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OPTIMIZATION OF 5-AXIS MACHINING PROCESS FOR REMOVAL OF INVESTMENT CASTING GATES

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Abstract: In this study, we solved the problem of product dents that might occur when removing the casting gate from the cyclic stick and collective lever by improving the 5-axis machining process. As a result, we could obtain the following productivity improvement effects: product quality improvement, cost reduction effect, and machining cycle time reduction of two to three minutes.

Keywords : Casting gate removal, Machining process improvement, 5-axis machining, MCT machining operation, Casting

1. Introduction

Since a metal generally has high deformation resistance, making it into the desired shape is very challenging. Casting is a technology that melts such a solid metal into a liquid state with low deformation resistance, injects the liquid metal into a mold of the desired shape, and solidifies it to produce a product of the desired shape at once. With an increase in industrial demands and applications, there has been a parallel increase in the demand for complex and high-quality products. Fortunately, there are different types of casting processes that can manufacture complex and precise products for various applications and user needs. In order to select the right method of casting for your manufacturing requirements, it is beneficial to realize the advantages and disadvantages of these methods [1,2].

Investment casting refers to a technology that creates metal products by combining cutting-edge technology while maintaining the advantages of casting technology. Thus, Investment casting is one of the specialized casting technologies that can produce sophisticated metal parts with high precision using a disposable pattern and mold. For this reason, the

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importance of Investment casting technology is gradually increasing as the industry develops and advances [3-5].

This Investment casting technology is widely used in various industrial fields, e.g., advanced fuel and exhaust systems, multi-turbochargers, direct fuel injection systems, hybrid and electric vehicle components, implants, diagnostic devices, medical and therapeutic devices, and aviation parts [6-7].

The investment casting process consists of several critical steps that must be engineered and carefully followed in order to produce compliant and repeatable parts. One of the most important steps in this process is designing and validating the gate and runner system. There are many key considerations when designing these systems, and if done incorrectly the mold will not function properly. Additionally, an incorrectly engineered gate and runner system can lead to cosmetic defects, reduced material properties, porosity, and high scrap amongst other things. A gate is simply an opening between the runner and part cavity that ushers the molten metal into the cavity and feeds the casting as it solidifies. A part cavity can have more than one gate if needed. The location, type, and size of the gate influences the finished parts which is why we pay special attention when sizing and designing these systems.

Among these application fields, the helicopter flight controls, such as the cyclic stick and collective lever, must be ergonomically designed, so Investment casting, not general casting, must be performed. In other words, it must be done with 5-axis machining, not 3-axis machining, because 5-axis machining can improve surface roughness by performing high-speed rotation faster than 3-axis machining [8-9]. However, when removing the casting gate of the cyclic stick and collective lever manufactured by Investment casting, the remaining residue may bounce off and damage the products.

In this study, we solved the problem of product dents that might occur when removing the casting gate through the improvement of the 5-axis machining process. As a result, we could obtain the following productivity improvement effects: product quality improvement, cost reduction effect, and machining cycle time reduction of two to three minutes.

2. Problem Analysis and Solutions

2.1 Product analysis and issues

The cyclic stick is used for basic directional control of the helicopter. It controls the pitch of the main rotor blades to direct the helicopter in the desired direction. The stick is ergonomically placed in the cockpit for the pilot's arm and shoulder to reach comfortably. The cyclic stick is moved to the left or right to move the helicopter sideways and forwards or backwards to move the helicopter forward or backward. The collective stick is used for controlling the altitude of the helicopter. It controls the pitch of all the main rotor blades together, which enables the helicopter to climb or descend. The collective stick is also placed ergonomically in the cockpit for the pilot's hand to reach comfortably. Although it may differ depending on the helicopter model, Fig. 1 shows the position of the cyclic stick and collective stick in the helicopter [10].

