

Metric Buttress Thread Milling and Turning on CNC Machines

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ABSTRACT

Present-day catalogues of tool manufacturers do not contain information on milling cutters for planetary milling of metric buttress threads with nominal pitches on computer numerical control (CNC) machines. This paper presents the results of theoretical and experimental investigation of buttress threads cutting on 3-axis CNC machines. The theoretical investigation is based on the kinematic method of envelope determination. This analytical solution has been verified by the solid modelling method and experiments. It has been proven that standard metric buttress threads with nominal pitches cannot be cut by planetary milling on the 3-axis CNC machines. At the same time, metric buttress threads with small pitches can be produced; such cases are described in this paper. However, thread surface quality after planetary milling is problematic. The technology of initial productive thread milling followed by final thread turning is suggested to obtain metric buttress thread using a new type of milling-turning cutters. The results of this investigation can be useful for industrial plants if buttress thread milling on 3-axis CNC machines is necessary.

Keywords: Thread; metric buttress; planetary milling; thread turning; buttress thread milling-turning cutter; CNC machine.

INTRODUCTION

Recently, thread cutting on 3-axis CNC milling machines has gained widespread acceptance in manufacturing. Among various thread types there are some special – buttress ones [1-3]. As an example, the authors set the task of obtaining S32x4 buttress thread with flank angles equal to 3° and 30° using a cutter with 22.9 mm diameter on the Mori Seiki NT-4200 DCG/1000S multi-axis mill-turn centre. This thread is analogous to DIN 513 metric buttress ($3^\circ/30^\circ$) screw thread. However, there are no suitable milling cutters available in the catalogues of tool manufacturers [4-5]. So, the question arises as to whether it is possible to obtain such buttress threads on 3-axis CNC machines with the application of planetary cutting method. This is the main aim of this investigation.

The problem to maintain buttress thread profile accuracy is present even in thread turning, although enveloping effect is absent in that case [6, 7]. Milling is always related to enveloping. It is well-known that the solution for planetary thread milling is a type of problem based on the kinematic method of envelope determination [8-13]. An analytical approach does not always guarantee the correct solution. Thus, numerical modelling [14-16] and CAD modelling [17] is often used. Calculating the helical groove profile and eliminating the trial and error approach are important tasks. Yet, there are

not usable solutions to determine thread profile when using planetary milling. Chiang and Fong proposed a geometric approach to determine the grinding wheel profile and conditions to avoid undercutting by using a tilt grinding wheel axis [10]. However, 3-axis CNC machines do not have such a tilt angle. Some theoretical investigations connected with thread flank surface generation modelling, undercutting and interference elimination are known [18-20].

Fromentin et al. proposed an analysis to detect and to calculate the cutting tool and work piece parameters influencing buttress thread overcut [21]. Thus, the main question mentioned above remains an open problem. Next, it is shown that this problem requires the determination of the cut cross section area and of cutting forces [22-25]. Thread milling cutter is described as a conical machining tool surface (or a set of surfaces). Either way, the profile of such conical surfaces cannot coincide with any of thread profiles. Usually these tasks are classified into two types. The first type is if the thread surface and tool movement are known and the tool profile has to be determined. The second is if the tool profile and its movement are known and the thread surface profile has to be determined. In the first case, a machine tool surface has to be created. In the second case, a machined surface has to be created. Taking these conditions into account, thread and tool parameters which enable the production of buttress threads, have been determined. First of all it has been necessary to modify some equations, as the existing ones cannot be used for planetary thread milling on 3-axis CNC machines.

THEORETICAL SOLUTION BASED ON THE KINEMATIC METHOD OF ENVELOPE DETERMINATION

Milling Cutter Profile Points Determination - First Tool Task

Source data: D and D_1 represent major and minor diameters of internal thread as depicted in Figure 1 (a); P – thread pitch; α – lesser flank angle; d_m – major diameter of the milling cutter. It necessary to determine: x_{mei} and z_{mei} – point coordinates of axial profile of the machining surface.

Solution: There are some well-known methods of axial profile calculation of a rotational tool in helical surface cutting [8]. However, the equations used for these methods are incorrect if the angle between the tool and the thread axis is equal to zero (as in the case with 3-axis CNC milling machines). So, these equations have to be modified. The method has several stages.

