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Research on Piston Avoidance Valve Pit Milling Method

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In order to improve the processing efficiency and surface quality of the piston avoidance pit, reduce labor costs, and make the processing of the piston avoidance pit meet the modern production requirements, it is realistic and feasible to combine Pro/E and Mastercam software to complete the processing of the piston avoidance pit. Two different kinds of piston pits are selected for machining, and the 3D model of the piston pits is established by Pro/E software, and the process preparation and parameter setting are realized by Mastercam software, and the NC machining simulation is converted into NC code to realize the machining of the piston pits; Under Mastercam software, two different surface finishing methods are used to complete the machining of the piston valve pit, and the impact of the two different surface finishing methods on the programming and processing of the piston valve pit is analyzed, so as to come up with a method that can improve the machining efficiency and surface quality of the piston valve pit, and to further improve the machining method of the piston valve pit, so as to provide a reference for the subsequent machining of the piston valve pit.

Keywords: Piston avoidance valve pit, CNC machining, Surface finishing, Mastercam

1 Introduction

The piston is an important component for the realization of the four-stroke engine function, and the four strokes of intake, compression, work and exhaust are realized through the cooperation of valve opening and closing and piston reciprocating motion [1, 2]. In the high speed and high load conditions of internal combustion engines, a larger valve stack opening period is often required to increase the sweep coefficient and increase the valve lift to improve the intake flow, so to avoid valve and piston interference, the normal operation of the engine is ensured by setting a valve avoidance pit in the piston head [3]. The geometry of the piston combustion chamber is designed to match the needs of combustion, and the absence of the valve avoidance pit not only affects the integrity of the combustion chamber profile, but also affects the oil-gas mixing and combustion process [4, 5].

From the process point of view, the piston is a high precision and reliability requirements, the shape of complex parts, the use of ordinary machining technology to produce pistons, processing difficulties, low efficiency, especially the piston avoidance pit processing; usually a single piston avoidance pit is composed of axisymmetric circular arc surface, which requires machine tools with better surface machining characteristics to improve productivity and processing quality. The traditional process usually uses customized forming end mills, and the use of ordinary vertical milling machine to process the valve pit, after processing also need to polish the excessive rounded corners and polishing the machined surface, but both processing efficiency, surface quality and the high requirements of personnel operating skills, can not meet the modern production requirements, so the piston valve pit processing process means, should have high processing accuracy, production efficiency and surface quality, and can quickly Adapt to the characteristics of piston varieties change, and CNC machining center can better meet these requirements, while with the application of CAD/CAM software such as Pro/E and Mastercam is more complementary, so that it can give full play to the advantages of its integration [6].

Pro/E software has powerful surface and solid modeling capabilities [7], simple and powerful in modeling and machining, and parametric modeling and direct modeling capabilities, and is the best choice for CAD applications in small and medium-sized enterprises [8], but the use of Pro/E software requires an understanding of top-down design concepts, inheritance, parametric [9], which is difficult to get started, and its parameter settings are more cumbersome in machining. Mastercam software has strong surface roughing capability and flexible surface finishing capability [10, 11], and is widely used in CNC machining because of its high cost performance, ease of use and reliable machining performance, but its capability in product modeling is not as good as that of Pro/E [12], and the use of both for model design

and its machining is currently the most common mode of work in the CNC machining industry. The work mode of the current CNC machining industry [13].

In this paper, the actual machining object is selected from two different overall cast aluminum piston pit, the 3D model of the part is designed using Pro/E software, and then the 3D model of the part machining process and tool path is prepared using Mastercam software, and the machining parameters are set, and the NC machining simulation is transformed into the NC code of the actual machining to realize the machining of the piston pit; among them, in the In the NC simulation under Mastercam software, we try two different surface finishing programming methods, discuss and analyze the effect of two different surface finishing methods on the machining efficiency and machining accuracy of piston avoidance valve pit.

