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COMPENSATION OF THE TRAJECTORY OF THE SHAPING ROLLER WITH A COMPLEX SURFACE-PROFILE IN THE MACHINE SPINNING PROCESS

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Summary

The paper raises the issues of the computerized support of the determination of the trajectory of the shaping roller movement with the compensation corrections taken into consideration, resulting from an complex profile of the working roller. Double radius rollers have been considered with a number of favourable operation features but requiring an increased amount of labour at the stage of the development of the control software. Two approaches to the solution of the problem have been suggested: analytical and geometrical one in both online and offline version. The work has been illustrated with practical examples.

Keywords: Machine spinning, CAPP, Parametric programming

Kompensacja trajektorii rolki formującej o złożonym zarysie w operacji wyoblania maszynowego

Streszczenie

W pracy przedstawiono niektóre zagadnienia komputerowego wspomagania wyznaczania trajektorii ruchu rolki formującej. Uwzględniono poprawki kompensacyjne wynikające ze złożonego zarysu części roboczej rolki. Przyjęto w rozważaniach rolki dwupromieniowe, mające wiele korzystnych cech eksploatacyjnych. Wymagają jednak zwiększonego nakładu pracy na etapie opracowania programu sterującego. Zaproponowano dwa podejścia do rozwiązania problemu: analityczne i geometryczne - w każdym z przypadków w wersji online i offline. Przedstawiono praktyczne przykłady rozwiązania omawianych zagadnień.

Słowa kluczowe: wyoblanie maszynowe, CAPP, programowanie parametryczne

1. Introduction

Conventional spinning is recognised as rotary shaping processes with long-standing traditions and promising great development perspectives. This is the method of material shaping that requires, for hand spinning, very high qualifications gained during a long-standing practice [1]. The first evidences of the use of that technology can be found in the ancient Egypt, in China in the 10th

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century, in England in the 14th century [2]. That technology has a number of merits the most important of which, among other thing, is saving in material, energy, relatively simple and cheap tooling, short time of preparation procedures, fast implementation of new processes, possibility to manufacture diverse thin-walled products, axis-symmetrical and also eccentric surfaces (Fig. 1), higher strength properties if compared to stamped products. The flaws of spinning processes include the possibility of the formation of crimps/wrinkles on the ring/circle and/or metal sheet cracking caused by the exceeding permissible stresses. At present hand spinning still predominates [1], but it requires a high worker experience and his permanent presence during spinning. Automated machine spinning gained a serious importance in of the 1990s. It was connected with the expansion of CNC machine tools, and at present also with more and more discernible shortage of high-skilled hand spinners.