- a) Let us have a set of points (i) that are placed on the right thread profile (Figure 1, a). Their radiuses are: $R_i = D/2 \dots D_1/2$.
- b) The coordinates of each point can be calculated as in Eq. (1).

$$Z_{0i} = (R_i - D_1/2) \operatorname{tg}(\alpha) \text{ and } X_{0i} = R_i \quad (1)$$

- c) According to the contact relations, the contact angles δ_{ei} , ($e = 1, 2$) of each point can be determined as in Eq. (2).

$$\delta_{ei} = \xi_{ei} + \eta_{ei} \quad (2)$$

where $\xi_{1i} = \operatorname{arctg}(X_{0i} \operatorname{tg}(\alpha) (2\pi)/P)$,

$$\xi_{2i} = \xi_{1i} + \pi,$$

$$\eta_{ei} = \arccos(2 \cos(\xi_{ei}) X_{0i} / (D - d_m)).$$

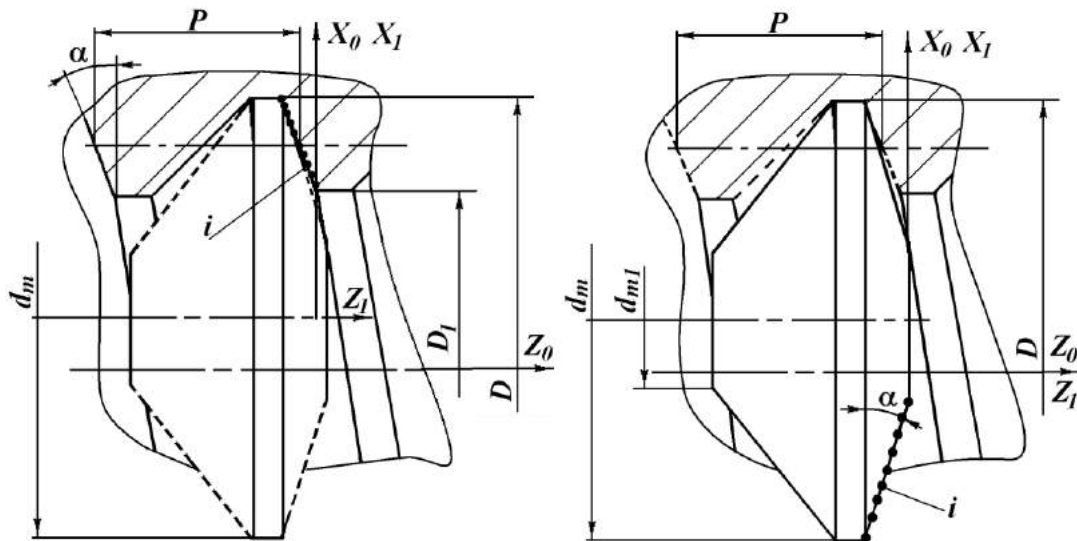


Figure 1. Profile solution scheme of (a) tool and; (b) thread.

- d) In the work piece coordinate system, the point coordinates of the contact line can be calculated as in Eq. (3).

$$x_{0ei} = R_i \cos(\delta_{ei}), \quad y_{0ei} = R_i \sin(\delta_{ei}), \quad z_{0ei} = z_{0i} + P\delta_{ei}/(2\pi) \quad (3)$$

- e) In the tool coordinate system, the coordinates of the same points can be determined as in Eq. (4).

$$x_{1ei} = x_{0ei} - (D - d_m)/2, \quad y_{1ei} = y_{0ei}, \quad z_{1ei} = z_{0ei} \quad (4)$$

- f) Finally, the coordinates of each point of milling cutter profile can be calculated as in Eq. (5).

$$x_{mei} = \sqrt{(x_{1ei}^2 + (y_{1ei}^2))}, \quad z_{mei} = z_{1ei} \quad (5)$$

Thread Profile Points Determination - Second Tool Task

Source data: d_m and d_{m1} are the major and minor diameters of the milling cutter (Figure 1, b); P – thread pitch; α – lesser flank angle; D – major thread diameter. Point coordinates of the thread profile x_{1i} and y_{1i} have to be determined.

Solution. The following calculation stages have been performed with the use of the above-mentioned method with modified equations:

- a) Let us have a set of points (i) that are placed on the tool profile as in Figure 1 (b). Their radiuses are: $R_i = d_{m1}/2 \dots d_m/2$.

- b) From the contact relation, the contact angles δ_i of each point can be determined as in Eq. (6).

$$\delta_i = -P \arcsin(\operatorname{tg}(\alpha)) / (\pi(D - d_m)) \quad (6)$$

- c) In the tool coordinate system, the point coordinates of the contact line can be calculated as in Eq. (7).

$$\begin{aligned} x_{0i} &= R_i \cos(\delta_i + (D - d_m)/2), \\ y_{0i} &= R_i \sin(\delta_i), \\ z_{0i} &= (R_i - d_m/2)\operatorname{tg}(\alpha) \end{aligned} \quad (7)$$

- d) In the work piece coordinate system, the coordinates of the same points can be determined as in Eq. (8).

$$x_{1i} = -y_{0i} + \varphi_i P / (2\pi), \quad y_{1i} = x_{0i} \cos(\varphi_i) - z_{0i} \sin(\varphi_i) \quad (8)$$

where, $\varphi_i = -\operatorname{arctg}(z_{0i}/x_{0i})$.

