of the cylinder design but also by specially designing the components within the sensor with the cooperation of the sensor manufacturer MTS Sensors in this development. As a result, we were able to improve the anti-vibration performance and anti-shock performance.

4.3 EMC-related Matters

Since this SSC is a product that uses electronic components, we performed EMS evaluations for the cylinder. In terms of test conditions and evaluation criteria, we performed tests as per the general standards as well as additional tests in accordance with customer requirements.

Although there are not many hydraulic cylinder products that contain electronic components, we manufacture vehicle-related products containing electronic components, such as steering by a wire system.

In this development, the Electronics Technology Center, which is the designated department to perform development evaluations for these electronic components, performed the evaluations. We were able to swiftly perform the evaluations on SSC, which is a hydraulic cylinder product, by utilizing the expertise and evaluation technologies of the above department.

Fig. 6 Developed stroke sensing cylinder

5 Conclusions

This newly developed SSC turned out to be a product that can satisfy all of the development requirements in the existing evaluations.

While SSC is a hydraulic cylinder, evaluations may differ with each customer due to the fact that it is an electronic component. KYB's testing facilities and evaluation technologies also enable us to individually perform such evaluations.

As with the standard KCH, this SSC is also designed so that it is compatible with output wiring guards, wiring brackets, etc. to respond to individual customers.

6 Future Outlook

There are 2 basic functions of hydraulic cylinders for construction equipment – to make telescopic movements and to be a structure. There are a number of issues in enhancing the functions of KCH, which is already almost a perfected model in terms of functions.

The same can be said about other hydraulic cylinders made by KYB.

We expect that the needs for stroke sensing will grow further in response to the sophistication of attitude control for construction equipment. KYB was able to respond to the needs for SSC, which can achieve highly sophisticated absolute position detection and the same level of equipment mountability as the standard KCH, with cylinders. In the future, in order to expand the product lineup for similar cylinders in addition to those for excavators, we must not compromise the model cylinder functions in the same manner as this development. Based on this concept, we hope to develop new products by utilizing the cylinder know-how that KYB, who has produced various types of cylinders, has accumulated as a cylinder manufacturer so that we can provide high quality stroke sensing cylinders for each environment.

We are currently developing an SSC (Fig. 7) for KCM (KYB-Cylinder-Middle pressure), which is a hydraulic cylinder for compact excavators, as the first project. KCM SSC is already in the prototype stage. In the same manner as KCH, we have incorporated a design that excels at quality and mass productivity, and we are currently evaluating the prototype with the aim of achieving the same user-friendliness as the standard KCM.

In this development, we enhanced the function to "sense strokes". We will continue proposing other sensing technologies such as cylinder function enhancement and promote development that can contribute to the enhancement of equipment.

Finally, I would like to express my sincere gratitude for various internal departments and relevant affiliated companies that have provided us with their cooperation in the course of the development of this product.

Fig. 7 Stroke sensing cylinder (KCM prototype)

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Product Introduction

Development of Oil Damper System for Seismically Isolated Structures with Lock Mechanism

ITO Yoshihiro, SUZUKI Takio

1 Introduction

When we experience massive earthquakes, safety measures are reinforced and earthquake measures are further developed based on the data. After the Hyogo Ken Nanbu Earthquake in 1995, the dissemination of buildings with seismically isolated structures was rapidly promoted. Due to the recent Great East Japan Earthquake in 2011 as well as our response to expected massive earthquakes in the future, etc., the expression "seismic isolation" is now widely recognized in society.

Seismically isolated structures generally have a seismic isolation layer between the ground and the building, reduce the oscillation transmitted to the building by using an isolator (such as rubber bearing), and damp oscillation with damping equipment. Damping equipment includes steel dampers [Note 1] and lead dampers [Note 2], but oil dampers have been regarded as the leading equipment since the Great East Japan Earthquake from the perspective of durability to allow continuous use even after large earthquakes. In this report, we would like to take the example of the oil damper system with a lock mechanism (maximum damping force: 1,000kN) which reduces wind shake in case of strong wind and introduce these systems.

