Technology Introduction

Development of Equipment for Evaluating Automotive Vane Pumps

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1 Introduction

As automotive manufacturers have been addressing production of environmentally friendly cars, components manufacturers are also required to improve the performance of automotive components for lower environmental load.

Under the daily efforts to improve the performance of KYB products, the Experiment Dept., which is responsible for evaluating product validity, has addressed many different challenges, including development of necessary technologies for product evaluation (testing machines), improvement of test accuracy and enhancement of test efficiency.

2 Product Introduction

The world's first vane pump for CVT [Note 1)], which was put into mass production in 2004, has successfully increased in production and is now one of KYB's key products.

KYB has developed many different models of vane pumps, including the world's first CVT vane pump (6K), the vane pump with aluminium die-cast cover for small and medium size cars (7K), its advanced model with even higher performance (6K2) and the lower torque model with the flow control valve eliminated (7K3, see Photo 1).

The company has a lot of overseas production sites, with recent additions in China, Thailand and Mexico, to produce several hundred thousand vehicles per month. They are highly rated by customers for their performance and quality.

Note 1) Stands for Continuously Variable Transmission.

Photo 1 CVT vane pump (7K3)

3 Efforts by Experiment Dept.

The vane pump is used as a hydraulic power source of CVT and greatly contributes to the transmission performance. For this reason, customers stringently require manufacturers to improve the performance. Engineers often argue the specification values for flow rate or driving torque at an accuracy as small as the 1/100 level, which is very minute compared to the case of multi-purpose pumps.

Product evaluation cannot be done accurately if the testing machine or measuring instrument used shows greater variations than those permitted by the product specifications. It is an important role of the Experiment Dept. to improve the measurement accuracy by eliminating various disturbances affecting the measurements and by sophisticating the data processing method, as well as to develop testing machines. This report introduces part of the efforts.

4 Development of performance testing machines

There are two major basic characteristics of pumps: P-Q characteristics and driving torque characteristics. The P-Q characteristics of a pump can be determined through a test to measure the flow rate (Q) of the pump applied with pressure (P). The driving torque characteristics can be determined through a test to measure the friction of the pump running.

Before the development of the new testing machine, all processes, including set-up and measurement, were manually carried out by humans. However, involvement by humans inevitably caused minute differences in operating procedures (adjustment of temperature, pressure and pump speed), which was one of the causes of the variations. To ensure accurate evaluation of product characteristics, it was necessary to eliminate any variations attributable to differences in operating procedures of the testing machine by humans (effects of individual humans).

To address the challenge, KYB has developed another performance testing machine with the following features:

(1) Automated pressure adjustment

(2) Modified torque measurement system

(3) Standardized measuring jigs

The following sections explain each of these features in detail.

4.1 Automated Pressure Adjustment

The most important role of the pump as a hydraulic power source is to discharge oil. Since the discharge flow rate varies by pressure, pressure adjustment is one of the critical control items in testing. Great pressure fluctuations may not only cause an unstable flow but also greatly affect the torque variations. To further stabilize the pressure, a balance piston type relief valve has been introduced for pressure adjustment.

In the conventional testing machine, flow rate variations occurred because the pressure adjusting valve was operated by humans at different speeds. When trying to identify a minute error, one could not determine whether the error was attributable to the specimen itself or to the variation in the measurements. Then we addressed an effort to automate the pressure adjustment.

First of all, we discussed the use of a commercially available proportional solenoid valve. For the proportional solenoid valve with an internal spool, however, we feared that the spool might oscillate when the oil was aerated or the characteristic frequency of the piping coincided with the resonance frequency of the spool. We then decided to continue using the existing relief valve, and invented an automatic valve for adjusting the relief valve opening pressure with a servo motor. Furthermore, the servo motor was designed to control its speed in response to the pressure feedback. Consequently, this automatic valve helped achieve pressure elevation at a fixed rate, eliminating the existing dispute over the pressure adjustment speed.

However, another problem arose a couple of months after the introduction of the automatic valve. That was wear of the pressure adjusting screw. The relief valve used was designed to work as a safety valve and was not supposed to be frequently opened or closed for pressure adjustment. The automation of pressure adjustment resulted in a change in feed rate and a longer feed travel to return to the origin, which probably caused the wear in the threaded portion of the pressure adjusting screw. To solve the problem, a grease nipple was provided to facilitate the lubrication (Phot 2).

