Forming technology for integrated forging of parking gear with bottomless teeth and fixed pulley half

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Summary

As a weight reduction measure for continuously variable transmissions, integrated forging of the parking gear and the fixed pulley half was previously adopted. Work was undertaken in this project to form a parking gear with bottomless teeth as a further weight reduction measure. This article describes the technical details of the practical application of a forming technology for integrated forging of the parking gear with bottomless teeth and the fixed pulley half. This was accomplished by using forging simulations to control workpiece deformation resistance.

1. Introduction

It has been necessary to further reduce the weight of continuously variable transmission (CVT) parts in recent years in order to improve fuel economy with respect to environmental performance. Because pulleys in particular are heavy CVT parts, reducing their weight is a key issue that should be resolved.

The parking gear has been integrated with the fixed pulley half as a means of reducing the weight of existing products. This paper describes the details of the practical application of a forming technology for integrated forging of the parking gear with bottomless teeth and the fixed pulley half for the purpose of achieving further weight reductions.

2. Parking gear performance requirements and forging method

2.1 Parking gear functionality and structure

Figure 1 shows the configuration of the integrated parking gear and fixed pulley half. When a vehicle is parked and the shift lever is moved to the P position, the parking gear functions to lock the transmission by engaging the tip of the parking pawl with the parking gear (Fig. 2).

Figure 3 illustrates the engagement of the parking gear and the pawl. In this locked position, the bottom of the parking gear teeth and the parking pawl are not in contact, so eliminating the tooth bottom can contribute to reducing the weight.

2.2 Mechanism of closed-die forging

Forging with burrs and closed-die forging are two types of forging methods (Fig. 4). Forging with burrs is a process in which excess material is pushed out to become burrs as forming of the part proceeds. Because this process provides excellent formability, underfill is not likely to occur and

Fig. 1 Integrated parking gear and fixed pulley half

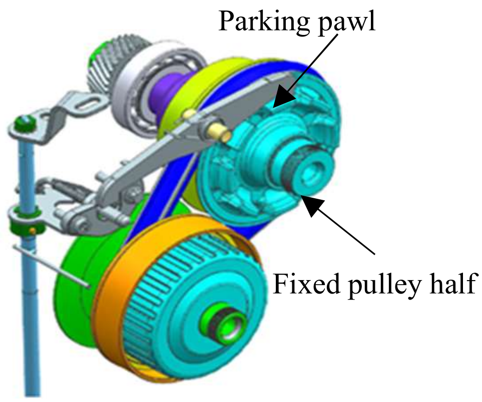

Fig. 2 Pulley assembly

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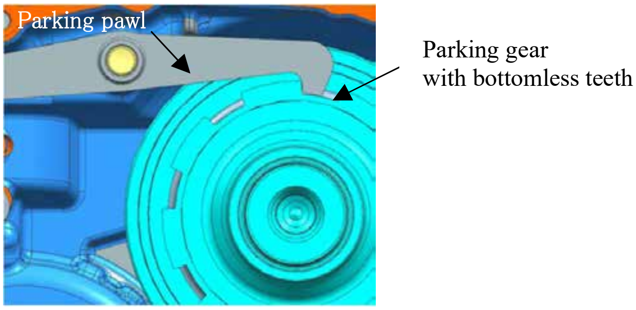

Fig. 3 Parking gear and pawl engagement

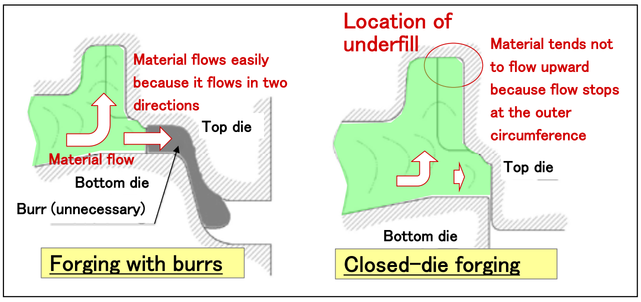

Fig. 4 Forging with burrs and closed-die forging

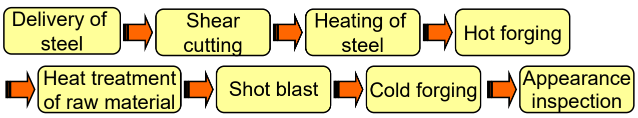

Fig. 5 Pulley production processes

low loading contributes to long die life. On the negative side, the input material weight increases because yield worsens to the extent that burrs occur.