Note 1) Hysteretic damper utilizing energy absorption through plastic deformation of steel materials

Note 2) Hysteretic damper utilizing energy absorption through plastic deformation of lead materials

2 Oil Damper with Lock Mechanism

Habitability of regular seismically isolated structures may be damaged due to wind shake caused by strong wind, such as typhoons.

Seismically isolated structures using the oil damper with a lock mechanism (Photo 1) are installed as shown in Photo 2. It functions as an oil damper for seismic isolation in the normal mode (lock: OFF), and the damper's telescopic movement can be locked (lock: ON) in case of strong wind. This function allows us to improve the habitability of buildings in case of strong wind better than regular seismically isolated structures (Fig. 1 and 2).

Although KYB TECHNICAL REVIEW No. 23 also introduced the concept of locking dampers to respond to wind shake for individual houses, the oil damper with a lock mechanism introduced in this report is for large buildings, such as high-rises.

Photo 1 Oil damper with a lock mechanism

Photo 2 Installation example of the oil damper with a lock mechanism

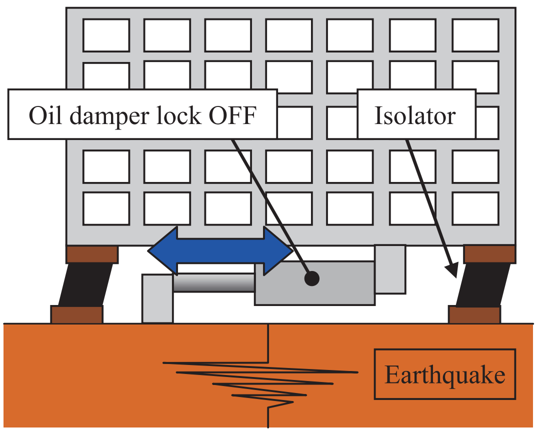

Fig. 1 The damper makes telescopic movements to attenuate oscillation in case of an earthquake

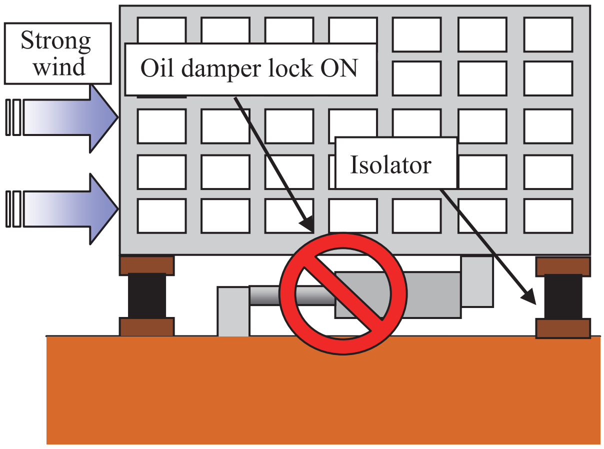

Fig. 2 The damper is locked in case of strong wind in order to reduce wind shake

3 System Development Background

The Japan Society of Seismic Isolation issued the "Guidelines for wind-resistant design of base-isolated buildings" in 2012 (in 2016 for English version) , in which wind resistance performance of buildings was clearly indicated in different ranks. Acquiring high evaluation on wind resistance performance also increases building added value, so demand for oil dampers with a lock mechanism has been increasing.

Due to such circumstances, we reviewed the construction workability, cost, and functions of the existing locking control system. We would like to introduce a new-standard control system, which was developed as the foundation for the product lineup.

In addition, the background for the development of the oil damper with a lock mechanism itself is discussed in KYB TECHNICAL REVIEW No. 29 (Oct. 2004), so please refer to it.

4 Structure and Functions of the Oil Damper with Lock Mechanism

4.1 Structure and Functions When the Lock is OFF

As Fig. 3 shows, in this oil damper with a lock mechanism, the damping valve to gain damping characteristics, the lock valve and solenoid valve to control the lock mechanism, and the safety valve to prevent damage due to excessive load when locked are all contained within a valve block.

