



THREAD TURN MILLING SIMULATION

Alexander S. Yamnikov, Olga A. Yamnikova, Dmitry I. Troitsky¹

¹ Manufacturing Technology Dept.; Tula State University; Russia 300012 Tula Lenin pr., 92, YamnikovAS@mail.ru

Corresponding author: YAMNIKOV Alexander, YamnikovAS@mail.ru

Submitted 20.05.2015; accepted 16.06.2015

Abstract. The paper proposes a hardware-in-the-loop simulation strategy applied to single cutter lather turn milling. The strategy significantly reduces experimental research costs. The turn milling process involves a synchronized tool (helical mill), and workpiece rotation with a radial oncoming feed through a mill and workpiece relative movement. The cutting rate occurs by the mill teeth movement over the workpiece. The machining depth in each pass varies from zero to the max value, a common milling process feature. The proposed approach simulates the process parameters through thread turning or incomplete circular groove turning of workpieces attached off-center to a lathe tooling.

Keywords: thread turn milling, simulation, lathe, single-point tool, thread, off-center turning.

1. Introduction

The threading with a helical tool involving a simultaneous synchronized tool and workpiece rotation was presented by S.I. Skukhtorov and V.N. Khlunov in 1941 in the Manufacturing Engineer magazine [1]. They proposed an efficient thread cutting process with a helical generating surface tool. In the process both a workpiece and a tool are synchronously rotated (D_T and D_P movements, correspondingly) about their respective parallel axes. They also have an approaching motion D_I with the equal axis steps P_0 of the tool and P of the surface being machined. The ratio k is constant and equals to one. A thread is cut over the entire length at once and without any axial feed as the \vec{V} and \vec{V}_D surface velocities of a tool point and a point on the surface being machined are oppositely directed at the contact area (Fig. 1).

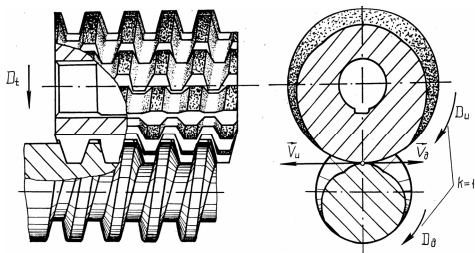


Fig. 1. Thread Cutting by a Helical Tool Synchronously Rotated with the Workpiece.

In 1971 V.V. Lotsmanenko proposed a method for determining a generatrix profile of the tool for opposed directions of rotation D_H and D_0 [2]. In 1978 Traub (Germany) equipped its turning-revolver machine tools with a dedicated attachment called Thread Turn Milling and Multi-Edge Lathe Tooling intended for external thread milling. The machine tool manual says: "The attachment is intended for external thread milling in brass and light alloys. Same mill can process any threads with identical shape and pitch all the way up to the shoulder. Besides, several different threads (e.g., left and right ones, with various pitch and shape, single and multiple-start, straight and taper) can be milled simultaneously."

In 1977 Khabarovsk Machine Tools Company developed and introduced a special device for circular external thread drawing in non-ferrous metals and free-machining steels. The tool diameter was 80 mm; 1B150, 1B125 capstans, and 1B-240-6 [3] six-spindle semiautomatic lathes were used. The cutting velocity in non-ferrous alloys was up to 600 m/min., for free-machining steels — up to 190 m/min. When radial oncoming feed was on, cutting velocity in non-ferrous alloys was up to 0.015...0.035 mm/rev., and 0.007...0.015 mm/rev for free-machining steels.

The device provided synchronous mill and workpiece unidirectional rotation with equal rpm, and radial mill feed. "A thread is milled along the entire length in single pass. High velocity makes the milling highly productive" [4]. These devices can be used for external

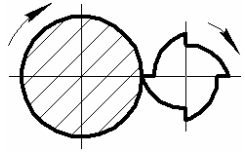
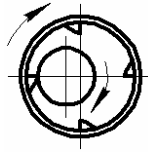
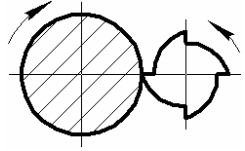
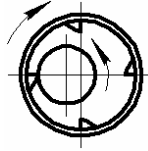
thread turn milling as shown in Fig. 1.1 for serial and mass production.