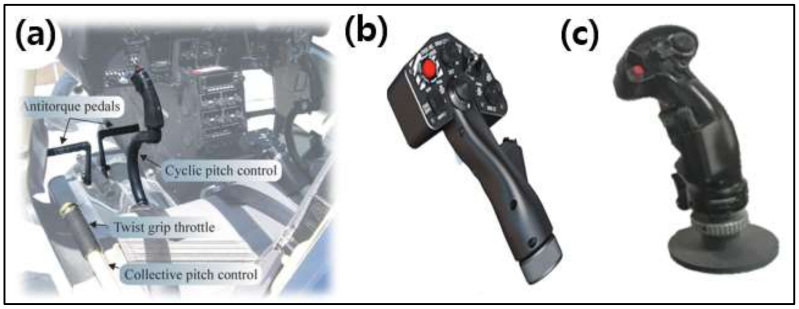

Figure 1: (a) inside the helicopter, (b) a collective stick in the helicopter, and (c) a cyclic stick in the helicopter [10]

In the investment casting process, gates and runners are essentially present, and it is important to completely remove these gates and runners for subsequent processes. As mentioned above, this study is about process improvement to remove the gate generated in the investment casting process.

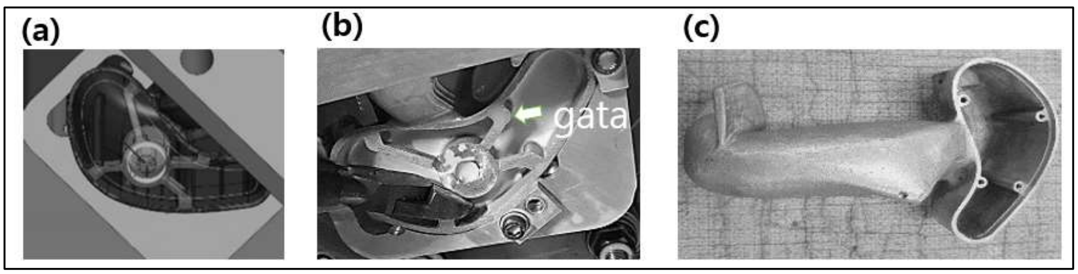

Figure 2: (a) 3D modeling of the tool path for removing casting gates, (b) Mounted on jig to remove casting gate (c) A cyclic stick product after casting gate removal processing.

Fig. 2(a) is a 3D model of the tool path for gate removal of a helicopter cyclic stick produced in the investment casting process. Fig.2(b) shows that it is fixed to the jig of the processing machine for gate removal, and the gate is marked. As shown in Fig. 2 (a), the cyclic stick is machined through the contour cutting path method using a Ø10 end mill. The contour-cutting path method moves the X, Y, and Z axes relative to the 3D model of machine the product from top to bottom along the Z axis. In order to solve the damage problem, stop processing leaving a 0.2 margin during gate processing in the area indicated by the arrow in Fig. 2(b). After that, the part is cut and removed with nippers, and the finishing process proceeds. Fig. 2(c) is a product processed and separated after visually checking for abnormalities.

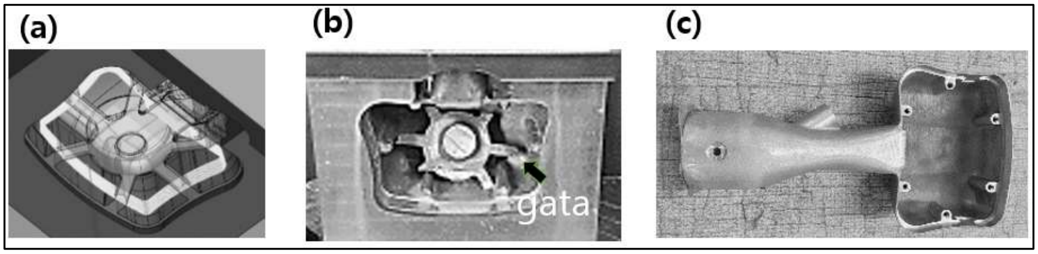

Figure 3: (a) 3D modeling of the processing process of collective stick, (b) A state in which the workpiece is seated in a jig designed for machining, and (c) A processed collective stick.