2 3D modeling of piston avoidance valve pit

According to the two-dimensional drawing of the piston valve pit, as shown in Figure 1 and 2, using the [Parts]/[Solid] module under the Pro/E software system, the piston valve pit three-dimensional model is created by rotating, stretching, rounding and other feature methods, as shown in Figure 3 and 4. From the 3D model, it can be seen visually that the equal-rounded piston avoidance pit rounded corners are a set of continuous rounded surfaces, while the variable-rounded piston avoidance pit rounded corners are composed of multiple rounded surfaces of different sizes.

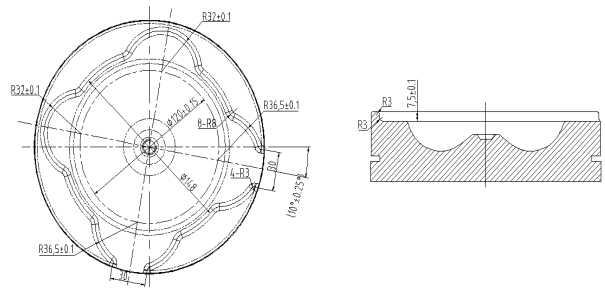

Fig. 1 *Two-dimensional drawing of equirectangular piston valve avoidance pit*

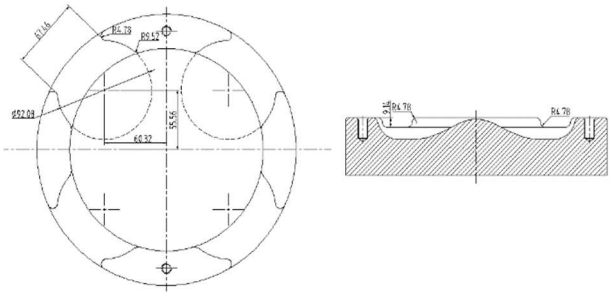

Fig. 2 *Two-dimensional drawing of a variable-angle piston valve avoidance pit*

Fig. 3 *Equally rounded piston avoidance valve pit 3D model*

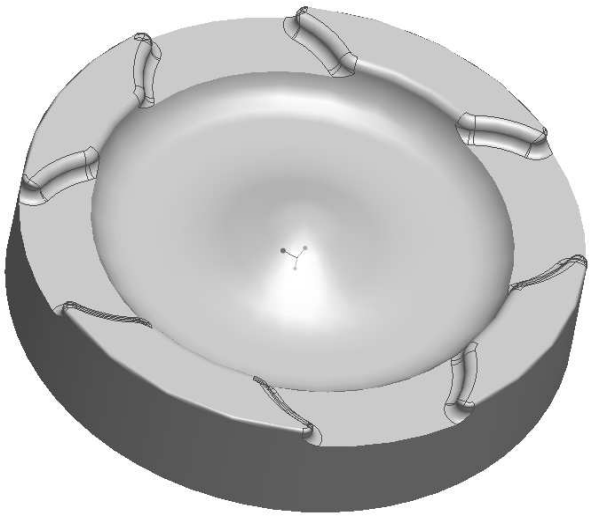

Fig. 4 *Variable angle piston avoidance valve pit 3D model*

3 CNC machining of piston avoidance valve pit

3.1 Process Technology

3.1.1 Determination of the processing scheme

From Figure 3 and Figure 4, it can be observed that the shape of both piston avoidance pits is axisymmetric, and the machining of both piston avoidance pits by CNC machining center can effectively utilize the surface machining characteristics of CNC machining center. In order to improve the machining efficiency and quality of the CNC machining center, it is necessary to design the machining scheme of the two piston avoidance pits.

Equally rounded piston avoidance pit processing program: first use the rough milling method along the avoidance pit contour line to remove the larger residual of the avoidance pit, and then use the finish

milling method to cut the bottom surface, side and arc of the avoidance pit, the bottom surface cutting amount is 0.3mm, the side and arc cutting amount is 1mm, Figure 5 is Equal rounded piston avoidance valve pit machining picture.

