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SYSTEM FOR COMPUTER AIDED PROGRAMMING OF CYLINDRICAL GRINDING ON TOOL GRINDING MACHINES

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Solid carbide cutting tools are mostly manufactured by abrasive processes on tool grinding machines. In many situations, the first operation represents a cylindrical grinding of the blank. The manual preparation of NC programmes for this operation is especially time intensive in manufacturing of small series. Several manufacturers of control systems offer an integrated solution for cylindrical grinding, but these applications are closed and with limited flexibility. In this paper, a system for computer aided preparation of NC programmes for cylindrical grinding is presented. The tool path is calculated from the given contour of the workpiece, the form of the grinding wheel and additional geometrical and technological parameters.

Keywords: cylindrical grinding, tool grinding, CAM, NC programme

1 Introduction

Rotary cutting tools of smaller diameter are mostly manufactured by grinding on tool grinders. Tool grinding machines are equipped with five or more simultaneously controlled axes, which give high flexibility to these machines that is necessary for the manufacturing of the complex geometry of cutting tools [1]. For manufacturing of solid carbide rotary cutting tools, the cylindrical rods made from tungsten carbide are used. The cylindrical carbide rods are made in different diameter series that are often used in machinery, e.g. 6, 8, 10, 12 mm. The carbide rods can be pre-ground by its manufacturer in the ISO tolerance of the outer diameter in the range form h5 to h6, which enables direct manufacturing of specific cutting tools without additional cylindrical grinding operation [2].

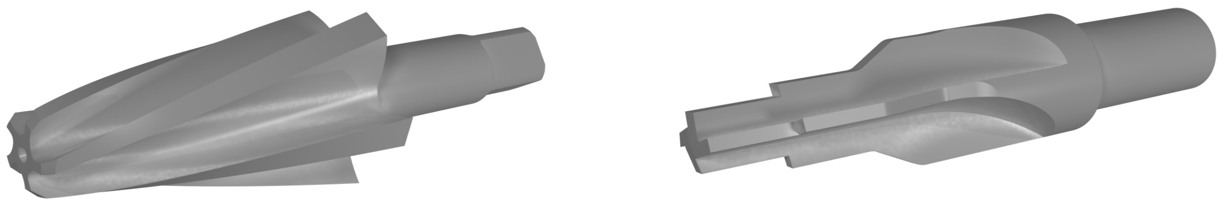

Fig. 1 Tapered reamer (left), step tool (right)

More complex cutting tools, such as tapered endmills and reamers or form cutters (s. Fig. 1), need the cylindrical grinding for the modification of the outer diameter to the desired shape. This operation can be realized on separate cylindrical grinders or directly on the tool grinder. The machines for cylindrical grinding offer better productivity, which is achieved due to the specialized design and grinding wheel with bigger diameter, and often also higher precision that can be reached due to the more simple kinematic chain. On the other hand, cylindrical grinders represent an additional investment. The longer time for setup of the machine and for the grinding process pre-determine these machines for bigger series of cutting tools. For the single-part production or grinding of small series of cutting tools, which is typical for many cutting tool manufacturers, the cylindrical grinding directly on the tool grinder offers higher efficiency. The cylindrical grinding on the tool grinding machine requires satisfying of two conditions: the grinder must be equipped with a universal rotary axis of the workpiece, which enables its rotation in cylindrical grinding and the software of the machine tool must support cylindrical grinding. The satisfying of the first condition is mandatory. The situation with software support of cylindrical grinding is more complex and depends on the control system of the machine and the specific style of the NC programming of the tool grinders. The programming of tool grinders is mostly based on the filling in of a form with geometrical parameters of the designed cutting tool. This system is very intuitive and enables the quick programming of machines directly on the shop-floor. The simple and intuitive interface is an efficient way of NC programming for cutting tools with standard geometry. The user selects and assembles the predefined grinding operations that are necessary for the grinding of the desired cutting tool. This system reaches its limits in grinding of special cutting tools with non-standard geometry. For these situations, the software developers offer another way of machine programming. The machine motions can be prescribed in an external NC programme that solves the problems with limited flexibility. The import of the external NC programme can substitute the missing module for cylindrical grinding.

