

Development of K3VLS Series Hydraulic Pumps for Use in Construction and Agricultural Equipment



Kawasaki has developed the new K3VLS series of medium pressure pumps for use in construction and agricultural equipment, which are effectively deployed worldwide. These pumps have achieved customer requirements for both performance and reliability as well as cost reduction, and have been highly rated by customers and applied to various machines.

Introduction

Because of global warming, increasing global population, and other social factors, environmental load reduction, automation, high functionality, and various other efforts are required for construction equipment and agricultural equipment, which are vital to our lives in that they play a role in social infrastructure development and food production.

1 Background

Regarding hydraulic pumps for excavators as core products in the construction equipment field, Kawasaki has been continuously improving products¹⁾ while incorporating social and customer needs, thereby increasing its market share in the construction equipment field.

With the aim of becoming a “global-standard” motion control manufacturer for further business expansion, Kawasaki is attempting to make a full-scale entrance into the construction and agricultural equipment (other than excavators) fields.

2 Product concept

Table 1 shows the specifications and needs for hydraulic pumps in both the excavator field and the construction and agricultural equipment field.

The specifications for hydraulic pumps for use in construction and agricultural equipment differ from those for use in excavators, and Kawasaki’s hydraulic pumps based on hydraulic pumps for excavators were less competitive than competing products in terms of performance at high speed, cost, and so on.

Table 1 Required specifications and demands for hydraulic pumps

Item	Excavator	Construction and agricultural equipment (for LS systems)
Efficiency/reliability	◎	◎
System pressure	◎	○
Controllability	◎	○
Low noise	◎	◎
High speed	○	◎
Space saving	○	◎
Low cost	◎	◎

(Note) LS : Load Sensing Significance of requirement : ◎>○

Therefore, using the technologies we had accumulated for pumps for excavators, Kawasaki decided to develop the K3VLS series of medium pressure pumps that fit the specifications of construction and agricultural equipment, including, in particular, construction and agricultural equipment with a load sensing system.

3 Structure and technical challenges of the K3VLS series

(1) Structure and features of the K3VLS series

Figure 1 shows the structure of the K3VLS series pump, which was designed to have a simpler structure than Kawasaki's pumps for excavators. With the aim of reducing cost through mass-production technology, with the K3VLS series we were able to reduce the number of parts by 10% and the mass by 20% as compared to the K3VL series, which is Kawasaki's existing pump series for construction and agricultural equipment, by various means such as applying a new assembled piston and shoe with excellent performance and reliability.

The operating principle of the K3VLS series is the same as that of the pump for excavators. The assembled piston and shoe, which rotates with the cylinder block, reciprocates in relation to the cylinder block hole, thereby allowing the pump to continuously suck and discharge hydraulic oil.

(2) Technical challenges in the development of the K3VLS series

In general, construction and agricultural equipment does not have much space for mounting a pump, so compact, small-displacement pumps are used under high-speed conditions. One of the greatest challenges in

developing hydraulic pumps for construction and agricultural equipment is reducing cost while maintaining the same level of performance and reliability as pumps for excavators. To expand our share in the competitive construction and agricultural equipment market, we needed to find solutions to these two conflicting issues.

Therefore, we worked on increasing speed and improving productivity for cost reduction.

4 Solutions to technical challenges

(1) Solution to speed increase

(i) Improving the self-priming capability

When a hydraulic pump rotates at a high speed, the flow rate increases, likely causing cavitation in a hydraulic oil passage. If cavitation occurs in the cylinder block, the effective displacement of the pump decreases, which means that the self-priming capability of the pump decreases. If cavitation appears and disappears repeatedly, the parts may erode. Therefore, cavitation prevention is important in ensuring adequate performance and reliability of hydraulic pumps for construction and agricultural equipment.