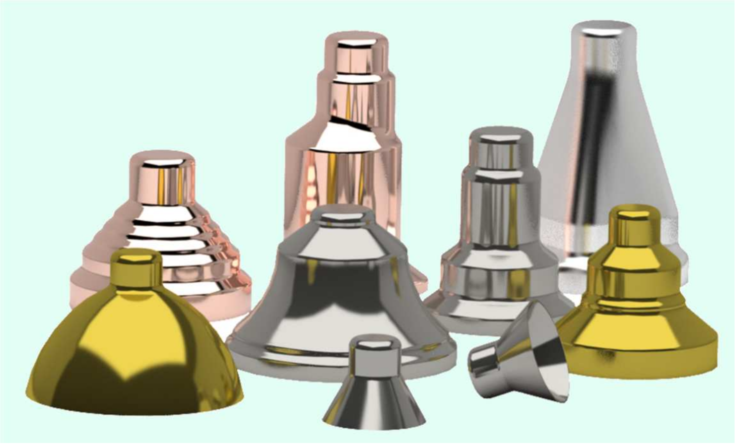


Fig. 1. Examples of the product shapes obtained with the spinning technique

At present the biggest barrier for the machine spinning technique is seen in the stage of the designing of spinning process. The benefits listed above, as short time and low costs of the implementation of new production can be achieved only when the first spinning attempts have proceeded correctly. Otherwise high material losses and delays could be expected at the stage of the implementation of a new product to production. Still not solved problem so far is the designing of the trajectory of the tool movements, and the “development of the software to control the roller movement is the most difficult part in the entire designing process” [3]. Hence, a work has been undertook in the Department of Machine Technology and Automation of the University of Bielsko-Biała aimed at the development and testing of the techniques supporting the stage of the designing and programming of the movement of the shaping roller in the operation of machine spinning. The paper presented here contains the propositions of the solution of one of the main problems occurring at the stage of the generation of the control software that comes down to the issue of taking into account the compensation corrections resulting from the rounding of the radius of the shaping roller. The automated radius compensation performed by the numerical control (NC) system is possible for the rollers with one, constant rounding radius only. As for the rollers with double rounding radius tangents the compensation corrections have to be calculated by hand. Because of that the rollers with the variable curvature of the roller profile are not used. That occurs often for some spinners manually operated since it would require the use of special, too complex techniques for the programming of movement trajectory.

At present the ability of the calculation of compensation corrections of the tool radius manually has vanished along with the popularisation of automated compensation of tool radius in 1980s. The last literature title that comprehensively described the intricate cases of radius compensation [4] also did not take into account the cases of complex tool profile. On the other hand engineers have advanced programming instruments and more and more functional numerical control systems at their disposal. In the authors' opinion the use of that potential to support the designing of manufacture operations, also within machine spinning category, would be an essential factor for the progress in this technique field.

2. Geometry of the shaping roller profiles

The shape of the roller profile should take into consideration the shape of the part being spun, wall thickness, and the dimensional accuracy of that part. Using smaller rounding radiuses can lead to exceeding the permissible stresses resulting in the manufacture of defective products. That is why most of the rough passes should be made with a roller having a bigger rounding radius. The typical shapes of spinning rollers are presented in Figs. 2a and 2b – as examples of rough rollers, and 2c – as an example of finishing roller. A reasonable solutions seems to be the all-purpose roller with two tangent radiuses of different size (Fig. 2d). A smaller, required due the construction reasons, radius shapes the metal sheet in finishing passes. This way the worked item can be shaped using one, appropriately designed

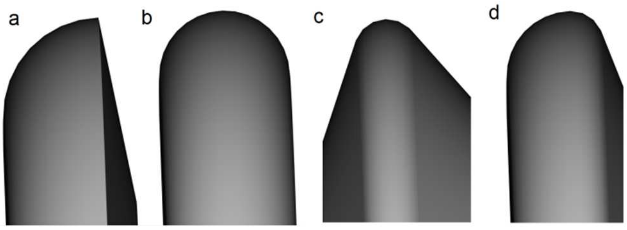


Fig. 2. Typical profiles of the shaping roller profile

and tilted roller. It is important particularly for the lathes adapted for spinning and having no turret for quick tool changing. This shortens the production cycle, often allowing for its full automation.

To obtain a correct shape of the part being spun in the last finishing pass it is necessary to take into account the compensation of the shaping roller profile radius [5]. If the rounding radius is not taken into consideration it would lead to the errors in shaping, can damage the working roller surface and bring the lathe drives to overload. In should be kept in mind that the radiuses of shaping rollers are big when compared to radiuses of the rounding of the machining plate blade. That is why the compensation corrections can be of high values. For the a, b, c, rollers shown in Fig. 2 an automated radius compensation can be applied, i.e. the G41 and G42 functions in the ISO code. For the roller shown in Fig. 2d compensation corrections have to be calculated manually, using either analytical or geometric method.

3. Analytical approach

Compensation corrections are the components of the vector in X and Z axes, said vector connecting the P point, that is the construction point of the pass between two adjacent surfaces, and the K code point (please see Fig. 3) the location of that is described by the directly programmed trajectory of tool movement.

