

# Development of a Hydraulic System for Large Press Machines



While the aircraft demand is expected to increase in the aircraft industry, and cutting-edge large press machines have been developed and deployed with the purpose of domestically producing large forged parts mainly for aircraft and power plants. Amid such a situation, Japan Aeroforge, Ltd. began operating a large press machine in April 2013.

Kawasaki was in charge of developing a hydraulic system, which constitutes the core part of the machine, and developed a hydraulic system having unprecedented high pressure and large flow rate and a high-pressure, large-capacity pump, which that serves as a drive source for the hydraulic system.

## Introduction

Amid the current globalization, the commercial aircraft market forecast says that the demand for aircraft, which is driven mainly by the Middle East and Asia-Pacific region, is expected to increase about 2.4 times in the next 20 years, and the number of jetliners in service is expected to double accordingly.

## 1 Background

Large forging presses owned by domestic forging manufacturers are used mainly for manufacturing pressure vessels for nuclear power generation as well as power generation turbines and crankshafts. Their maximum power, which represents their press force, is 10,000 to 15,000 tons. However, manufacturing large forged parts for aircraft, which are generally made of titanium and nickel, requires presses with even larger power, which is why the industry has been dependent on only a few overseas forging manufacturers for all these parts. While the demand for aircraft is expected to increase, Japan Aeroforge, Ltd. was established in 2011 with investments by material manufacturers, airframe and engine manufacturers, and trading firms with the purpose of domestically producing large forged parts so the domestic aircraft industry can be more globally competitive, and it was decided to develop a hydraulic forging press with the largest power in the world of 50,000 tons.

In developing the 50,000-ton press, Kawasaki was in charge of establishing a high-pressure, high-flow hydraulic

system and developing a high-pressure, large-capacity pump, which serves as the drive source for the hydraulic system.

## 2 Overview of development

The 50,000-ton press is a die forging press for forging titanium, nickel, and other materials that require a large load to deform into complicated shapes along the die mounted on the press slide as shown in **Fig. 1**. Therefore, in addition to a maximum power of 50,000 tons, the following functions are required:

- ① It must be possible to set a wide range of pressing speeds, from very low to high speed, and to set the optimal pressing speed pattern according to the distortion characteristics of the material and fluidity in the die.
- ② It must be possible to control the parallelism of the press slide with high accuracy and responsiveness to allow the forging of asymmetric products that put an eccentric load on the slide center.

Until the 50,000-ton press, the largest press Kawasaki had delivered a hydraulic system for a power of 15,000 tons, which means the hydraulic system for the 50,000-ton press had the highest pressure and control flow rate range Kawasaki had ever handled. In addition, the highest level of responsiveness and control accuracy for a large press were required. To meet these requirements, we decided to increase the pressure in the entire system, develop an optimal hydraulic system and control logic, and increase the responsiveness of the hydraulic pump.



Fig. 1 Large forged parts produced with 50,000-ton press

### 3 Development of the hydraulic system

#### (1) Increasing the pressure and flow rate

##### (i) Increasing the pressure

The pressure specification for the hydraulic system was 45 MPa, far higher than the highest pressure for the hydraulic systems for presses Kawasaki had delivered up to that point at 35 MPa. Therefore, it was essential to increase the pressure in the hydraulic equipment including the hydraulic pump as well as the manifolds and joints

forming oil passages. The large manifold shown in **Fig. 2** has a maximum weight of over 8 tons and was the largest in number and total weight but we were able to reduce its size while maintaining its strength even at 45 MPa by using FEM analysis to design optimal oil passages.

For the final engine performance, we port matched the intake and exhaust parts and achieved torque characteristics that have a wide power band with a flat torque curve as shown in **Fig. 3** and can easily be handled by the rider.