Fig. 3(a) shows 3D modeling for the gate removal processing of the collective stick. Fig. 3(b) is an image of the state where the workpiece (collective stick) is fixed to the jig designed for processing. And Fig. 3(c) shows the processed collective stick. Collective stick processing is performed in the same way as the cyclic stick processing process. However, in the case of cyclic stick processing, an end mill with a diameter of Ø 10 is used as the processing tool, but in this case, an end mill with a diameter of Ø 16 is used.

Besides the process being stopped to prevent product damage, there is a case where the product is accidentally damaged because of an operator's mistake during the nipper-cutting process. As shown by the arrow in Fig. 4(a), residues left during product processing sometimes bounced off and damaged the product. In particular, there is a case where the product is depressed, as shown by the red circle and the arrow in Fig. 4(b).

The first primary reason for this damage is the problem of determining the tool diameter without considering the thickness and width of the gate. Second, while the machining path is counterclockwise, the tool rotates clockwise simultaneously.

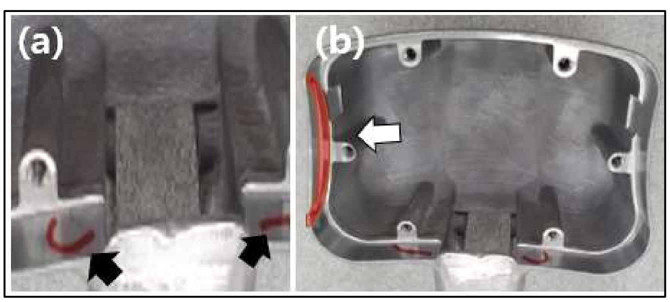

Figure 4: Poor machining process of the collective stick

2.2 Solutions

Some cutting processing methods need to be improved to solve this product damage problem. It needs to determine the tool diameter with consideration of the thickness and width of the casting gate. In addition, in some precision areas, a special machining method must be considered to effectively remove the remaining residue of the final gate, as well as change the machining tool path from 3D machining to 2D contour machining.

The improved process cut the cyclic stick sequentially through the 2D contour machining path method using a Ø4 end mill cutter. A Ø6 end mill cutter was used to cut the gate of the collective lever. In addition, the A-axis was tilted at a specific angle in the final gate removal stage, and the remaining residue dropped to the chip conveyor right away not to damage the product.

3. Experiments and Discussion

Fig. 5(a) shows the contour finishing processing path of the cyclic stick, and (b) shows the 2D contour processing path of the cyclic stick. A contour finish is a tool path used to create a smooth finish on a part surface. This includes moving the cutting tool along the surface of the part and removing any remaining material along the surface contour. The contour finish is usually used as the final pass to achieve the desired surface finish and accuracy of the part. On the other hand, 2D contour processing is a tool path used to create the desired shape along the edge of a 2D object or a flat surface of a 3D object. It involves cutting along the edges of the object in a 2D plane, creating a flat or angled surface with a specific contour. This type of machining is typically used to create features such as slots, holes, or pockets on the surface of a part. In summary, the main difference between contour finish and 2D contour finish is that contour finish is used to create a smooth finish on the part surface, while 2D contour finish is used to cut 2D objects or 3D objects to create specific shapes or features along the edges of flat surfaces.

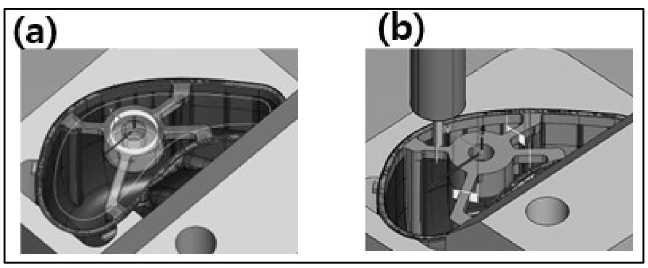

Figure 5: (a) Contour finishing path of the cyclic stick and (b) 2D contour machining path of the cyclic stick.

