Analysis of the algorithms of the movement of forming during planetary boring and milling on CNC machines

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Abstract. The article discusses methods for processing large-diameter holes in CNC machining centers. The possibility of implementing each method on existing equipment in the form of standard cycles or macro programs is analyzed.

1. Introduction
Currently, when machining large-diameter cylindrical holes (over 150-200 mm) on CNC milling machining centers, the following 2 methods are mainly utilized:
a) boring with axial feed;
b) planetary milling.
Milling of holes is more universal, and allows using one tool to process holes of different diameters in a wide range. However, boring provides a more stable surface roughness [1]. In addition, the processing depth during milling is limited by the working length of the cutter.

Paper [2] considers the principle of planetary (interpolation) boring; i.e., the simulation of turning on a milling machine. Continuity of the process is ensured by the coordinated movement of feeds and spindle rotation. The relevance of the use of planetary boring is as follows:
• with one tool it is possible to process several holes close in diameter;
• continuity of the process should provide indicators of accuracy and surface quality comparable to conventional boring;
• planetary boring allows one to process stepped holes, as well as grooves in one transition.

In more detail, the advantages and disadvantages of each of the sounded methods are considered in the article [3]. The classification of methods is presented in Figure 1.
Despite the wide possibilities of modern CNC systems and control program preparation environments (CAM-systems), the use of these processing methods is currently fraught with a number of problems:
• manufacturers of CNC machine tools, demonstrating these capabilities, as implemented on their equipment, do not provide specific typical processing cycles or recommendations for writing control program code;
• in the technical literature there are no specific recommendations on the appointment of processing modes;
• insufficient data on the accuracy and quality indicators achieved with these types of processing.
It is worth noting that there is also milling with a size-forming tool, i.e. a special milling cutter made to fit a specific size. Setting up such a tool is possible only in a limited range (several millimeters). The disadvantage of the application is the high cost of the cutters, which is impractical for single and small-scale production, as well as the need to use a set of cutters for machining holes of different sizes. In mass production, this method can be applied if it is economically feasible, for example, when the cost of manufacturing a tool is offset by an increase in processing productivity.

2. Analysis of the possibility of implementing the considered processing methods in existing CNC systems

2.1. Axial boring
With this type of processing (Figure 2), the tool is adjusted to the diameter of the hole being machined, and the feed movement is carried out along the axis of the tool. For boring with axial feed there are constant cycles that greatly simplify the setup of the program. In addition, it is possible to write a program directly from the CNC stand. For this, there are cycles G76 and G86.

![Figure 2. Tool movement pattern for boring with axial feed.](image-url)
An example of the implementation of boring with axial feed in the code of the control program of the CNC system:

\[ \text{G76 X Y Z R Q P F K,} \]

where X, Y - hole coordinates;
Z - the coordinate of the bottom of the hole;
R - the safe distance (the point from which the tool begins to move with the working feed);
F - the value of the working feed;
K - the number of repetitions (if required);
Q - the magnitude of the shift of the cutter after processing;
P - delay at the base (used when processing a blind hole to form a flat bottom).

The disadvantages of this method are the rather expensive equipment for fixing the cutting tool, as well as the limited size adjustment, which indicates the need to use a set of boring heads depending on the size of the hole. For each technological transition, a dimensional adjustment of the outreach of the cutter or even a change of mandrel is required.

2.2. Planetary milling

When milling with circular interpolation with preliminary deepening, the tool movement algorithm is as follows: the tool is lowered by the amount of deepening, then the working stroke begins in the interpolation plane (Figure 3). If processing is carried out in several working strokes, the cycle is repeated until the specified depth is reached.

![Figure 3. Path of the tool during milling with circular interpolation.](image)

At the moment, manufacturers of CNC machines do not offer ready-made planetary milling cycles, but most CAM systems are able to create control programs using circular interpolation. Important for finishing according to this method is the incision along a conjugate arc of a circle (Figure 3). The larger the radius of this arc, the smaller the error in the shape of the hole when cutting the tool [4].