The oil damper with a lock mechanism functions as an oil damper for seismically isolated structures when the lock is OFF. Due to the fact that this is a "uniflow" type, in which working fluid passes a common damping valve when the damper makes telescopic movements, it operates as shown in Fig. 4 and Fig. 5 during these telescopic movements. In terms of damping characteristics, this system utilizes a linear type, in which the damping force is controlled solely through the damping valve without using relief valves, etc. and the damping force increases along with the velocity.

As Fig. 3 shows, the ratio of "inner tube inner diameter cross-sectional area (chamber A: 2)" and the "value obtained by subtracting the rod's cross-sectional area from the inner tube inner diameter cross-sectional area (chamber B: 1)" is 2:1. This structure maintains the equal pressure and the working fluid flow volume flowing to the damping valve with telescopic movements. Since the working fluid's flow volume is converted into the oil damper's velocity and the pressure is converted to damping force, the oil damper's damping characteristics during telescopic movements can be maintained equally by maintaining the equal pressure and the working fluid flow volume during telescopic movements.

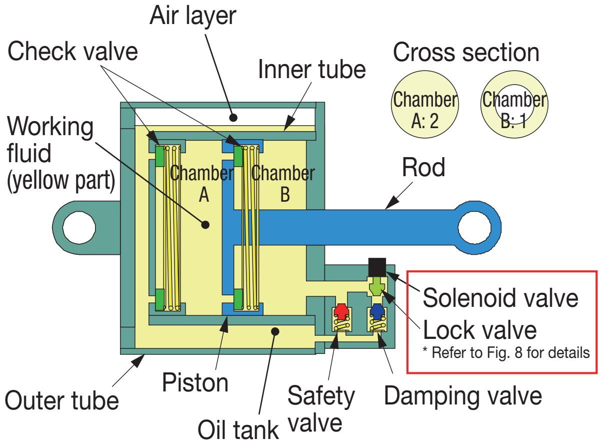

Fig. 3 Damper structure

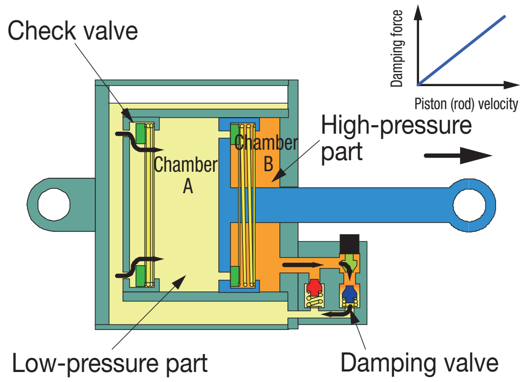

Fig. 4 Damper function (extension direction)

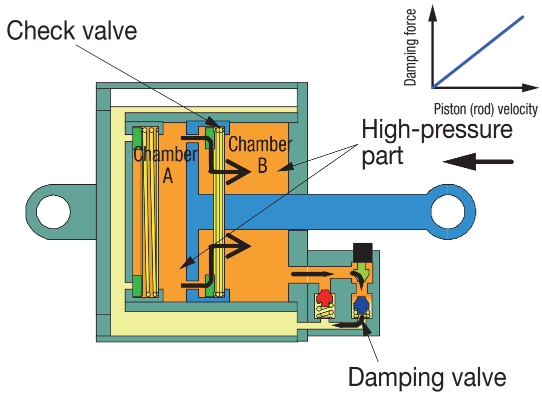

Fig. 5 Damper function (contraction direction)

4.2 Structure and Functions When the Lock is ON

When the lock is turned ON, the lock valve closes as shown in Fig. 6, closing the passage to the damping valve. As previously mentioned, the oil damper with a lock mechanism is a uniflow type. Due to this, when the passage to the damping valve is closed, it cannot make telescopic movements and becomes locked.