In 1987-1993 V.N. Voronov further advanced thread cutting with a helical tool [5-7]. The research has mostly focused on actual implementations of the process.

In 1994 E.V. Serova and S.I. Lashnev developed a theory for creating shaped thread milling tool profiles [8, 9]. They have proved that cutdown threading is less efficient as compared to cutup threading. The surface quality is also impaired with extra facets. She has also proved that only three turn milling patterns are feasible out of all the patters proposed by V.N. Voronov (see the Table). They are 1.1; 2.2 and 2.3, when the tool is rotated towards the workpiece. The cutdown patterns cannot form acceptable thread profiles along the entire cutting path. They are suitable only in the workpiece centerplane. Actually, just one line on this plane is formed.

Table.1

Helical Tool Radial Feed Threading Patterns (as proposed by V.N. Voronov)

Main motion	External threading	
	External touchdown V_1	Internal touchdown V_2
Two unidirectional rotations F_1	 1.	 1.2
Two Reverse Rotations F_2	 2.	 2.2

2. Contents of article

Most researchers have shown that helical tool threading with simultaneous and coordinated tool and workpiece rotation, and radial oncoming (cutting-in) feed is efficient for cutting fine pitch threads up to 10 pitches long. Otherwise, either excessive cutting forces occur, or the feed has to be reduced considerably, and the process with extremely low feeds becomes unfeasible, or at least inefficient. So, helical tool threading with simultaneous and coordinated tool and workpiece rotation has existed for a long time. Domestic and international researchers and designers have developed a number of devices for this machining strategy. Still the listed papers have failed to investigate some general theoretical issues for integrated turn mill threading definition and machining results. It hampers the development of optimal tool designs, and cutting mode selections. It also reduces the number of equipment options to implement the process.

D.Yu. Solyankin, A.S. Yamnikov, O.A. Yamnikova [10-14] have considered these issues using 3D simulation with COMPASS CAD [15].

A turn milling simulation software has been developed. The application offers an objective thread shaping and thread profile error definition. The errors are evaluated both qualitatively and quantitatively. It has been shown that a thread vee profile (even when a four-tooth mill is used) can be obtained in three passes, not just in one or two, as Voronov V.N. has claimed.

To quantitatively evaluate the feasibility of the calculated errors we propose an equation for the diametral error (vee undercuts or overcuts) compensation. The errors have been simulated and measured normally to the reference thread profile.

Fig 2 represents a 3D part model being a result of the turn milling simulation.

The figure shows that the helical thread surface has been generated as an envelope over many traces left as the mill teeth machined the workpiece body.

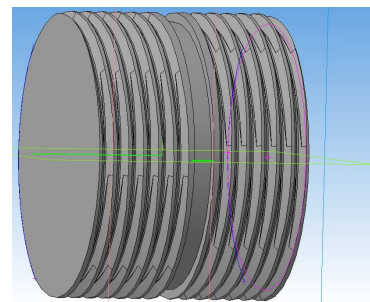


Fig. 2. A 3D model of a part

Fig. 3 represents a 3D model of thread vee undercuts. It has been generated by subtracting a 3D model of a surface obtained with turn milling from a reference 3D helical surface.

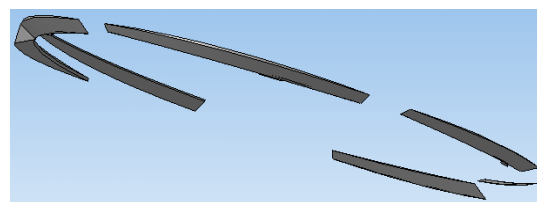


Fig. 3. A 3D model of thread vee undercuts

The figure clearly shows the appearance of undercuts as a 3D image. It helps better understand such a complicated helical shape formation process. A 3D model enables measuring the volume of errors and any linear dimensions over cross sections. To make the measurements more credible the paper presents simulation results as individual thread cross sections, and measured error tables.

However, to implement the process under consideration one has to know not only the reference geometric errors, but also its physical properties: cutting force values and tool life, that cannot be calculated. Additional

realistic experiments are required to identify the tool life and the cutting force values.