The manual preparation of NC programmes for cylindrical grinding is time-consuming. Furthermore, this kind of NC programming is very sensitive to the errors that can be made by the programmer due to many repeating computations of the grinding wheel coordinates. The productivity of the NC programming can be increased significantly by using of automated computer aided NC programming. This self-developed system offers several advantages over any integrated module for cylindrical grinding. The most important property represents the open algorithms. The access to the algorithms provides maximal flexibility and enables the optimization of grinding strategies to the actual demands. A slight disadvantage represents the necessary knowledge of some programming language for the realization of such an NC programming system [3].

2 Computation of the workpiece contour

The final NC programme is based on the given contour of the ground workpiece. In the proposed system, the input of the contour control point coordinates $C_i = [x'_i, y_i]$ and the associated radii r_i have been selected as shown in Fig. 2. For the simplification of the computation of workpiece contour shape, some conditions for the workpiece contour have been introduced:

- the workpiece contour starts and ends with linear segment,
- the contour of the workpiece is without pockets,
- the minimal radius of a counter clockwise arc (CCW) is greater as the abrasive layer radius of the grinding wheel.

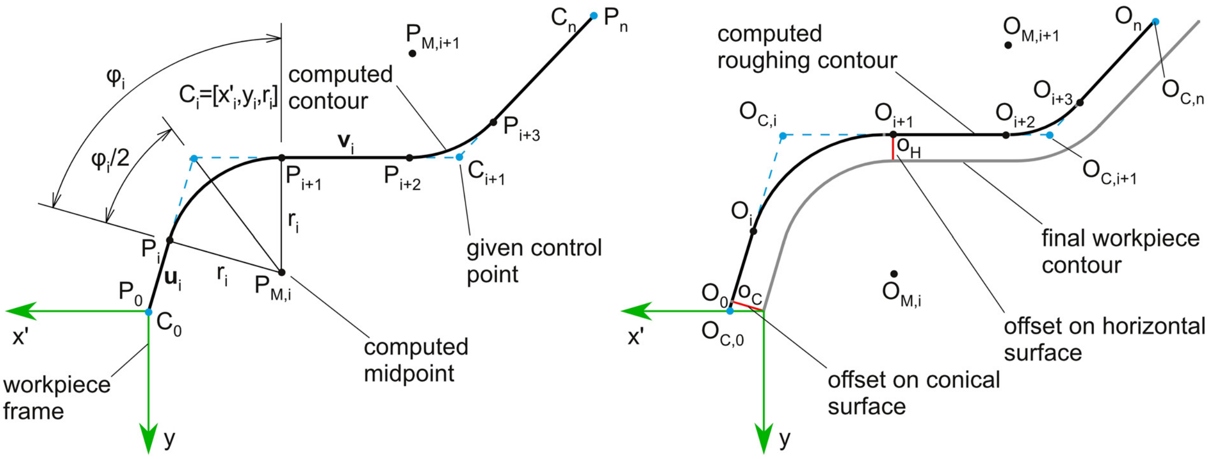

Fig. 2 Principle of final (left) and offset (right) workpiece contour

The workpiece contour consists from several segments that are defined by its kind (line, circular arc CW or CCW) and coordinates of its endpoints P_i and eventually midpoint $P_{M,i}$. The coordinates of these additional points can be computed from given control points and radii. For the computation of the angle between two following segments, the two direction vectors $\mathbf{u}_i$ (from C_{i-1} to C_i) and $\mathbf{v}_i$ (from C_i to C_{i+1}) must be determined. The angle φ_i between two following line segments of a control polygonal curve is defined by equation (1) as follows:

$$\cos\varphi_i = \frac{\mathbf{u}_i \cdot \mathbf{v}_i}{|\mathbf{u}_i| \cdot |\mathbf{v}_i|} \tag{1}$$