Fig. 5 *Equal rounded piston avoidance valve pit machining picture*

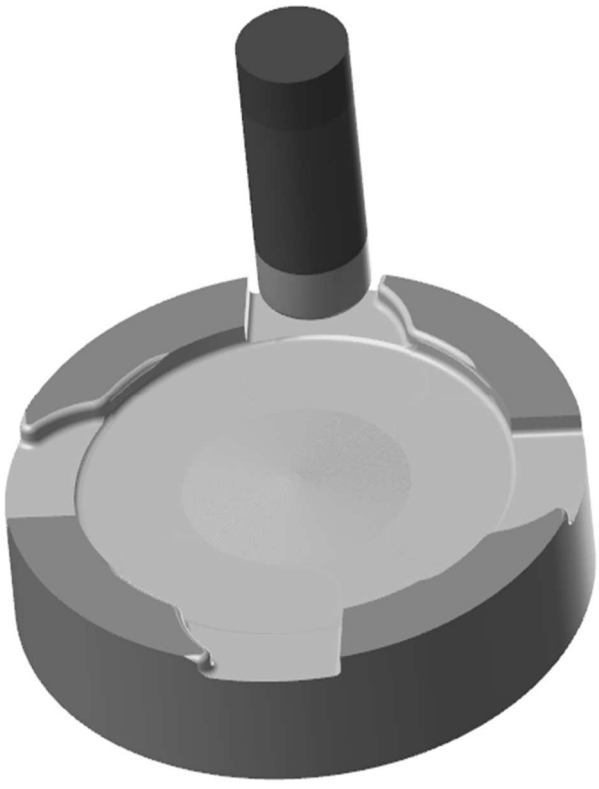

Fig. 6 *Pictures of Variable Rounding Piston Avoidance Valve Pit Machining*

Variable round angle piston avoidance pit processing program: due to the characteristics of the variable round angle piston avoidance pit itself, its single avoidance pit itself is also axisymmetric graphics, so the processing can be rough and finish milling of a single avoidance pit one by one, and finally complete a processing cycle, avoidance pit processing is complete, where the theoretical cutting volume of the bottom surface of the finish milling is 0.2mm, Figure 6 is a picture of the machining process of variable rounding piston avoidance valve pit.

3.1.2 Determine the workpiece machining origin

Since both piston avoidance pits are uniformly distributed along the circumference of the top of the piston, the workpiece origin is selected on the center of the top plane of the piston in order to facilitate process processing and CNC machining center calibration, find the workpiece origin, and simplify programming [14, 15], and unify the machining process datum and design datum.

3.1.3 Selecting the tool

From Fig. 1, we can know that the maximum radius of the equal-angle piston pit is 36.5 mm and the opening size is 30 mm, and because the processing of the equal-angle piston pit needs to remove a large margin during rough milling, a customized four-flute round-nose end mill with a diameter of 50 mm and an indexable insert with a fillet angle of R3 is used to effectively improve the processing efficiency; in order to avoid overcutting when cutting the opening fillet, a round-nose end mill with a diameter of 20 mm and a fillet angle of R3 is used for the finish milling of the circular overrun surface. In order to avoid the overcutting in the open corner cutting, the round nose end mill with a diameter of 20mm and a fillet angle of R3 is used for the finish milling of the overcut surface.

From Figure 2, we can learn that the maximum diameter of the piston pit is 92.08 mm, and the opening size is 67.46 mm. The tool selection for the piston pit needs to improve the machining efficiency while avoiding machining interference, so the tool selection for the piston pit machining is the above-mentioned customized four-flute round nose end mill with a diameter of 50 mm, and the insert is an indexable insert with a fillet angle of R3.

3.1.4 Cutting volume selection

The two piston materials selected in this paper are ZL109, which can reach the hardness of HB85-HB140 after heat treatment; the cutting volume needs to consider the hardness of the tool and the piston material when selecting, and the appropriate cutting volume is derived comprehensively.

The cutting volume when rough milling the piston avoidance valve pit with equal rounded corners:

cutting speed v_c=235m.min^{-1}, spindle speed n=1500min^{-1}, feed f=1500mm.min^{-1}. Finishing milling cutting volume: cutting machining allowance of 0.3mm on the bottom surface of finishing milling, feed f=300mm.min^{-1}, cutting speed and spindle speed remain unchanged. Cutting volume for round corner milling: cutting speed: v_c=150m.min^{-1}, spindle speed n=240min^{-1}, feed f=1500mm.min^{-1}.