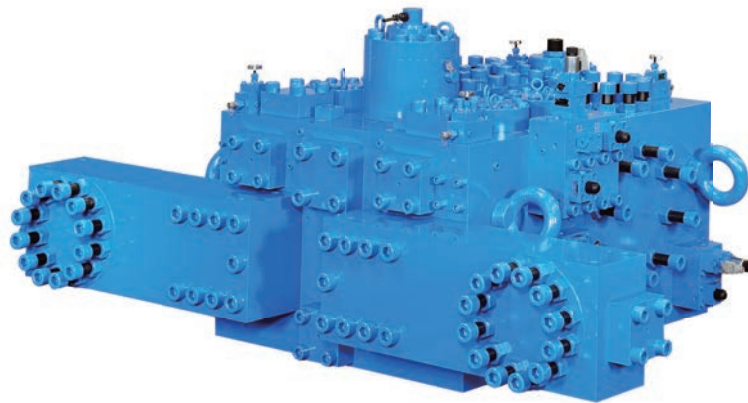


Fig. 2 Large manifold

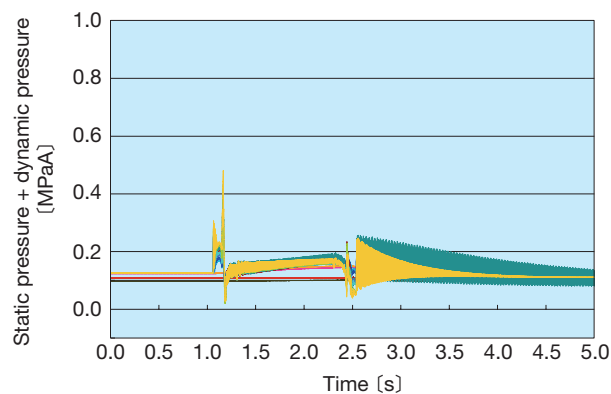


Fig. 3 Example of analyzing return piping pressure with buffer tank

## (ii) High flow control

Large hydraulic systems have a large piping length, and a kind of shock called “oil hammering” is expected to occur in the return piping to the tank if the flow rate changes rapidly when the pressing speed increases or decreases or when reversing the direction of operation. Oil hammering may cause the press to vibrate and can damage the piping. Therefore, shock absorbers (small oil tanks sealed with nitrogen gas) were arranged to mitigate oil hammering. By conducting fluid analysis on the tank return piping as shown in **Fig. 3**, we verified how the pressure behaves and studied the optimal layout of the shock absorbers.

## (2) Pressing speed control

A wide range of pressing speeds, from very low speed to high speed, is required, so the flow rate in the hydraulic system needs to be controlled in a wide range from 1-2 L/min to 10,000 L/min. In addition, in order to achieve the optimal pressing speed according to the distortion characteristics of the material and fluidity in the die, this ultra-large press with a power of 50,000 tons is required to have the same level of responsiveness and controllability as small and medium presses. To achieve this, the hydraulic pump, which controls the pressing speed, is required to have a high-capacity, high-responsiveness, high-accuracy flow control function. To achieve pressing speeds in the range of the minimum flow rate of 1 to 2 L/min, we adopted ECO SERVO, which controls the pump discharge flow rate with speed control using a servo motor, exclusively for the very low speed region.

## (3) Parallelism control

The press slide is subject to eccentric loads depending on the shapes of the material and die and fluidity in the die. Therefore, the slide table must be kept parallel to achieve the designed shape of the forged part, protect the press, and reduce the number of heating cycles. For parallelism control, we adopted a control method in

