A NEW METHOD OF MACHINING THE COUNTERSINKS DISTRIBUTED IN MULTI-DIRECTIONAL BACK-FACES

Wang Zhun[1]

ABSTRACT: In traditional manufacturing, a large number of countersinks for bolt-fastening on the shell/box-type part could be cut with repeatedly mounting and manual intervention. It is a bottleneck process and has a great negative contribution to the efficiency and cost of production. For this reason, the paper presents a new method that realize full-automatic NC machining all countersinks in rear face: First, the codes of NC back-boring countersinks are created by combining CAM with minimum manual modification; Second, the parameters of the cutter-structure of NC back-boring are deducted out by infusing the variables of NC cycle into CAD package; Lastly, the Post-NC verification is employed to check and improve the design of NC program and cutter-structure. The final optimized NC program and cutter can be used to full-automatically fabricate the shell/box-type part.

KEY WORDS: Countersink in back-face, Cutter of NC Back-boring, CAM/CAD, Post-NC Verification

1 INTRODUCTION

There are a lot of through-holes for bolt-connection in the parts with shell/housing body, and these holes are often distributed in multi-directional end faces. Corresponding to the holes, there are the equal numbers of countersinks (used for location of nut) in back faces, which are intractable for cutting. In traditional production, the countersinks distributed in multi-directional back-face (or rear face) are manually or semi-auto machined by the special back-boring cutter (or backspot facing tool) with collapsible/scalable function (Burr, et al. 2007). This is a bottleneck in the efficiency and cost of production. In today's NC machining, the back boring cycle (G87) can be used for cutting the countersink in rear face, but the manual programming is poor in efficiency and accuracy. In addition, the design and preparation of cutter for back boring is not an easy work with traditional way.

Taking the fabrication of valve-body part as an example, this paper study the programming of NC back boring and the designing of back-boring cutter. The research findings are as follows: the code of NC back-boring multi-directional countersinks can be gotten by combining CAM method with manual NC programming; the correctness of the code as well as the validity of the structure and the limit dimension of the cutter of NC back boring can be assured by infusing the technique of Post-NC verification (Wang Zhun, 2014-1), and full-automatic NC machining countersinks distributed in multi-directional back-face (or rear face) can be realized finally.

The structure of this paper is as follows. after analysis to a part of valve body, the scheme of NC back-boring the countersinks distributed in multi-directional back-faces is gotten in section 2. Section 3 involves the design of the program of NC back boring. The design of the cutter used for NC back boring is presented in section 4. In section 5, the author infuses the Post-NC verification into the checking of full automatic NC back boring with the designed codes and cutters. The end section is the conclusion.

2 ONE CASE OF NC BACK BORING A PART OF VALVE BODY

2.1 Technological difficulty and solution

Figure 1 shows one part of valve body. The three flanges are distributed in different orientations of the part. There are a lot of holes and faces needed to be cut on each flange, such as through hole, rear anchor-ring face (for positioning of nut), outside and inside cylindrical surface, end face, slot, and so on. Among these cutting demands, the difficulty focuses on machining the back face (anchor-ring face) on each flange. Turning can be adopted to challenge the difficulty, but at least two setups are needed in addition to mass balance problems occurred in the rotation with high velocity. If NC back-boring is used to machine the rear face, all the cutting demands can be satisfied during one setup,

[1]School of Mechanical and Automobile Engineering, Anhui Polytechnic University, Wuhu 241000, People's Republic of China
E-mail: CADCAM_246@126.com

in which a set of machine center (MC) can be applied to support the work.

