Product Introduction

Hydraulic Track Motor for 20t Class Excavator MAG-170VP-4000H

SUGIMOTO Junichiro, SAKAI Yuki

1 Introduction

With the recent rising awareness of environmental conservation, the demand for energy saving has increased year by year. The construction equipment industry has promoted exhaust gas control and the development of energy-efficient equipment.

The industry's conventional development of energy saving technology has been mainly concentrated in hydraulic systems. Actuators have not been the target of the development.

From now on, energy conservation is expected to be further promoted. It is a challenge to effectively use the engine output power without waste.

The engine size of construction equipment is decided by power consumption during traveling. Improving the efficiency in the traction motor will reduce pump output power. It has become necessary to develop a high-efficiency motor with which fuel consumption can be reduced. In addition, as the operation environment has recently been diversified, today's construction equipment is frequently used in severe environments. They are also required to offer improved durability.

We have then developed a higher-efficiency hydraulic traction motor for 20t class excavators. This article describes the structure, specifications and efficiency of the motor.

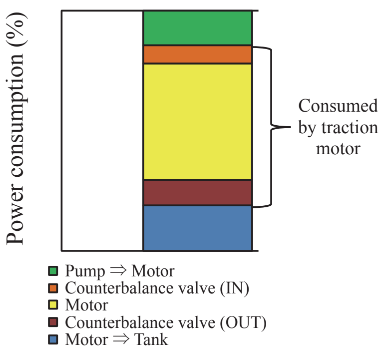


Fig. 1 Breakdown of power consumption

2 Market Demand

2.1 Demand for energy saving

Fig. 1 shows a breakdown of energy consumption by 20t class excavators during normal travelling (low pressure, maximum flow rate) at 2nd gear mode (high-speed):

With power consumption including the energy lost in the piping of an actual vehicle taken as 100%, the traction motor consumes about 65% power. To reduce pump output power, it is a must to improve the efficiency in the traction motor.

3 Product Specifications

3.1 Requirements for this new product

This product is a hydraulic motor equipped with a case-rotating reduction gear for crawlers and consists of three units: control valve, swash plate piston motor and reduction gear. Fig. 2 shows the appearance of the product and Fig. 3 shows the cross-sectional configuration.

This is a full-model-changed product to meet market demand (energy saving and improved durability). The development requirements are as follows:

① Improve mechanical efficiency from the conventional product by 8.0 % or more.
(Ensure that the improved mechanical efficiency exceeds the competitors).

② Achieve higher heat balance performance than

Fig. 2 Appearance of product (MAG-170VP-4000H)

conventional products.

③ Establish a new evaluation calculation technology, a technique to ensure certain friction properties and a machining technique to achieve higher efficiency.

④ Ensure that the new product is interchangeable with conventional counterparts.

⑤ Improve the seal performance of floating seals.

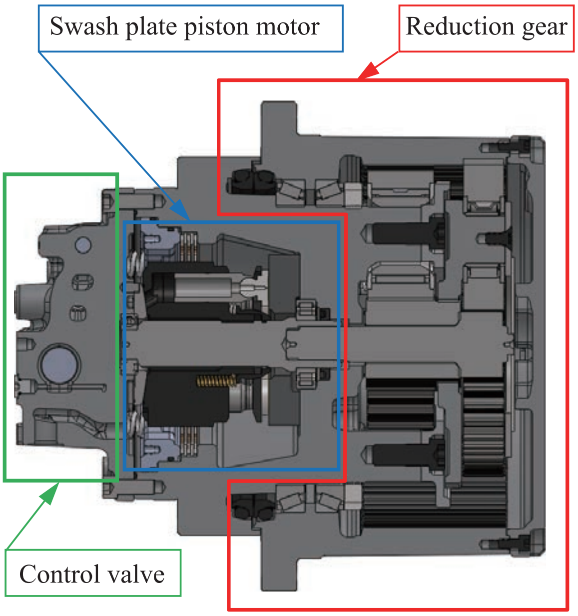


Fig. 3 Cross section of hydraulic traction motor

3.2 Product specifications

The product specifications are shown in Table 1. The maximum pressure and maximum speed remain the same as conventional specifications. The maximum output torque is higher than that of conventional products (MAG-170VP-3800G Series) by about 5 % and can support a diversified operating environment. The maximum motor capacity is set to 192.7 cm^3/rev. so that the maximum output torque can be attained at maximum pressure.

