Development of Toolkit for Formalizing the Programming of Canned Cycles on CNC Machine Tools

Georgi M. Martinov^{1,}, Liliya I. Martinova¹, and Nikolay N. Fokin¹*

¹MSTU “STANKIN”, Moscow, Russia

Abstract. The analysis shows that the development of programming tools for CNC systems is focused on the development of new machine canned cycles, including those for processing complicated surfaces, their complex combinations or complex mutual arrangement, but does not concern such issues as the universalization of cycle parameters. This does not make it impossible to transfer control programs from one CNC system to another. This work proposes an approach to the development of tools for creating universal cycles of typical technological transitions of machining on machines with different CNC systems.

1 New requirements for canned cycles

An important attribute of modern CNC and CAM systems are the canned cycles that implement typical technological transitions, such as machining pockets, holes, grooves, undercuts and chamfers, contour turning and milling, as well as machining of holes, grooves, etc. [1-3]. Using of canned cycles significantly reduce the programming time for CNC systems.

A large number of researches and developments on the creation of machine cycles are being implemented, their nomenclature is expanding, including through the creation of cycles for processing complex surfaces, their complex combinations or complex mutual arrangement [4-7], which is dictated by the growing demand for parts of complex shapes. However, enterprises in practice face some problems that reduce the effectiveness of using of cycles [8-10].

First, CNC systems from different manufacturers on machines of the same functionality have unique sets of parameters for programming machine cycles. Moreover, these sets differ both for CNC systems of different manufacturers and developers (Fanuc, Siemens, HAAS, AxiOMA Ctrl, etc.) and for CNC systems of different versions from the same manufacturer. This circumstance makes it impossible to use control programs on other machines that are developed for a specific CNC machine, while such a need in production conditions arises very often, in particular, in connection with the current load, scheduled maintenance or repair of machines.

* Corresponding author: martinov@ncsystems.ru

Secondly, modern production conditions are such that at the workshop level, more and more universal mobile applications (on laptops, tablets and smartphones) are required for programming CNC systems [11-13].
The development of toolkit for creating universal cycles of typical technological transitions of machining on machines with various CNC systems is based on the analysis of existing canned cycles and the identification of the main geometric and technological parameters that ensure the shaping and quality of surfaces [14-17], and additional parameters that determine the strategy of movement of the cutting tool during the cycle [18].

2 Analysis of syntactic constructions for calling of canned cycles

The results of the analysis of cycles of different CNC systems are summarized in Table 1. As you can see, different syntactic constructions are used to call similar cycles in different CNC systems, which limits the transfer of control programs from one CNC system to another

Table 1. Examples of canned cycles.

Canned cycle	Siemens 810, 840d, 840dSL	Fanuc Mate	AxiOMA Ctrl
Longitudinal turning	Cycle95	G71	-
Cross turning	Cycle95	G72	-
Radial groove turning	Cycle93	G75	G288
Face groove turning	Cycle93	G74	G289
Radial undercut turning	-	-	G281
Face undercut turning	-	-	G282
Cylindrical and conical threading	Cycle97	G76	G276
Partoff	Cycle92	-	-
Drilling	Cycle83	G83	G83
Deep Drilling	Cycle83	-	G83
Tapping	Cycle84	G84	-
Thread Milling	Cycle70	-	-
Milling straight slot	Slot1	-	G388
Milling circle slot	Slot2	-	-
Milling pocket	Pocket3	-	G387
Milling round pocket	Pocket4	-	G389
Milling edge	Cycle76	-	-
Milling round edge	Cycle77	-	-
Milling multiedge	Cycle79	-	-

For a detailed analysis of syntactic structures and execution strategies, below is a cycle for drilling holes with a retraction for chip breaking from different CNC systems (table 2).

Table 2. Parameters of the cycle of drilling holes with retraction in different CNC systems.