V.N. Voronov [5-8] proposed the term "turn milling". In this process just like in turning a workpiece is rotated at high RPM by a lathe while its material is removed with a tool similar to a group thread mill. For the same reason it is clear that the laws of turning and milling cannot be applied to turn milling. As the above description shows a turn milling tool is a multi-tooth one. The available experimental data suggest that its life is extremely long so an experimental approach to determining its life would take a lot of time, and workpieces. Another difficulty is that the existing equipment would have to be either significantly retrofitted, or some dedicated equipment would have to be manufactured. Hardware-in-the-loop simulation is the preferred approach [16 - 19].

Fig. 4 represents an external thread turn milling process.

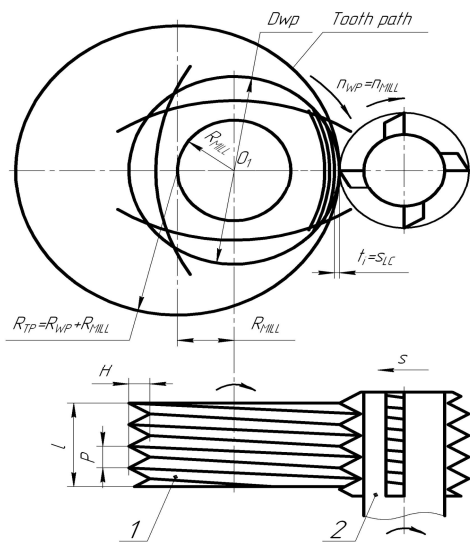


Fig. 4. External Thread Turn Milling.

A D_{ϕ} diameter mill and a D_{MILL} diameter workpiece rotate with equal RPM ($n_{\phi} = n_{\phi}$) and approach each other at the S_p radial feed. Each mill tooth makes one cut per each workpiece and mill revolution. Thus, in turn milling tooth loading is equal to chip load per revolution $S_z = S_{po}$. Correspondingly, the cut depth is also $t_i = S_{po}$. Let us consider the turn milling cutting process to develop a simulation method. The analysis of external thread turn milling tool paths [5-8] has shown that a single mill tooth relative path is a R_{TP} radius circle, while $R_{TP} = R_{\phi} + R_{\delta}$. A single tooth removes a layer with specified length and thickness per each workpiece (and mill) revolution.

To completely machine a thread with the H profile depth the mill (the workpiece) shall make k revolutions:

$$k = \frac{H}{S_{po}}. \quad (1)$$

To make the experimental research faster and cheaper we have applied simulation of a turn milling process executed on a lathe with a single-point threading tool.

We have used a hardware-in-the-loop approach. The turning milling process has been simulated with turning an eccentrically fixed workpiece (fig. 5).

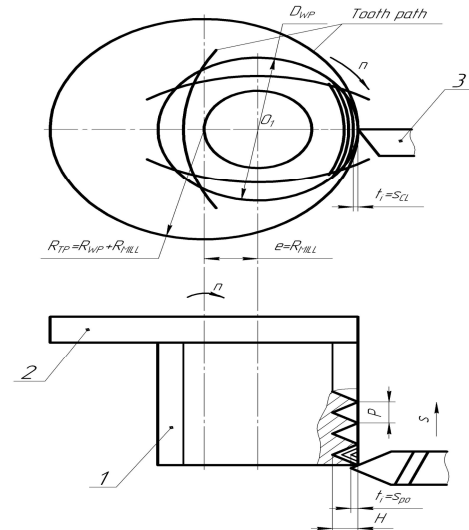


Fig. 5. External Thread Turn Milling Simulation.

The workpiece (pos. 1) with its center at O_1 is fixed to the chuck plate (pos. 2), and the chuck plate with the workpiece is rotated about its center O . The single threading tool (pos. 3) is attached to the lathe carriage and is fed.