The described method has been tested by cutting buttress threads conforming the requirements of the main standards – DIN 513 (FDR), GOST 10177-82 (RU) and ANSI B 1.9 – 1973 (USA). The obtained results are depicted in Figure 2. The two rows of numbers on the horizontal axis represent the thread diameters and their nominal or maximal pitches. Four graphs correspond to four diameters of the milling cutters: $k = d_m/D$, $k = 0.3; 0.5; 0.7; 0.8$, respectively.

As depicted in the figures, the results of the first and the second tasks indicate close proximity between their values, proving their reliability. The results also illustrate that it is impossible to cut buttress threads ($\alpha = 3^\circ$) with the use of planetary milling and that decreasing the milling cutter diameter allows for a decrease of work piece thread profile angle.

As mentioned above, the correct cutting is possible if the machined surface has been calculated using modelling. However, this calculation is insufficient. As follows in Section 3, none of the calculated profiles is placed between the minor and major diameters of these threads. The cylindrical part of the milling cutter machining surface can cut only the cylindrical part of the thread. It means that the helical part of the thread that is placed between the minor and major diameters can only be cut by cutting edges placed on the circle connecting the cylindrical surface of the milling cutter to its conical surface.

A new formula for the second tool task has been developed to prove this suggestion as shown in Figure 3. Obviously, in this case, the described scheme is correct, except for $z_{0i} = 0$ and $R_i = d_m/2$. The angle δ_i has to be calculated from 0 to δ_{\max} , as in Eq. (9).

$$\delta_{\max} = \arccos[((D/2 - (D - D_1)/2)^2 - (d_m + (D - d_m))^2) / (d_m (D - d_m)/4)] \quad (9)$$

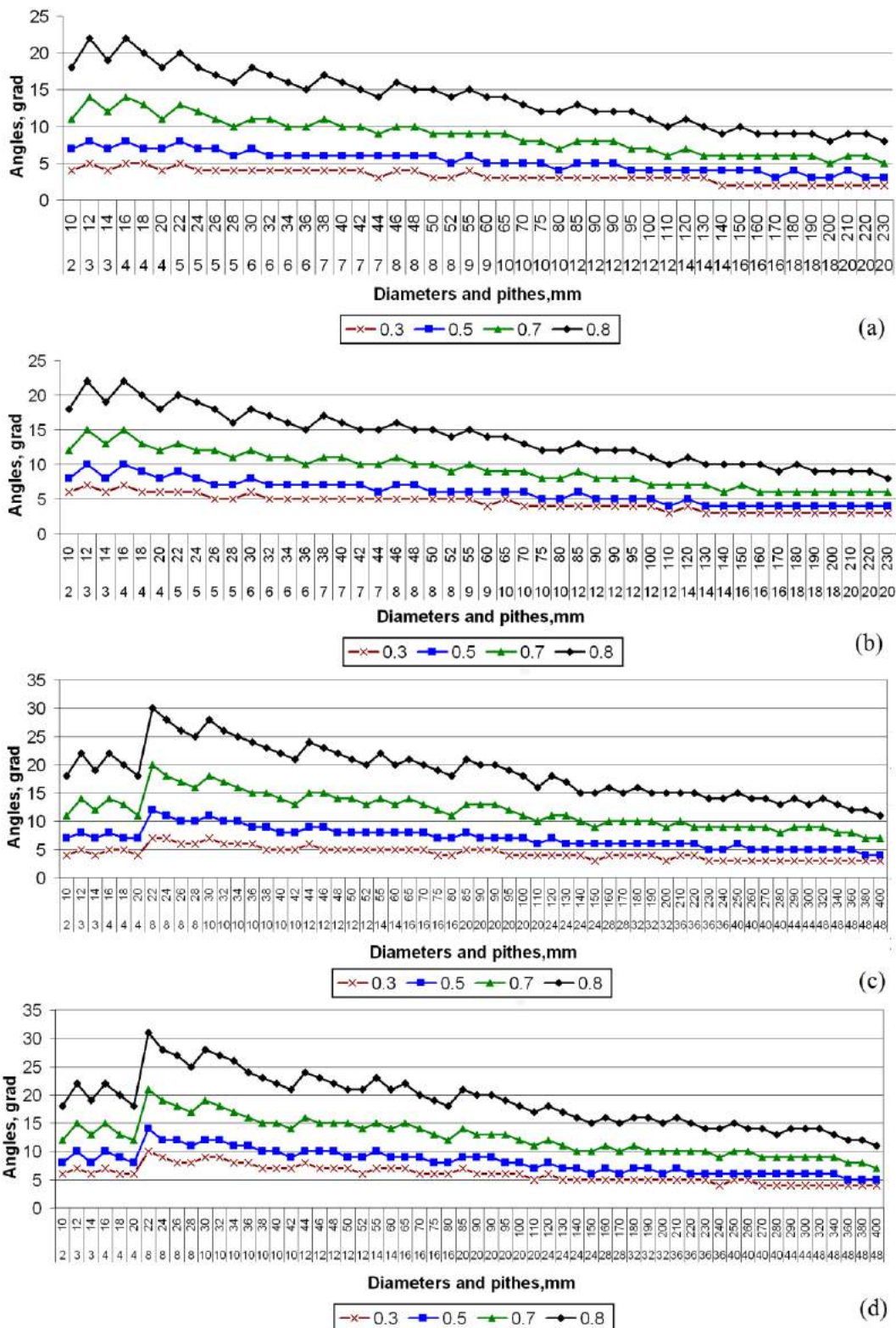


Figure 2. Minimal flank angles of threads with nominal pitches of the (a) first and; (b) second tool task. Maximal pitches of the (c) first and; (d) second tool task.

