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TURN MILLING TOOL WEAR RESISTANCE SIMULATION

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Abstract. A hardware-in-the-loop turn milling simulation process is presented. This approach reduces efforts and material consumption for tool life investigation by a factor of hundreds. It has been found that a single tool life exceeds tool life in multipass thread turning two- or threefold. It has been shown that a helical close-pitch cutter life exceeds a single tool life up to 260 times.

Keywords: wear resistance, thread turn milling, tool life, wear.

1. Introduction

As we have stated [1] hardware-in-the-loop simulation [9-20] is suitable for investigating turn milling tool life [2-8].

In turn milling all the single threading tools within each mill tooth chaser remove a uniform thickness layer at each revolution. They operate in virtually similar conditions and have identical service life. Therefore, tool life testing can be performed for a single threading tool. The tool is used in a turn milling process first, and then in a multipass turn threading process.

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.

2. Contents of article

Let us consider the turn milling cutting process to develop a simulation method. The analysis of external thread turn milling tool paths has shown that a single mill tooth relative path is a R_{TP} radius circle, while $R_{TP} = R_{\phi} + R_{\partial}$. A single tooth removes a layer with specified length and thickness per each workpiece (and mill) revolution.

Fig. 1 shows a hardware-in-the-loop turn milling simulation with a lathe. 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.

Thus a lathe simulates the turn milling conditions and 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.

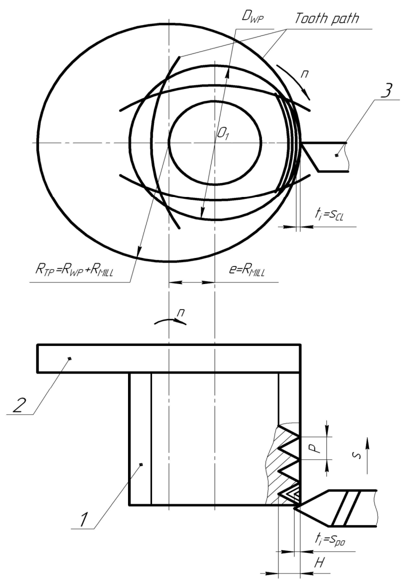

Fig. 1. External Thread Turn Milling Simulation.

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 test 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.

$$N = \frac{zl}{P}, \qquad (1)$$

where l is the thread length;

P is the thread pitch;

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

The experiments have included an external and internal M42×1 threading with two processes:

- multipass turning
- mill turning.

The testing conditions have been as follows:

- for the external thread machining: workpiece material: Steel 45, GOST 1050-74, HB 187...200; D_∂=42 mm; length is l=90 mm; tool: threading tools, GOST 18875-73, Type I, HSS R6M5; HRC 61...63; rake: $\gamma = 0^\circ$, relief angle: $\alpha = 12^\circ$;
- for the internal thread machining: workpieces: bushings, Steel 45 GOST 1050-74, HB 187..200, external diameter D_∂=52 mm, internal diameter 40 mm, length l=50 mm, tool: threading tools GOST 18885-73 Type 3, HSS R6M5; HRC 61...63, γ=0, α=0^0, equipment: 1M63 turning lathe.

A reference part has been a part with a M42x1 thread, the thread length is l=10 mm, D_∂=42 mm, R_∂=21 mm, the thread height is H=0.65 mm, the pitch is P=1 mm.

The testing has simulated external and internal threading with a $D_ф$=32 mm ($R_ф$=16 mm) mill, number of teeth: z=8. The calculations using the equation (1) have shown that a single workpiece processing in the hardware-in-the-loop external thread turn milling simulation is identical to turn milling of 720 reference parts. For the internal thread the amount is 400 reference parts. Cutting speeds for thread turn milling are affected by the fact that the radial feed is set as for a wide formed cutter turning with radial feed. The cutting speed is set as for thread turn milling with a chaser mill. Finally, the following values have been used: cutting speed is V=40 m/min, S_{po}=0.1 mm/rev. No coolant has been used.

Same cutting modes have been applied to for both the multipass turning, and the turn milling.

The tool wear has been measured with a measuring probe normally to the machined surface. The accuracy is 0.002 mm. The tool dulling criterion is its maximum wear causing the thread depth to exceed the tolerance. The external thread turn milling HIL simulation has involved a testing of 5 tools. Subsequently the tools have been resharpened and used in further multipass turning tests.

The internal thread turn milling HIL simulation has involved a testing of 3 tools. Subsequently the tools have been resharpened and used in further multipass internal thread turning tests. The tool wear has been measured after each pass. Table 1 represents the testing results grouped by the number of workpieces and reference parts.