The position of the first and last point of the circular arc can be calculated from parametric equations of the control polygonal curve. The values of the parameters t_S and t_E, which correspond to the first and second point of the arc, are given by equations (2):

$$t_{S,i} = 1 - \frac{r_i \cdot \tan\frac{\varphi_i}{2}}{|\mathbf{u}_i|} \quad \text{and} \quad t_{E,i} = \frac{r_i \cdot \tan\frac{\varphi_i}{2}}{|\mathbf{v}_i|} \tag{2}$$

The coordinates of a circular arc midpoint $P_{M,i}$ can be calculated from the known position of the start and endpoint of arc and given radius r_i. The midpoint lies on the normal to the control polygonal curve in the start and end point of the arc.

The contour of the workpiece is important for the NC programming of the finishing operation. For roughing, the offset contour to the workpiece must be determined. Due to the different grinding conditions on different oriented segments (horizontal, conical and vertical) of the workpiece contour, the three different offset parameters (o_H, o_C and o_V) have been introduced. The orientation of the segment can be determined from the comparison of its start and end point coordinates. The shape of the offset contour is given by coordinates of the additional control points $O_{C,i}$ and modified radii $r_{C,i}$. The coordinates of the start and end points of the offset contour O_i can be determined in exactly the same manner as the workpiece contour.

3 Machining strategies

The machining strategies in the proposed system are divided between roughing and finishing. The main differences can be found in the contour and method that is used for the computation of the toolpath and in the different location of the setup point of the grinding wheel. The position of the setup point, which is used in roughing and finishing operations, is shown in Fig. 3.

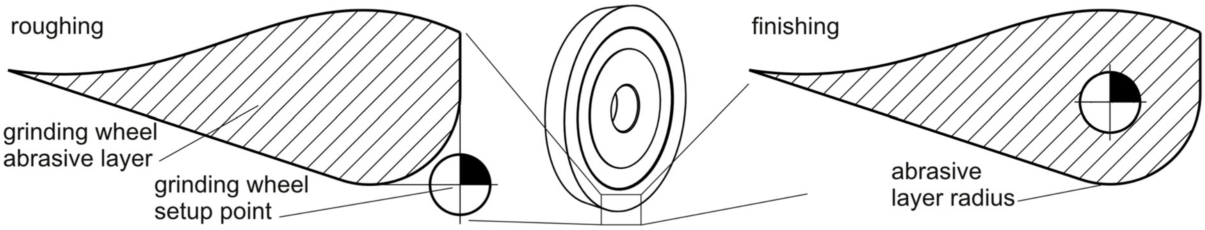

Fig. 3 Location of setup point for roughing (left) and finishing (right) operations

3.1 Roughing

For roughing of the workpiece, two different machining strategies have been implemented. The first one can be used for radial and the second one for longitudinal roughing. Between these two strategies several differences in the computation algorithm can be found. In the radial roughing strategy, the x' coordinate of the grinding wheel is selected at first and then the y coordinate of the grinding wheel is found. The movement in this strategy is started from the front face of the workpiece. In the longitudinal roughing strategy, the y coordinate is selected at first and then the x' coordinate of the grinding wheel is computed. The grinding wheel motion starts from the outer diameter of the workpiece.

The computation of the roughing toolpath is based on searching of the segment of the offset contour that is appropriate to the selected coordinate (x' or y) of the grinding wheel position. For every segment of the contour, the location of the start point, end point and eventually midpoint is known. On the edge of the grinding wheel abrasive layer, a small radius r_C is located, which has an influence on the searched position of grinding wheel. The main problem in computing of the grinding wheel coordinates is the evaluation of the differences Δx' and Δy, which are caused by tangent contact between grinding wheel and workpiece contour.