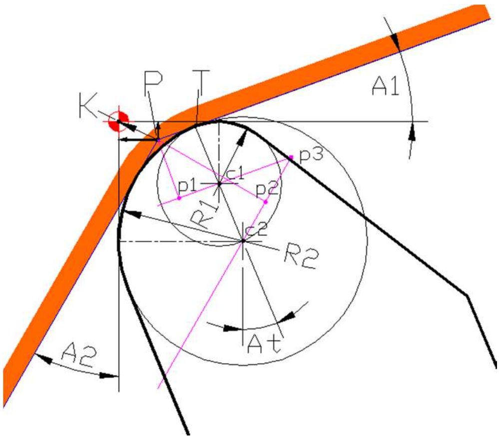


Fig. 3. Variable parameters affecting the values of compensation corrections

In Figure 3 a very typical situation of the passing between the first conical surface (in particular case the cylindrical surface for $A_1 = 0$) and the next conical surface is presented. The figure contains a sketch of the roller with identification of variable arguments affecting the values of the compensation corrections. Five variable parameters should be taken into account: R_1 and R_2 – as the radiuses of the rounding of the roller profile, A_1 and A_2 – as the angles of the tilt of the surfaces being spun, And A_t as the angle determined by the "T" tangency point of the rounding radiuses. The A_r angle (Fig. 4) of the roller tilt does not affect directly the compensation corrections but it has an essential impact on the A_t angle value.

Based on the sketch shown in Fig. 3 the formulas for the PK_Z, PK_X compensation corrections can be derived. The origin of the local system of coordinates was located in the P point. First, the coordinates of the 2 auxiliary p_1 and p_2 points should be determined that are the points of crossing the straight lines drawn from the P point and being perpendicular to the offset lines going through the c_1 and c_2 (1, 2, 3, 4) centres. The point of crossing of the two offset lines is determined by the p_3 point (5, 6). The solution of the $p_3 \rightarrow c_1 \rightarrow c_2$ triangle makes it possible to determine the components of the c_1 and c_2 (9, 10) section in the adopted system of coordinates. Finally compensation corrections are calculated from the (11) and (12) formulas:

$$Z_1 = R_1 \cos(90 - A_1) \tag{1}$$

$$X_1 = R_1 \sin(90 - A_1) \tag{2}$$

$$Z_2 = R_2 \cos(A_2) \tag{3}$$

$$X_2 = R_2 \sin(A_2) \tag{4}$$

$$Z_3 = \frac{X_2 - Z_2 \tan(90 + A_2) - X_1 + Z_1 \tan(180 - A_1)}{\tan(-A_1) - \tan(90 + A_2)} \tag{5}$$

$$X_3 = Z_3 \tan(-A_1) + X_1 - Z_1 \tan(180 - A_1) \tag{6}$$

$$dR_z = (R_2 - R_1) \cos(270 - A_t) \tag{7}$$

$$dR_x = (R_2 - R_1) \sin(270 - A_t) \tag{8}$$

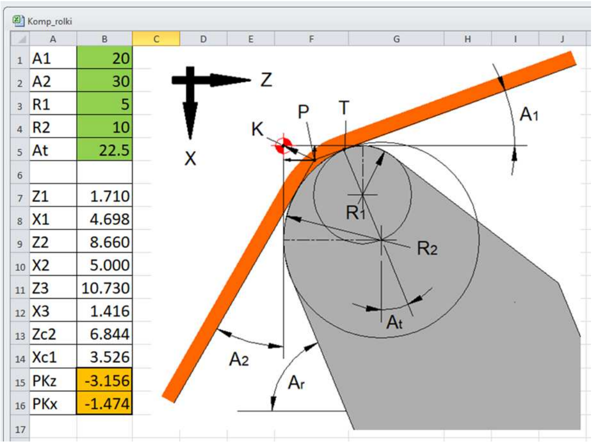
$$ZC_2 = \frac{dR_z * tan(-A_1) + Z_1 \tan(180 - A_1) - X_2 + \tan(90 + A_2) - dR_x}{\tan(90 + A_2) - \tan(-A_1)} \tag{9}$$

$$XC_1 = ZC_2 \tan(90 + A_2) + X_2 - \tan(90 + A_2) + dR_x \tag{10}$$

$$PK_Z = ZC_2 - R_2 \tag{11}$$

$$PK_X = XC_1 - R_1 \tag{12}$$

The analytical approach can be edited in two versions: offline and online. With the online approach individual spreadsheets for the most often occurring geometric cases can be drawn up (Fig. 4). So calculated compensation corrections require a manual consideration in the programmed code describing the trajectories of the tool movement.