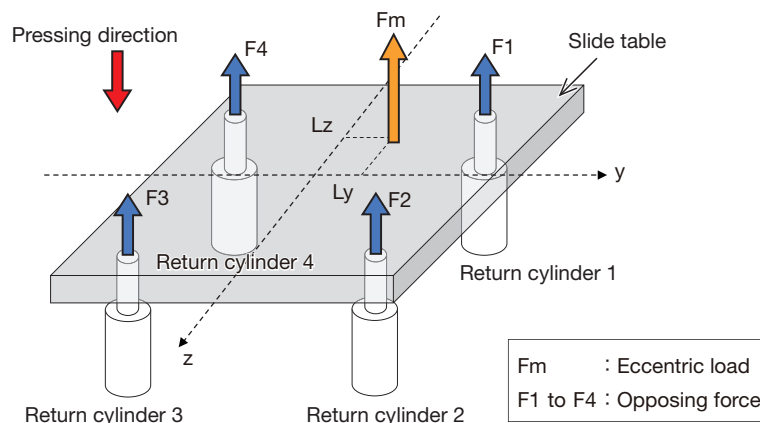
which the pressures of the four return cylinders arranged on the press slide opposite the pressing cylinders are controlled individually. As shown in **Fig. 4**, the slide table is made to tilt when eccentric load  $F_m$  acts on it. At this time, return cylinders 1 to 4, arranged on the slide table, generate forces  $F_1$  to  $F_4$  in the direction opposite to the pressing direction to cancel the eccentric load and keep the slide table parallel. The parallelism control capability is determined by the sum of the opposing forces, and so was designed to be equivalent to the weight of the moving parts of the press so as to ensure a maximum pressing force of 50,000 tons.

## (4) Hydraulic system evaluation test

We developed a new hydraulic system by applying the previously mentioned measures and controls and mounting the newly developed pump described below. Each piece of hydraulic equipment has specifications that satisfy the service conditions of the 50,000-ton press, and the hydraulic circuits and hydraulic units were designed based on Kawasaki’s design concept.

However, this hydraulic system was the largest system using the highest pressure we had ever handled, so an unexpected problem causing a system shutdown had the potential to have a substantial impact, including secondary damage. Therefore, we decided to conduct a long-term durability evaluation test under the same conditions as the service conditions of the 50,000-ton press, including the overall configuration of the hydraulic system, hydraulic oil, load, and cycle. The large pump unit shown in **Fig. 5** was installed in the 50,000-ton press. The evaluated unit has the same equipment and circuit configuration as the actual unit with a reduced size. **Figure 6** shows the test data on durability.

We conducted the evaluation test by simulating the actual service conditions of the entire hydraulic system, and identified problems that could not be identified by verifying the specifications of the large pump unit alone or