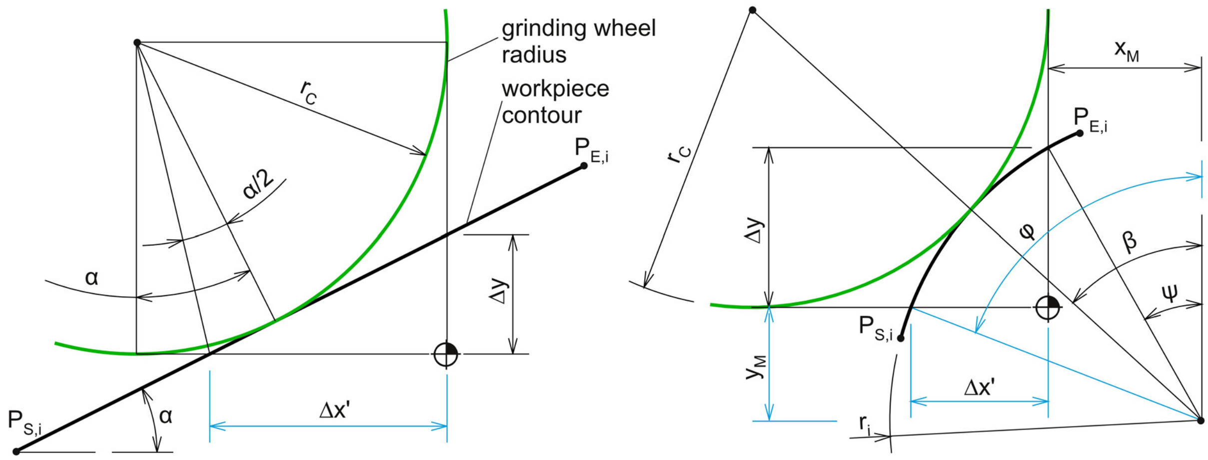

Fig. 4 Deviations caused by the wheel abrasive layer radius for a line segment (left) and a CW arc (right)

For a linear segment of the workpiece contour (s. Fig. 4), the differences in both directions can be calculated from the slope angle of the linear segment α. This angle can be calculated (3) from location of the start point $P_{S,i}$ and end point $P_{E,i}$ of the segment as follows:

$$\alpha = \arctan\left(\frac{P_{E,i,Y} - P_{S,i,Y}}{P_{E,i,X} - P_{S,i,X}}\right) \tag{3}$$

The differences in both directions Δx' and Δy for the linear segment of the workpiece contour are given by equations (4).

$$\Delta x' = r_C - \left(r_C \cdot \tan\frac{\alpha}{2}\right) \quad \text{and} \quad \Delta y = r_C - \left(r_C \cdot \tan\frac{\alpha}{2}\right) \cdot \tan\alpha \tag{4}$$

For a clockwise circular arc, the angles β, φ and ψ between the vertical axis and the intersections of tangents to the abrasive layer radius and workpiece segment must be calculated at first. For computing, the equations (5) can be used.

$$\beta = \arccos\left(\frac{y_M + r_C}{r_i + r_C}\right),\quad \varphi = \arccos\left(\frac{y_M}{r_i}\right) \text{ and } \psi = \arcsin\left(\frac{x_M}{r_i}\right) \tag{5}$$

The differences in both directions Δx' and Δy for a clockwise circular arc can be calculated from the equations (6).

$$\Delta x' = (r_i \cdot \sin\varphi) - ((r_C + r_i)\cdot \sin\beta - r_C) \text{ and } \Delta y = (r_i \cdot \cos\psi) - ((r_i + r_C)\cdot \cos\beta - r_C) \tag{6}$$

The situation for a counter-clockwise circular arc is shown in Fig. 5. The principle of computation of both differences Δx' and Δy is similar to the CW circular arc. For the calculation of angles β, φ and ψ, the equations (7) can be used.

$$\beta = \arcsin\left(\frac{x_M - r_C}{r_i - r_C}\right),\quad \varphi = \arcsin\left(\frac{x_M}{r_i}\right) \text{ and } \psi = \arccos\left(\frac{r_C}{y_M}\right) \tag{7}$$

The differences in both directions Δx' and Δy for counter-clockwise circular arc can be calculated from the equations (8).