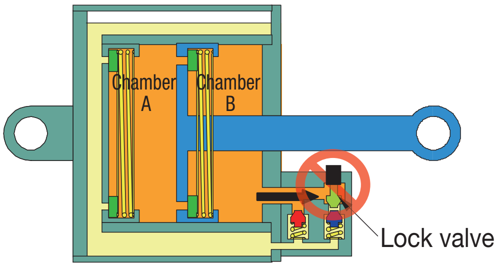

Fig. 6 Damper function when locked

4.3 Safety Valve

The maximum damping force of the oil damper with a lock mechanism is 1,000kN. When the load exceeds this and reaches 1,100 to 1,200kN due to an earthquake, etc. while the lock is ON, the safety valve operates as shown in Fig. 7 and prevents the damper from being damaged due to excessive load.

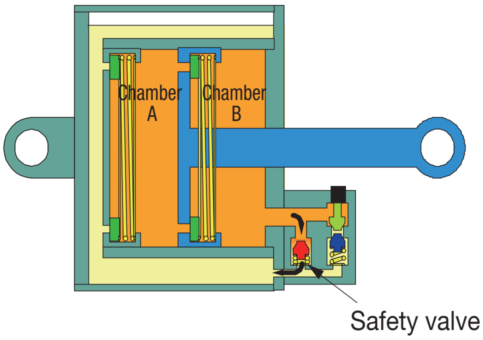

Fig. 7 Safety valve function

4.4 Lock Valve and Solenoid Valve

Lock valves and solenoid valves are structured within valve blocks as shown in Fig. 8.

When the lock is OFF, the solenoid valve is open, keeping the passage to the oil tank open. Due to this, the inner pressure due to the damper's telescopic movements is applied to the cross-section ① as force to open the lock valve. It is also applied to the cross-section ② as force to close the valve, but the force to open the lock valve is greater due to the fact that the area of the cross-section ① is greater, thus opening the passage to the damping valve.

When the lock is ON, the solenoid valve is closed, and inner pressure due to the damper's telescopic movements is applied to the cross-sections ①, ②, and ③. However, in this status, the force to close the lock valve is applied to the cross-sections ② and ③, so the force to close the lock valve is greater, thus closing the passage to the damping valve.

4.5 Solenoid Valve and Connector

Solenoid valve opening and closing are controlled through electric signals. There are 4 valve blocks, which contain solenoid valves, installed on the rod side of the damper, as shown in Photo 3.

A connector (shown in Photo 4) is attached to each solenoid valve, and the damper is connected to the control system with it.