In contrast, in closed-die forging the part is formed with the top and bottom dies engaged. This process has the advantage that yield improves because burrs do not occur. On the other hand, because forming is done in a closed-die state, it has the disadvantages that the load tends to increase, heightening the risk that the dies may crack or wear. In addition, because productivity declines, underfill is apt to occur, resulting in quality defects. Generally, the closed-die forging method entails a greater degree of difficulty.

2.3 Method of producing integrated parking gear and fixed pulley half

The production processes of the integrated parking gear and fixed pulley half are shown in Fig. 5. As mentioned in the preceding subsection, closed-die forging has been adopted for this product. It is formed through a combination of hot forging and cold forging.

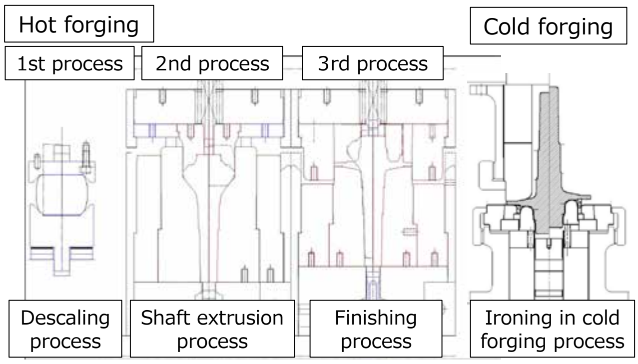

Fig. 6 Role and geometry of each process in hot and cold forging

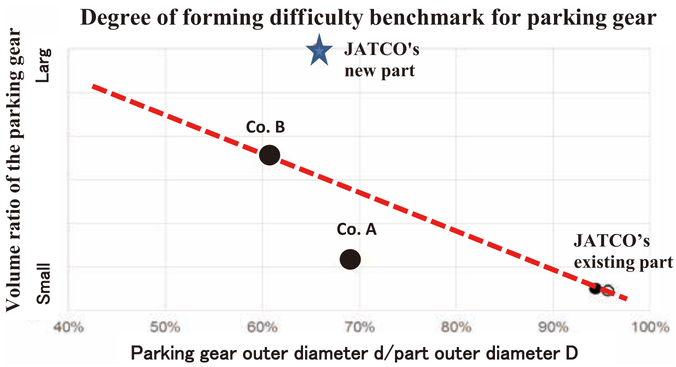

Fig. 7 Degree of forming difficulty of integrated parking gear and fixed pulley half

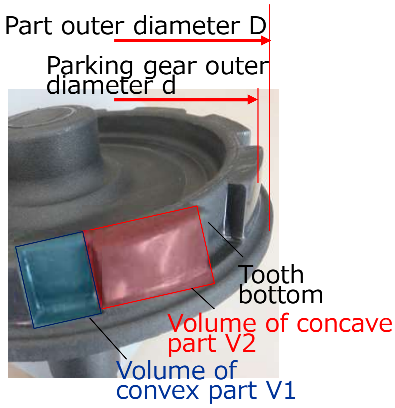

Fig. 8 Parking gear geometry

The product is formed in a total of four processes, three hot forging processes and one cold forging process (Fig. 6). The hot forging processes form the shafts of the fixed pulley half, which have a high rate of cross-sectional area reduction, and the parking gear with its difficult-to-form shape. Ironing of the parking gear is done in the cold forging process to form the tooth profile with high accuracy.