	A	B
1	A1	20
2	A2	30
3	R1	5
4	R2	10
5	At	22.5
6		
7	Z1	1.710
8	X1	4.698
9	Z2	8.660
10	X2	5.000
11	Z3	10.730
12	X3	1.416
13	Zc2	6.844
14	Xc1	3.526
15	PKz	-3.156
16	PKx	-1.474
17		

Fig. 4. The variables determining the profile of the shaping roller with a complex profile

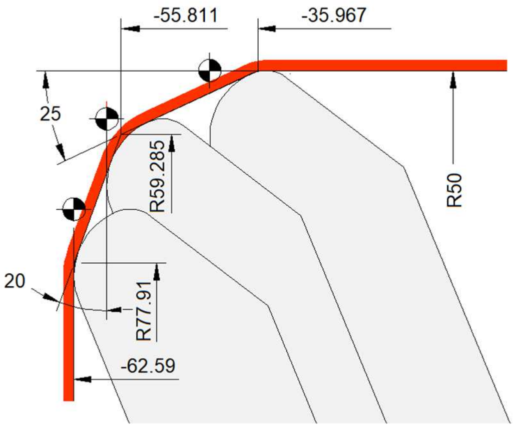
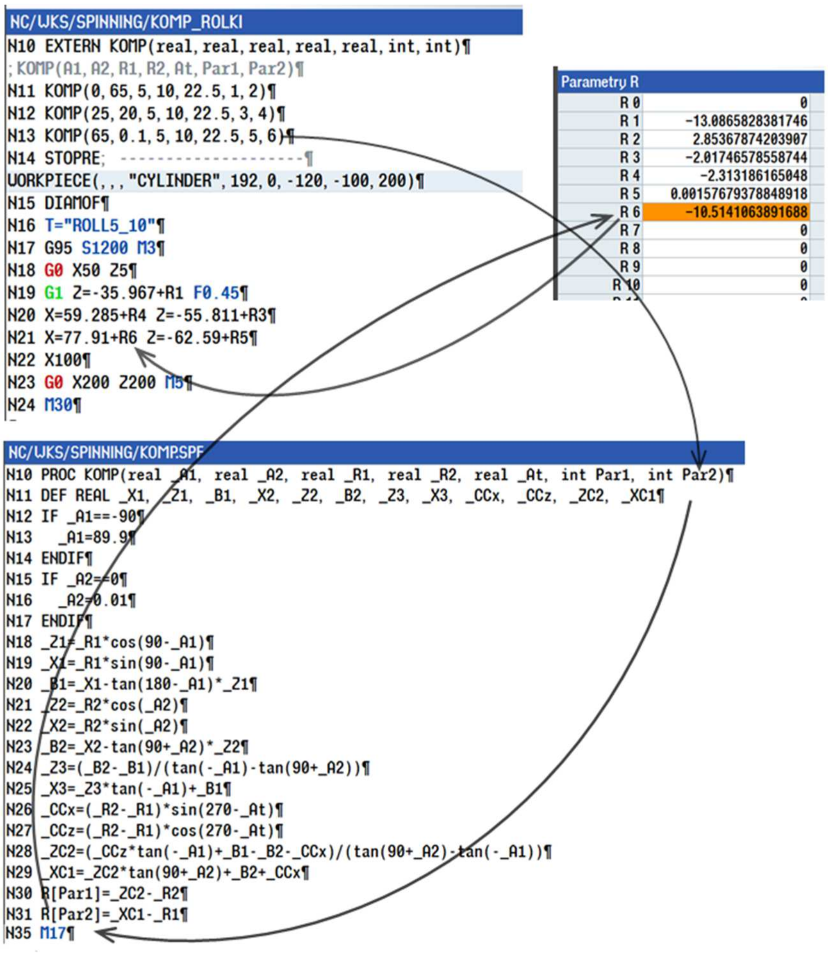


Fig. 5. Example of shaping with the use of a roller with a complex profile

A more advanced way is the workshop-oriented method basing on the possibilities of parametric programming. By using in the control program the procedures [6] connected with the calculations with the use of variable parameters correct movement trajectories can be quickly generated directly on the lathe. In figure 5 an example of the shaping of metal sheet with the use of a roller with complex profile is shown. This would require to calculate compensation corrections for three points. Figure 6 shows the connections in the machining program with the use of the technique of program procedures. In the beginning of the main program the procedure name and the type of variables should be defined, whereas the last two variables are the indices of the R-parameters, available as a standard in the numerical control system. Then in the main program a procedure is called up for each calculated program. After that step the tool movement trajectory can be edited where corresponding values of the geometric addresses are represented as the rated value plus compensation correction (blocks N30 and N31 in Fig. 6).