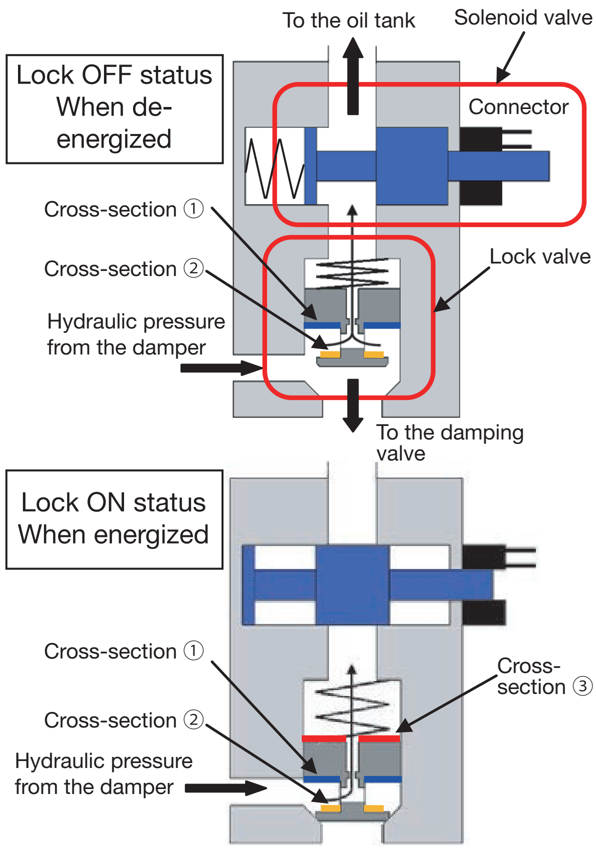

Fig. 8 Lock mechanism

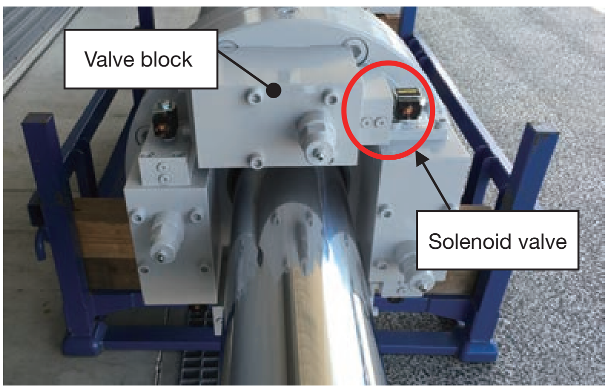

Photo 3 Valve block

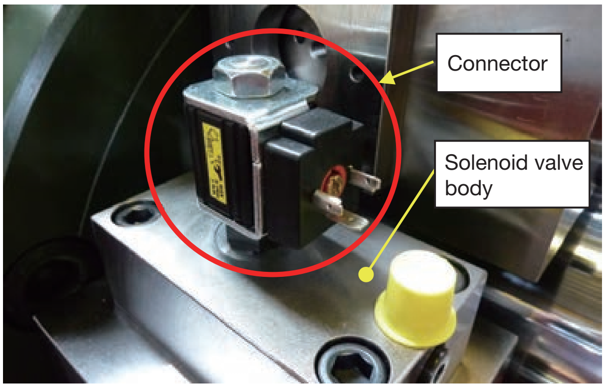

Photo 4 Valve block connector

5 Control Method

In terms of the control method, we have established the standard control method, which uses both wind information and earthquake information, and the simplified system (2 types), which considers the building's usage condition and cost and uses either wind information or earthquake information for the control.

The standard control method description is as follows.

5.1 System Configuration for the Standard Control Method

Fig. 9 shows the system configuration of the standard control system. This system uses accelerometers (Photo 5) to detect earthquakes, anemometers (Photo 6) to detect strong wind, a control panel (Photo 7) to control the electric signals to solenoid valves based on information from each detector, and the junction box (Photo 8) to split 1 cable from the control panel into 4 cables due to the 4 solenoid valves used in each oil damper with a lock mechanism. We recommend that customers use at least 2 units of each detector as a failsafe measure.

We also install an accelerometer on top of the seismic isolation layer to respond to customers' requests to verify the seismic isolation effects of the oil damper with a lock mechanism in case of earthquakes, and acceleration data is recorded during earthquakes.