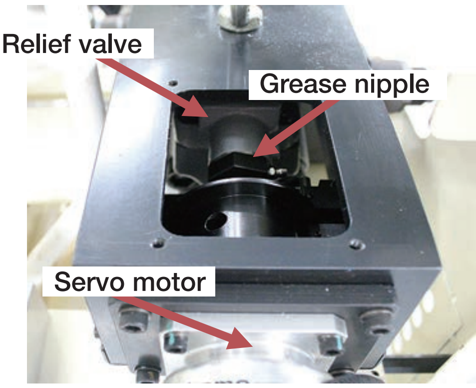

Photo 2 Developed automatic valve

4.2 Modified Torque Measurement System

Along with the introduction of automated pressure adjustment, the torque measurement system was also reviewed. Conventionally, the pump torque measurement was made with the pump speed and pressure set to a specified value and the average of the measurements was calculated. For this system, however, it was unavoidable for different operators to set the pressure to an exactly same value, resulting in minute differences in the test results.

Thus, averaging method has been changed to another torque measurement system in which the pressure is gradually increased across a specified value, and torque values corresponding to different pressure levels are given by a linear interpolation. Finally the specified pressure value can be assigned to the formula to obtain the torque value.

The new system also includes a process to warm up the pump for a certain period of time to stabilize the local temperature of the jigs, measuring instruments, pump bearings and internal parts.

Fig. 1 gives a graph of the measurements. This modification resulted in a smaller variation.

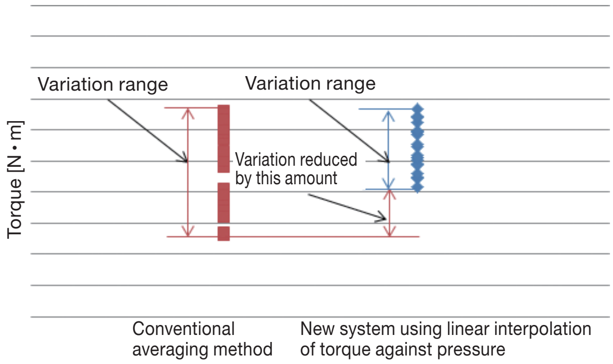

Fig. 1 Variation reduction by modified torque measurement system

4.3 Standardized Measuring Jigs

The existing two jigs have been standardized.

The conventional testing machine (before development) was equipped with two jigs: a P-Q measuring jig and driving torque measuring jig. The belt over the pulleys on the input shaft had to be replaced before another type of measurement (Photo 3). The main reason for the replacement was to prevent an expensive torque meter, if kept installed, from getting broken in the event of an excessive torque.

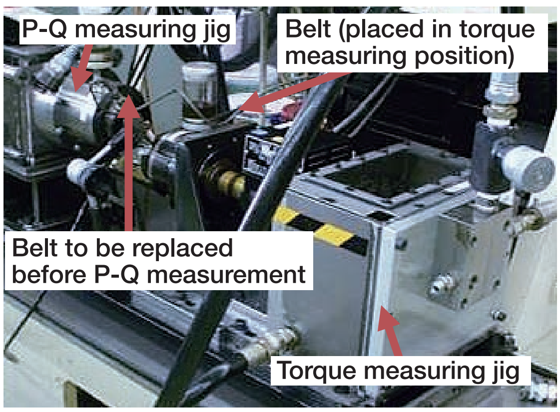

Photo 3 Conventional performance testing machine

To standardize the jigs, an intermediate shaft was added to the machine with reference to the jig used to measure the P-Q characteristics. The machine has been redesigned so that the torque meter and the intermediate shaft can be replaced along a linear guide. Through the improvement, the set-up change man-hours have been substantially reduced (Photo 4).