NC/WKS/SPINNING/KOMP_ROLKI

```
N10 EXTERN KOMP(real, real, real, real, real, int, int)¶
; KOMP(A1, A2, R1, R2, At, Par1, Par2)¶
N11 KOMP(0, 65, 5, 10, 22.5, 1, 2)¶
N12 KOMP(25, 20, 5, 10, 22.5, 3, 4)¶
N13 KOMP(65, 0.1, 5, 10, 22.5, 5, 6)¶
N14 STOPRE;  --------------------¶
WORKPIECE(,,,"CYLINDER", 192, 0, -120, -100, 200)¶
N15 DIAMOF¶
N16 T="ROLL5_10"¶
N17 G95 S1200 M3¶
N18 G0 X50 Z5¶
N19 G1 Z=-35.967+R1 F0.45¶
N20 X=59.285+R4 Z=-55.811+R3¶
N21 X=77.91+R6 Z=-62.59+R5¶
N22 X100¶
N23 G0 X200 Z200 M5¶
N24 M30¶
```

Parametry R

R 0	0
R 1	-13.0865828381746
R 2	2.85367874203907
R 3	-2.01746578558744
R 4	-2.313186165048
R 5	0.00157679378848918
R 6	-10.5141063891688
R 7	0
R 8	0
R 9	0
R 10	0

NC/WKS/SPINNING/KOMP.SPF

```
N10 PROC KOMP(real _A1, real _A2, real _R1, real _R2, real _At, int Par1, int Par2)¶
N11 DEF REAL _X1, _Z1, _B1, _X2, _Z2, _B2, _Z3, _X3, _CCx, _CCz, _ZC2, _XC1¶
N12 IF _A1==-90¶
N13   _A1=89.9¶
N14 ENDIF¶
N15 IF _A2==0¶
N16   _A2=0.01¶
N17 ENDIF¶
N18 _Z1=_R1*cos(90-_A1)¶
N19 _X1=_R1*sin(90-_A1)¶
N20 _B1=_X1-tan(180-_A1)*_Z1¶
N21 _Z2=_R2*cos(_A2)¶
N22 _X2=_R2*sin(_A2)¶
N23 _B2=_X2-tan(90+_A2)*_Z2¶
N24 _Z3=(_B2-_B1)/(tan(-_A1)-tan(90+_A2))¶
N25 _X3=_Z3*tan(-_A1)+_B1¶
N26 _CCx=(_R2-_R1)*sin(270-_At)¶
N27 _CCz=(_R2-_R1)*cos(270-_At)¶
N28 _ZC2=(_CCz*tan(-_A1)+_B1-_B2-_CCx)/(tan(90+_A2)-tan(-_A1))¶
N29 _XC1=_ZC2*tan(90+_A2)+_B2+_CCx¶
N30 R[Par1]=_ZC2-_R2¶
N31 R[Par2]=_XC1-_R1¶
N35 M17¶
```

Fig. 6. Diagram for the calculation and flow of the data for the R6 parameter

An intermediate solution between the analytical and geometric approaches is to create an application (Fig. 7) in the CAD system enabling the user, with the use of simple measures, in the dialog box, to declare the data for a concrete case. The result is receiving immediately the correction values and graphical visualisation of the declared geometry of the roller profile. A change of any input data dynamically changes the graphical image.

