Product Introduction

Development of KCH-8 High Pressure Cylinder for Construction Machinery

KOBAYASHI Toshio

1 Introduction

KYB manufactures and sells cylinders for construction machinery including hydraulic excavators as its main products. Among these, hydraulic excavators of an operating mass of the 20 to 40 ton class are high in demand and can be often seen in various places throughout the world from urban construction sites to mines. KYB has continued manufacturing cylinders for hydraulic excavators of the class stated above (hereinafter "KCH") for about 50 years. However, the company is now exposed to a very competitive environment due to the globalization of hydraulic excavator manufacturers, and the emergence of competitive cylinder products. Particularly in terms of price competition, it is difficult for us to find a competitive edge.

To improve this disadvantageous situation, we have developed a new model (KCH-8: Kayaba Cylinder High pressure model-8) that is not bound by the existing structure. This paper introduces the existing product we focused on this time, its technical challenges, and the newly developed product.

2 Hydraulic Cylinders

2. 1 What is a Hydraulic Cylinder?

A hydraulic cylinder uses hydraulic fluid supplied by a pump as a means to apply a pressure to its pressure area, which will thereby generate a thrust. A hydraulic excavator uses the thrust and expansion/contraction of its hydraulic cylinders linked to a bucket to accomplish various tasks including digging, transport, and lifting of heavy soil (Fig. 1).

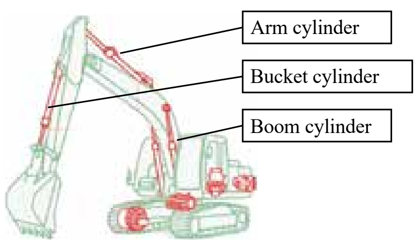

Fig. 1 Example of use of hydraulic cylinders in construction machinery

2. 2 Major Cylinder Components

A hydraulic cylinder consists of less than 50 kinds of parts, which is fewer than other hydraulic components (such as pumps and valves). The mechanical structure of a hydraulic cylinder is rather simple. Although a detailed introduction of cylinder parts is omitted here, Fig. 2 shows an overview of a hydraulic cylinder and Table 1 shows its typical functions.

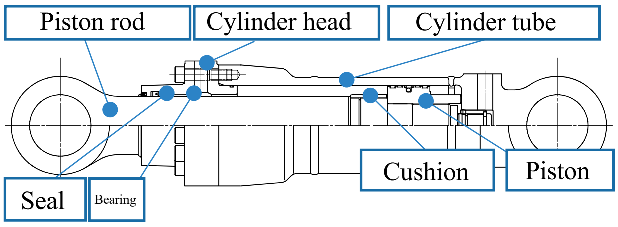

Fig. 2 Cylinder model

Table 1 Components and typical functions of a hydraulic cylinder

Component	Typical function
Cylinder tube	Structure, sealing
Piston rod	Structure, sliding
Cylinder head	Structure, sealing, bearing retention
Piston	Structure, bearing retention
Seals	Sealing, pressure resistance
Bearings	Structure, sliding
Cushion	Buffering

2. 3 Characteristics of Hydraulic Cylinders

Hydraulic cylinders used in a hydraulic excavator play the twin roles of performing the required exterior work and accommodating the counterforces and external forces applied to the excavator. They can deliver various functions related to workability/operability of the hydraulic excavator including sealing of hydraulic fluid for ensuring thrust generation, slidability for smooth expansion/contraction, and buffering with cushions at the stroke ends. At the same time, many of the cylinder components serve as structural members to bear the pressure of hydraulic fluid, tensile/compressive loads, bending, buckling, and vibration as well as holding the structure themselves.

The major dimensions of cylinders are decided by the thrust and stroke required by the hydraulic excavator. Since many cylinder products are long and narrow, their components are required to be long in the direction of the cylinder axis.

3 Development Challenges and Improvement Points

3.1 Clarification of Challenges

KCH is exposed to severe price competition as stated in the Introduction. Cost reduction is the top priority. To clarify the challenges, we conducted a cost analysis on the cylinder. The analysis revealed that the material cost of cylinder tubes accounted for the largest proportion of the cylinder cost (piston rod material is the second largest). These long parts are dominant cost contributors (Fig. 3). Therefore, it can be expected that thinning the walls of these long parts will substantially reduce the cylinder cost.