Fig. 6 represents an internal thread turn milling process. V.N. Voronov has obtained a parametric mill tooth path equation [5-8]

$$\begin{cases} X_1 = (R - r)\cos \alpha + r \cos 2\alpha, \\ Y_1 = (R - r)\sin \alpha + r \sin 2\alpha. \end{cases} \quad (2)$$

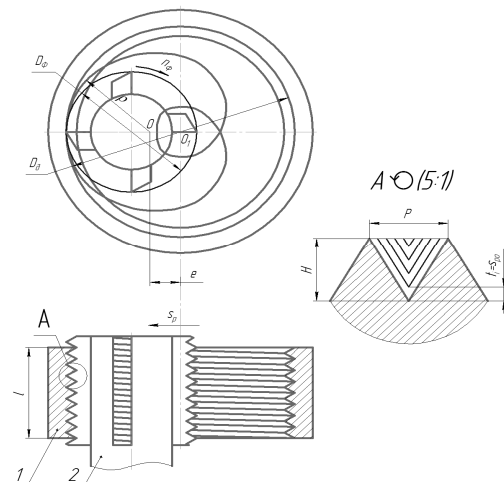


Fig. 6. Internal Thread Turn Milling.

V.N. Voronov has compared this expression to Pascal snail and has concluded that they are identical. Therefore, a relative mill tooth path for the process under consideration (see Fig. 3) shall be a Pascal snail. Its parametric equation is presented as (2). In implicit form:

$$\left[(x_1 + r)^2 + y_1 - 2r(x_1 + r) \right]^2 = (R - r)^2 \left[(x_1 + r)^2 + y_1^2 \right] \quad (3)$$

To simulate the internal thread turn milling on a lathe (Fig. 7) a workpiece (pos. 1) is held in a three-jaw chuck eccentrically relative to the chuck's axis of rotation

$$e = R_d - \rho, \quad (4)$$

where ρ is the Pascal sail curvature radius -at the maximum mill tooth penetration into the workpiece;

R_d is the thread radius, $R_d = 0,5D_d$.

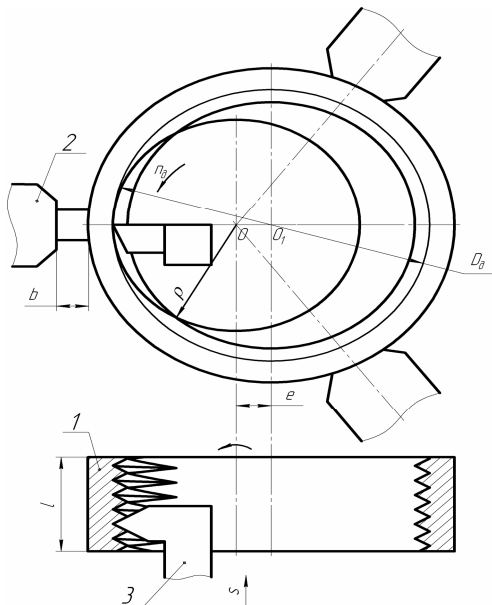


Fig. 7. Internal Thread Turn Milling Simulation.

To provide eccentricity a plate is installed under one of the chuck jaws. The plate thickness is

$$b = 1,5e \left(1 + \frac{e}{2D_0} \right), \quad (5)$$

where D_0 is the primary diameter (workpiece external diameter).

By changing the eccentricity the required arc length of the tooth to workpiece contact has been obtained.

Thus, the workpiece shall be rotated about the O center point. A single threading tool (pos. 3) is attached to the lathe carriage and is fed. It means that the lathe simulates the turn milling tool movements (same relative movement path radius; similar intermittent machining with the same cycle length; same single cutter path length, same contact length.) The cutting modes and

conditions (rpm, feed, depth of cut, cooling) are the same as for the turn milling.

In turn milling process each mill tooth is a thread chaser. As a single workpiece is machined each single threading cutter of the chaser cuts one thread vee at the corresponding helical surface sector. Therefore, for the simulation the machining of a single thread vee at the corresponding workpiece sector would be identical (in terms of the cutting path, and the single threading tool wear rate) to a single workpiece turn milling. Thus, to reduce the number of workpieces, and the testing time it is advisable to cut as many thread vees as possible on one and the same workpiece. This can be obtained by multi-pass thread turning with longitudinal feed. At every pass the depth of cut - t_i shall be equal to the chip load per revolution S_{po} used in the turn milling process.