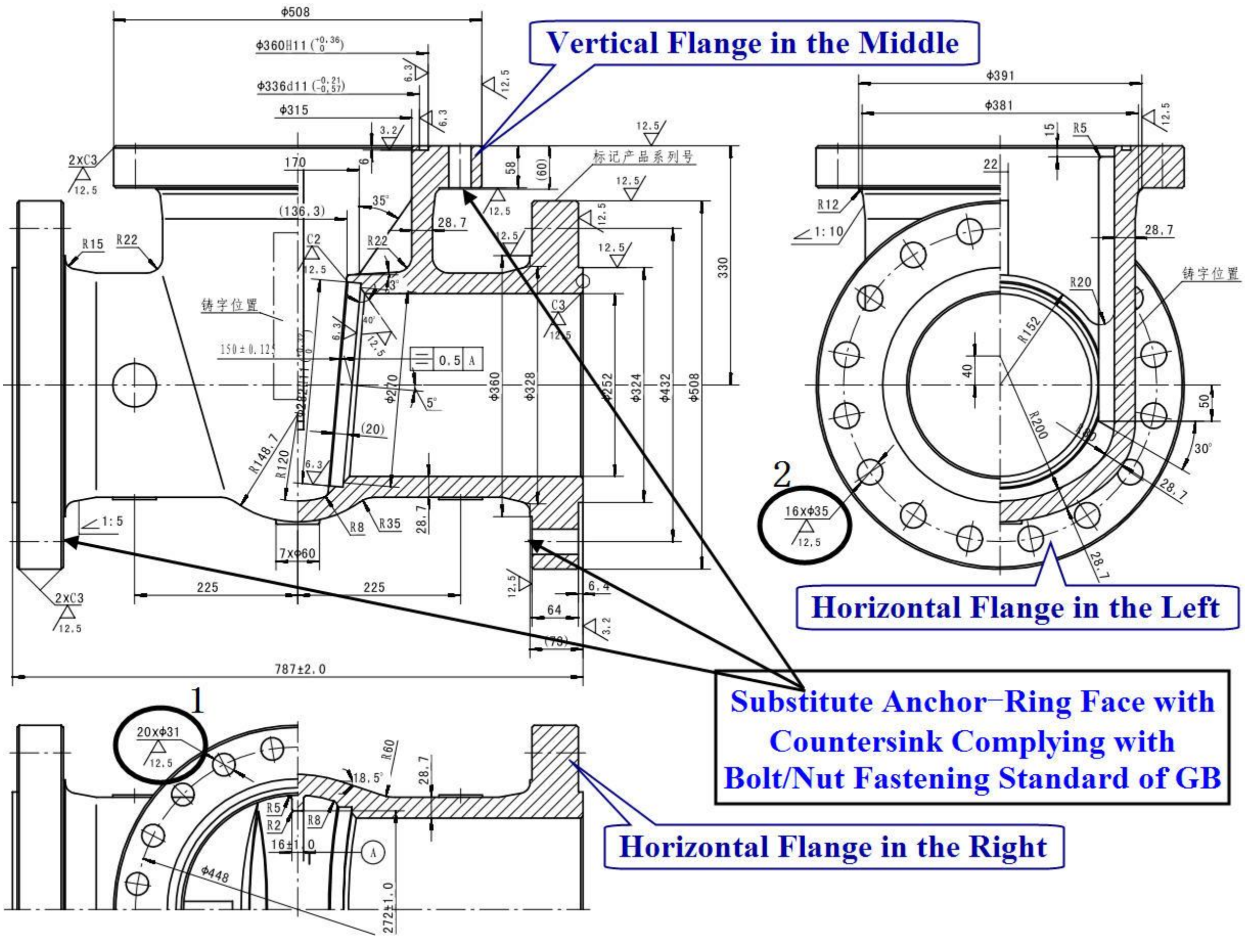

Figure 1. Sketch drawing of one part of valve body

2.2 Structure modification and introduction of back boring

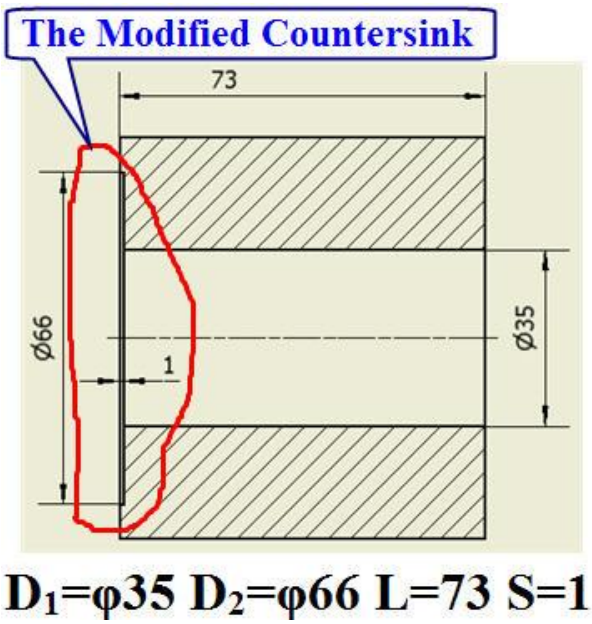

Figure 2. Sketch drawing of one hole and its countersink in horizontal flange

According the specification of bolt/nut fastening in standard of GB (GB152.4-88) (FAN Houjun, 2007), a new structure of countersink can be used to substitute the original structure of anchor ring. For example, on the horizontal flange, the original structure -- unbroken anchor-ring face with span of 74 mm (matching to 16 through-holes of the bolt with diameter of Φ35 mm), can be substituted by 16 separated countersinks with diameter of Φ66 mm (see Figure 1). After the modification of structure, all countersinks on the rear face locating in three different directions can be machined with NC back boring. Figure 2 shows one modified through-hole and its countersink in the horizontal flange, and the denotation and value of parameters are as follows:

$D_1=\Phi 35$————diameter of through-hole,
$D_2=\Phi 66$————diameter of countersink,
$S=1$ ————depth of countersink,
$L=73$ ————thickness of flange.