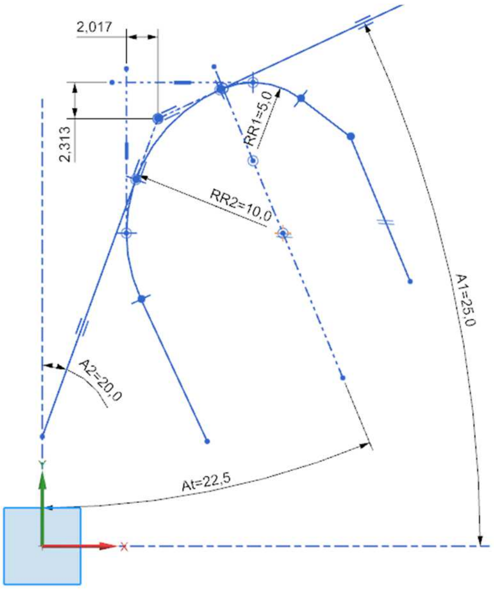


Fig. 7. Example of a graphical application to determine compensation corrections

4. Geometric approach

The geometric approach enables to use the possibilities of the modern CAD/CAM systems and numerical control systems to generate the code of the program that automatically carries out the control process based on the existing trajectory of the movement of the tool code point. The user using the diagram containing the selected roller shape and the location of the tool code point adjusts the roller profile to the characteristic profile points of the part being spun (please see Fig. 8). Then the user connects next points with straight lines or arcs, depending on the shape of the part being spun. It is good to keep so generated tool movement trajectory on a separate drawing layer and save the drawing in drawing exchange format DXF format.

Next steps require a CAM specialist software. This software is made available by, among others, the manufacturers of numerical control systems. After the file in DXF is loaded the unnecessary drawing layers have to be removed but remaining the elements of the code point patch only (Fig. 9). Then the automatic conversion of geometric data to the G-code is initiated (Fig. 10). A machining simulator enables the verification of the generated program code (Fig. 11). In the online mode, the newest versions of numerical control systems enable to carry out the same task directly in the production workshop in the system of the numerical control of machine tool.