Table 1 Product specifications

Max. motor capacity	cm^3/rev	192.7
Reduction gear ratio		43.240
Reduction gear type		Simple planetary gears (double)
Max. motor speed	rpm	2700
Max. rated pressure	MPa	34.3
Max. output torque	kN·m	39.2
Product weight	kg	265
Parking brake function		Equipped as standard
Parking brake torque	kN·m	25.1
Relief valve		With shockless function
Speed change gear		Equipped as standard Note 1)

Note 1) Either automatic or manual speed change can be selected.

4 Technical Challenges for Improved Efficiency

4.1 Efficiency performance

In general, efficiency of hydraulic track motors can be divided into volumetric efficiency and mechanical efficiency (torque efficiency). The volumetric efficiency refers to the ratio of the actual motor speed, which is affected by leakage or compression loss in the sliding parts, to the theoretical motor speed. Mechanical efficiency indicates the actual output torque, which is affected by frictional loss in the sliding parts, oil resistance to stirring and oil passage loss, to the theoretical output torque.

The efficiency contributing to lower pump output power (= lower fuel consumption) is overall efficiency. An equation that "Volumetric efficiency x Mechanical efficiency = Overall efficiency" holds. Fig. 4 gives an efficiency diagram for the conventional product (MAG-170VP-3800G).

For effective reduction of the power consumption loss, it is a must to improve efficiency in the normal travelling zone (low pressure, high speed) (the section enclosed by a red line in the figure below) that is most frequently used.

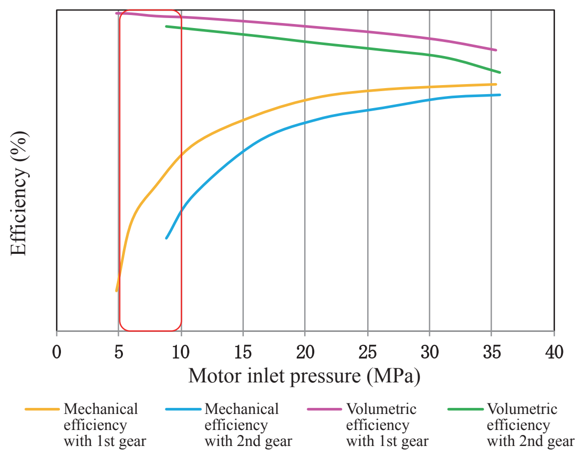


Fig. 4 Efficiency diagram for conventional product

4.2 Efficiency improvement

For the conventional product (MAG-170VP-3800G), its components consume power as shown in Fig. 5.

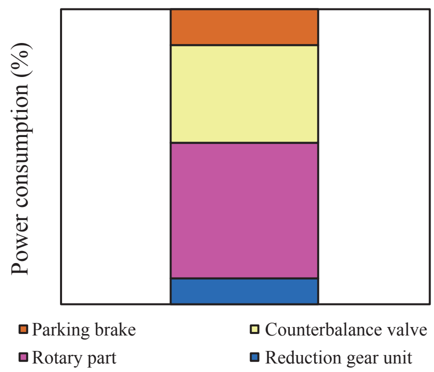


Fig. 5 Power consumption of traction motor

The rotary part and counterbalance valve units account for about 80 % of total power consumption. Since the majority of power consumption is lost in relation to mechanical efficiency according to Fig. 4, a focus was placed on the improvement of mechanical efficiency of these units.

5 Hydraulic Track Motor Design

5.1 Using a spherical rotary part

The rotary part is the core of the hydraulic track motor. The design of this critical part decides the efficiency, durability and robustness. The hydraulic track motor for travelling is required to resist the surge pressure during quick operation on slopes, resist the seizure during high-speed rotation and ensure efficiency stability. The motor needs to be designed to meet these requirements. While the conventional product uses a plane rotary part, the new product uses a spherical rotary part in order to improve efficiency.