The impossibility of obtaining buttress threads with large and nominal pitches does not exclude cutting of such threads with small pitches. So, the second tool task has

been solved. Thread pitches from 1 to 10 mm have been examined. In addition, the absence of major diameter restriction of the buttress threads has been considered in accordance with the standards. Figure 3 depicts the smallest possible thread diameters and pitches that can be cut by planetary milling on 3-axis CNC machines.

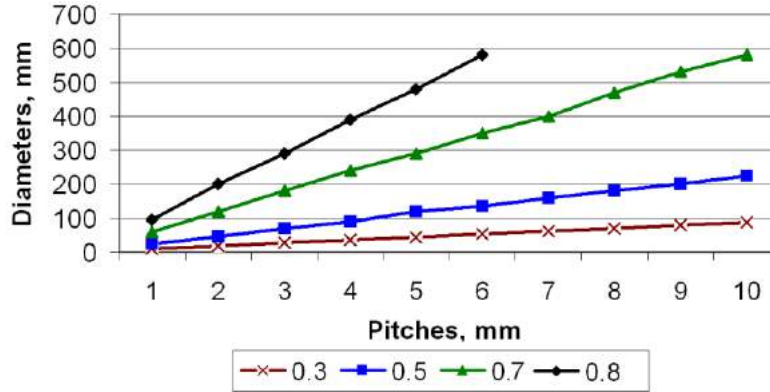


Figure 3. Minimum possible thread diameters with standard pitches.

DEVELOPMENT OF PROCESSING METHOD OF PRELIMINARY PRODUCTIVE THREAD MILLING FOLLOWED BY FINAL THREAD TURNING

As not all of required buttress thread diameters and pitches can be obtained by thread planetary milling it is offered to use this processing method as preliminary high-efficiency operating step followed by final turning, a less effective step.

Obviously, operation productivity depends heavily on metal volume removed during the first milling pass. In that case, minimal metal volume has to be deleted during the second turning pass. So, this pass is a single one. In view of this fact, it is necessary to find a point on the milled thread profile to locate the turning tool corner at this point.

The coordinates of the thread points can be determined from 1.2 in the work piece coordinate system. In rotation of the coordinate system on complementary flank angles (equal to $90 - \alpha = 87^\circ$) points coordinates are transformed as in Eq. (10).

$$x_{2i} = x_{1i} \cos(90 - \alpha) + y_{1i} \sin(90 - \alpha), y_{2i} = -x_{1i} \sin(90 - \alpha) + y_{1i} \cos(90 - \alpha) \quad (10)$$

Next, the derivation has to be determined and equalled to zero as in Eq. (11).

$$\left(\frac{d}{d\delta_t} x_{2i} \right) / \left(\frac{d}{d\delta_t} z_{2i} \right) = 0 \quad (11)$$

From this equation, the parameter δ_t of the tangent line and contact point coordinates can be obtained. Correspondingly, the parameter b of tangent line equation can be calculated by Eq. (12).

$$b = x_{1i}(\delta_t) - z_{1i}(\delta_t) \tan(\alpha) \quad (12)$$

The point of intersection between the tangent line and the line on the major diameter of the thread cutter can be determined by z coordinate as in Eq. (13).

$$z_{1t} = x_{1i}(\delta_t) / \tan(\alpha) \tag{13}$$

The point coordinates of the left and right profiles give the crest width of the new milling cutter. This size and the crest width of the thread give a machining allowance for turning. It also gives thread turning tool corner location respective to the profile points as shown in Figure 4.

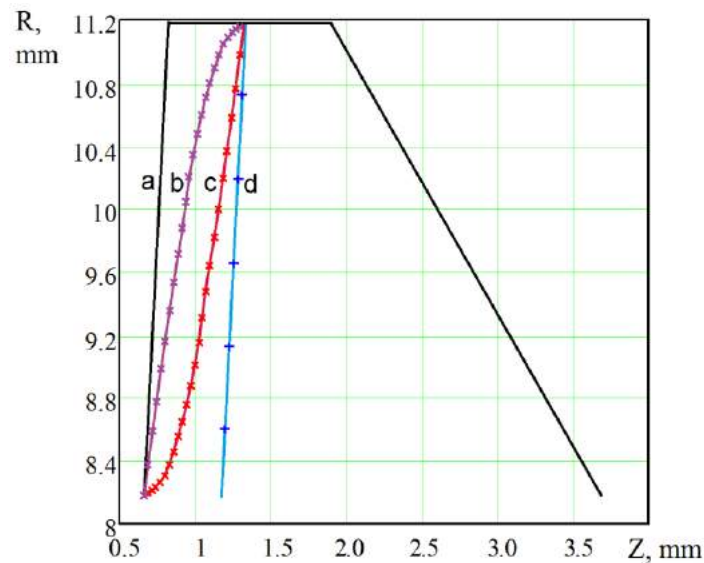


Figure 4. Profile of (a) standard thread, (b) thread obtained by milling cutter, (c) calculated milling cutter profile based on standard work piece thread profile, (d) straight line of the milling cutter forming the profile (b).