Variable fillet piston avoidance valve pit rough milling cutting volume: cutting speed v_c=235m.min^{-1}, spindle speed n=1500min^{-1}, feed f=1200mm.min^{-1}. finishing milling cutting volume: cutting allowance of 0.2mm on the bottom surface of finishing milling, feed f=300mm.min^{-1}, cutting speed and spindle speed remain unchanged.

3.2 CNC machining simulation under Mastercam

The purpose of finishing is to remove the remaining material after rough machining to achieve the shape and dimensional accuracy of the part. , Mastercam provides 10 types of finishing methods, 5 for surface finishing and 5 for complementary machining, among which parallel milling, radial machining, surface flow, contour profile, and surround isometric belong to surface finishing, steep bevel machining, projection machining, intersection line clearance, residual material clearance, and Shallow plane machining is supplementary machining. The types of surface finishing are shown in Table 1.

Tab. 1 *Types of surface finishing*

Type	Features
Parallel	Generate a set of finishing toolpaths for cutting parallel to each other at a specific angle
Radial	Generate radial finishing toolpaths
Flow line	Generate finishing toolpaths along the surface flow direction
Contour	Generate finishing toolpaths along the contour of the surface
Scallop	Generate a set of finishing toolpaths in equal steps around the workpiece surface in the 3D direction
Par.Steep	Generate finishing toolpaths for removing residual material from surface slopes
Project	Generate finishing toolpaths by projecting existing toolpaths or geometry onto the surface
Pencil	Generate finishing toolpaths to remove residual material from the intersection of surfaces
Leftover	Generate finishing toolpaths for removing material left over from machining with larger diameter tools
Shallow	Generates a finishing toolpath for removing material from the shallow part of the surface, with the shallow plane area determined by the slope angle

3.2.1 Curved surface machining flow line finishing

Surface machining streamline finishing refers to the generation of tool paths along the streamline direction of a surface that vary according to the shape of the surface [16, 17]. This type of machining is suitable when multiple surfaces are connected and can be combined together for machining along the flow lines of the surface. It is less effective in the finishing of simple non-streamlined surfaces, but it is more effective in the machining of complex streamlined surfaces, and the resulting parts have higher dimensional accuracy and surface roughness, so this method is suitable for machining high-precision complex streamlined surfaces [18]. Equally rounded piston avoidance pit transition fillet continuous and uniform size are R3, choose the finishing surface streamline method for equivalently rounded piston avoidance pit CNC simulation, streamline finishing parameters are shown in Figure 7, the tool path simulation results are shown in Figure 8.