$$\Delta x' = ((r_i - r_C)\cdot \sin\beta + r_C) - r_i \cdot \sin\varphi \text{ and } \Delta y = ((r_i - r_C)\cdot \cos\beta + r_C) - r_i \cdot \cos\psi \tag{8}$$

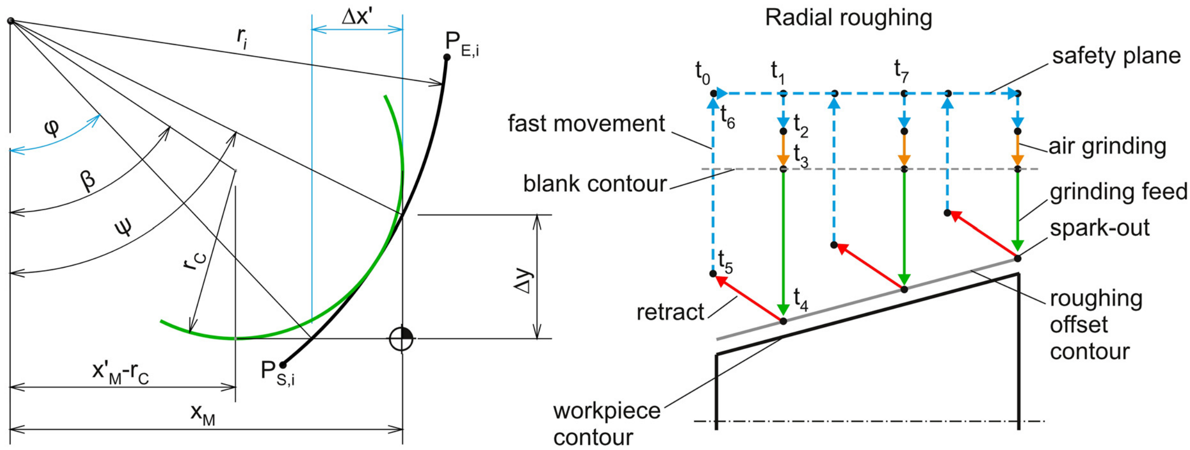

Fig. 5 Deviation for a CCW arc (left) and roughing toolpath patterns (right)

The toolpath patterns for radial and longitudinal roughing strategies are shown in Fig. 5. The motion of the grinding wheel is divided into several sub-steps that are realized with different feedrates. In the proposed system, the user can set the lengths and feedrates of all auxiliary motions. After the reach of the desired coordinate on the workpiece surface, the spark-out is inserted. This spark-out is necessary for the grinding of the whole perimeter of the rotating workpiece.

3.2 Finishing

The finishing strategy is based on the computation of an additional offset contour with constant offset that is identical with the radius of the grinding wheel abrasive layer r_C. For this offset value, the setup point of the grinding wheel lies directly on the new contour. The grinding wheel toolpath can be generated from the coordinates of points of the finishing offset contour. The principle of toolpath computation for the finishing strategy is shown in Fig. 6.