To predict the occurrence of cavitation in a hydraulic pump, we improved the simulation technology for the flow of hydraulic oil in a pump as shown in Fig. 2. We began studying the shape of the internal passage, which is effective for cavitation prevention, in the design stage, and developed a pump with excellent self-priming capability without having to rework the entire pump.

(ii) Improving rotary stability

Allowing the parts inside a pump to rotate stably at high speed requires an accurate understanding of the various forces acting on each part and the lubrication

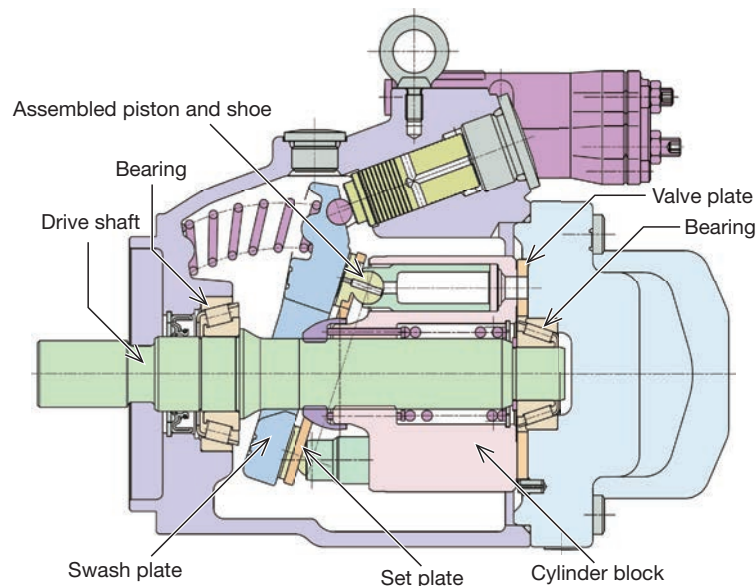


Fig. 1 Structure of K3VLS series pump

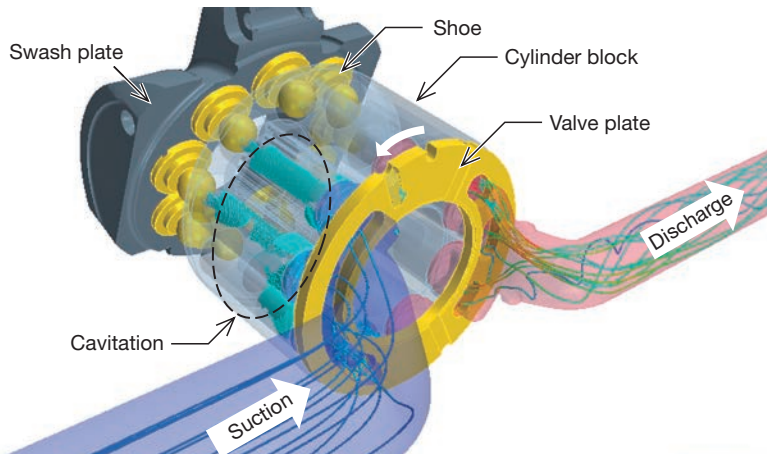


Fig. 2 Fluid dynamics simulation inside the pump

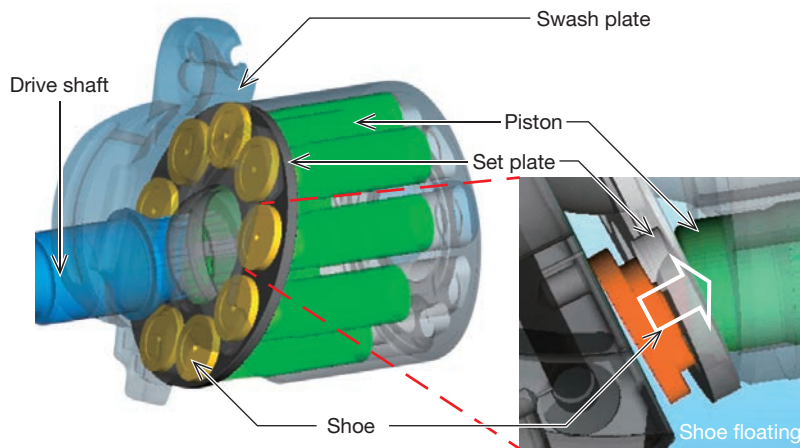


Fig. 3 Multibody dynamics simulation

conditions. However, it is not easy to grasp the characteristics of oil films between parts and various design parameters affect one another in a complicated way; therefore, it is difficult to study these forces and lubrication conditions. To address this, we applied the multibody dynamics simulation technology as shown in **Fig. 3** which takes account of mechanical factors related to the behavior of the parts in the pump, such as contact, deformation, and force by pressure, in the design stage of the K3VLS series.

The behavior of the shoe at high speed is given below as an example. The assembled piston and shoe, which rotates with the cylinder block, is subject to a floating force from the swash plate caused mainly by the inertia force caused by rotation and the viscous force of the hydraulic oil. To prevent shoe floating, which affects performance and reliability, the shoe is mechanically pushed against the swash plate by the set plate. As the speed increases, the floating force acting on the shoe increases, and if the floating force exceeds the pushing force generated by the set plate, the shoe floats from the swash plate.

We studied the floating clearance of the shoe from the swash plate by means of multibody dynamics simulation, and found that the obtained floating clearance was consistent with the measurement result with the actual pump as shown in **Fig. 4**.

