Essay

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

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1. Introduction

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

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

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

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

Photo 2 Example of large-scale residential area development

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

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

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

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

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

2. The Road to KCH

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

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

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

3. The Grass is Greener on the Other Side

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

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

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

At that time, the Shock Absorber function already put into effect the product usage verification based on actual vehicle measurement. The obtained measurement data was subjected to various analyses, including frequency and correlation analyses, to actively study how the design elements were associated with the riding comfort and durability of actual cars. Motorcycle function implemented the actual vehicle measurement with fewer burdens on motorcycles and their riders by commercializing radios (telemeters). This product usage verification was also linked to bench tests and computer simulation. The current reliable evaluation of product usage under various road surface conditions in the KYB Development & Experiment Center is based on these accumulated efforts.

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

4. Toward No-Leak Hydraulic Cylinders

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

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

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

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

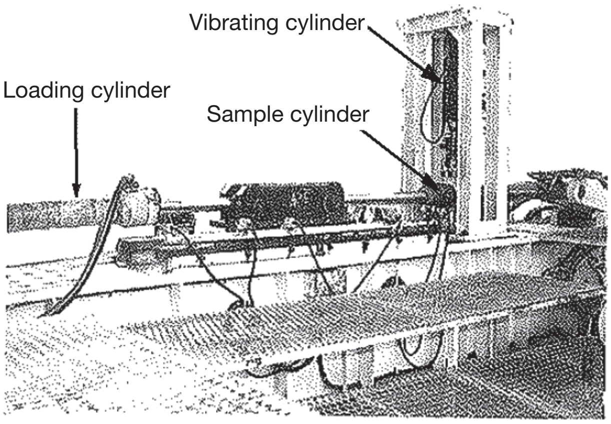


Photo 4 Vibration/sliding endurance test [1)]

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

Apart from the verification of product usage on the actual machine, speeding up the in-house experiments was another challenge. Even bench test evaluations using actual cylinders involves time and cost issues. In the KCH development process, the element test focusing on the evaluation items for each part, which has been developed from the "hydraulic cylinder quality and technology development system", was encouraged. Pressure, speed and other parameters were changed to achieve linear or planar evaluation, not point evaluation, for wider application of the result and fewer experiments.

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

5. Experience and Track Records as Obstacles

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

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

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

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

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

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

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

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

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

The bearing is located on the side of the hydraulic

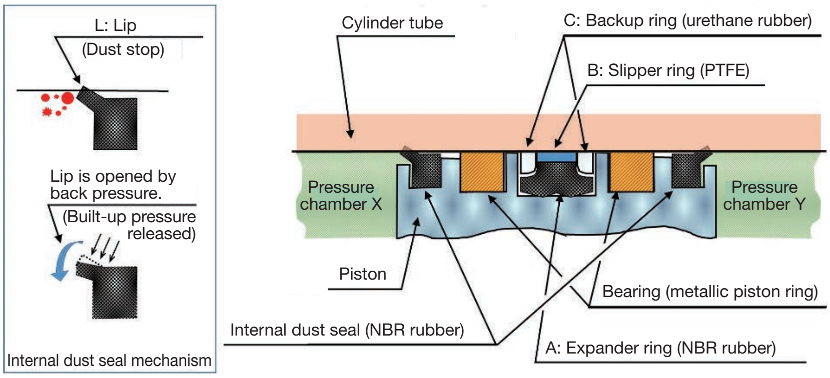


Fig.1 Original seal ring type piston structure with internal dust seal

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

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

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

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

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

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

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

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

6. Visualization

The development of the KCH seal system involved

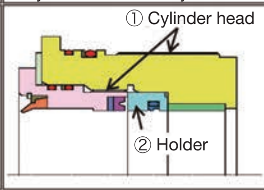
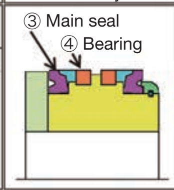
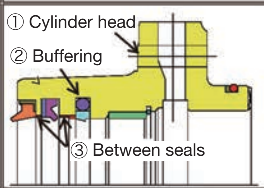
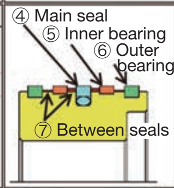
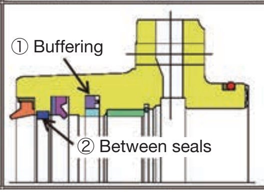
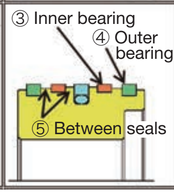
Year	Model	Pressure	Cylinder head seal system	Changes	Purpose	Piston seal system	Changes	Purpose
1984	High-pressure type (old model)	24.5MPa		Conventional high-pressure cylinder model for construction equipment ① Screw-in type ② Non-ferrous material			Conventional high-pressure cylinder model for construction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