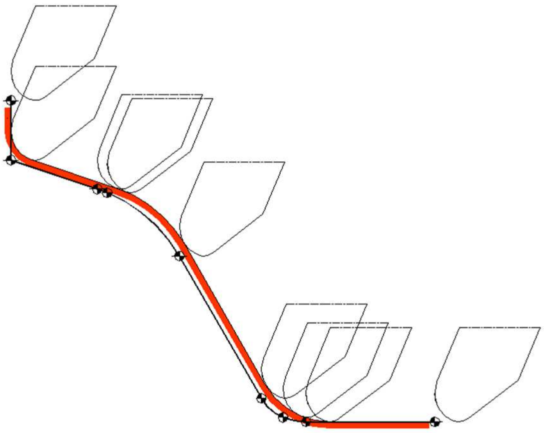


Fig. 8. An example of the generated patch of the code point of shaping roller

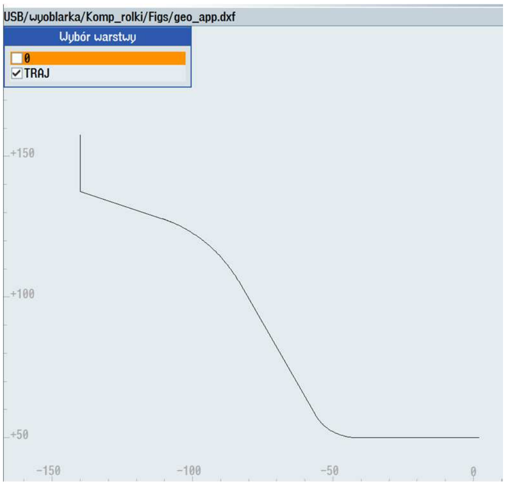


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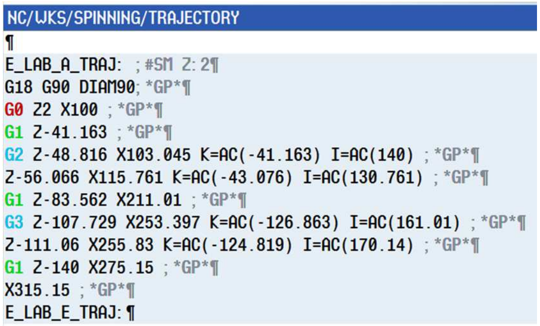
Fig. 9. The patch of the code point with removed unnecessary drawing layers



```
¶
E_LAB_A_TRAJ:  ; #SM Z: 2¶
G18 G90 DIAM90; *GP*¶
G0 Z2 X100 ; *GP*¶
G1 Z-41.163 ; *GP*¶
G2 Z-48.816 X103.045 K=AC(-41.163) I=AC(140) ; *GP*¶
Z-56.066 X115.761 K=AC(-43.076) I=AC(130.761) ; *GP*¶
G1 Z-83.562 X211.01 ; *GP*¶
G3 Z-107.729 X253.397 K=AC(-126.863) I=AC(161.01) ; *GP*¶
Z-111.06 X255.83 K=AC(-124.819) I=AC(170.14) ; *GP*¶
G1 Z-140 X275.15 ; *GP*¶
X315.15 ; *GP*¶
E_LAB_E_TRAJ: ¶
```

Fig. 10. Generated G-code describing the coded trajectory of the tool movement

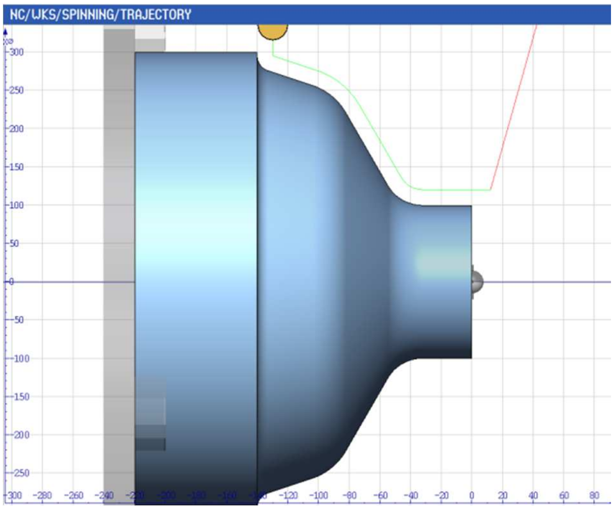


Fig. 11. Verification of the software correctness through graphical simulation

5. Intricate case of movement trajectory

Starting from 1960s the most appropriate trajectories of initial passes in the process of rotary shaping were examined. Predominant is the view that the most appropriate movement trajectory is that of arc-concave type, preventing to some degree, the formation of crimps/wrinkles [3, 7-10]. The most often some attempts to model it as a Bezier quadratic curve are made [10]. The issue of taking into account the compensation of the roller profile rounding radius is even more complicated in this case. A more practical solution seems to be the use of an ellipse section. That shape can be obtained in the NC software by re-scaling of the circle arc within the selected machine tool axis (e.g. Z in the Fig. 12).