Table I describe the differences between the two processes of the gate removing for the cyclic stick, and the most significant differences are the effect of reducing the machining time and how to dispose of the residue. In the case of cyclic stick processing, 25 minutes of processing time was required when using the existing contour finishing processing, but 22 minutes of processing time is required for 2D contour processing. In other words, the processing time was shortened. In addition, the process of using a nipper is necessary in the existing process for residual treatment, but in the present process, the chip conveyor floor drop treatment was able to solve the printing problem.

Table I. The Difference Between the Two Processes for the gate removal process of cyclic stick

Variables	Existing Tool Path	Improved Tool Path
Machining Method	Contour machining in a counterclockwise direction	2D contour machining

Machining Time	25 minutes	22 minutes
Residue Disposal Method	using a nipper	Drop to the bottom of chip conveyor

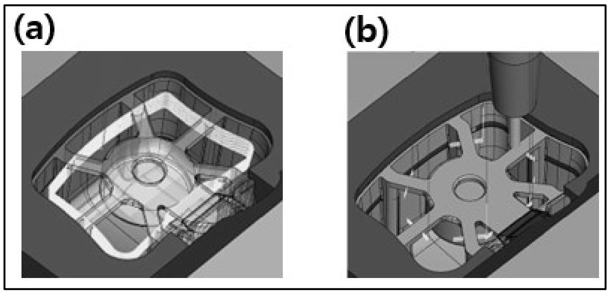

Figure 6: (a) Contour finishing path of the collective stick and (b) 2D contour machining path of the collective stick.

Fig. 6(a) shows the contour finishing processing path of the collective stick, and (b) shows the 2D contour processing path of the collective stick. Table 2 describes the differences between the two processes of gate removal for the collective stick and the most important differences are the reduction of processing time and the treatment of residues. These results are shown in Table 1.

Table II. The Difference Between the Two Processes For the gate removal process of collective stick

Variables	Existing Tool Path	Improved Tool Path
Machining Method	Contour machining in a counterclockwise direction	2D contour machining
Machining Time	35 minutes	33 minutes
Residue Disposal Method	Cut by entering counterclockwise	Drop to the bottom of chip conveyor

In collective stick processing, 35 minutes of processing time was required when using the existing contour finishing process, but 33 minutes of processing is required for 2D contour processing. The processing time has also been shortened. In addition, in the existing process, the process of entering counterclockwise and cutting the processing is necessary, but in the present process, the printing problem could be solved through the chip conveyor floor drop treatment like the cyclic stick process.

Table III compares the effects of the two machining processes. For instance, conventional machining of the collective stick performs two processes, i.e., contour machining and 5-axis swap curve machining using Ø16. However, the improved process performs only 2D contour machining using Ø6, so removing the gate without damaging the product is possible. Furthermore, using smaller tools results in reducing tool diameter, and data processing time can be faster.

The machining process of the cyclic stick also has similar effects to that of the collective stick. For example, the improved one performs only one machining using Ø4 rather than Ø10, reduces tool diameter, and has faster data processing time. Table III below summarizes such differences.

Table III. Compare the Effectiveness of the Two Machining Processes

	Existing Tool Path		**Improved Tool Path**	
	Cyclic stick	**Collective stick**	**Cyclic stick**	**Collective stick**
Number of Machining	2	2	1	1
Tool Diameter	Ø10	Ø16	Ø4	Ø6
Processing Time	150 seconds	180 seconds	120 seconds	160 seconds

4. Conclusion

In this study, we compared the two processes for gate detachment of two helicopter sticks produced in the precision casting process. Solutions such as tool paths, processing methods, and optimal tool selection were proposed to improve product damage and processing problems when cutting the gate more efficiently. As a result, we have achieved cost savings by changing the tool diameter suitable for machining. In addition, the overall production process time is reduced by two to three minutes compared to traditional processes, improving productivity.

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