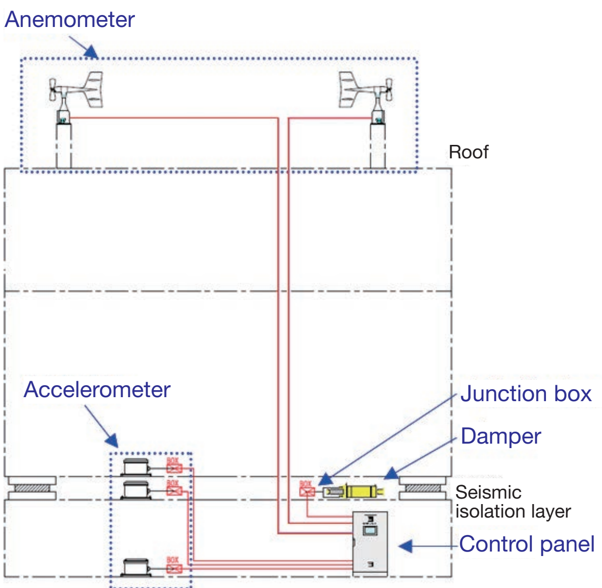

Fig. 9 System configuration

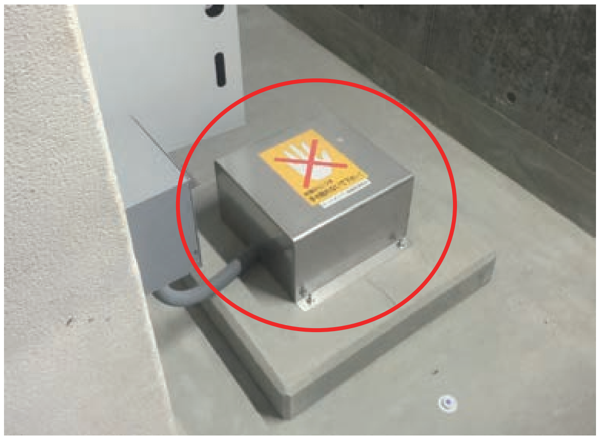

Photo 5 Accelerometer

Photo 6 Anemometer

Photo 7 Control panel

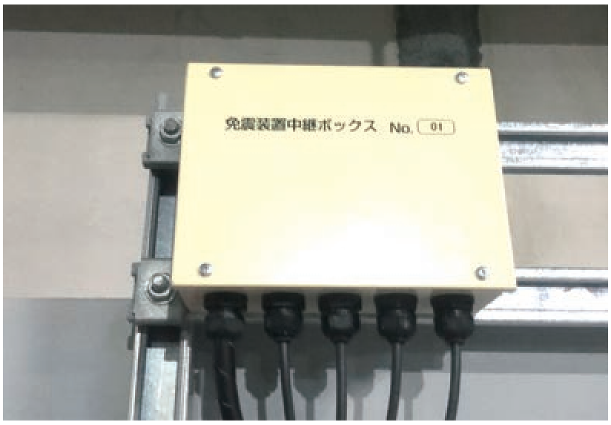

Photo 8 Junction box

Photo 9 Control screen

5.2 System Control

Fig. 10 shows the flow chart for the standard control method. The oil damper's lock is OFF in the initial state, and it has an automatic mode and manual mode. However, the automatic mode is normally used. When the wind velocity signal exceeds the set value, the automatic mode automatically locks the oil damper with a lock mechanism. When the acceleration signal exceeds the set value during the lock status or after a certain time period, the lock is turned OFF, and the system returns to the seismic isolation damper status.

In manual mode, the user selects lock ON or OFF by operating the touch panel switches on the control panel (Photo 9). However, the condition to automatically turn the lock OFF is the same as in automatic mode.

The set value for each detector and the set value for each timer can also be easily changed after starting the operation through the same touch panel (Photo 10).

Power failure is a problem in electric control. However, this system uses normal open solenoid valves, meaning that no electricity runs through the solenoid valves. Due to this, the lock is turned OFF in the oil damper with a lock mechanism to make the damper function as an oil damper for seismically isolated structures, thus securing the building's safety.