The following is an example macro program for Fanuc CNC using variables for milling holes with circular interpolation. The macro program is called in the same way as setting a constant cycle; i.e., the letter addresses of variables and their values are indicated.
Table 1. Macro program example for planetary milling.

| Program code | Frame description |
|--------------|-------------------|
| G65 P9010 X100 Y100 R0 Z-50 D150 T0.5 H15 Q1 F100 S1000 M30 | Calling a macro program with the necessary arguments |
| O9010; #1=#18-#26; #2=FUP[#1/#11]; | Macroprogram start |
| #3=#1/#2; #8=#7/2-1.1*#20; #4=#25/#8; | Depth calculation |
| #5=#25-#8; #6=#24+#7/2-#8; | Determining the number of passes rounded to the nearest larger integer |
| G90 G17 G54 G00 Z[#13+#18]; | Tool insertion / exit radius |
| X#24 Y#25 S#19 M03; Z#18; IF [#2 EQ 1] GOTO 1; | Setting the absolute coordinate system, setting the interpolation plane, accelerated movement to the original height |
| #21=0; WHILE [#21 LT #2-1] DO 1; | If the number of passes is 1, then go to frame N1 |
| G91 Z-#3; G90 G01 G41 D#17 X#6 Y#4 F#9; | Defining a helper variable for a loop |
| G03 X[#24+#7/2] Y#25 R#8; I-#7/2; | Repeat the cycle from DO to END until the number of passes is 1 less than the specified number |
| X#6 Y#5 R#8; G00 G40 X#24 Y#25; | Setting the relative coordinate system, lowering to the depth of the passage |
| #21=#21+1; END 1; | The absolute coordinate system, the task of correcting the radius of the tool, moving to the start point of the tool with a working feed |
| N1 G00 Z#26; G01 G41 D#17 X#6 Y#4 F#9; | Incrementing auxiliary variable by 1 |
| G03 X[#24+#7/2] Y#25 R#8; I-#7/2; | Cycle end |
| X#6 Y#5 R#8; G00 G40 X#24 Y#25; | Lowering to the depth of the last pass |
| Z[#13+#18]; | Radius correction task, moving to the start point |
| M99; | Cancellation of radius correction, exit at accelerated feed to the center of the hole |
| | End of macroprogram |

Milling with helical interpolation differs from the considered option in the coordinated movement of the tool feeds along the axis of the hole and around the circumference. To simplify programming, it is possible to write a similar macro program presented above. Then, to program the hole machining, it is enough to call the macro program with the parameters of the hole machining.
2.3. **Planetary (interpolation) boring**

It is carried out due to the coordinated movement of feeds and spindle rotation, i.e. the tip of the cutter does not come off the surface being machined (Figure 4). The setting procedure for the planetary boring machine is as follows:

a) The tool is positioned at the center of the hole;
b) The spindle is rotated so that the straight line connecting the tip of the cutter and the axis of rotation of the tool becomes parallel to one of the axes of the interpolation plane;
c) The tool is brought along the same axis by the value of the equidistant radius;
d) A consistent spindle rotation and rotation of the tool center around the center of the hole at the same time as the axial feed begins.

Manufacturers of CNC equipment demonstrate the possibility of implementing this method on their systems [5], but there is no technical information about the general programming algorithms for CNC systems. This prevents the spread of planetary boring.

![Figure 4. Planetary boring scheme.](image)

3. **Conclusion**

Based on the analysis of the shaping algorithms when machining holes using various methods and the possibility of their implementation in modern CNC systems, we can conclude that there are problems with programming planetary boring. However, manufacturers of CNC equipment demonstrate the possibilities of such processing, therefore, we can say that in the near future planetary boring can be quite widespread, which makes its study even more relevant. There is also no information on the obtained parameters of the accuracy of the shape and surface roughness of the hole during planetary boring; recommendations for the appointment of processing modes.

The absence of ‘finished’ processing cycles is not critical in conducting experimental studies of planetary milling or boring, as shown by the example of using a macro program (table 1). In addition, a frame-by-frame description of the shaping movements is acceptable for laboratory conditions.

In this regard, it is planned to conduct experimental studies in order to compare the methods considered and obtain a relationship between the method used, cutting conditions and quality and accuracy indicators.
References

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