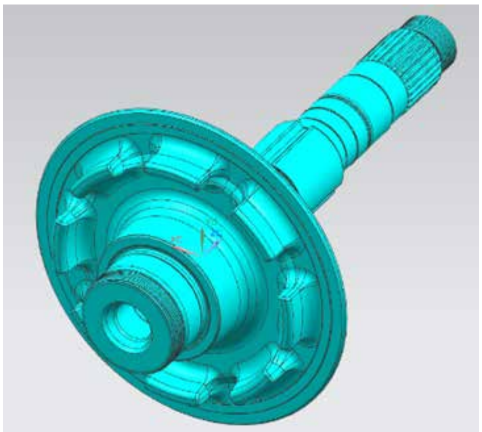

Fig. 9 Integrated parking gear with bottomless teeth and fixed pulley half

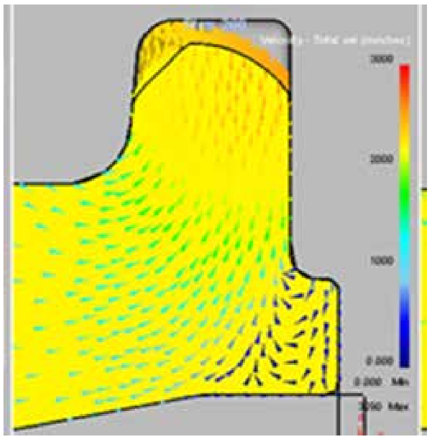

Fig. 10 Results of defect analysis by simulation

2.4 Degree of difficulty in forming integrated parking gear and fixed pulley half

Figure 7 shows the degree of difficulty involved in forming the integrated parking gear and fixed pulley half. The horizontal axis shows the ratio of the parking gear outer diameter d to the part outer diameter D (d/D). The vertical axis shows the volume ratio of the parking gear (V1/(V1+V2)) as indicated in Fig. 8. It is seen that the parking gear is positioned more to the outside as the diameter ratio d/D becomes larger. That makes it necessary to apportion more material volume to the outer side, which complicates the forming of the parking gear. In addition, as V1 becomes larger, it signifies a bigger difference in the convex and concave portions of the parking gear, making the gear more difficult to form.

The integrated parking gear with bottomless teeth and the fixed pulley half adopted in this project is shown in Fig. 9. Because this part shape is a top-level benchmark in the automotive industry, it was expected to be highly difficult to form and that problems like underfill, seizure and shortening of die life, among other things, might occur.

The following sections describe the closed-die forging methodology proposed for the difficult-to-form shape of this integrated parking gear with bottomless teeth and fixed pulley half.

3. Forging process design

3.1 Forging simulation

The finite element method was used to conduct a forming simulation in order to predict the material flow and forming timing in the forming process for this forged part. In the simulation, the dies were treated as rigid bodies and the material as an elastic body. The coefficient of friction, material temperature, die temperature and the force and speed applied by the press in the compression direction were defined as the parameters for conducting the forging simulation.

The forming load, forming flow and die stress are among the principal judgment criteria for determining the die geometry in each process for a forged part. A more excellent part shape can be expected as the forming load in the simulation decreases.

An ideal material flow is to fill the long and short shafts of the fixed pulley half, the parking gear and the outer diameter of the part in that order. A simulation is therefore conducted to determine the optimal die geometry. If the die geometry is unsuitable, the forming timing can differ, resulting in cases where the parking gear is underfilled or reverse material flow occurs. Reverse flow can cause marks or depressions in the product that become quality defects. This means that the die geometry is an extremely critical factor in the forging process. It is also necessary to determine the die geometry so that stress is below the threshold level because high stress can damage the die.

3.2 Issues in developing a parking gear with bottomless teeth

The first step toward developing a parking gear with bottomless teeth was to conduct a simulation of part forming in the forging process. Eliminating the tooth bottom would reduce the volume of the parking gear, thus quickening the filling timing of the outer diameter. Consequently, using the previous die geometry could worsen the underfill defect of the parking gear mentioned above or cause depressions in the back side of the sheave. These potential problems were revealed in a prior simulation.

The results of a forming simulation of the parking gear portion in the third forging process are shown in Fig. 10. It was predicted that underfill would likely occur because the upper part of the die was not fully filled.

The arrows show the direction in which forming proceeds. Generally, forming in the forging process ordinarily proceeds from the inside toward the outside. However, the results in Fig. 10 indicate that some of the arrows on the back side of the parking gear were in the opposite direction. This indicates reverse flow of material during forming. Because it is known that reverse material flow can cause marks or depressions, some measure had to be taken to prevent it.

As a corrective measure against underfill defects and depressions on the sheave back side, the die geometry in the second forging process was changed and a forming simulation was performed again. As a result, it was confirmed that underfill and depressions on the sheave back side did not occur.

Figure 11 compares the simulation results before and after the corrective measure was taken. A time history of the material flow begins from the left side. The yellow color indicates places that were not fully filled. Figure 11(a) shows that the corners of the parking gear portion were not fully filled before the die geometry was changed, and Fig. 11(b) shows that even the corners were filled after the die geometry was changed.

4.1 Experimental results and forging simulation improvement

A forging trial was performed using the die modified on the basis of the simulation results in subsection 3.2. It was found that an underfill defect occurred in the parking gear portion of the die (Fig. 12), indicating that there was a significant difference in formability between the actual die and the simulation.

The following reason is presumed to account for the difference in the results between the simulation and the actual die. The adoption of bottomless gear teeth thinned the geometry of the parking gear portion, causing a decline in thermal energy. In addition, because the surface area of the parking gear was increased, it tended to cool more easily so the material temperature dropped. The decrease in the material temperature increased deformation resistance of the workpiece, which presumably caused more material flow defects than was predicted by the simulation.