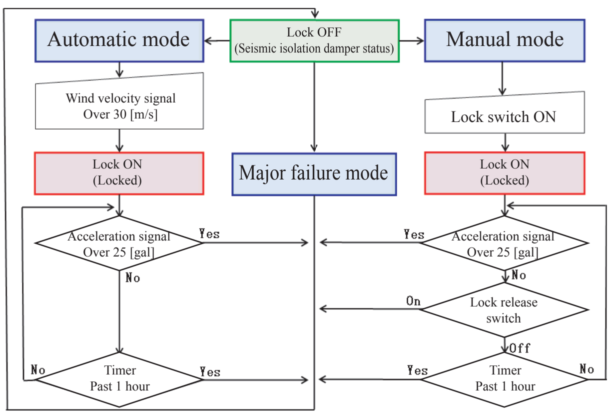

Fig. 10 Standard control system flow chart

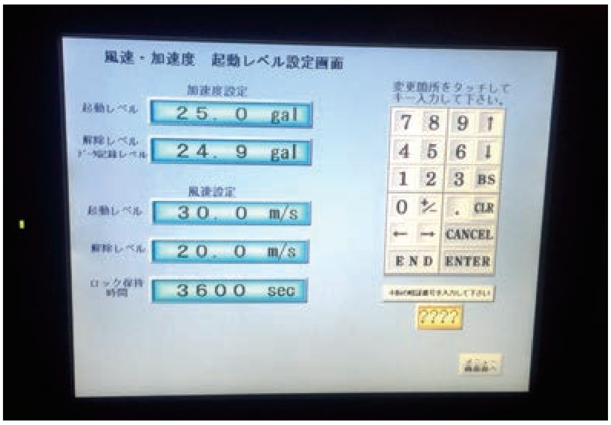

Photo 10 Wind velocity/acceleration startup level setting screen

6 Introduction Example

We would like to introduce some of the buildings to which this system was introduced.

6.1 Roppongi Grand Tower

In this building with 2 underground floors and 43 above-ground floors, we introduced a standard control system with 2 anemometers, 8 accelerometers (2 for both control/recording, 6 exclusively for recording), and 4 oil dampers with a lock mechanism (Photo 11).

6.2 Tekko Building

In this building with 3 underground floors and 26 above-ground floors, we introduced a standard control system with 3 anemometers, 7 accelerometers (2 for both control/recording, 5 exclusively for recording), and 32 oil dampers with a lock mechanism (Photo 12).

In this example, the signals output from the earthquake/wind observation device, which was introduced by the customer, are imported to the control panel, thus controlling the ON/OFF for the lock of the oil dampers with a lock mechanism.

Photo 11 Roppongi Grand Tower

Photo 12 Tekko Building

7 In Closing

By developing the oil damper system for seismically isolated structures with a lock mechanism and establishing 3 types of control systems, we expect that introduction of this system will further increase and that it will contribute to the improvement of habitability in seismically isolated buildings.

We expect that we will be able to enhance the technology to quickly comprehend the oil damper system's status by utilizing the IoT Note 3) technology, etc. in the future.

Finally, we would like to express our sincere gratitude for everyone who has provided us with their cooperation in the course of this system's development as well as everyone who has given us their approval to post photos.

Note 3) Short for "Internet of Things". It refers to communication of measurement data, etc. by connecting things to the internet.

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Editors Script

It’s been over a year since I made it my goal to ride my bicycle the 10km one-way distance to work twice a week for health reasons. I sometimes don’t achieve this goal. It’s always a fight with my own will and weakened body, and, needless to say, there is no immediate or obvious result. However, I do feel definite changes (health = achievement), looking back on the past year. I truly feel the importance of continuing my efforts. After being appointed an editorial member for this review, I thought that the same can be said about technology/product development in companies. I hate to be self-applauding, but I feel a great change (achievement) compared to 10 years ago. To think that the technologies being developed now will be utilized in products 5 or even 10 years from now, I have more excitement than concerns.
(NAKAMURA)

It seems as though bookstores sell more books on “communicating”, such as “how to write”, nowadays. Indeed, I do often encounter reports that are difficult to comprehend on the first read. Now that I’m in the position to correct them, I myself am experiencing the difficulty of expression through writing. I can see the selections of books covering this “communicating” that I mentioned in the beginning. What these books have in common is “being aware of the reader”. As a representative of readers, I hope to fulfill my role as an editing committee member with the aim of creating articles that are easy for the readers to read. (YONEZAWA)

I am in charge of the Editorial Secretariat from this issue. Since joining KYB, I had been involved in product development for more than 20 years. However, I was transferred to the head office a year and a half ago, and I’m now in a position to support product development. This review is widely transmit the technologies of the KYB Group to both inside and outside the company, and we will continue aiming to make it that are enjoyable and useful for everyone who are daily involved in design and development of product. We appreciate your continued cooperation in the future.

It's a personal matter, I will be able to start the new fiscal year with a refreshed mind by the time this issue is published, as my move and my child’s school acceptance examination would be over. (HIROSE)

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