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

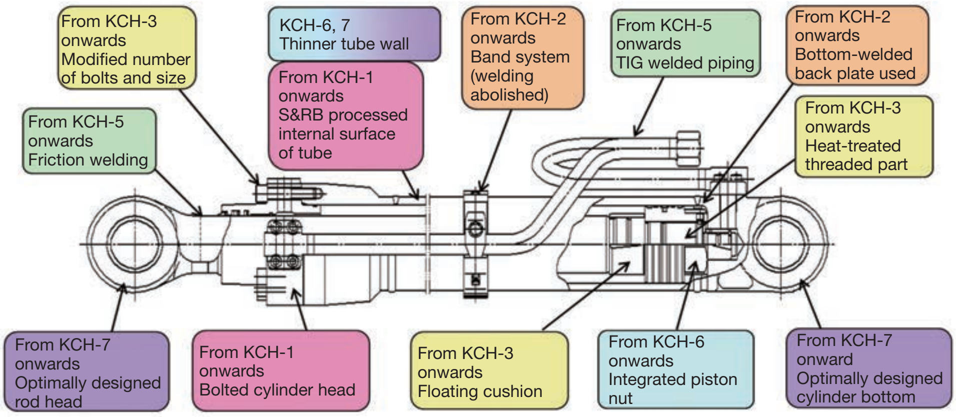


Fig. 3 Features of major KCH components [Source: Reference 2)]

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

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

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

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

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

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

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

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

7. In Closing

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

References

1) Obata: History of Development of Hydraulic Cylinders for Construction Equipment, KYB Technical Review No.3, (October 1991).

2) Takai: Changes in Cylinders for Hydraulic Excavators, KYB Technical Review No.50, (April 2015).

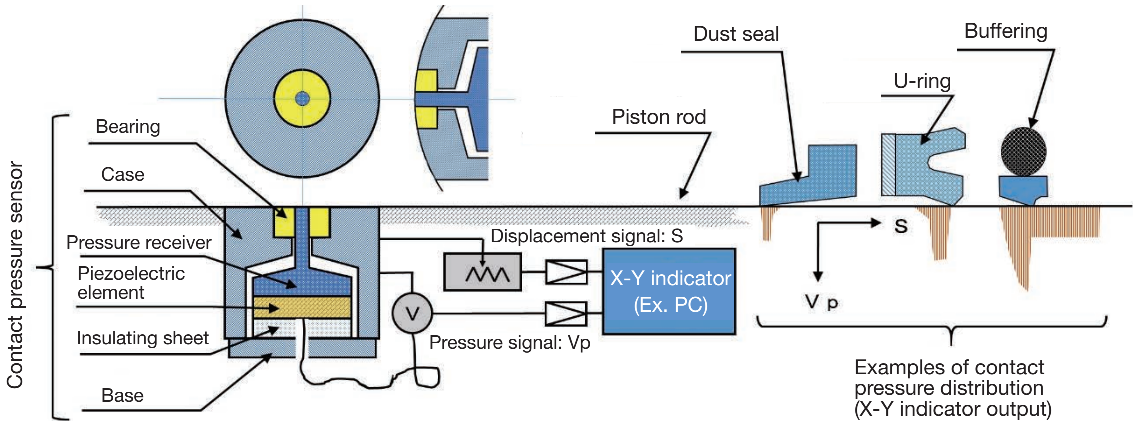


Fig. 4 Measurement of contact pressure distribution

Author

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Joined the company in 1979.
President of KMV.
Taken present post after working as Hydraulics Engineering Dept. Manager in Gifu South Plant, Motorcycle Engineering Dept. Manager in Automotive Components Operations and Quality Management Dept. Manager in Corporate Officer Quality Div.