This simulation technology was applied in designing the shoe pushing mechanism and studying the optimal shape of the set plate for Kawasaki's hydraulic pumps including the K3VLS series.

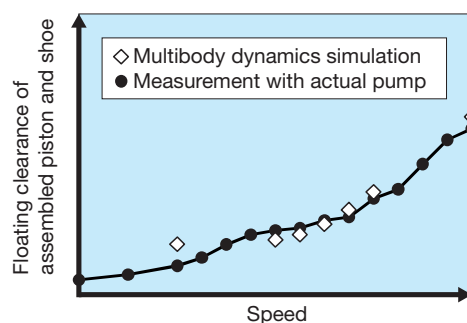


Fig. 4 Simulation results of shoe floating

(2) Improving the productivity of the assembled piston and shoe (cost reduction)

(i) Structure of the assembled piston and shoe for the K3VLS series

The assembled piston and shoe for Kawasaki's pumps for excavators has a structure in which the piston has a convex spherical surface and the shoe has a concave spherical surface as shown in **Fig. 5 (a)**. To significantly improve productivity by eliminating the need for machining while maintaining the performance and reliability required for the piston with the required specifications, the K3VLS series adopts an assembled piston and shoe structure where the concave and convex spherical surfaces are reversed as shown in **Fig. 5 (b)**.

This structural change has enabled the application of a new technology aimed at cost reduction through mass production, contributing greatly to the improved productivity of the assembled piston and shoe for the K3VLS series.

(ii) Cold forging of the piston material

The entire inner surface of the piston for the K3VLS series pump, including the concave spherical surface, is not machined after cold-forging as shown in **Fig. 6**, thereby reducing the total machining time significantly. To ensure the shape and accuracy required for the concave spherical surface of the piston, which slides with the shoe, various cold forging parameters were optimized.

(iii) Method of joining the steel ball and steel plate

To join the round part and plate part of the shoe, we developed a new technique to join the steel ball and steel plate while in contact with each other under pressure as shown in **Fig. 7**. This technique has made it possible to use a commercially available, low-cost, high-precision steel ball as a convex spherical part and eliminate the need for high-precision spherical surface machining and finishing, thereby significantly reducing the machining time.