After the multi-pass machining of a single thread surface sector the workpiece is rotated about its axis by the angle equal to the mill tooth angular pitch, and the next sector is machined, and so on. In this way a one workpiece machining would be identical (in terms of a single threading tool wear rate) to turn milling of N workpieces.

$$N = \frac{zl}{P}, \quad (6)$$

where l is the thread length;

P is the thread pitch;

z is the number of machined sectors equal to the mill teeth number.

3. Conclusion

Turn milling 3D simulation with COMPASS CAD clearly visualizes thread shape formation errors.

The proposed hardware-in-the-loop simulation approach enables experimental studies of the turn milling process without designing and manufacturing such complex tools as worm bobs and machine tools retrofiting. It significantly reduces costs and time required to perform experimental research.

References

1. Skukhturov S.I., Khlunov V.N. Thread Milling Generating Process. // *Manufacturer*, 1941, No. 2. Pp. 6-9.
2. Patent #380409 (USSR). A Thread Cutting Process. // V.V. Lotsmanenko - *Scientific Information Bulletin*, 1973, No. 15.
3. V.V. Lotsmanenko *Cutdown Thread Milling with Radial Worm Mill Feed* / Research Report 49-69. Vladivostok, Kuibyshev Far East Polytechnic Institute, 1971. - p. 57
4. Butuzov V.V. A General Purpose Device for Thread Milling on Automated Lathes. // *Advanced Manufacturing Experience and Industrial Engineering NIIMNASH Express Info*, Vol. 4, 1977. - p. 2
5. V.N. Voronov *Threading with Helical Tools*. // *Machine Tools and Tooling*. 1991, No. 10. p. 14-16.

6. V.N. Voronov, A.S. Yamnikov, V.B. Protasyev Automated Radiator Nipple Machining. // Assembly Automation and Mechanization: Regional Conference Proceedings. Izhevsk, DNTP, 1990. P. 21-22.

7. V.N. Voronov, A.S. Yamnikov, V.B. Protasyev Turn Milling Tools for Rotary Transfer Lines. // Tooling for Automated Machining: Regional Conference Proceedings. - Irkutsk, USSR Academy of Sciences, NTsSO. 1990. P. 12-13.

8. V.N. Voronov, Ye. V. Serova Thread Geometry Generation with Radial Feed Helical Tool. // Manufacturing and Assembly Technology: Tula: TSU, 1993. P. 87-95.

9. S.I. Lashnev, Ye.V.Serova Mill Broach Generatrix Parameters Evaluation for Round Thread Machining // Automated Manufacturing Systems and Robotics: Collection Volume. Tula: TSU, 1993. P. 87-92.

10. D.Yu. Solyankin, A.S. Yamnikov Relative Thread Turn Milling Productivity / Orel State University Proceedings. Basic and Applied Technology Studies. Vol. 6 (284), 2010. P. 109-114.

11. D.Yu. Solyankin, A.S. Yamnikov, O.A. Yamnikova Material Layer Parameters Evaluation for Thread Turn Milling // TSU Proceedings. Engineering, 2011, Vol. 3, part 1. P. 272-278.

12. A.S. Yamnikov, O.A. Yamnikova, D.Yu. Solyankin Thread Turn Milling Simulation // High Tech Manufacturing Technologies. 2011, No. 6. P. 15-20.

13. D.Yu. Solyankin, A.S. Yamnikov, O.A. Yamnikova Thread Turn Milling. Process and Tool Design Feasibility Study. Monograph. Lambert Press, Germany. 2012. 176 pp.

14. O.A. Yamnikova, A.S. Yamnikov Manufacturing System Components Simulation: Tutorial. Tula: TSU Publishing, 2013. 191 pp.

15. COMPASS 3D v15 CAD. Serial number: AS-CON_OO-0014661. OS: Windows XP/Vista/7/8.

16. A.A. Gukhman Introduction to Similarity Law. LKI Publishing, 2010, 296 pp.

17. S.S. Silin Similarity Law Applied to Cutting. Moscow, Manufacturing Press, 1979. 152 pp.

18. O.M. Zamyatina System Modeling: Tutorial. – Tomsk: TSU Publishing, 2009. 204 pp.

19. V.I. Finayev System Modeling: Tutorial. Taganrog: SFU Publishing, 2013. 181 pp.