**Fig. 4** Opposing force and eccentric load

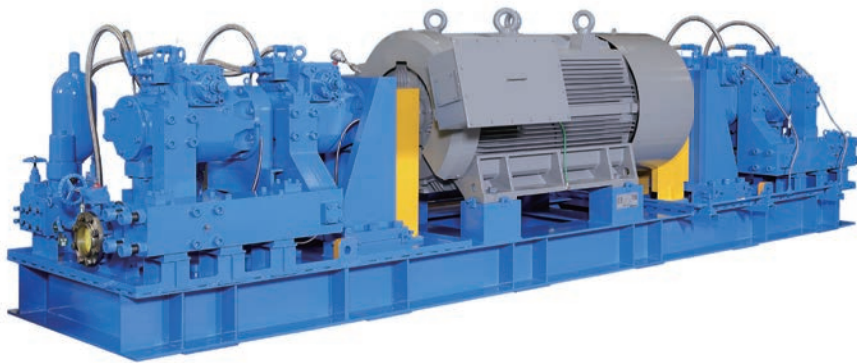


Fig. 5 Delivered large pump unit

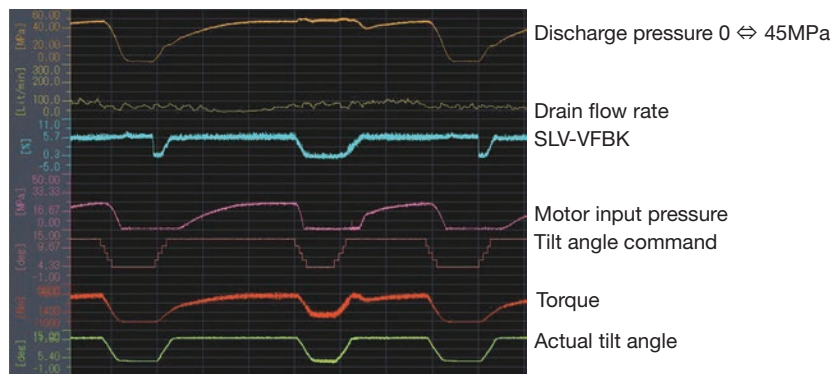


Fig. 6 Simulation test data with actual machine

evaluating the large pump unit alone before delivery. In addition, we were able to verify the reliability of the entire hydraulic system by fixing identified problems with the large pump unit and delivering the large pump unit with a higher degree of refinement.

#### 4 Development of a high-pressure, high-flow pump

To satisfy the specifications required for the 50,000-ton press, the hydraulic pump is required to support a high-

pressure, high-flow, high-accuracy system. Kawasaki had been offering bent-axis pumps as high-flow pumps, but their rated pressure was 35 MPa, which did not satisfy the required specification of 45 MPa. In addition, bent-axis pumps cannot respond quickly to changes in inclination due to a structural problem. Therefore, we decided to develop a new swash plate pump, which is mainstream in the hydraulic industry as well as in Kawasaki.

Table 1 shows the specifications of the developed pump. Figure 7 shows the structure of the developed pump. To increase the responsiveness as mentioned

Table 1 Specifications of pump

Model		K7VG500
Displacement [cm <sup>3</sup> ]		500
Speed [min <sup>-1</sup> ]	Rating	1, 200
	Max. priming	1, 350
Discharge pressure [MPa]	Rating	45
	Max.	50
Control method		Servo valve control method
Pump tilt step response		0.1 sec or less (0 ↔ 100%)

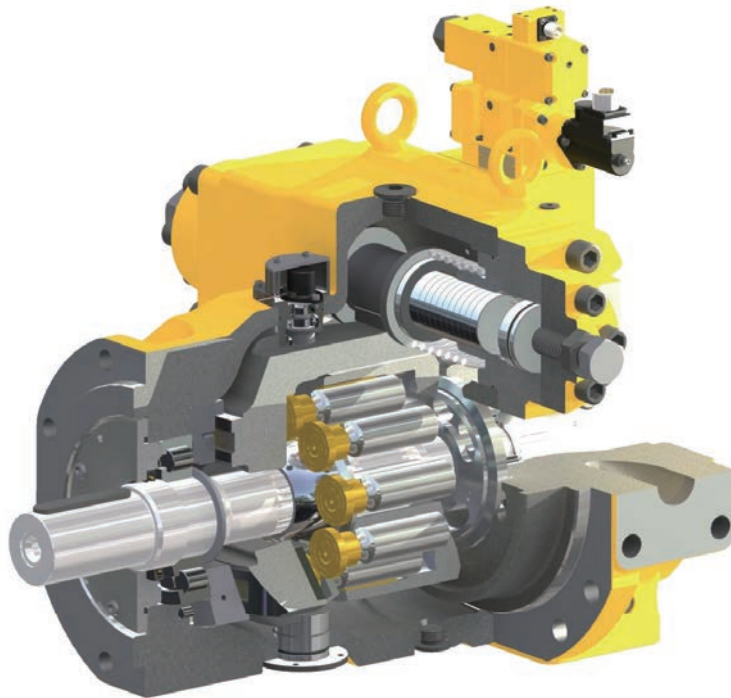


Fig. 7 Construction of pump

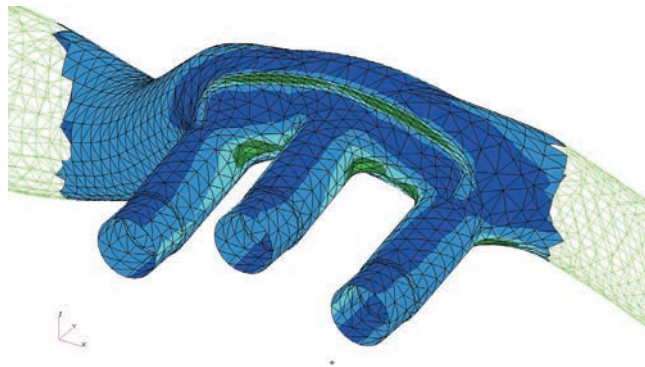


Fig. 8 Example of FEM analysis (stress in valve cover oil passage)