Table 1
Numbers of workpieces, reference parts, and tools

Value	External thread	
	Turning	Turn milling
Number of machined samples	32	16
Number of tools	5	5
Number of reference parts, N psc.	288	11500
Mean number of machined parts per one tool	6.4	3.2
Mean number of reference parts per one tool	57.6	2300

An existing method [15] has been applied to process the test results. A mean value, a mean-square deviation, and a coefficient of variation have been found for each point on the experimental curves.

Table 2 represents the testing results grouped by the tool path lengths and the number of reference parts.

Fig. 2 shows the tool wear vs. total cutting path lengths and machining time relations.

Table 2
Testing results

Value	External thread	
	Turning	Turn milling
Tool path length for one part, L	7.5	0.095
Tool life $\sum L$, m	50	165
Tool life T, min	1.3	4.2
Tool life CV	0.32	0.36
Number of reference parts machined within the efficient tool life, N, psc.	6.7	1750
Max wear limit U_{np}, mm	0.17	0.17
Specific wear U_0, m/m	3.4	1.03
Specific wear per part U_0 m/psc.	25.4	0.097

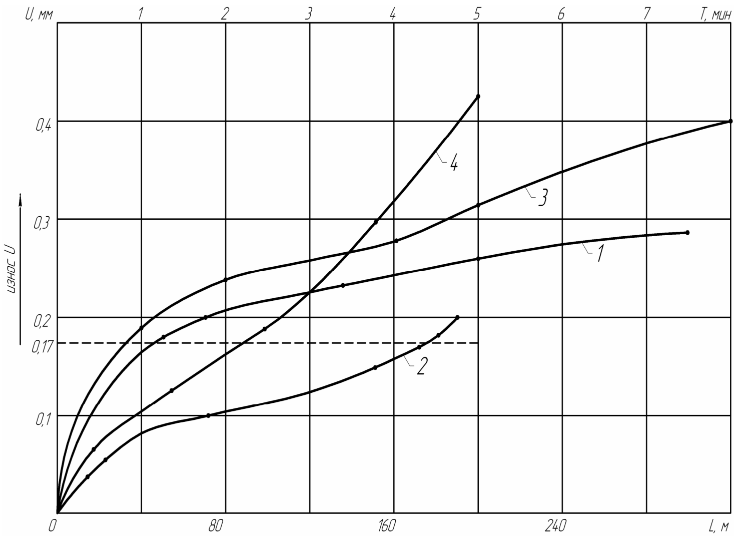

Fig. 2. Wear curves: 1 – external thread turning; 2 – external thread turn milling; 3 – internal thread turning; 4 – internal thread turn milling.

The diagrams (Fig. 2) and the results listed in Table 2 show that tool life of the turn milling process exceeds that of the multipass turning by 2.2 times (internal thread) or 3.3 times (external thread); the specific relative wear per a unit of cutting path is 2.2 and 3.3 times fewer, correspondingly. A possible explanation is that in turn milling each single threading mill cutter contacts the workpiece just for a fracture of a revolution, and the rest of the time it is cooled.

Within the tool life (to the max wear limit) the number of reference parts machined with the turn milling process has exceed the number of reference parts machined with the multipass turning by 260 (external thread) and 180 (internal thread). The reason is that in the turn milling process for a single reference part the cutting path length per a single threading tool for external thread machining is 80 times fewer while the specific wear per a unit of cutting path length is 3.3 times fewer. Taking into account the (1) relation we may propose that tool life in external thread turn milling process extends by 80×3.3=260 times.

Tool life in the internal thread turn milling is almost 2 times fewer than in the external thread turn milling. A possible explanation is that in the internal thread turn milling the tool-to-workpiece contact arc length is longer, thus the tool cooling and heat transfer conditions are significantly poorer.

The tool life CV (Table 1) for the external thread machining experiments is within the 0.32...0.36 range. It confirms that the experimental conditions have been satisfactory [21]. The tool life CV for the internal thread machining is within the 0.16...0.24 range. It confirms that the experimental conditions have been good [21].

Extra research has been carried out to determine the part and tool material properties, and coolant effects on the tool life. The parts machined have been steam radiator nippels. The nippels join cast iron radiator sections (Fig. 3). It is a common part with two reverse threads.

The material is KCh-6F cast iron, HB 130...200. G 1 1/4" pipe thread has been machined. Its external diameter is 41.9 mm, the pitch is P =2.309 mm, the thread depth is H =1.48 mm, the thread length is l =30 mm.

Fig. 3. A Radiator Nippel.

The tools are threading tools compliant to GOST 8875-73 Type 1, rake: $\gamma = 0^\circ$, relief angle: $\alpha = 12^\circ$. The cutting head materials are R6M5 HSS, HRC 63...65, and VK6M hard alloy.