3 PROGRAM DESIGN OF NC BACK BORING

3.1 General recommendation parameters of G87 and its value

The format of back boring cycle (G87) is as follow: G87 X_ Y_ Z_ R_ Q_ P_ F_ K_ (Peter Smid, 2007). Figure 3 shows principle parameters and the corresponding cycle of motion, in which the key parameters are Q, R and Z. The value of Q is the shifting amount in the direction opposite to tool nose, which is related to the difference between D_1 (the diameter of through-hole) and D_2 (the diameter of countersink); the value of R is the feeding amount to the limit point of hole bottom, which is related to the L (the thickness of flange); the value of Z is the back-boring distance from the limit point, which is related with S (the depth of countersink).

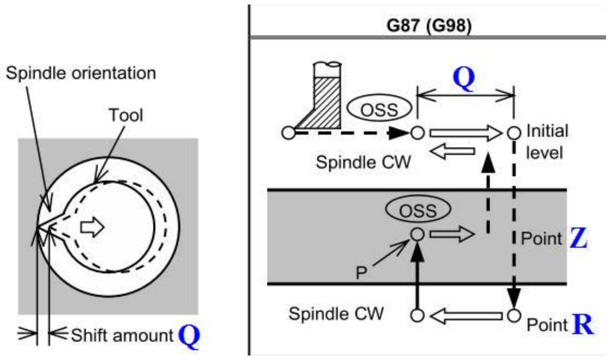

Figure 3. Parameters of back boring (G87)

According the analysis in section 2.2, in order to make a boring cutter go through the hole in the horizontal flange, the value of Q/R/Z should satisfy the following relations:

$Q > (D_2-D_1)/2=15.5$;

$R > L=73$;

$Z > S=1$.

So, tentatively Q=16, R=116 (considering the safety distance before and after the cutter going through a hole), Z=7 (considering the value of R and the safety distance after the cutter going through a hole).

Above method can be used to define the parameters of G87 during NC machining all other holes in the part of valve body. The validation of the final value of the parameters of G87 can be checked out by Post-NC verification, and the details are analyzed in section 5.

3.2 Creation of the code of NC back boring all countersinks

Generally, the NC program can be finished with CAM software packages, such as Catia/CAM, CREO/CAM, MasterCAM, Topsolid/CAM, etc. (Marius Andrei MIHALACHE et al., 2014), (Kuang-Hua Chang, 2015) , but the correct code of G87 cannot be directly created by normal postprocessor inside CAM package. In order to get the appropriated code of G87, adding manual modification after post-processing of CAM package is a practical solution to quickly create the code of G87 (Carean et al., 2013). The detailed job steps are as follows:

Firstly, simple NC cycle of machining hole, such as drilling cycle (G81), boring cycle (G85/86), and so on, is created with CAM package.

Secondly, text editor is used to open the NC program generated in the first step, and the tool of 'Find/Replace' is applied to modify the original NC code to get the correct parameters of Q/R/Z inside back boring cycle (G87).

Figure 4(a) shows the original NC program, and Figure 4(b) shows the final correct back-boring code (G87).

4 DESIGN OF THE CUTTER USED FOR NC BACK BORING

According the analysis in section 3.1, the value of Q is the shifting amount that the boring bar moves opposite to the nose of cutter during OSS (Oriented Spindle Stop). The diameter of the bar and its rotating center should be adjusted to prevent any collision between the bar and the through hole. So, the structure and value of boring bar can be established by CAD methods (Vlad DICIUC et al., 2011), (Kuang-Hua Chang, 2015). As shown in Figure 5, an elliptic cross section and its diameters are deducted out with a CAD package (e.g. CREO/CAD), in which the detailed value are as follows:

$L_b > R$

$Q_o = 8$ mm

Where, L_b = the axial length of boring bar, Q_o = the offset amount between the center of ellipse and the center of rotating.