VERIFICATION OF THE OBTAINED RESULTS BY SOLID MODELING

As mentioned above, the obtained theoretical results show that planetary milling of S32×4 buttress threads is impossible on a 3-axis machine. Previously, using the obtained equations, some data about the tool and work piece has been calculated. Then, a model has been developed with SolidWorks software to test this analytical calculation.

The First and Second Tool Task Calculations

The milling cutter profile for S32×4 buttress threads was calculated using the equations obtained above. This calculation shows that the correct profile can be obtained if the milling cutter diameter is equal to 12.679 mm ($d_m/D = 0.3953$), profile angle equal to 4° , and tooth height equal to 7 mm. At the same time, y_{lei} coordinates are almost two times more than the expected tool radius (Table 1, Part №1), thus, the work piece is defective.

The second tool task has been solved to test this result. The milling cutter must have a profile angle equal to 4.745° , diameter equal to 16.6 mm, and tooth height equal to 4.67 mm. Other parameters are given in Table 1, Part №2.

These results show that even if the thread profile height is 3 mm, this profile is still placed much lower than the minor thread diameter. So, the required thread cannot be obtained. Moreover, the other solutions show that none of the standard threads can be obtained either.

As mentioned above, the required thread profile can be cut only by cutting edges placed on a circle, connecting the cylindrical surface of a milling cutter with its conical surface. Test calculations have been completed for the milling cutter with a diameter of 22.9 mm and profile angle equal to 3° . Using the described equations, the following data has been calculated (Table 1, Part №3).

Table 1. Milling cutter parameters and thread parameters.

<i>i</i>	1	2	3	4	5	6	7	8	9	10
Part №1 – Milling cutter parameters (for S32×4)										
R_i , mm	13.00	13.33	13.67	14.00	14.33	14.67	15.00	15.33	15.67	16.00
δ_{ei} , deg	23.40	25.80	28.10	30.50	33.00	35.50	38.30	41.30	45.00	52.40
x_m , mm	4.26	4.30	4.35	4.39	4.44	4.48	4.53	4.58	4.64	4.74
z_m , mm	5.65	6.25	6.87	7.50	8.15	8.83	9.54	10.30	11.18	12.68
Part №2–Thread parameters obtained from the conical milling cutter surface (for S32×4)										
R_i , mm	3.63	4.15	4.67	5.19	5.71	6.23	6.75	7.27	7.79	8.30
δ_i , deg	85.25	85.25	85.25	85.25	85.25	85.25	85.25	85.25	85.25	85.25
x_1 , mm	0.34	0.34	0.37	0.38	0.40	0.42	0.44	0.46	0.48	0.50
y_1 , mm	8.78	9.04	9.33	9.63	9.96	10.29	10.65	11.01	11.39	11.78
Part №3 – Thread parameters obtained from the milling cutter circle (for S32×4)										
R_i , mm	11.45	11.45	11.45	11.45	11.45	11.45	11.45	11.45	11.45	11.45
δ_i , deg	0.00	8.95	17.89	26.84	35.78	44.73	53.67	62.62	71.56	80.51
x_1 , mm	1.00	0.93	0.93	0.93	0.71	0.64	0.57	0.57	0.41	0.33
y_1 , mm	16.00	15.96	15.84	15.65	15.37	15.03	14.61	14.13	13.59	13.00
Part №4 – Thread parameters obtained from the conical milling cutter surface (for S100×3)										
R_i , mm	8.950	9.23	9.51	9.78	10.06	10.34	10.62	10.89	11.17	11.45
δ_i , deg	13.58	13.58	13.58	13.58	13.58	13.58	13.58	13.58	13.58	13.58
x_1 , mm	0.598	0.61	0.63	0.64	0.65	0.67	0.68	0.70	0.71	0.72
y_1 , mm	47.55	47.82	48.09	48.36	48.64	48.91	49.18	49.46	49.73	50.00

This profile is almost straight, but its profile angle is 12.6° – much more than the required angle $\alpha = 3^\circ$. Obviously, this result has to be verified through the solid modelling method using CAD software.