The cutting speed is V =33 m/min, the radial feed is S_{po} =0.1 mm/rev. The workpieces have been processed both without cooling, and with Ucrinol 1 coolant. The tool wear has been measured with a dedicated indicator normally to the machined surface with the tool still attached to the lathe. The indicator's scale factor is 0.002 mm.

The machining has been a turn milling simulation on a lathe [1]. A set of 5 tools has been tested. The tool dulling criterion is the thread height exceeding the tolerance being 0.18 mm.

An existing method [21] has been applied to process the test results. A mean value, a mean-square deviation, and a coefficient of variation have been found for each point on the experimental curves.

The experimental results are listed in Tables 3 and 4.

Table 3
Mean tool wear in the thread turn milling process

Mean tool wear U, m	Cutting path length, m			Number of Reference Parts		
	R6M5		VK6M hard alloy	R6M5		VK6M hard alloy
	No coolant	Coolant	Coolant	No coolant	Coolant	Coolant
20	10	35	74	42	148	316
35	20	60		84	254	
50	30	90	5312	127	381	22860
70	50	125	5605	211	529	24124
85	60	150	6303	254	635	27126
100	70	185	13096	296	783	56359
115	80	210	18786	388	889	80851
130	90	255		381	1080	
150	110	310	19950	466	1313	85855
165	130	350		550	1483	
180	135	419	20806	572	1775	89541

Fig. 4 shows the tool wear vs. total cutting path lengths $\sum L$.

The curves 1 and 2 are based on the experimental data listed in Table 3. The curve 3 is shown partially since all its experimental points do not fit into the diagram for the selected scale. This highlights the fact that hard alloy tool wear is significantly less that HSS tool wear.

From the relations presented in Fig. 4 and the results listed in Tables 3 and 4 the following conclusions can be made:

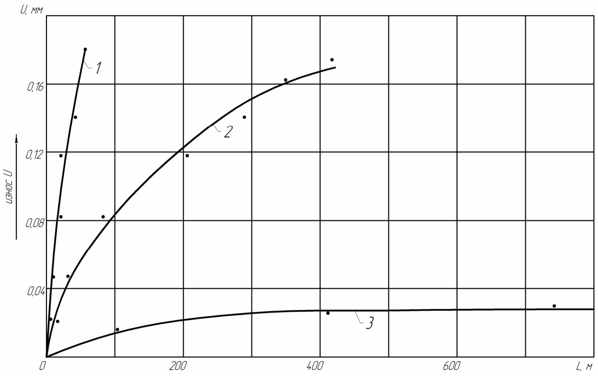

Fig. 4. Tool wear curves: 1 – R6M5 HSS, no coolant;
2 – R6M5 HSS, with coolant; 3 – VK6M hard alloy, with coolant.

The R6M5 HSS tool life in thread turn milling with coolant is 3 times longer than without coolant.

The VK6M hard alloy tool life in turn milling with coolant is 50 times longer than the R6M5 HSS tool life.

The operational tool life (expressed as the number of parts machined within the tool life) for VK6M tools in turn milling with coolant is 50 times higher than that of R6M5 HSS tools.

Exact values are listed in Table 3.

Table 4 represents the statistical processing results.

Table 4
Testing results

Values	Threading		
	R6M5		VK6M hard alloy
	No coolant	Coolant	Coolant
Tool path length for one reference part L_i, m	0.236	0.236	0.236
Tool life $\sum L_i$, m	135	419	20806
Tool life mean square deviation σ_L, m	17.3	74.459	1739
Tool life T, min	4.09	12.69	630.5
Tool life CV	0.128	0.177	0.11
Number of reference parts machined within the efficient tool life, N, psc.	572	1775	89542
Wear limit U_{np}, mm	0.18	0.18	0.18
Specific wear U_0, m/m	1.333	0.429	0.0086
Specific wear per part U_0 m/psc.	0.314	0.101	0.002

The proposed turn milling HIL simulation approach reduces the number of machined reference parts by 710 times for external threading, and 400 times for internal threading. It has also saved time and costs.

It has been found that

- as the thread pitch decreases, the number of mill teeth increases, and the thread length increases the tool life is extended compared to turn threading of the same thread;
- as the thread pitch decrease and the mill diameter increases the tool life is extended compared to mill threading of the same thread;
- accordingly, turn milling is beneficial for fine pitch threads.

With turn milling the tool path per single threading tool (mill tooth) is 80 times shorter than with turning, and 5 times (for external threads) or 17 times (for internal threads) shorter that for milling with a group thread mill.

3. Conclusion

We have confirmed V.N. Voronov's conclusion that a specific wear per a unit of tool path in turn milling is 2.2 (for internal threads) or 3.3 (for external threads) times fewer compared to thread turning, and the tool life is longer.

The operational tool life expressed as the number of parts machined within the tool life for turn milling of the same thread is 260 (external thread) or 180 (internal thread) times higher than in thread turning.

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