Accordingly, the friction coefficient used in the simulation between the die and the workpiece was revised and a forging simulation was performed again. As a

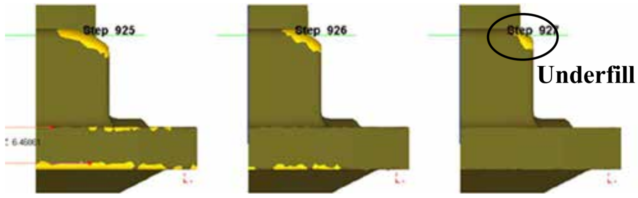

Fig. 11(a) Simulation results before corrective measure

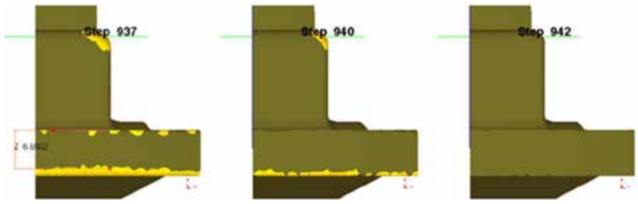

Fig. 11(b) Simulation results after corrective measure

Fig. 12 Parking gear underfill defect

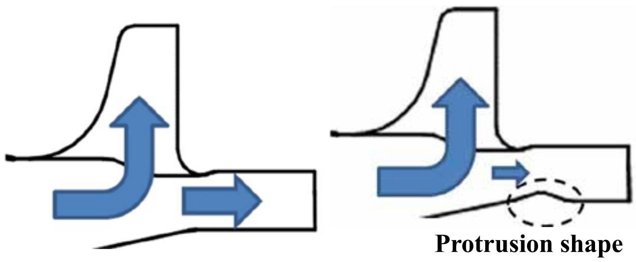

Fig. 13 Material flow with addition of small protrusion to modify finishing die geometry

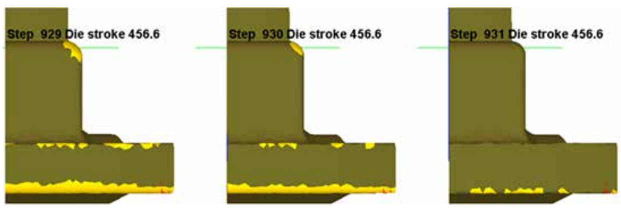

Fig. 14 Simulation results following addition of protrusion to finishing die

Fig. 15 Parking gear after addition of small protrusion

result, the actual forging and the simulation showed good agreement. This confirmed that forging defects could be predicted by simulation even for this integrated parking gear with bottomless teeth and fixed pulley half.

4.2 Improvement of material flow by adding a protrusion in the finishing die

As mentioned in subsection 3.1, the ideal material flow is in the order of the short and long shafts of the fixed pulley half, parking gear and the part outer diameter. On the other hand, in the prototype forging trial explained in subsection 4.1, it was found that the parking gear portion tended to cool more easily, causing an increase in the deformation resistance of the workpiece. That gave rise to underfill defects as a result of the part outer diameter filling with material before the parking gear portion.

Therefore, a study was undertaken of a proposed measure for improving material flowability to the parking gear portion by increasing deformation resistance in the direction of the part outer diameter so as to delay the timing for filling with material.

A die geometry was devised with a small protrusion provided as shown in Fig. 13 for the purpose of delaying the forming timing of the part outer diameter. A simulation was conducted again using a die with this protrusion and the results are shown in Fig. 14. Good results were obtained, and no forging flow defect was observed that would lead to an underfill defect in the parking gear.

4.3 Validation results for improved forging simulation

Underfill occurred in the first prototype trial, but in the second prototype trial an underfill occurrence rate of 0% was obtained for the same forming load as in the first trial. No other quality problems were observed, including other underfill locations and marks (Fig. 15).

The defect rate following the production launch has continued to remain at a low level of no more than 0.2%, thereby confirming that good results were obtained with the improved forging simulation.

5. Conclusion

A forming technology was developed for integrated forging of the parking gear with bottomless teeth and the fixed pulley half in a closed-die forging process. This part has one of the most difficult shapes to form in the automotive industry. The following knowledge was gained in this project.

(1) A forming simulation was conducted for integrated forging of the parking gear portion with bottomless teeth and the fixed pulley half. It was found that the friction coefficient between the die and the material had to be increased because the parking gear portion tended to cool easily.

(2) Material flow to the parking gear portion was improved by providing a small protrusion in the die to increase workpiece deformation resistance in the direction toward the outer circumference.

6. References

Shunsuke OHSHIMA and Knwon YOUNGJO, Forging Dies, Japanese Unexamined Patent Application Publication No. 2019-76943 (filing date: October 26, 2017)

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