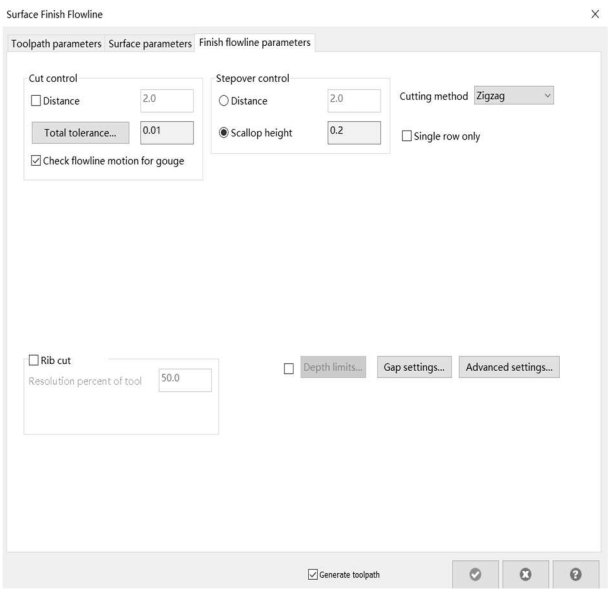

Fig. 7 *Streamline finishing parameters*

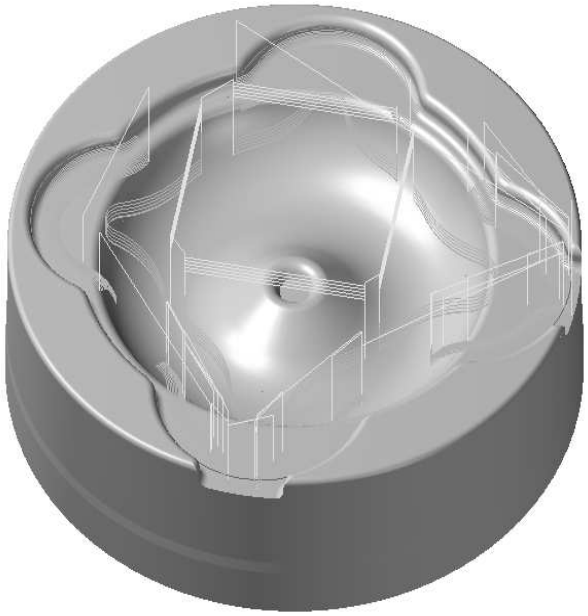

Fig. 8 *Simulation of tool path of equirectangular piston avoiding valve pit*

The rounded corners of a variable-angle piston pit are made up of different sized arc surfaces, so when using surface machining streamline finishing, you can't focus on the combination of the arc transition surfaces, and you need to select different transition surfaces several times, increasing the programming content. In the process of selecting the transition surfaces for multiple times, the order of selecting the surfaces is different, and there is an impact on the actual jointing effect of the different surfaces after processing, so the surface machining flow line finishing method is not applicable to the processing of piston avoidance pits with variable rounded corners.

3.2.2 Curved contour finish machining

Curved contour profile finishing is a layer-cutting machining method that moves the tool along the contour of the workpiece profile and, after machining one layer, uses a variety of layer-to-layer movements to move to the next layer to continue machining, enabling complex 3D shapes to be divided into many layers of simple 2D shapes for machining [19, 20]. Considering that the variable fillet piston avoidance valve pit is machined surface fillet excess surface more, the slope is small, and the machining accuracy requirements are high, in order to avoid sparse tool paths due to the same amount of feed between the layers, the complementary machining method is used to increase the tool paths in the shallow plane area, so as to achieve a reasonable sparsity of tool paths in all parts of the part. Specific machining methods are as follows, shallow plane machining layer milling depth set 0.01 for the minimum depth of cut, surface contour finishing specific parameter settings shown in Figure 9. This type of machining method is also applicable to the machining and programming of the equal-angle piston valve avoidance pit, equal-angle piston valve avoidance pit and variable-angle piston valve avoidance pit contour as shown in Figures 10 and 11, the tool path simulation results as shown in Figures 10 and 11. From the results, surface contour finishing is suitable for the machining of the variable corner piston valve pit, surface contour finishing toolpath is along the contour of the workpiece shape, compared with the surface streamline finishing, surface contour finishing can effectively avoid the complexity of the program and the problem of multiple selection machining arc transition surface.