As shown in Fig. 6, the spherical rotary part has a spherical valve plate (hereinafter "V/P") designed to make spherical contact with the cylinder block (hereinafter "C/B").

This product has been tried to be optimally designed with a focus on achieving higher efficiency while maintaining the durability and seizure resistance levels of conventional products.

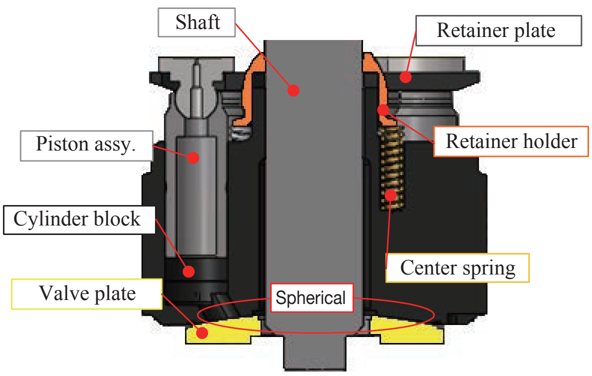


Fig. 6 Cross section of spherical rotary part

We focused attention on the fact that the shaft distortion varies by the pressure applied (the C/B position varies accordingly), thereby affecting the contact force (contact radius) between the C/B and the V/P.

When a high pressure is loaded, the shaft distortion is large to cause a higher contact force on the outside of the V/P. When a low pressure is loaded, the shaft distortion is small to cause a higher contact force on the inside of the V/P, leading to a loss of the sliding friction torque. Then, we provide a difference in spherical radius (hereinafter "SR") between the C/B and V/P (C/B SR > V/P SR). This will alleviate the strong contact on the outside of the V/P under high loading and reduce the torque loss generated under low loading, eventually contributing to higher mechanical efficiency. However, the difference in SR means that there is a clearance between the C/B and V/P. So, the leakage from the clearance will increase, resulting in lower volumetric efficiency. In order to enhance mechanical efficiency while suppressing the decrease in volumetric efficiency, it is essential to optimize the SR and SR difference to be suitable for shaft rigidity.

Usually huge amounts of time and money are needed to accomplish optimization verification. Then, we developed a model shown in Fig. 7 and created an analysis program that calculates the force on each part at any given rotation angle, with the aim of enhancing design efficiency.

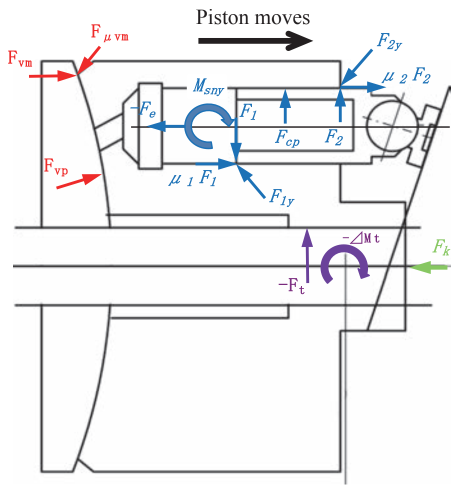
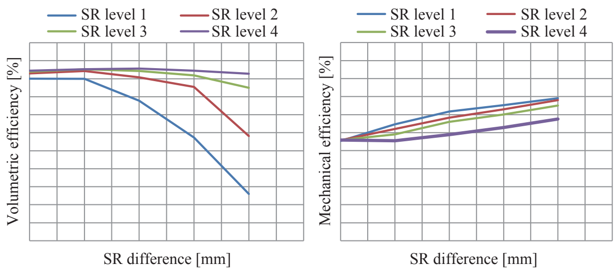


Fig. 7 Hydraulic balance calculation model

We entered the dimensions and pressure of each component in the program to determine the efficiency of the C/B and V/P separately, which was then subjected to an analysis using the model above. The results are shown in Fig. 8.