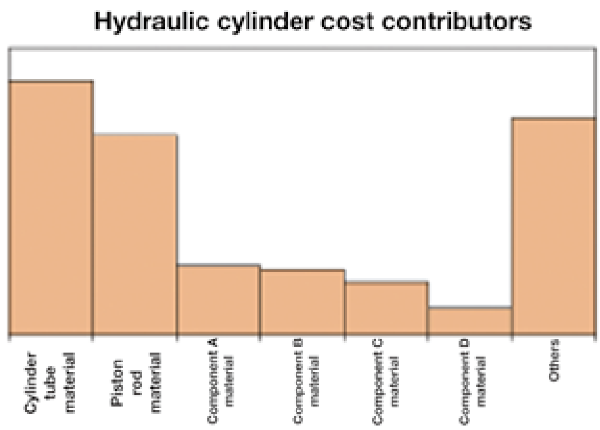

Fig. 3 Cylinder cost contributors

3.2 Properties and Technical Hurdles of Cylinder Tubes

Examples of hydraulic cylinders used in a hydraulic excavator (Fig. 1) include boom, arm, and bucket cylinders. Since the way in which cylinders are used depends on where they are installed, the load applied to the cylinders naturally depends on their location. Therefore, the required strength varies by cylinder, so cylinders are specifically designed to attain their own relevant strength. Fig. 4 shows the cylinder tube assembly, which is one of the components of the hydraulic cylinder, and its configuration. Our conventional cylinder tubes are designed to have an appropriate wall thickness selected from up to four thickness levels, in order to attain an optimal design for the required strength.

The wall thickness of the cylinder tube can be reduced as long as it has adequate strength. We analyzed the rate of change in various properties of a cylinder tube with a wall thickness 20% less than the conventional thickness and determined whether the cylinder tube met the required strength (requirements). The results are shown in Table 2.

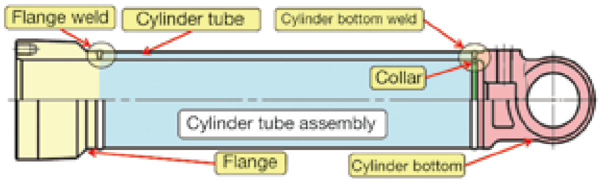

Fig. 4 Existing cylinder tube assembly model

Table 2 Major mechanical properties of cylinder tube with thinner wall

Property	Rate of change	Requirements
Endurance strength	-57.0%	Not acceptable
Strength against external force	-24.7%	OK
Compressive strength	-18.5%	OK
Pressure deformation	-16.0%	OK
Rigidity	-4.3%	OK

Among the various properties, the endurance strength decreased at the highest rate. The analysis implies that simply thinning the wall of the cylinder tube will not meet the requirements. Particularly, the cylinder bottom weld (Fig. 4) is the weakest point, posing a strength bottleneck. You might question why thinning the cylinder tube wall should affect the endurance strength of the cylinder bottom weld. However, endurance strength is inversely proportional to stress concentration. The endurance strength of the cylinder bottom weld is proportional to the wall thickness of the cylinder tube. A strength analysis (using the Finite Element Method; hereinafter the "FEM") showed, through a trial calculation, that thinning the cylinder tube wall would increase the stress in the weld and lower the endurance strength.

It should be noted here that the cylinder bottom weld is a welded joint between the cylinder tube and the cylinder bottom and has a dramatic change in geometry in contrast to the straight cylinder tube. Due to this geometry change, stresses are concentrated in the weld. Moreover, the weld, which is directly connected to the cylinder tube, has a higher mean stress in proportion to the lower wall thickness of the cylinder tube. Thus, the already stress-concentrated weld has an even higher stress.

In the light of these characteristics of the cylinder bottom weld, we thought that, if the stress concentration in the cylinder bottom weld was suppressed, a cylinder tube with a thinner wall could maintain a conventional endurance strength, in spite of the increased mean stress of the cylinder bottom weld caused by thinning of the tube wall.

Then, we set a challenge of "thinning the cylinder tube wall by improving the endurance strength of the cylinder bottom weld" and decided to work on the improvement of the weld.

3.3 Conventional Cylinder Bottom Weld Structure and its Characteristics

Fig. 5 shows various cylinder bottom variants (four geometries) that have been used so far. These geometries have been developed to ensure the necessary functions of the cylinder bottom weld, including pressure resistance, endurance, and coaxiality of the cylinder tube and the cylinder bottom.

The cylinder bottom weld geometry before the development of KCH-8 was Type 4.

Type 1: The initial geometry of the hydraulic cylinder tube assembly. Type 1 features the simplest design, lower number of parts, and a rather good production yield. But the endurance strength is the worst among the four types.

Type 2: Compared to Type 1, the weld is farther away from the cylinder bottom to reduce the stress concentration, delivering better endurance. Type 2 consists of the same number of parts as Type 1, but shows a lower production yield.

Type 3: Designed to reduce the stress concentration in the cylinder bottom weld by considering deformation due to hydraulic pressure applied to the cylinder bottom section. Type 3 shows better endurance than Type 2. Uses the same number of parts, but involves complex machining to cut a circular groove in the bore of the cylinder bottom.

Type 4: To further reduce the stress concentration due to hydraulic pressure applied to the cylinder bottom, a three-piece structure has been introduced. Type 4 is constructed to weld the cylinder bottom to the cylinder tube using a collar (a part equivalent to a back board). Type 4 delivers the best endurance among the conventional types. The production yield of the cylinder bottom section has been improved from Type 3.