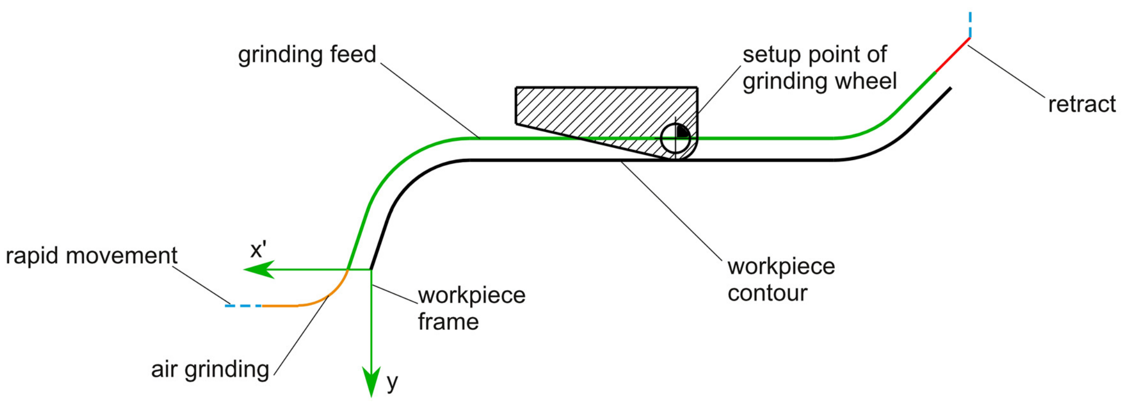

Fig. 6 Toolpath for the finishing strategy

To the finishing toolpath, the air grinding and retract movement of the grinding wheel are added. For the smooth approach, the circular arc, which is tangential to the first segment of the finishing toolpath, has been selected. The retract is realized by tangential elongation of the last segment of the contour. Similar to the roughing strategies, the user has the full control over lengths and federates of all auxiliary motions in the proposed system.

4 Postprocessor development

The toolpath coordinates are stored in the CL data format. All coordinates are related to the workpiece frame 0_W. The toolpath in CL data format is machine independent. For the conversion of the CL data to the machine dependent NC programme, the utilization of an NC postprocessor is necessary. In presented work, the postprocessor for the tool grinding machine Walter Helitronic has been developed. This tool grinder is equipped with five numerically controlled axes that enable to reach any orientation of the grinding wheel. The translational axis X is attached to the table, axes Y and Z with the spindle. The primary rotational axis C turns the whole table, the secondary rotational axis A turns the workpiece clamping device as shown in Fig. 7. In the workspace of the grinding machine several coordinate systems are located. The fixed system 0_M (x_0, y_0) is attached to the machine frame and is used as NC programme zero. On the flange of the spindle another important point 0_T is located that refers to the programmed point on the spindle stock. On the front face of the workpiece the zero-point of the machined part O_W (x', y) is positioned. All CL data coordinates are related to the coordinate system in this point. The length of the workpiece is measured from the zero point of the clamping device 0_C that is located on the flange of the workpiece rotary axis.

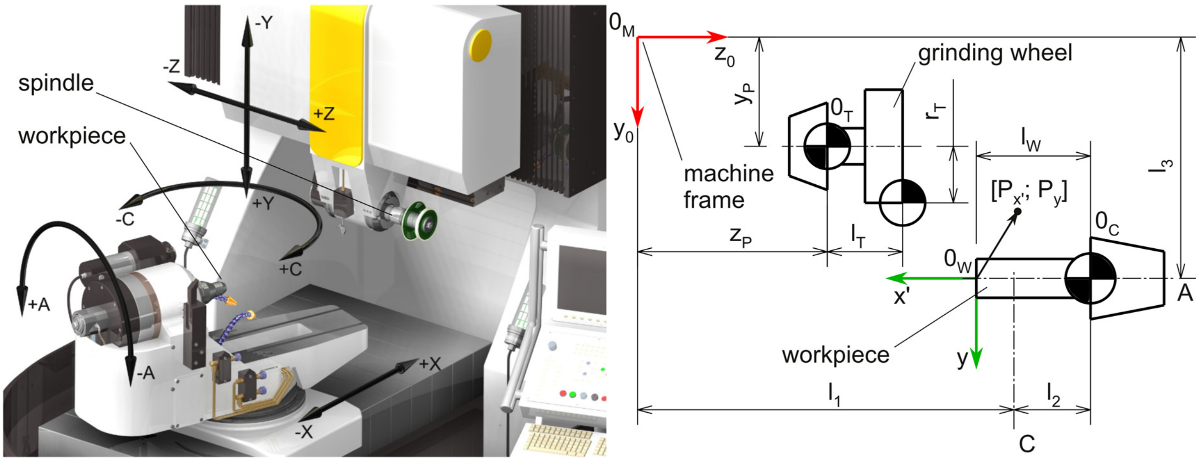

Fig. 7 Driven axes of Walter Helitronic (left), dimensions of workspace (right)