(1) Volumetric efficiency (2) Mechanical efficiency

Fig. 8 Relationship between SR difference and efficiency

When the SR is smaller and SR difference is larger, volumetric efficiency is lower while mechanical efficiency is higher. This model was used for optimization to successfully improve mechanical efficiency without lowering volumetric efficiency.

5.2 Changing the counterbalance valve

As shown in Fig. 1, the counterbalance valve (hereinafter "CV") accounts for about 18 % of total power consumption. Then, we tried to develop a plan to enhance mechanical efficiency by modifying the CV.

To improve mechanical efficiency by modifying the CV spool, it is necessary to enlarge the maximum valve opening area during the full stroke of the CV spool, in order to reduce the pressure loss generated when the hydraulic fluid passes through it. However, enlarging the maximum opening area without changing the stroke will likely cause an abrupt opening, leading to poor operability of the actual machine. In order to avoid an abrupt opening and ensure the opening characteristics in the subtle steering zone equivalent to conventional counterparts, the maximum stroke of the CV spool is increased by about 20 % and the maximum opening area is enlarged by about 45 %.

Fig. 9 shows the CV opening characteristics diagram of the new and conventional products.

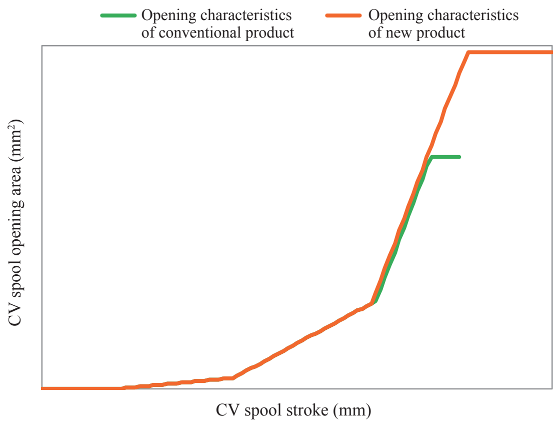


Fig. 9 CV opening characteristics diagram

5.3 Efficiency performance of new product

The efficiency diagram of the new product (MAG-170VP-4000H Series) to which the mechanical efficiency improvement plan was applied is shown in Fig. 10. Fig. 11 compares the efficiency with conventional products.

Compared to conventional products, the new product has been proven to have higher mechanical efficiency by about 9.0 % in the frequently-used normal travelling zone (indicated by arrows), which is equivalent to about 11.4 % reduction of pump output power.

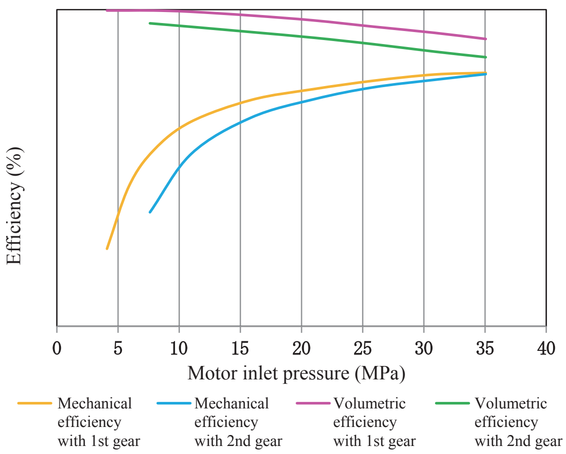


Fig. 10 Efficiency diagram of new product

Fig. 12 shows motor output power during normal travelling and pump output power under the same conditions.