	Siemens	Fanuc	AxiOMA Ctrl
Name Parameter	CYCLE83	G83	G83
Holes positions	XY or Call Holes Cycle	XY	XY
Reference plane	RP	R	Q1
Return plane	PL	Equivalent to reference plane R	Q2
Safe distance	SC	Equivalent to reference plane R	Equivalent to return plane Q2
First cut value	D	Equivalent to Cut value Q	Q7
Cut value	DF	Q	Q8
Bounce value	V2	automatically	Q9
Time delay at final drilling depth	DTB	P	Q6
Start depth point	Z0	Z	Z
Finish depth point	Z1	Z1	Q5
Processing strategy	VARI (0 -drilling with bounce distance or 1- drilling with return to return plane)	Only drilling with bounce distance	If Q9 > 0 – drilling with bounce distance, if Q9=0 – drilling with return to return plane

For CNC Siemens, the cycle call is:

G1 F_
 CYCLE83 (PL, RP, SC, Z0, VARI, Z1, D, DF, V2, DTB,)
 G0 X_ Y_
 F – work feeding,
 PL – return plane,
 RP – reference plane,
 SC – safe distance,
 Z0 – Start depth point,
 VARI : 0 -drilling with bounce distance or 1-drilling with return to return plane,
 Z1 – finish depth point,
 D – first cut value,
 DF – cut value,
 V2 – bounce value,
 DTB – time delay at final drilling depth.

For CNC Fanuc, the cycle call is:

G0 X_ Y_
 G83 X_ Y_ Z_ R_ Q_ F_ P_
 G80

XY – Holes positions,
 Z – Finish depth point,
 R – Reference plane
 Q – Cut value,
 F – work feeding,
 P – Time delay at final drilling depth

For CNC AxiOMA Ctrl, the cycle call:

G83 Q1=_ Q2=_ Q3=_ Q4=_ Q5=_ Q6=_ Q7=_ Q8=_ Q9=_

G0 X_ Y_
Q1 – reference plane,
Q2 – return plane,
Q4 – work feeding,
Q5 – finish depth point,
Q6 – time delay at final drilling depth,
Q7 – first cut value,
Q8 – cut value,
Q9 – bounce value.

3 Universalization of the structure of canned cycles

Within the framework of this work, the universalization of cycles was carried out on the basis of the identified set of variable cycles and the creation of preparatory subprograms for technological operations and preparatory programs for technological transitions to support the correct operation of the cycle.

Fig. 1. The mechanism of forming the structure of the control program based on canned cycles.

Figure 1 shows the mechanism for forming the structure of the control program:

1) local variables of the technological operation are introduced: coordinates of the zero point and activation of its coordinates, maximum tool rotation speed, position of the safety plane, tool change point;

2) local variables are written to global variables of the CNC system (# 1- # 21 for Fanuc CNC controls, R1-R21 for Siemens CNC controls, \$ dPerm [1] - \$ dPerm [21] for AxiOMA Ctrl controllers) for further use in the cycle;

3) local variables of the technological transition are introduced: number, standard size of the tool, cutting speed, working feed, the possibility of using auxiliary M-codes)

4) the local variables of the technological transition are written into the global variables of the CNC system (# 31- # 43 for Fanuc CNC controls, R31-R43 for Siemens CNC controls, \$ dPerm [31] - \$ dPerm [43] for AxiOMA Ctrl controllers) for further use in work cycle;

The preparatory subprogram of the technological operation (it is named O6999) implements the algorithm for assigning the entered local cycle variables to the global variables of the CNC system. This subprogram ensures the correct interaction of the developed cycles with the algorithms of the CNC systems, since it transfers to the CNC memory the variables responsible for changing the tool, the correct retraction and approach of the tool to the workpiece and restrictions on the spindle rotation. Geometric information and subprogram variables are shown in Figure 2 and Table 3.

Fig. 2. Variables of the preparatory subprogram O699.

The call of the subprogram O6999 for different CNC systems is carried out observing the system syntax:

- for Siemens controllers:

O6999 (wp1, wp2, wp3, wp4, wp5, wp6, wp7, wp8, m1, m2, m3, m4, m5, m6, m7, m8, m9, m10, m11, m12, m13)

- for Fanuc Mate CNC controls:

G65 P6999 Awp1 Bwp2 Cwp3 Dwp4 Ewp5 Fwp6 Hwp7 Iwp8 Jm1 Km2 Mm3 Qm4 Rm5 Sm6 Tm7 Um8 Vm9 Wm10 Xm11 Ym12 Zm13

- for Axioma Ctrl controllers:

#include "O6999.c"

O6999 (wp1, wp2, wp3, wp4, wp5, wp6, wp7, wp8, m1, m2, m3, m4, m5, m6, m7, m8, m9, m10, m11, m12, m13)

Table 3. Variables of the preparatory subprogram O6999.