Figure 6 shows the 3-dimensional (3-D) model of back-boring cutter and the workpiece with hole and countersink. The correctness of the structure/dimension of the back-boring cutter designed with CAD method should be checked by the Post-NC verification, which will be discussed in next section.

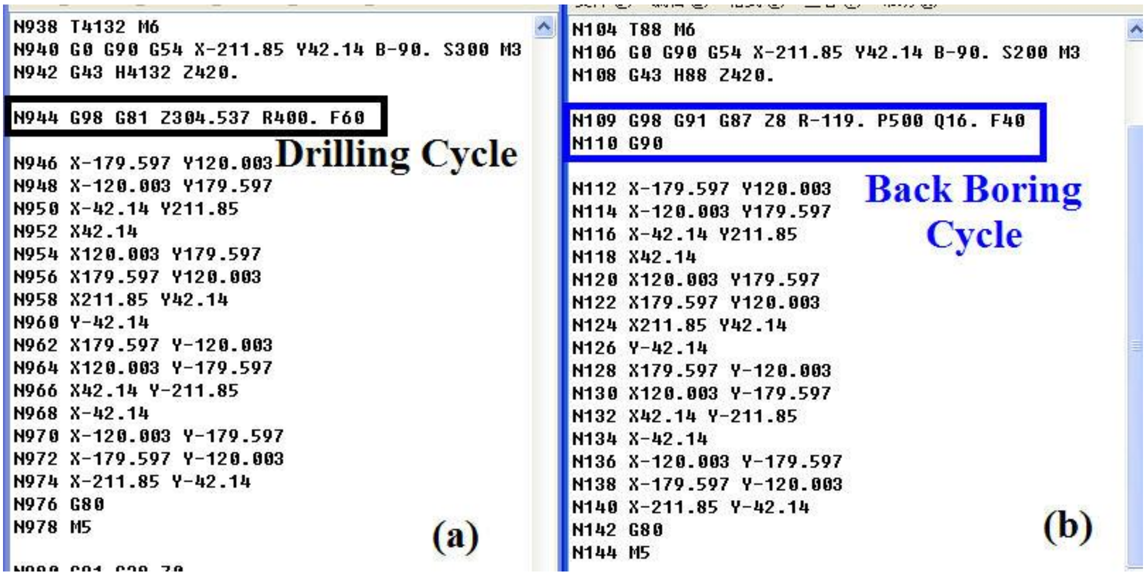

Figure 4. Original program and modified code

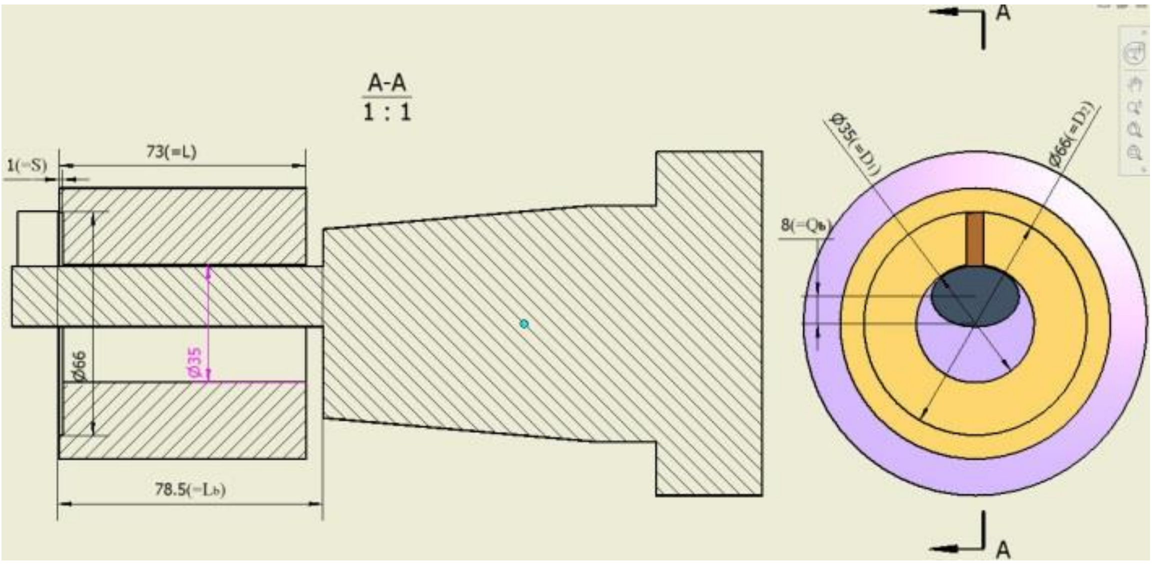

Figure 5: Structure and parameters of back-boring cutter

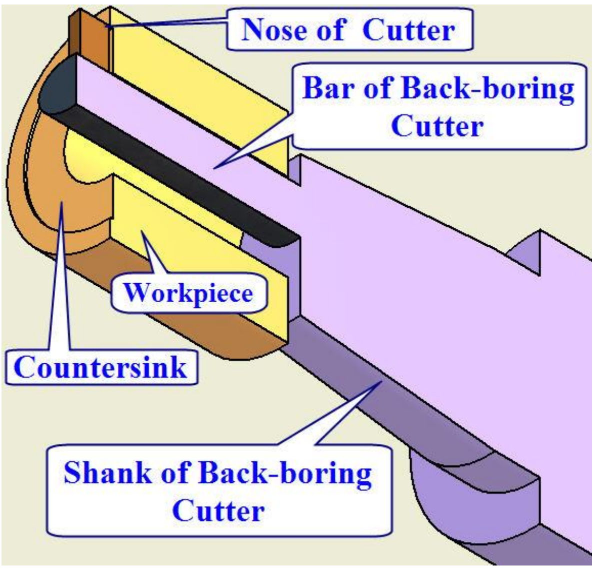

Figure 6. 3-D model of back-boring cutter

5 VERIFICATION TO FULL AUTOMATIC NC BACK BORING

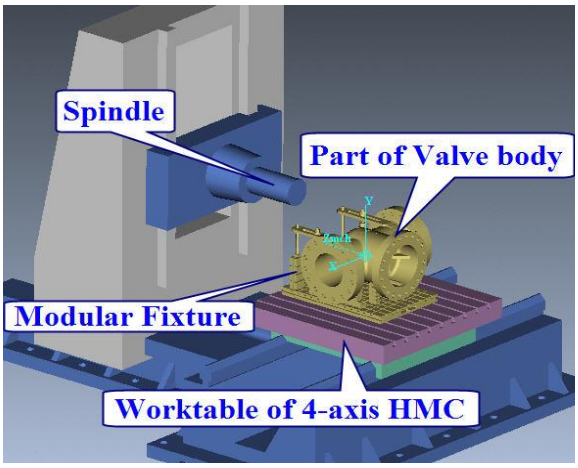

Figure 7. One 4-axis HMC and part of valve body

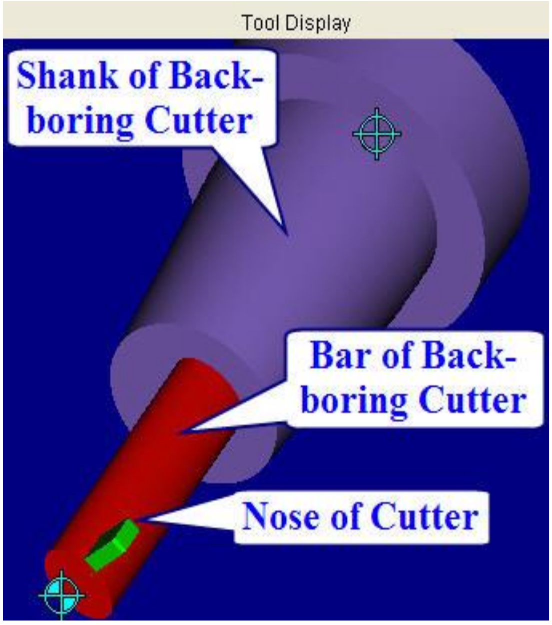

Figure 8. Back-boring cutter in Post-NC verification

Traditionally, the Post-NC verification is applied in the checking and optimization of NC code (Anjiang Cai et al., 2012). Here, the paper focuses on justification to the parameters of NC back-boring cycle and cutter. In this research, a 4-axis HMC with CNC of Fanuc is applied to machine the part of valve body, as shown in Figure 7 (Wang Zhun, 2014-2). The designed cutter in Post-NC verification is shown in Figure 8.

Figure 9 shows the back-boring cutter in the state of OSS, which the bar has offset a distance of Q opposite to the nose of cutter. There is a clearance between the bar and the hole, and there is no any collision occurring. Figure 10 shows that the cutter is just going through the hole and preparing to return to the center of rotation for back boring. Figure 11 shows that one countersink in back-face (or rear face) has been cut out following some sequential actions of spindle, such as OSS again, second offsetting radially and withdrawing into the hole axially after finishing job.