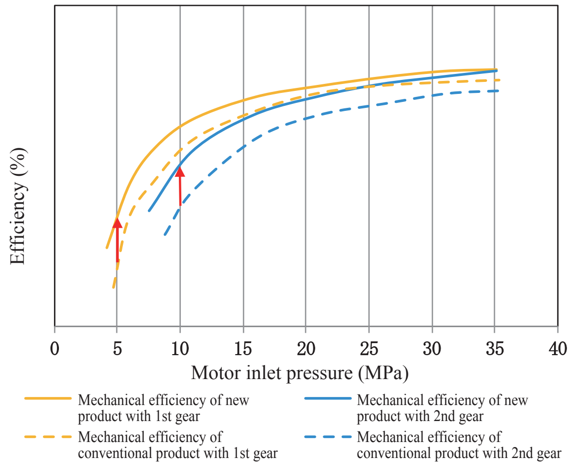


Fig. 11 Efficiency comparison diagram

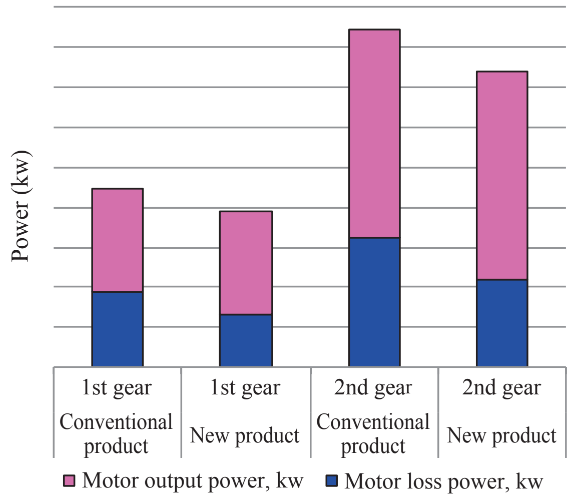


Fig. 12 Comparison of pump output power

6 Reduction Gear Unit Design

6.1 Output enhancement

To meet the higher output requirements for the new product, conventional products have been improved in several points. Some of them are described below:

(1) Gear strength

To reduce the number of components (thereby keeping costs at the conventional level), the number of gears on the 2nd stage in the planetary reduction gear unit has been changed from 4 to 3.

When the number of gears is reduced, the input load on each gear increases by 33.3 %. Moreover, if the development goal of higher output by 5 % is achieved, the input load on each gear would increase by 39.7 %. Gear strength cannot be secured without increasing the gear module.

To achieve the same outer diameter and reduction gear ratio as those of conventional products, it is necessary to review the gear specifications including tooth profile, pressure angle, rack shift and face width. Optimizing the gear specifications has made it possible to maintain the dimensions of the conventional product and to enhance the output. If the new product is operated according to the conventional product specifications (output torque and output speed), the reduction gear achieves an about 1.4 times longer life than conventional products.

(2) Gear shaft rigidity

If the gears have a larger face width for theoretically higher strength, the tooth surface may be damaged (for example, pitting) unless proper engagement is attained. To secure proper engagement, not only the crowning in the tooth trace direction of the gears but also the shaft rigidity are critical factors.

The lower number of gears and the 5 % higher output lead to a higher input load on the shaft by 39.7 %. To raise shaft rigidity and secure face durability, an integrated structure of the flange (motor case) and holder (gear shaft) has been introduced. In addition, another plate has been installed and the fastening method has been changed. These improvements have resulted in shaft rigidity with which proper engagement can be attained (tooth face strength ensured) in spite of the smaller shaft diameter compared to conventional products. Fig. 13 shows the structural profile of the 2nd stage of the planetary gear unit using this structure.

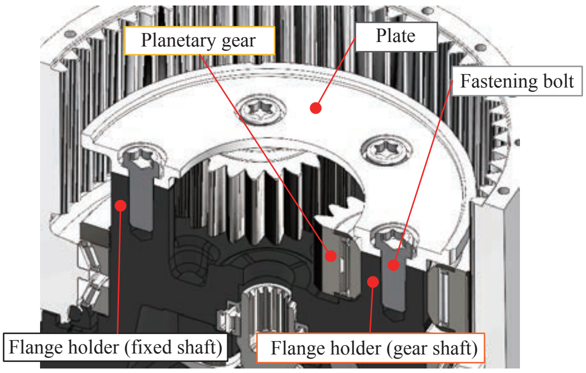


Fig. 13 Structural profile of 2nd stage of planetary gear

(3) Gear bearing

As the input load on the shaft increases by 39.7 %, it is indispensable to use a bearing with high load carrying capacity. However, a high load carrying capacity bearing would be larger than the existing and would not fit within the specified product dimensions. Then, special needle crowning and plastic cages have been used to ensure conventional durability even with high-output specifications.