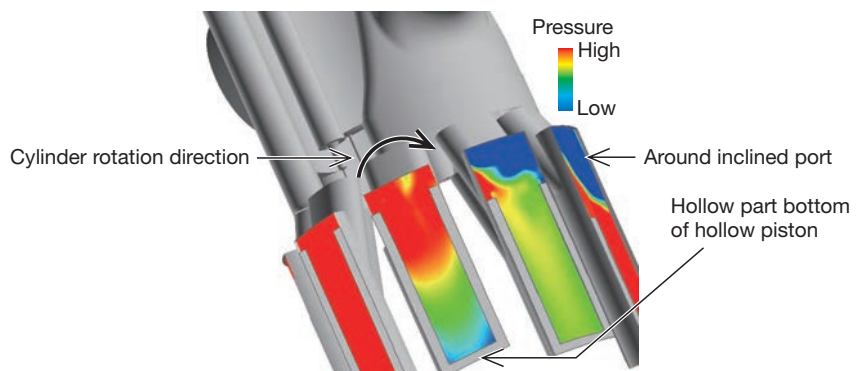


Fig. 9 Example of CFD analysis (pressure in piston and cylinder)

before and increase the pressure, flow rate, and efficiency, we conducted the following developments.

### (1) Increasing the pressure

For the pump to withstand a rated pressure of 45 MPa, higher strength is required than with the conventional 35 MPa, so we examined both materials and structures. For the rotary part, which is the core part of a pump, Kawasaki has basically been using carbon steel for the cylinder, and copper alloy for the shoe. However, as a result of strength calculations, such as FEM, we decided to use alloy steel for the cylinder and shoe. For the valve covers with pump delivery ports, we initially considered using cast materials in light of workability, but as a result of strength calculations, we decided to use nodular graphite cast iron. We improved the oil passage shape as shown in **Fig. 8**, which is an example of FEM analysis, thereby reducing the stress by approximately 30%.

### (2) Increasing the flow rate

To increase the flow rate, we set the pump's displacement to 500 cm<sup>3</sup> and the rated speed to 1,200 min<sup>-1</sup>. However, to achieve these numbers, we needed to increase the pump's suction capability. Therefore, using CFD analysis, we minimized the pressure loss even at high flow rates and optimized the oil flow at the suction part, thereby increasing the suction capability. Also, in order to optimize the pressure distribution and flow inside the pump under various operating conditions, including high pressure and high flow rate, we determined the shape by conducting CFD analysis for each section. **Figure 9** shows how the pressure changes in the piston and cylinder while the press is operating. We identified where the pressure dropped and negative pressure was generated, and modified the shape to prevent the generation of negative pressure.

### (3) Improving the efficiency

Because the pressure and flow rate are high, extremely large energy is required to operate the pump, so it would be better for the pump to have higher efficiency. Therefore, we conducted CFD analysis to reduce the pressure loss in the internal passages and improve leakage inside the pump, and we also conducted simulations to optimize pressure fluctuations inside the pump and minimize loss.

The technology for estimating pump efficiency in the



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development stage had already been established, and it was applied this time as well. With this technology, the efficiency during operation is estimated based on the specifications of internal parts, characteristic values of hydraulic oil, and temperature increases in the sliding parts.

## Conclusion

The 50,000-ton press has been operating stably since it began operating in April 2013, and Japan Aeroforge, Ltd. began mass-producing airframe parts, landing gear parts, and aircraft engine parts in 2014 after being certified as an aircraft parts manufacturer. In the industrial machinery industry, higher power and higher responsiveness will be required, and so we will be working to develop products that can meet such market needs.

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