The algorithms of the NC postprocessor are based on the analysis of the machine workspace as shown in Fig. 7. In the workspace of the machine two unknowns y_P and z_P can be found. These two variables represent the two programmed coordinates of the machine. The value of these unknowns can be calculated from the coordinates of the actual point on the toolpath $P_{x'}$, P_y, from the position of the grinding wheel setup point l_T, r_T, from the length of the workpiece l_W and from the dimensional parameters of the grinding machine l_1, l_2 and l_3. The value of programmed coordinates y_P and z_P is described by the equations 9.

$$y_P = l_3 - r_T - P_y \quad \text{and} \quad z_P = l_1 + l_2 - l_W + P_{x'} - l_T \tag{9}$$

The position of the X axis is given by an additional dimensional parameter of the machine. In desired position of the workpiece, the rotary table is tilted and the workpiece axis x' lies in the plane of the spindle stock movement.

5 Verification of algorithms

The developed algorithms have been implemented in the object oriented programming language JAVA. The application can be used for automated creation of NC programmes from given control points of a workpiece contour and additional technological parameters. The functionality of the developed system has been tested on the workpiece with a contour that consists of several linear and circular (CW and CCW) segments. For machining, a grinding wheel with rectangular cross section (1A1 according to the FEPA specification) has been used. The verification of the generated toolpaths has been realized by the simulation of the material removal process in the software simulation system VERICUT. During the simulation, the grinding wheel toolpath for the roughing and finishing strategy has been verified. The expected shape of the workpiece has been achieved successfully in both grinding operations. The results of the verification process are shown in Fig. 8.

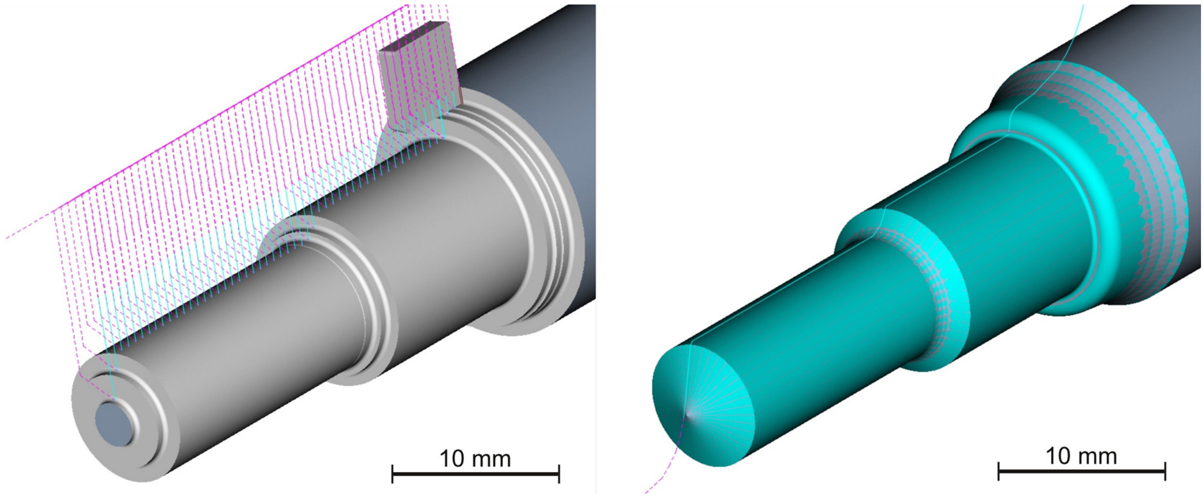

Fig. 8 Software verification of the toolpath for radial roughing (left) and finishing (right)

6 Conclusion

The automated system for computer aided NC programming offers a powerful tool for effective preparation of NC programmes. The presented system features the strategies for roughing and finishing. Due to its open architecture, the user has full control over all details of implemented algorithms. The access to the source code of the application allows the implementation of new functions and the optimization of the existing algorithms in the future.

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