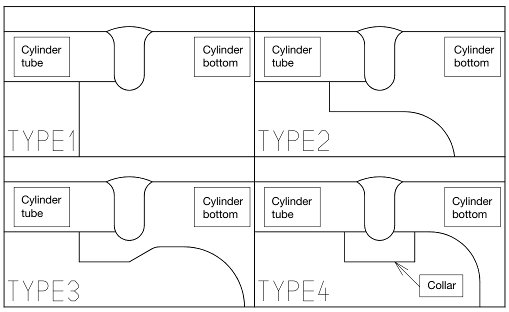

Fig. 5 Bottom weld geometries that have been used so far

4 How to Improve Weld Endurance

4. 1 Structural Study

We studied how to improve the endurance of the cylinder bottom weld by modifying the geometry of the weld section. The farther the weld is from the cylinder bottom, the lower the stress. This is a typical stress reduction measure, but unavoidably extends the total length of the structure, posing a configuration disadvantage. Then, we conducted an FEM analysis to look for an optimal geometry (Fig. 6). Various configurations were analyzed, including different wall thicknesses of the cylinder tube, the presence/absence of a collar, and different machining geometries of the cylinder bottom section. From the results of the analysis, we predicted that forming a groove-like cavity inside the bore of the cylinder bottom weld section would enable the stress concentration to be suppressed without modifying the conventional configuration. We thought that the presence of the groove would allow the axial load to be evenly distributed to the structure, and not intensely applied to the stress concentrated part, thereby enabling improvement of the endurance strength (Fig. 7)

4. 2 Confirmation of Effectiveness

The geometry variants of the cylinder bottom weld subjected to the stress analysis were narrowed down to six good candidates, which were further subjected to endurance tests. We checked whether the candidates exceeded the endurance strength requirements and whether they showed the endurance strength as analyzed. As a result, assuming that the endurance test result of the conventional cylinder tube was 1.0, the finally selected geometry variant showed about 1.1 even with a reduced wall thickness. Thus, we confirmed a higher than conventional endurance strength for the selected variant. Also, an endurance test on a cylinder tube assembly with conventional tube wall thickness with only the cylinder bottom geometry modified showed an endurance strength twice that of the conventional counterpart, proving that the geometry change adequately improved the strength (Fig. 8).

In addition to endurance, machinability and workability were added to the test evaluation items to build a geometry variant that also considered productivity.

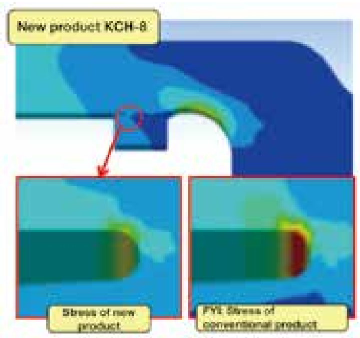

Fig. 6 Stress distribution around the weld

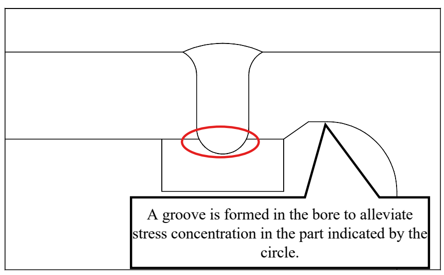

Fig. 7 Geometry of bottom weld of newly developed KCH-8

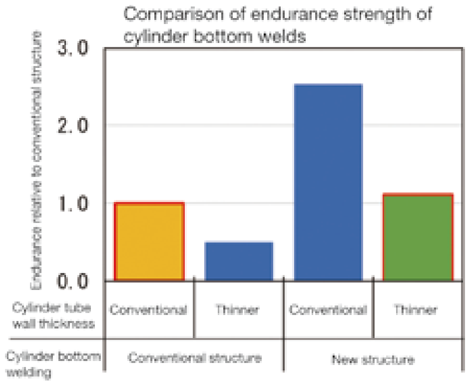

Fig. 8 Comparison of endurance strength

5 Concluding Remarks

In this development project, we were told by our predecessors that this type of product is difficult to improve. However, we have kept the conventional geometry and successfully improved the endurance strength of the cylinder tube assembly even with the thinner tube wall. I am pleased with this achievement.

Based on the outcome of this development project, I will continue my efforts as part of the team developing new hydraulic cylinders.

Finally, I would like to take this opportunity to cordially thank all those concerned from the construction machinery manufacturers, related corporate partners, and related KYB departments who extended cooperation to the development of this product.

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Author

KOBAYASHI Toshio

Joined the company in 2007.
Experiment Sect. No. 2, Developmental Experiment Dept., Hydraulic Components Operations
Used to be engaged in this development in the former Design Sect., Gifu South Hydraulic Engineering Dept., HC Operations