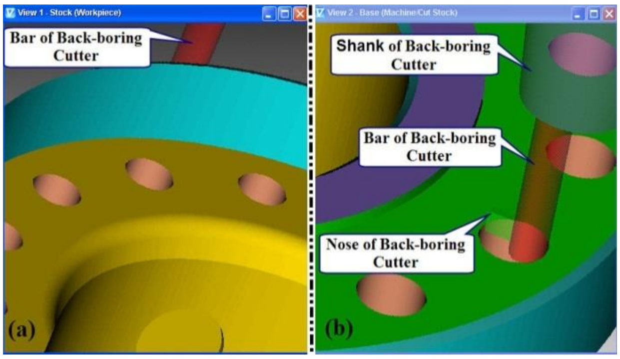

Figure 9. Scenario 1 -- back-boring cutter going into hole

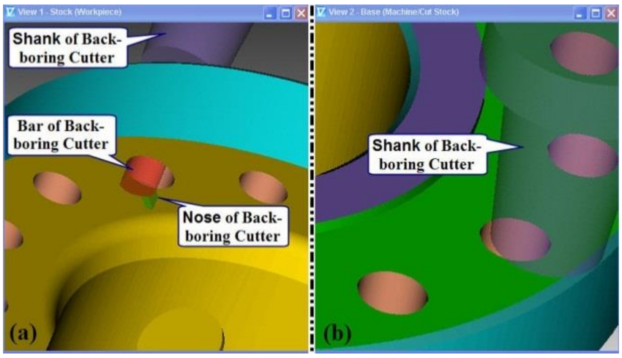

Figure 10. Scenario 2 -- back-boring cutter walking out hole

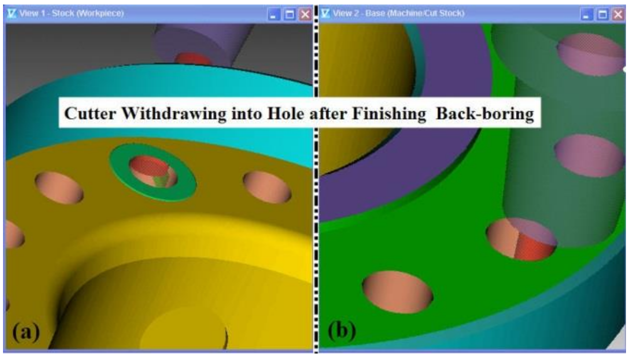

Figure 11. Scenario 3 -- back-boring cutter withdrawing into hole

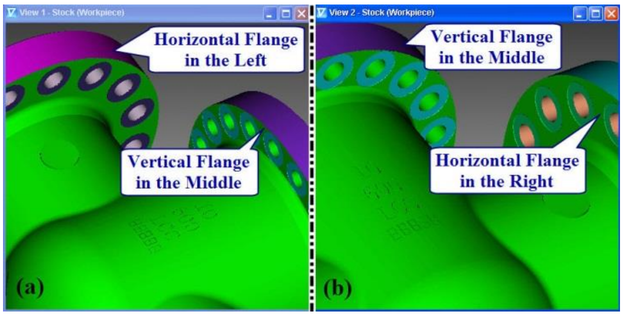

Figure 12. Final result machined by full-automatic way

If any collision occurs, the value of Q/R/Z can be modified according the information provided by tools of Post-NC verification. The parameters of back-boring cutter, such as the diameter of bar, L_b (=axial length of bar), Q_o (=offset amount of bar center), etc. can also be adjusted to get a correct value. Figure 12 shows the final countersinks on the back-faces distributed in three flanges of valve-body that are machined with the established NC back-boring program and cutter. The result demonstrates that the NC program and back-boring cutter have been correctly designed, and this information (NC program and parameters of cutter) can be transferred into workshop for preparations for the physical production.

6 CONCLUSION

All cut jobs to the three flanges of valve-body can be automatically finished in one setup by a 4-axis HMC and NC program plus corresponding cutter. This production way can eliminate a lot of negative factors occurred in traditional manufacturing process, such as job interruption, opening machine-tool door for adjusting cutter, and so on.

CAM combined with manual modification can be used to quickly create the NC program of the back boring with different orientation; CAD can be efficiently applied to design an appropriated cutter of back boring; Post-NC verification can be infused to check and optimize the design of the cutter and NC program. As a result, the high automation, integration and flexibility in the production of part with shell/housing body can be achieved.

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