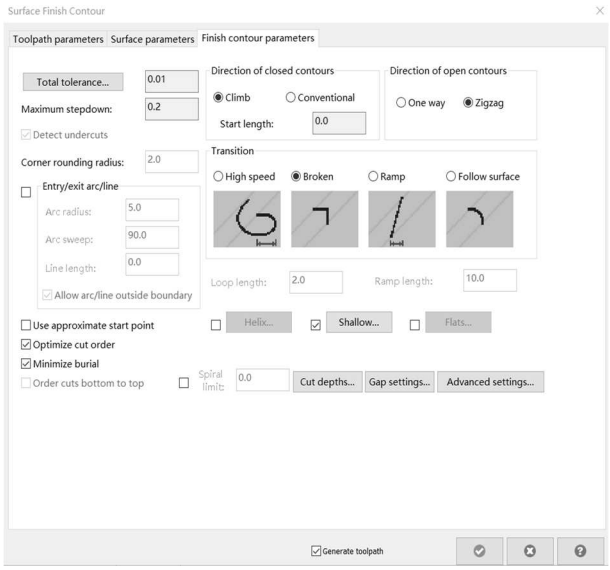

Fig. 9 *Curved contour profile finishing parameter setting*

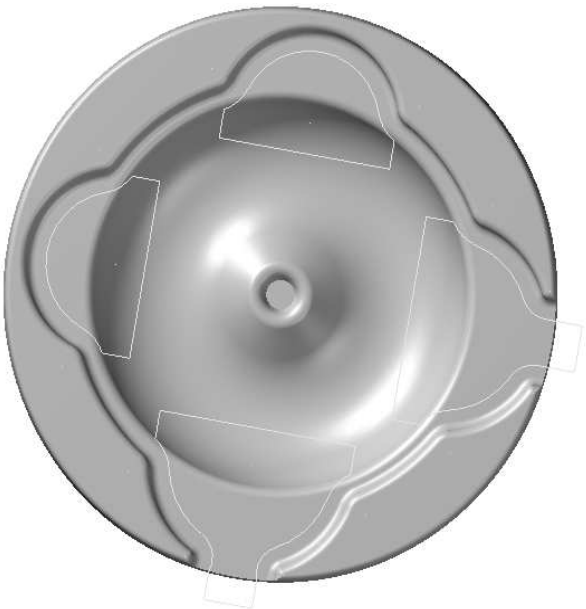

Fig. 10 *Isoconical piston avoidance valve pit contour map*

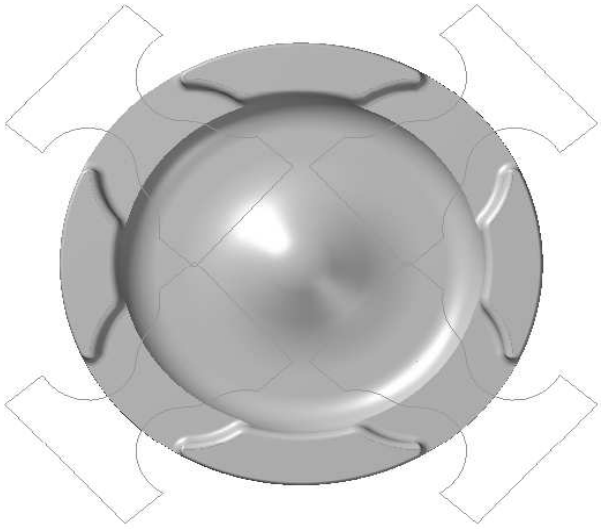

Fig. 11 *Contour map of valve pit avoidance by piston with variable rounded corners*

4 Piston avoidance valve pit machining results analysis

From the real processing effect, the piston avoidance valve pit dimensional accuracy can be controlled within the tolerance band ±0.15, and the surface roughness is Ra1.6μm, which fully meets the requirement of roughness value not more than Ra3.2μm, and the real processing efficiency can be improved by 30%-40%, as shown in Table 2.

The real results obtained by the two machining methods are shown in Fig. 12 (a) and (b), from the real machining effect of CNC machining center, there is no substantial difference between the two machining methods on the processing results of the equal-angle piston avoidance pit. However, the advantages of applying surface contour finishing to the processing of piston avoidance pits with variable rounded corners are more obvious, and the program output from surface contour finishing has the advantages of simple operation and convenient change. For surfaces with more rounded surfaces and inconsistent corner dimensions, the use of surface streamline finishing to process such piston avoidance pits requires a long and complicated debugging procedure in the actual application, and it is difficult to change the operation, so the use of surface contour finishing is recommended for programming piston avoidance pits with complex surfaces.