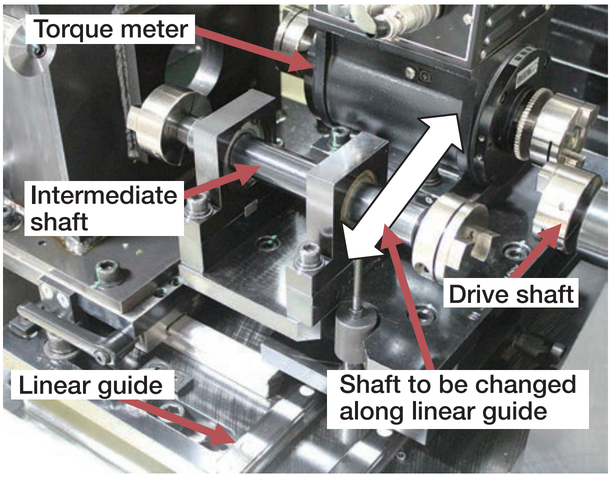

Photo 4 Developed jig

4.4 Effects of Full Automation

With the newly developed performance testing machine, the operator only has to press the Start Evaluation button after a set-up change. The machine then automatically carries out all the processes, including raising the oil temperature, zero adjustment of the measuring instruments and evaluation. The full automation contributes to not only higher measurement accuracy but also higher evaluation efficiency.

The developed performance testing machine is laterally spread to overseas production sites in response to strong requests. Copies of the Japanese testing machine have been introduced to KST (Thai Plant), KMEX (Mexico Plant) and KIMZ (China Plant).

Japanese staff have travelled to the sites to support installation of the testing machines. The staff have also widely provided training and education on how to determine the correlation of measurement data and how to utilize the results, routine and periodical maintenance, and even staff education. Now the overseas sites are able to evaluate the equipment to the same quality as of that in Japan.

The performance testing machines are generally used today for routine evaluation in all the sites of KYB Group (Photo 5).

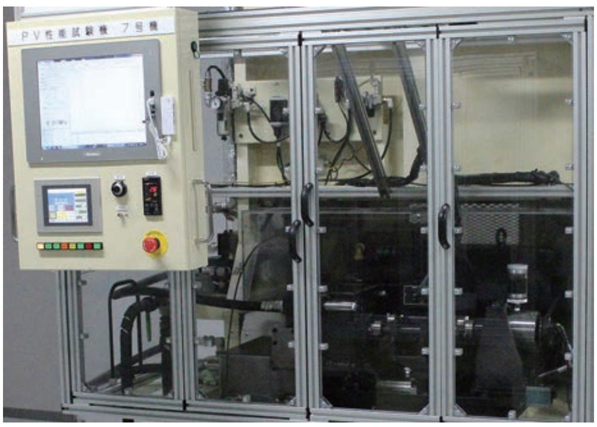

Photo 5 Fully automated performance testing machine

5 Development of Micro Torque Testing Machine

This section introduces a micro torque testing machine that enables the measurement of 1/100 order torque mentioned above (Photo 6).

The specification item critical to fuel efficiency is the torque value at a low speed over a low pressure range, which is a very small value. Its actual measurements are close to the theoretical value with an efficiency of 100%.

The conventional testing machine caused large variations in measurements and required the operator to carry out tests over and over again in order to identify any differences caused by a change in the pump specifications. We then addressed the development of a testing machine for micro torque measurement at a high accuracy.

To develop a new testing machine, we first tried to identify possible factors affecting torque. Finally we decided to review the following items:

(1) Accuracy of measuring instruments (torque meter, pressure gauge)
(2) Drive system
(3) Shaft run-out
(4) Oil temperature control

5.1 Accuracy of measuring instruments (torque meter, pressure gauge)

The conventional torque testing machine stated above was fabricated for the purpose of achieving measurement across the total operation range. The machine used a torque meter of a capacity corresponding to the maximum value stipulated in the pump specifications.

First of all, we discussed torque meters so as to improve the measurement accuracy and eventually selected an optimal torque meter by taking into account accuracy, delivery date and cost. Similarly, we discussed pressure gauges and selected one that was most suitable for the measurement conditions.

5.2 Drive system

The conventional testing machine transmitted the motor torque output to the pump via the belt. In fact the belt often slipped and caused rotational fluctuations, which adversely affected the torque fluctuations.

To prevent rotational fluctuations, the new machine uses a directly coupled pump drive. It also uses a servo motor to achieve a speed change rate of 0.01% or lower.

5.3 Shaft Run-out

When the jig and the pump are misaligned with each other, shaft run-out occurs to cause torque fluctuations, which may result in variations in the measurements. That's why the jig accuracy has been stringently designed. To minimize the shaft run-out, a total manufacturing system from jig machining to assembly has been introduced. A 3-dimentional measuring instrument has been used to control the height dimensions of the shaft.

5.4 Oil Temperature Control

The viscosity of hydraulic oil affects the sliding wear of the pump, thereby changing the torque value. Thus, the oil temperature (viscosity) was stringently controlled.