6.2 Sprocket bearing design

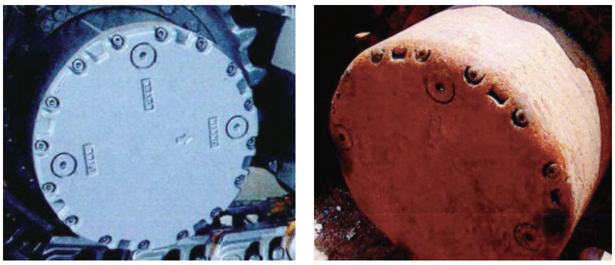
Since the flange holder structure has been used to ensure the required gear strength and shaft rigidity after output enhancement, the sprocket bearing needs to have a smaller cross section. Then, a tapered roller bearing with a low-profile cross section is used. Fig. 14 show the low-profile tapered roller bearing.

Fig. 14 Low-profile tapered roller bearing

Compared to conventional angular contact ball bearings, this tapered roller bearing provides 2.8 times higher rigidity for radial displacement and 1.3 times higher rigidity for axial displacement. The higher rigidity helps ensure proper gear engagement against any external input load variations and suppress displacement of the floating seal section, thereby improving the seal performance.

6.3 Strengthening the reduction gear unit

Today's excavators are more and more frequently used in even more severe environments due to diversified operating environments as mentioned at the beginning of this article. It is more often for their traction motors to be damaged on the external surface and fastening bolts. Fig. 15 gives pictures of the reduction gear cover.



(1) Reduction gear cover of new unit

(2) Reduction gear cover of unit in service

Fig. 15 Reduction gear cover of units in the field

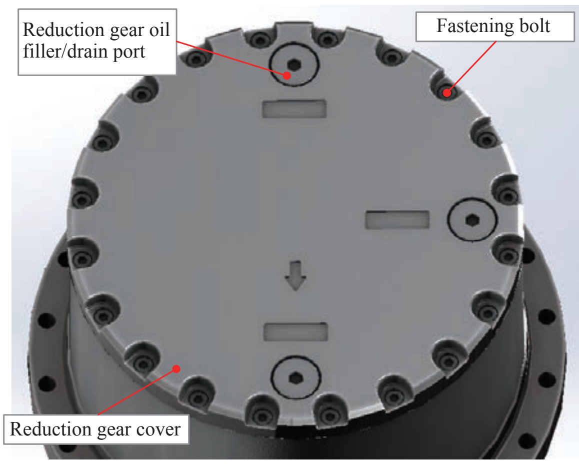


Fig. 16 Appearance of reduction gear cover

To make it harder for the reduction gear to have oil leakage even under such harsh environments, the cover has been redesigned to be thicker at its outer perimeter and to physically protect the fastening bolts. In addition, the number of fastening bolts has been increased from 16 to 20 in order to enhance strength.

The appearance of the reduction gear cover of the new product is shown in Fig. 16.

7 Future Outlook

The new product achieves, in the frequently used normal travelling zone, higher mechanical efficiency by about 9 % and lower pump output power by 11.4 % from conventional products.

Probably, the need for energy saving is increasingly rising. By making use of the expertise with which we have developed and produced a variety of hydraulic pumps and motors, we would like to develop products that can quickly meet even more demanding needs and continue providing high-performance, high-quality products to constantly satisfy market needs.

The new product has already been started to be produced in volume and delivered to customers.

The new product is packed with a great deal of expertise on design techniques and production engineering. Finally we would like to cordially thank all those concerned who extended substantial support and cooperation in the technical development.

Author

SUGIMOTO Junichiro

Joined the company in 2000.
Staff manager, Pump & Motor Design Sect., Sagami Hydraulics Engineering Dept., Engineering Headquarters, Hydraulic Components Operations.
Engaged in development of hydraulic motor products.

SAKAI Yuki

Joined the company in 2009.
Pump & Motor Design Sect., Sagami Hydraulics Engineering Dept., Engineering Headquarters, Hydraulic Components Operations.
Engaged in development of hydraulic motor products.