The conclusion obtained above poses a practical question: if standard buttress threads with nominal pitch cannot be produced, then is it possible to cut threads with small pitch? To check this possibility, a thread with small pitch (3 mm) and large diameter (100 mm) has been cut. In this case a milling cutter with the same diameter equal to 22.9 mm ($d_m/D = 0.229$) has been used. The solution shows that the required thread profile is cut by the conical tool surface only until the diameter is within 49.75

mm. The rest of the profile has been obtained using the previously described circle. This fact is obviously not good for cutting. So, it would be better for the cutting conditions if the tool would be shifted from the workpiece axis by 0.25 mm. Data for this solution is shown in Table 1, Part №4. The profile angle for S100×3 equals to $\arctg((0.724-0.598)/(50.002-47.546)) = 2.94^\circ$.

Solving the Second Task using SolidWorks

The main goal of this stage is to check the theoretical calculations using solid modelling. At first, modelling of nominal pitch thread cutting has been accomplished. A milling cutter with diameter of 22.9 mm has been used. The modelling consists of four steps: modelling the tool conical body, modelling the tube-form work piece, modelling the helical tool motion, and subtracting the first from the second. The logical conjunction has been applied to obtain a contact line. The result of the computer modelling is shown in Figure 5 (a). The contact line is shown in Figure 5 (b) in red. As expected, this line is formed by the mentioned circle. The axis section of the work piece with the thread obtained and standard thread profiles are shown in Figure 5 (c). The points obtained by the described formulas are also shown in this figure. The coordinates of these points are shown in Table 1, Part №3.

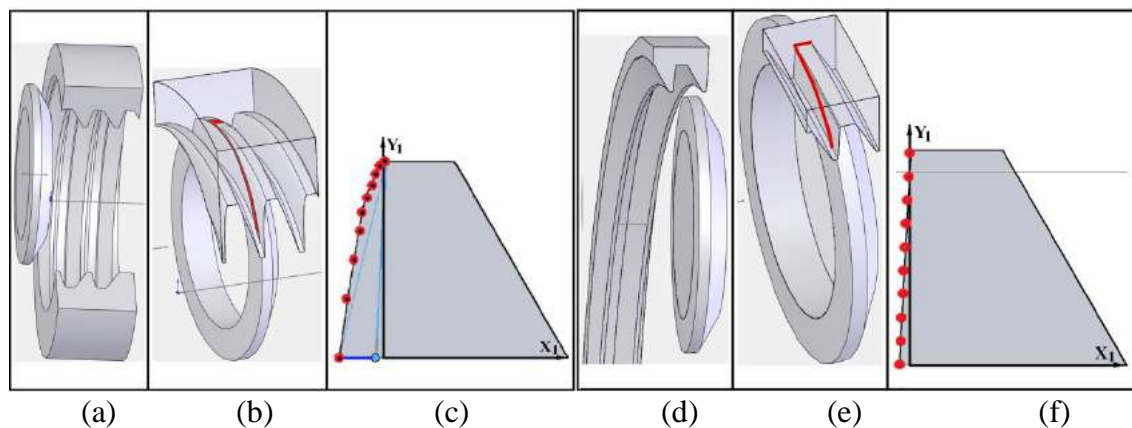


Figure 5. CAD models of (a) tool model with d22.9 mm and thread with D32 mm, (b) contact line between the tool and work piece, (c) work piece thread profile, (d) tool model with d22.9 mm and thread with D100 mm, (e) contact line between the tool and work piece, (f) work piece thread profile obtained theoretically and using SolidWorks.

In Figure 5 (c), the profiles obtained by different methods have a good agreement. In a sense, theoretical investigations and solid modelling prove the same thesis about the impossibility of cutting standard buttress threads with nominal and large pitches on 3-axis CNC milling machines. In the next stage of investigations, cutting of standard buttress threads with small pitches was examined. As stated above, solid modelling of thread cutting with diameter of 100 mm and pitch of 3 mm using a milling cutter with diameter of 22.9 mm is necessary. The models of tool and work piece are shown in Figure 5 (d). The contact surface is shown in Figure 5 (e) in red. As can be seen, the conical tool surface contacts thread surface from minor to major diameters. The remaining small part of thread is formed by the cutting edges of the above-mentioned circle.

In Figure 5 (f), thread profile modelled using SolidWorks is aligned with the theoretical profile (Table 1, Part №1). The profile angle is 2.99° . The final confirmation of the obtained theoretical method was conducted experimentally. It seems that the task of milling buttress threads with small pitches is solved. However, favourable conditions of effective chip forming for mill pressure flank edge have not yet been provided. Just a single point, a tool corner, cuts this flank surface. It is obviously inconvenient.

EXPERIMENTAL INVESTIGATION

Experiments have been performed to confirm the considered hypothesis. These experiments have been conducted using a Mori Seiki NT- 4200 DCG/1000S mill turn center and a Vargus company tool as shown in Figure 6. A milling cutter with the mentioned above diameter equal to 22.9 mm has been used. The machine settings were: internal tool holder – «NVRC17-4 156/007»; insert for thread S32×4 – «4FIR4.0SAGE 156/007» and for thread S100×3 – «4FIR3.0SAGE156/007» as shown in Figure 7 (a) [4]. Carbon steel AISI 1040 was used as a work piece material. Work pieces with overall diameters of 80 and 120 mm for S32×4 and S100×3 threads have been machined as shown in Figure 7 (b).