The measurement results are shown in Fig. 2. The variation in the torque measurements was calculated with a standard deviation of 3σ. The result did not reach the target value. Another trial to improve the processing method was made.

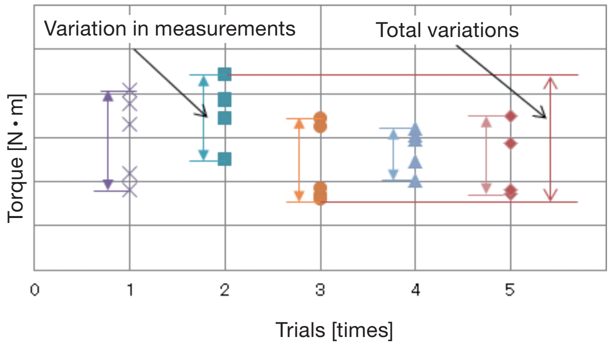

Fig. 2 Variations in measurements

To further diminish the variation in measurements, we decided to carry out measurement five times and then recorded the average, instead of the conventional single measurement. As a result, accuracy was improved by one digit order with 3σ.

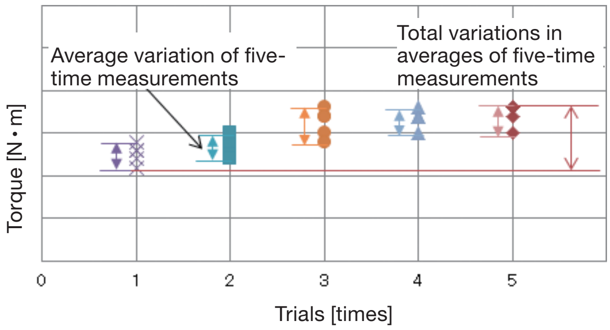

Fig. 3 Variations in measurements by averaging

With the increasingly rising demand for lower fuel costs, it will be even more difficult to determine whether a micro value is attributable to the pump characteristics or to variations of the testing machine. We are committed to aggressively address achieving even more accuracy-focused measurement so as to evaluate micro values.

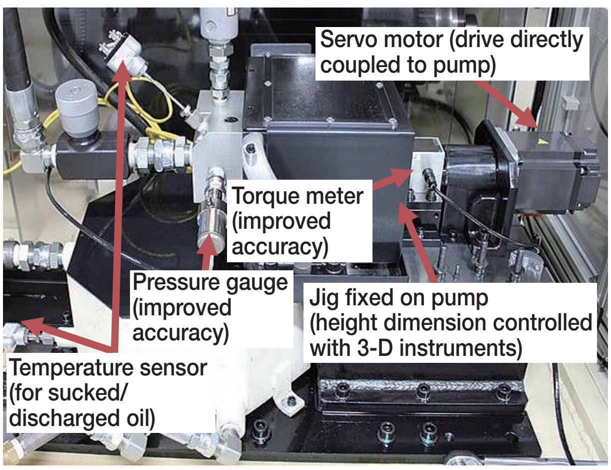

Photo 6 Developed micro torque testing machine

6 Development of Environmental Performance Testing Machine

A vane pump has vanes accommodated in the slits of a rotor. The vanes are tensioned to maintain contact with the bore of a cam ring. The volume of the room formed by the rotor, the vanes and the cam ring is increased or decreased as the pump rotates, thereby sucking or discharging oil. To keep the vanes in contact with the bore, it is necessary to establish a back pressure of the vanes in addition to the use of the centrifugal force. The pump remains unable to discharge oil for the time being until the vanes are brought into contact with the bore.

The time is the longest in cold climate areas. The vanes have a higher sliding resistance for oil with a higher viscosity. The pump needs a longer time until it is ready for discharging oil.

In addition, the pump has more pressure loss in the intake piping at a lower temperature, thereby reducing the discharge flow. In this case the required flow to the CVT may not be ensured. Therefore, reliable evaluation at low temperatures is essential to the development because of the vane pump's construction, as seen in the high utilization of low-temperature evaluation testing machines.

Next is an environmental performance testing machine for which the low-temperature evaluation man-hours have been reduced. The conventional low-temperature evaluation testing machine had a jig installed in its thermostatic chamber. The oil temperature was controlled using the room temperature in the chamber, requiring a very long time to cool the oil. Once the pump was started, the oil temperature increased as the pump generated heat. This limited the number of times of measurements per day.