Parameter		Siemens		Fanuc Mate		AxiOMA Ctrl	
		Local variable	Global variable	Local variable	Global variable	Local variable	Global variable
Workpiece coordinate system		wp1	R1	A	#101	wp1	\$dPerm[1]
Maximum spindle speed	Smax	wp2	R2	B	#102	wp2	\$dPerm[2]
Security plane external X-axis	Xe	wp3	R3	C	#103	wp3	\$dPerm[3]
Security plane internal X-axis/ external Y-axis	Xi / Ye	wp4	R4	D	#104	wp4	\$dPerm[4]
Security plane external Z-axis	Ze	wp5	R5	E	#105	wp5	\$dPerm[5]
Tool change point type		wp6	R6	F	#106	wp6	\$dPerm[6]
X-axis tool change point	Xh1 / Xh2	wp7	R7	H	#107	wp7	\$dPerm[7]
Z-axis tool change point	Zh1 / Zh2	wp8	R8	I	#108	wp8	\$dPerm[8]
M-code for coolant activation		m1	R9	J	#109	m1	\$dPerm[9]
M-code for coolant deactivation		m2	R10	K	#110	m2	\$dPerm[10]

4 Unification of work with auxiliary functions

The preparatory subprogram of the technological transition O7000 is necessary for the correct operation of the cycle and the organization of the interaction of the cycle with M-codes and taking into account the geometric characteristics of the tool for the correct calculation of the trajectory of its movement. The variables of the subprograms are shown in Table 4.

Table 4. Variables of the preparatory subprogram of the technological transition (cycle) O7000.

Parameter		Siemens		Fanuc Mate		AxiOMA Ctrl	
		Local variable	Global variable	Local variable	Global variable	Local variable	Global variable
Tool number	Tt	mp1	R31	A	#131	mp1	\$dPerm[31]
Corrector number	Td	mp2	R32	B	#132	mp2	\$dPerm[32]
Tool width / tool diameter	b / d	mp3	R33	C	#133	mp3	\$dPerm[33]
Tool radius / tool angle	r / a	mp4	R34	D	#134	mp4	\$dPerm[34]
Feed units	mpr mm / min	mpp5	R35	E	#135	mp5	\$dPerm[35]
Feed value	F	mp6	R36	F	#136	mp6	\$dPerm[36]
Cutting speed units	m / min rpm	mp7	R37	H	#137	mp7	\$dPerm[37]
Cutting speed value	V	mp8	R38	I	#138	mp8	\$dPerm[38]
Spindle rotation direction	CV/CCV	mp9	R39	J	#139	mp9	\$dPerm[39]
Use in the coolant cycle	0=yes 1-no	mp10	R40	K	#140	mp10	\$dPerm[40]

The presented development of the preparatory subprogram of the technological operation and the preparatory program of the technological transition have a similar form of entering local variables in the body of the control program, which facilitates the development of control programs for the considered CNC systems Siemens, Fanuc and AxiOMA Ctrl.

5 Implementation of the ring groove milling cycle

To clarify the logic of the developed strategy for the development of control programs using calls to the subprogram of the technological operation and the subprogram of the technological transition and machining cycles, we will consider the circular groove milling cycle, since its implementation was carried out only by Siemens controllers, where the cycle is called by the Slot2 function.

The algorithm of the circular groove milling cycle provides for: moving the tool with a rapid traverse feed G00 from the tool change point XhZh to the safety plane - to the XeZe point, moving the tool with a rapid traverse feed G00 to the start point of the cycle X0Y0Z0, plunging the tool to a depth dZ depending on the selected machining planes and making a longitudinal movement along the horizontal axis of the slot or pocket element, displacement of the tool by the amount dXY, depending on the selected plane and making cutting movements parallel to the contour of the slot or pocket until the specified length and

width, taking into account the finishing allowance, plunge the tool along the axis Z and repetition from item 3) and item 4) until the specified depth Z1 is reached, tool movement with rapid traverse feed G00 to the safety plane - to the XeZe plane, tool movement with rapid traverse feed G00 to the tool change point XhZh. A block diagram of the generalized algorithm of the milling cycles is shown in Figure 3.

Fig. 3. Algorithm of the milling circle slot cycle.