(iv) Roller caulking

For the assembled piston and shoe for excavators, the

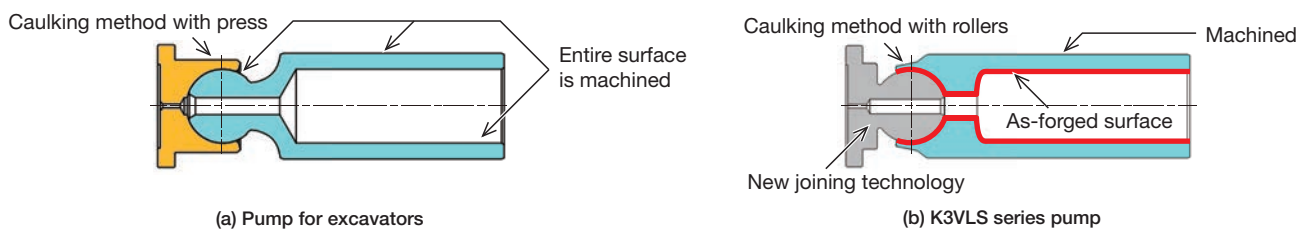


Fig. 5 Structure of assembled piston and shoe

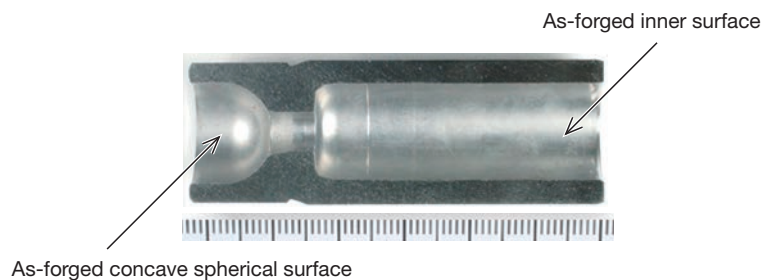


Fig. 6 High-precision inner surface of forged piston

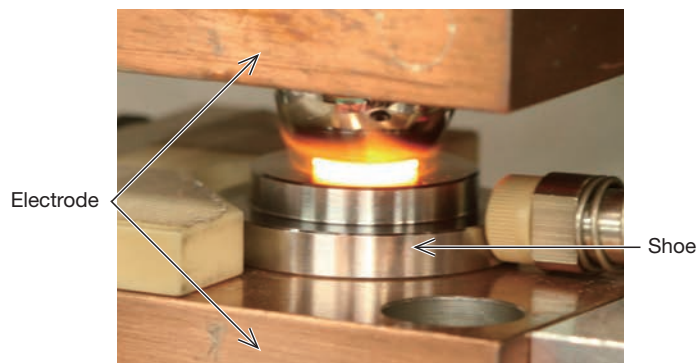


Fig. 7 New method for bonding steel ball and steel plate

shoe is caulked to the round part of the piston with a press. For the K3VLS series, the piston is caulked to the shoe using rollers.

As shown in **Fig. 8**, the tip of the piston is plastically deformed with three rollers while being rotated, forming a round joint with the shoe. The precise control of this process has enabled high-precision caulking, contributing greatly to the improved reliability of the assembled piston and shoe.

In addition, this process makes it possible to caulk all types of pistons for the K3VLS series without any setup by precisely controlling the position of each roller. This caulking method has provided significantly improved

productivity compared with the conventional caulking method, which requires different press dies for different models.

We began mass-producing the K3VLS85 in April 2015, and now all six models of the K3VLS series shown in **Table 2** are available.