Then we developed a new testing machine with the aim of reducing the oil cooling time and achieving continuous operation at low temperatures.

6.1 Oil Cooling in a Shorter Time

To improve the hydraulic oil cooling efficiency, the first thing to do was to change the cooling system from ambient temperature cooling to heat exchanger cooling. Aside from the main hydraulic circuit, a sub hydraulic circuit was provided to be cooled first. The cooled sub circuit was used for heat exchanging to reduce the temperature of the main hydraulic circuit. This system allows direct cooling of hydraulic oil, substantially reducing the cooling time.

As a cooling medium, we decided to use oil with a low freezing point to ensure liquidity, even at -40°C.

6.2 Design of Optimal Testing Machine

The cooling capacity is substantially affected by radiation cooling and frost forming. We then decided to install the jigs and piping inside the thermostatic chamber. With the effect of radiation cooling suppressed and an optimal heat exchanger selected, the testing machine has come to be able to deliver maximum cooling capacity. This resulted in higher cooling efficiency, obtaining a cooling capacity equivalent to the calculated value. The completed testing machine is shown in Fig. 7.

With the testing machine introduced, the time conventionally required to cool the oil was substantially reduced as shown in Fig. 4, leading to higher test efficiency. The direct cooling of hydraulic oil enabled continuous operation at low temperatures.

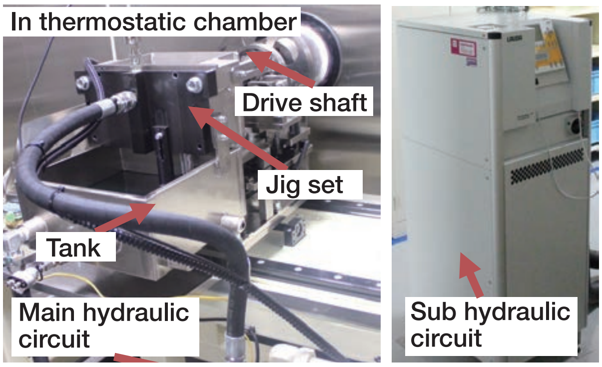

Photo 7 Completed environmental performance testing machine

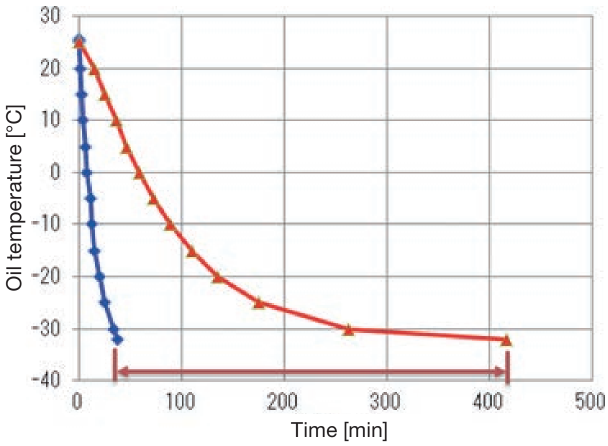

Fig. 4 Time reduction by the testing machine introduced

The new equipment fabricated in this project raised evaluation efficiency, greatly contributing to faster improvement of the low-temperature characteristics of vane pumps.

7 Future Challenges

A dozen or so years have passed since the launch of the evaluation of CVT vane pumps. Our experiments are entering a new phase.

We have evaluated the pump independently from the equipment. In fact the evaluation jigs and conditions for the separate unit testing machine are different from the actual operating environment of the transmission. We believe that we should develop products based on our understanding of our customers' product configuration and service environment. This will lead to the creation of products wanted by customers and customer satisfaction. Now we have to be sure to proceed in that direction.

Actually we should look at customer products directly with our eyes and touch them directly with our hands, and develop a service environment for such products. By focusing on the whole unit, not just looking at the pump alone, we hope to hit upon new ideas or inspiration we have never come up with before.

8 In Closing

This report has introduced the efforts of the Experiment Dept. with a focus placed on the development of evaluation equipment. We have encountered more and more opportunities to be required to develop an evaluation method and improve accuracy at the same time as developing a product. Under these conditions, we are committed to reliably play the role of the Experiment Dept. by making use of our expertise and knowledge.

Finally, we would like to take this opportunity to cordially thank the related companies and those concerned in the development of the testing machine, as well as those who have extended their guidance and support to us.

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