Figure 6. (a) Mori Seiki NT- 4200 DCG/1000S mill turn center; (b) workpiece and tool.



Figure 7. (a) Insert S32×4 and; (b) work pieces of 32 and 100 mm thread diameters.

The first steel work piece was held in the three-jaw chuck of the machining centre. Initially a hole with 26 mm diameter was cut, while the thread was cut using the same location at eleven passes. The work piece with S31×4 threads is shown by the left

work piece in Figure 7 (b). The second work piece with S100×3 threads was machined in a similar way as shown by the right work piece in Figure 7 (b).

The sections of the work pieces have been scanned on a HP 4370 scanner with a resolution of 9600 dpi. Figure 8 (a) shows a photograph of the S32×4 thread profile and the calculated profile (Table 1, Part №3). The agreement of these profiles proves the validity of the theoretical method and the conclusion that it is impossible to obtain buttress threads with nominal pitches by conical tool surfaces. Figure 8 (b) shows a photograph of the S100×3 thread profile and the calculated profile (Table 1, Part №4). The agreement of these profiles proves the possibility to obtain buttress threads with small pitches with conical tool surfaces. Therefore, we have verified Eq. (6) to (9). Using them for $d_m/D = 0.7$, graphs in Figure 2 (a) and (b) and graphs in Figure 3 have been obtained. The thread with pitch $P = 4$ for major diameter $D = 32$ cannot be milled and this fact is in agreement with this theory. At the same time the thread with pitch $P=3$ for major diameter $D=10$ can be milled, that is shown by the graphs in Figure 2 (a) and (b) and the graph in Figure 3 for $d_m/D = 0.229$.

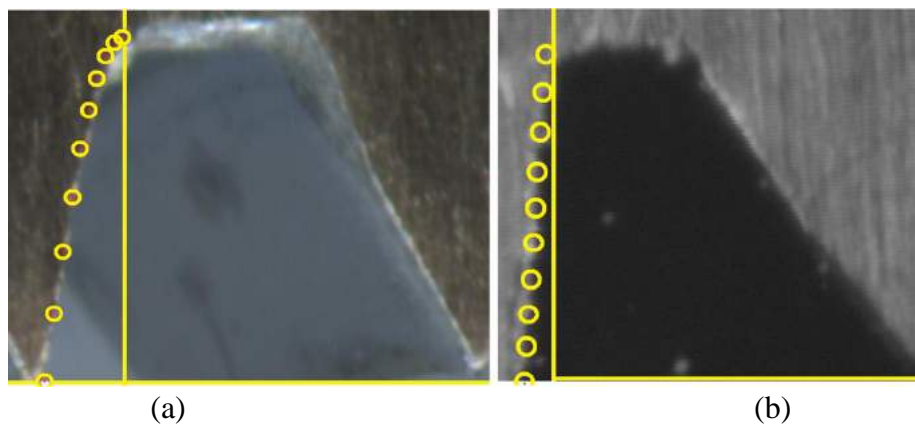


Figure 8. Thread profile of (a) S 32×4 and; (b) S 100×3.

The obtained results only give us theoretical basis to mill some of these threads. However, there is a second problem which is the problem of surface quality. In Figure 9 (a) profile surface shown has unsatisfactory roughness. So, the method of preliminary productive thread milling followed by final thread turning that gives good surface roughness has been experimentally investigated.

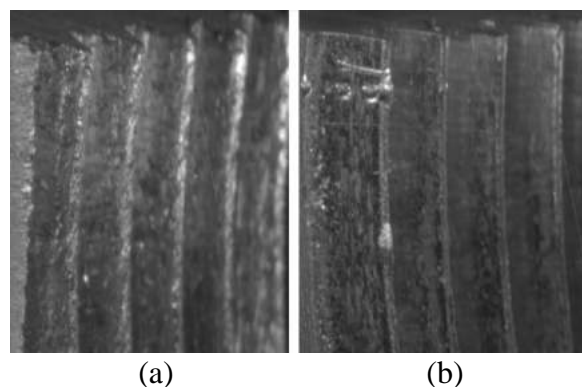


Figure 9. Thread flank of (a) 3° and (b) 30°.

To check this method a special tool with an undersized insert was made. The same Mori Seiki NT- 4200 DCG/1000S mill-turn centre and Vargus tool have been used. The work piece made of Plexiglas (polymethylmethacrylate) with the same sizes has been machined. Insert sizes have been calculated using Eq. (10) to (13). The insert, work piece and thread profiles after milling and turning operations are presented in Figure 10.