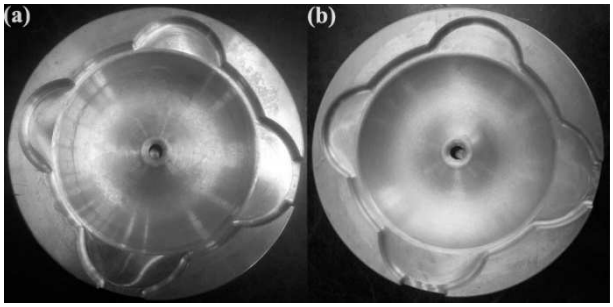

Fig. 12 *Real machining results of equirectangular piston avoiding valve pit [(a) Real results of streamline finishing for surface machining; (b) Real results of curved contour profile finishing]*

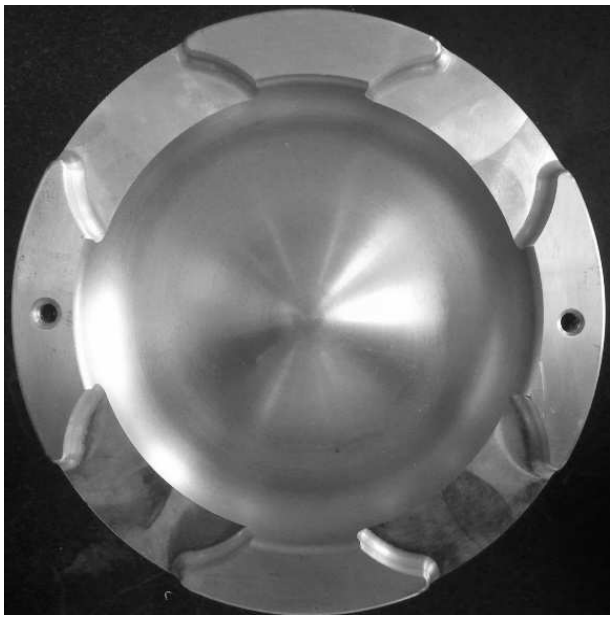

Fig. 13 *Variable fillet piston avoidance valve pit surface contour finishing actual machining results*

Tab. 2 *Real machining dimensions of the piston avoidance pit with equal rounded corners*

Size Name	Theoretical size	Valve pit 1	Valve pit 3
Valve pit X-directional position	X59.09±0.15	59.061	59.06
Valve pit Y-directional position	Y10.42±0.15	10.522	10.512
Valve pit radius	R32±0.1	R32.092	R32.062
Roughness	Ra3.2μm	1.035μm	1.07μm
Size Name	Theoretical size	Valve pit 2	Valve pit 4
Valve pit X-directional position	X10.42±0.15	10.494	10.511
Valve pit Y-directional position	Y59.09±0.15	59.066	59.166
Valve pit radius	R36.5±0.1	R36.595	R36.579
Roughness	Ra3.2μm	1.059μm	1.036μm

5 Conclusion

In this paper, Pro/E and Mastercam software are combined to complete the simulation of CNC machining of two piston valve pits and transformed into NC code. From the actual machining effect of the piston valve pits, this combination not only ensures the positional and dimensional accuracy of the piston valve pits but also improves the surface quality of the piston valve pits, which solves the problem of low positional accuracy of the valve pits and high roughness of the machined surfaces in the traditional milling machine compared to the traditional machining. Compared with the traditional machining method, it solves the problems of low positional accuracy between the pits and high roughness of the machined surfaces that occur in the profiling machining of piston valve pits on the traditional milling machine, and gets rid of the dependence on manual post-processing in the traditional machining process. By comparing the actual processing results of surface streamline finishing and surface contour finishing, it can be seen that surface streamline finishing is suitable for a single surface or a group of continuous and neatly arranged multi-surfaces, while surface contour finishing is more suitable for processing occasions with more complex surface structure and steeper sidewalls, and it has the advantages of simple programming principle, short debugging and modification time, fast program generation, and high efficiency of actual processing. It also has the advantages of simple programming principle, short debugging and modification time, fast program generation, high efficiency in actual processing, and it is also one of the processing methods commonly used in other three-dimensional programming software. Therefore, under the same conditions, priority should be given to the machining of piston valve pits by using surface contour finishing as much as possible.

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