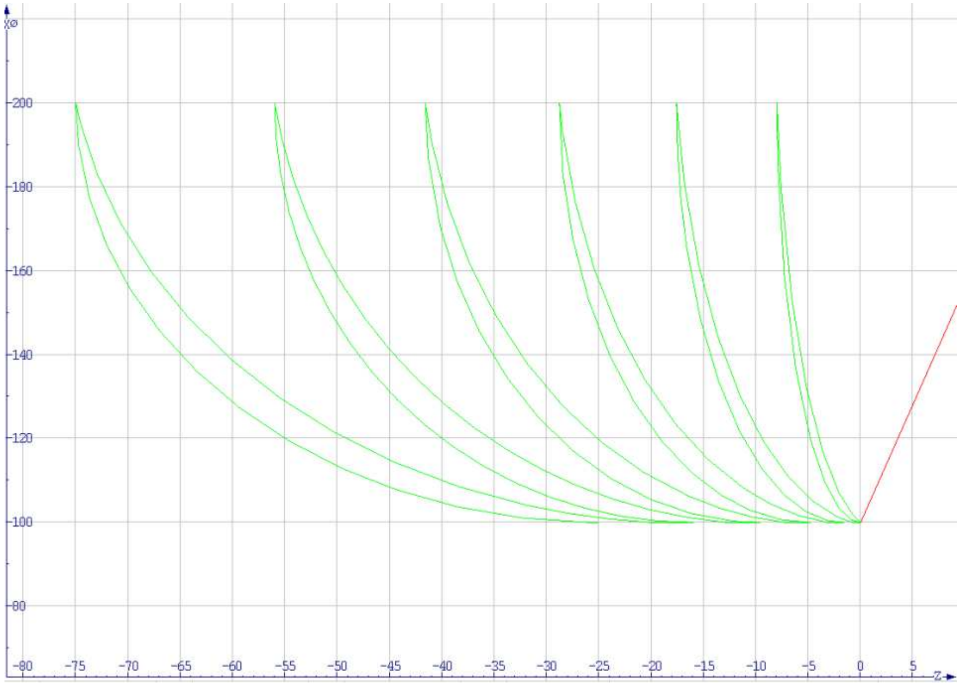
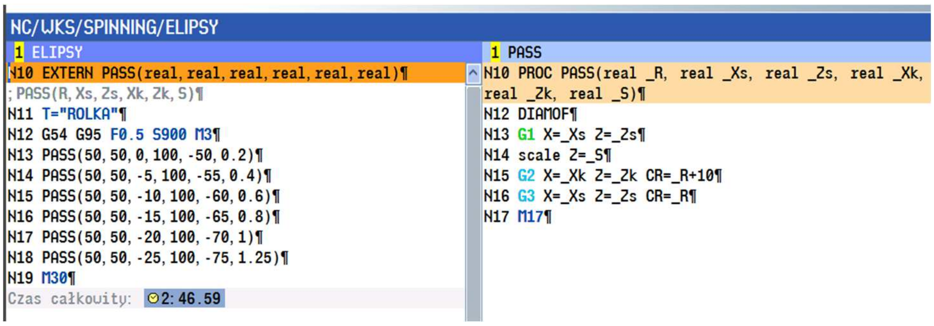


Fig. 12. An example of arc-concave trajectories

Assuming that the point of the contact of the shaping roller with the material being spun will be located in the area of the profile of the roller with constant radius the code point will be moving along the trajectory generated as the arc offset with requested radius, shifted by the values of compensation corrections. The use of the automated compensation in this case can lead to undesirable tool movements. Figure 13 is the conformation that the programming of the trajectory of this type is simple.



```
N10 EXTERN PASS(real,real,real,real,real,real)¶
; PASS(R,Xs,Zs,Xk,Zk,S)¶
N11 T="ROLKA"¶
N12 G54 G95 F0.5 S900 M3¶
N13 PASS(50,50,0,100,-50,0.2)¶
N14 PASS(50,50,-5,100,-55,0.4)¶
N15 PASS(50,50,-10,100,-60,0.6)¶
N16 PASS(50,50,-15,100,-65,0.8)¶
N17 PASS(50,50,-20,100,-70,1)¶
N18 PASS(50,50,-25,100,-75,1.25)¶
N19 M30¶
Czas całkowity: 2:46.59
```

```
N10 PROC PASS(real _R, real _Xs, real _Zs, real _Xk,
real _Zk, real _S)¶
N12 DIAMOF¶
N13 G1 X=_Xs Z=_Zs¶
N14 scale Z=_S¶
N15 G2 X=_Xk Z=_Zk CR=_R+10¶
N16 G3 X=_Xs Z=_Zs CR=_R¶
N17 M17¶
```

Fig. 13.Technological programs generating an arc-concave trajectory for the spinning roller

6. Conclusion

The production potential for the machine spinning is immense, but so far used to a limited degree only. This is because there are some difficulties technologists come across at the phase of the designing of an appropriate course of the machine spinning process. The stage of the implementation of a new production can be extended and generate high material costs. To help to solve those problems the first thing is to generate correctly the trajectories of the movement of the shaping roller with taking into account its actual profile. No correct control of the thickness of the wall of the element being shaped as well as the stresses in the material being spun can be maintained if the relative location of the shaping roller, plastically deformed material, and the former is not precisely determined. Lack or incorrectly calculated compensation corrections can cause an overload of the machine tool driving systems, particularly at the finishing passes, and consequently downtimes in operation. The paper presents a set of the methods facilitating to overcome those barriers and achieve a progress in the popularization of the machine spinning technology.

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