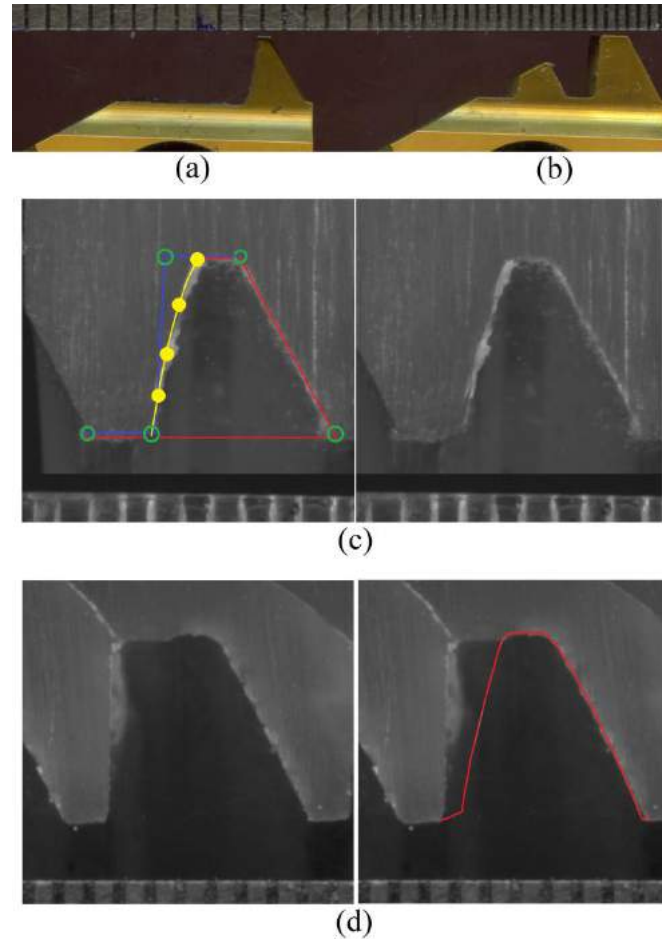


Figure 10. Inserts for S32×4 (a) milling and; (b) turning. Thread S32×4 profiles after (c) milling and; (d) turning.

In Figure 10 (c), the resulting thread profile after milling principally coincides with calculated profile (solid yellow points) and also is within the standard thread profile (non-shaded green points). Therefore, it has been theoretically demonstrated that buttress thread can be machined by a new type of cutting tools – milling-turning thread cutting tools with inserts as shown in Figure 10 (a). During the experiments heavy processing conditions in milling with a tool cutting edge inclination of 3° have been met. To improve surface quality and obtain standard buttress thread profile, this tool has been used on turning operating step. As shown in Figure 10 (d) it is geometrically possible. However, the following turning has not resulted in the required thread parameters. The identical preliminary milled helix has been missed. As a result, obtained thread profile has the required flank angles but too full-width root. In Figure 10 (d), the groove after milling is shown by the red line in the groove profile after turning.

A problem to pick up the thread in two different passes – milling and turning is related to machine programming, CNC system possibilities, spindle rotation and tool head movement sensors [26]. One way to solve the problem is to use G1-code for helical tool feed motions both for milling and turning NC programs.

Theoretical and experimental results show that the absence of milling cutters for many of buttress threads is reasonable. It is impossible to obtain such threads through planetary milling on 3-axis CNC machines. However, there are some threads with large diameters and small pitches for which buttress profile can be milled. The small diameters can only be obtained if the major diameter of the thread is overcut. In this case, the cutting edges on the mentioned above circle work hard, which is not good for tool life. In practice, engineers have to calculate all the parameters using the method given above and make a decision on the applicability of using thread milling cutter and planetary milling on 3-axis CNC machines. Nevertheless, problem of the milling cutter clearance angle small value and accompanied consequences as poor surface quality has to be solved properly. It is necessary to provide favourable conditions of effective chip forming on pressure flank edge.

Application of preliminary productive thread milling followed by final thread turning has promising results for thread profile. However, further research is required to pick up the thread in the second turning pass after the first milling pass. One way to solve the problem is to use G1-code for helical tool feed motions both for milling and turning NC programs.

CONCLUSION

The results obtained in this work show:

- a) Standard metric buttress thread with nominal and large pitches cannot be cut by planetary milling on 3-axis CNC machines.
- b) Decreasing milling cutter diameter it is possible to decrease the profile angle of the work piece thread.
- c) Increasing thread diameter and decreasing its pitch makes it possible to cut work pieces with a profile angle equal to 3° . However, only a portion of this profile can be completed with the conical tool surface and there is overcut of the major diameter by cutting edges placed on the circle connecting the cylindrical surface of the milling cutter to its conical surface.
- d) Using new milling-turning cutters for preliminary productive thread milling followed by final thread turning is practical. However, further investigation of CNC systems is necessary to pick up the thread in the second turning pass after the first milling pass. It is necessary to provide favourable conditions of effective chip forming for milling pressure flank edge. Problem of the milling cutter clearance angle small value and accompanied consequences as poor surface quality has to be solved properly.

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