5 Future activities

The K3VLS series was designed with the aim of achieving weight reduction and smaller size to meet the required specifications. As an effort to meet the

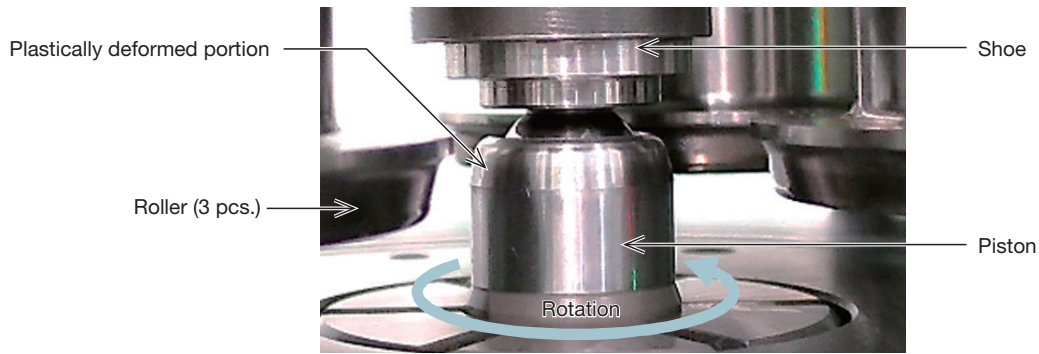
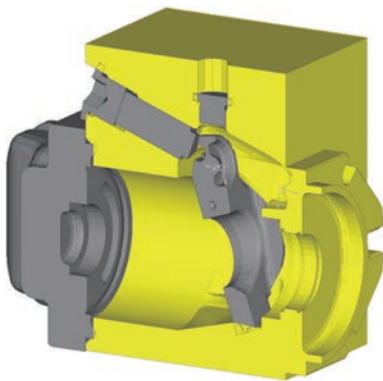


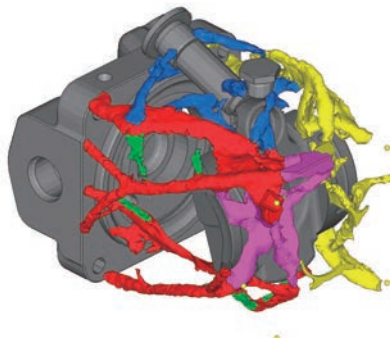
Fig. 8 Joining of piston and shoe by roller caulking

Table 2 Specifications of K3VLS series pump

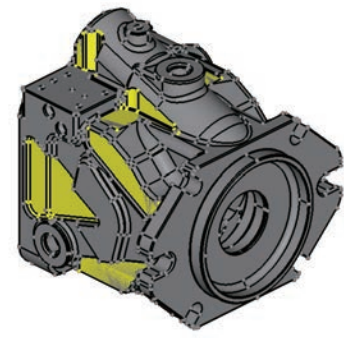
Displacement [cm ³]		50	65	85	105	125/150
Discharge pressure [MPa]	Rating	28				
	Peak	35				
Max. self-priming speed [min ⁻¹]		2,700	2,600	2,500	2,300	2,200



(a) Setting of design region



(b) Topology optimization result



(c) Shape determined by engineer

Fig. 9 Weight reduction of casing using structural optimization technology

requirement of further weight reduction of construction and agricultural equipment, we are considering applying the structural optimization technology to the pump casing as shown in **Fig. 9**. The optimization method used is topology optimization, which uses the element density of the finite element method (FEM) as a design variable to obtain the optimal density distribution.

With this method, a casing shape with the minimum total mass and optimal stiffness can be obtained by creating a design region where parts can be arranged with an FEM model and specifying the stiffness of each part required for the casing. In addition, the mechanical meanings indicated by the optimization results are analyzed and incorporated into the shape of the casing to which other necessary functions have been added so as to achieve a lightweight, compact, stiff casing.

Conclusion

Selling over 50,000 units in total, the K3VLS series has been highly evaluated as hydraulic pumps that meet the needs for construction and agricultural equipment, and they have been used in various machines.

We will be working hard to develop products that meets diverse market and customer needs.

Reference

- 1) Komada, Shimazaki, Ohnishi: "Development of K7V Series Hydraulic Pump for Construction Machinery," Kawasaki Technical Review, No. 168, pp. 6-9 (2009) (in Japanese)



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