For the Siemens CNC system, all movements are specified using the movements of the working stroke G1, G2, G3 in the X, Y and Z coordinates, since the system converts the movement along the Y axis into an angle of rotation along the C axis; For the Fanuc CNC, G12.1 polar coordinate interpolation is used for the XY plane, or G7.1 cylindrical interpolation mode for the ZY plane using travel movements G1, G2, G3; for the AxiOMA Ctrl CNC system, the algorithm is calculated in XY coordinates using the movements of the working stroke G1, G2, G3.

A cycle is a sequence of radial circular working movements of the tool to make an annular groove with a given width, angles and depth. The cycle can be performed in the XY or ZY planes. Can be multi-pass for oversize roughing and single-pass for finishing. The geometric and technological parameters of the cycle are shown in Figure 4.

Fig. 4. Geometrical and technological parameters of the milling circle slot cycle.

The variables responsible for all parameters used in the cycle are presented in Table 5.

Table 5. Geometrical and technological parameters of the milling circle slot cycle.

Parameter		Siemens, Axioma Ctrl	Fanuc Mate
Processing location	Type I	rslt08	A
Purity of processing	Type II	rslt09	B
Cutting direction	Type III	rslt10	C
Plane infeed	dXY	rslt11	D
Depth infeed	dZ	rslt12	E
Finishing allowance in the plane	uXY	rslt13	F
Finishing depth allowance	uZ	rslt14	H
X-axis start point	X0	rslt15	K
Y-axis start point	Y0	rslt16	M
Z-axis start point	Z0	rslt17	Q
Z-axis finish point	Z1	rslt18	R
Slot width	W	rslt19	V
Slot axis radius	R	rslt20	W
Angle of deviation from the leading axis	A0	rslt21	X
Increment angle	A1	rslt22	Y

6 Implementation of the interface for entering parameters and generating macrocode

The interface for inputting parameters and outputting the macrocode of the control program demonstrating the operation of the circular groove milling cycle using the developed solution for the development of control programs in a mobile operating system is presented in Figures 5 - 7.

Fig. 5. The interface for entering variables of the subprogram O6999.

Fig. 6. The interface for entering variables of the subprogram O7000 and variables of the milling circle slot cycle.

Fig. 7. Generation of the control program for the CNC FANUC Mate.

7 Conclusion

The analysis of the mechanisms for the formation of control programs using canned cycles, as well as the geometric and technological parameters of the cycles of different CNC systems, made it possible to create universal cycles of typical technological transitions of machining. Preparatory subprograms of the technological operation and technological transition were developed, as well as subprograms of cycles of technological transitions, which have the same number and value of sets of geometric and technological variables for all considered CNC systems, mechanisms and cyclic algorithms for the operation of subprograms were developed, and a classification system was developed and interaction of programs.

The developed toolkit is applicable for creation, implemented on CNC machines and has been successfully applied for programming canned cycles in FANUC Mate, Siemens and AxiOMA Ctrl CNC systems.

The reported study was funded by RFBR according to the research project № 20-07-00305/20.

References

1. Martinova, L. I., Pushkov, R. L. and Fokin, N. N. (2020). Development of standardized tools for shopfloor programming of turning and turn-milling machines. In IOP Conference Series: Materials Science and Engineering (Vol. 709, No. 4, p. 044064). IOP Publishing. doi:10.1088/1757-899X/709/4/044064
2. S.N Sheth, Prof. A.N. Rathour. (2014). Development of Canned Cycle for CNC Milling Machine. In: 2014 International Journal of Engineering Research and General Science Volume 2, Issue 4, June-July, 2014 ISSN 2091-2730, pp. 71-79.
3. Evstafieva S. V., Pushkov R. L., Salamatina E. V. Collecting and visualizing operational data from technological equipment // Automation in Industry, No. 5. 2019. pp. 26-28.
4. Abbas, A.. "Enhancement of the Capabilities of CNC Machines via the Addition of a New Counter boring Cycle with a Milling Cutter." *Mechanical Engineering Research* 5 (2015): 45.

5. Abbas, Adel. (2012). Enhanced CNC Machines Capabilities by Adding Circular Patterns Cycle. *International Journal of Precision Engineering and Manufacturing*. 13. 10.1007/s12541-012-0230-0.
6. Martinova, L., Obukhov, A. and Sokolov S. Practical Aspects of Ensuring Accuracy of Machining on CNC Machine Tools within Framework of “Smart Manufacturing”. 2020 International Russian Automation Conference (RusAutoCon). IEEE, 2020. Page(s): 898 - 902.
[doi: 10.1109/RusAutoCon49822.2020.9208079](https://doi.org/10.1109/RusAutoCon49822.2020.9208079)
7. Omirou, Sotiris & Rossides, S. & Lontos, Antonios. (2012). A new CNC turning canned cycle for revolved parts with free-form profile. *International Journal of Advanced Manufacturing Technology - INT J ADV MANUF TECHNOL*. 60. 10.1007/s00170-011-3586-x.
8. Martinov, G., Martinova, L. and Ljubimov, A. (2020). From classic CNC systems to cloud-based technology and back // *Robotics and Computer-Integrated Manufacturing*, 2020, Vol. 63, June. [doi: doi.org/10.1016/j.rcim.2019.101927](https://doi.org/10.1016/j.rcim.2019.101927)
9. Kumar K., Ranjan C., Davim J. (2020) Canned Cycle. In: *CNC Programming for Machining. Materials Forming, Machining and Tribology*. Springer, Cham. https://doi.org/10.1007/978-3-030-41279-1_9
10. Islam M.N., Rafai N.H., Phaopahon C. (2010) Effect of Canned Cycles on Drilled Hole Quality. In: Ao SI., Gelman L. (eds) *Electronic Engineering and Computing Technology. Lecture Notes in Electrical Engineering*, vol 60. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-8776-8_53
11. Martinov, G. and Kovalenko, A. (2020). Additive Process Equipment Control System for Integration into a Flexible Manufacturing System. In: *2019 XXI International Conference Complex Systems: Control and Modeling Problems (CSCMP)*. Samara: IEEE. doi:[10.1109/CSCMP45713.2019.8976558](https://doi.org/10.1109/CSCMP45713.2019.8976558)
12. Sokolov, S., Pushkov, R. and Evstafieva, S. (2019). General-purpose Control System Adaptation for Gear Milling Tasks. In: *2019 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon)*. Vladivostok: IEEE, pp.1-5. doi: [10.1109/FarEastCon.2019.8934441](https://doi.org/10.1109/FarEastCon.2019.8934441)
13. Martinov, G., Kozak, N. and Nezhmetdinov, R. (2018). Approach in Implementing of Logical Task for Numerical Control on Basis of Concept “Industry 4.0”. *2018 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM)*. <https://doi.org/10.1109/ICIEAM.2018.8728584>
14. Liliya I.Martynova, Nikolay N.Fokin (2018). An approach to creation of a unified system of programming CNC machines in the dialog mode. In: *MATEC Web Conf. Volume 224, 2018. International Conference on Modern Trends in Manufacturing Technologies and Equipment (ICMTMTE 2018)*. Sevastopol, Russia, September 10-14, 2018. pp.1-5 <https://doi.org/10.1051/matecconf/201822401101>
15. Roman Pushkov, Evgeniy Salamatina, Svetlana Evstafieva (2018). Method of developing parametric machine cycles for modern CNC systems using high-level language. In: *MATEC Web Conf. Volume 224, 2018. International Conference on Modern Trends in Manufacturing Technologies and Equipment (ICMTMTE 2018)*. Sevastopol, Russia, September 10-14, 2018. pp.1-7 <https://doi.org/10.1051/matecconf/201822401116>
16. Georgi M.Martinov, Anna V.Stas, Oleg A.Kudinov (2018). The approach of creating a particular postprocessor and using CNC measuring cycles. In: *MATEC Web Conf. Volume 224, 2018. International Conference on Modern Trends in Manufacturing Technologies and Equipment (ICMTMTE 2018)*. Sevastopol, Russia, September 10-14, 2018. pp.1-7 <https://doi.org/10.1051/matecconf/201822404023>

17. Martinova L. I., Fokin N. N. Approach to creating a unified programming system for CNC lathes in the interactive mode // Automation in Industry, No. 5. 2019. pp. 14-17
18. Pushkov R. L., Salamatina E. V., Evstafieva S. V. Practical aspects of the use of high-level language in the CNC system for the implementation of group processing // Automation in Industry, No. 5. 2018. pp. 31-34