Intelligent Solutions for Machine Tools Using System Sinumerik

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Abstract **– The management of computerized numerical control (CNC) machines in production processes often involves complexities associated with programming efficiency and precision. This study investigates whether the Sinumerik system can enhance the productivity and flexibility of CNC machine programming. The integration of the Sinumerik system into CNC machines will lead to increased programming efficiency and reduced errors, thereby improving overall productivity in manufacturing operations. The study utilized a comparative analysis approach, examining the programming capabilities of CNC machines with and without the Sinumerik system. This involved the use of the Sinutrain Operate training program and the ShopTurn software environment to simulate and analyse different programming methods and their impacts on machine tool performance. Results indicate that the Sinumerik system significantly enhances the programming flexibility and efficiency of CNC machines. Machines equipped with Sinumerik demonstrated a higher precision in component production with considerably reduced programming times.**

The use of advanced managerial systems and interfaces provided by Sinumerik allowed for a streamlined programming process and minimized human error, confirming the system's effectiveness in improving manufacturing productivity.

Keywords **– Sinumerik systems, managerial structures, Shopturn, technological competence.**

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1. Introduction

The current economic situation is characterized by the predominance of supply over demand, which is an incentive for increased demands on the optimization of the factors such as flexibility, quality, and costs. Reduction of costs is the current task for most companies, while the costs most often arise in production processes. For this reason, the priority is to optimize production processes, so it is currently one of the most common tasks in production. The current market environment forces companies to focus primarily on the improvement of operating conditions and to ensure optimal consumption of production inputs when transforming into production outputs using an optimal production process.

The development of science and technology has led to the usage of computer technology in the management of machine tools. This is related to creation of managerial systems that serve for communication between man and machine, and through this way, we can produce complex components in terms of shape in a relatively short time. The advantage of computerized numerical control (CNC) is the high repeatability, accuracy and speed of the performed operations and to a large extent suppressed the occurrence of errors by the human factor. From the earliest managerial methods, such as punched tapes, to the contemporary CAD/CAM systems that offer integrated solutions from design to production, managerial systems have evolved significantly.

Besides standard programming, these systems now incorporate workshop programming, which significantly enhances and simplifies the program creation process.

The Sinumerik System supports multiple programming methods, such as G-code programming (ISO programming), workshop programming, and the use of CAD/CAM technologies. Sinumerik 840 D consists of the following components [9]:

- NCU unit.
- Control panel with MMC or PCU unit and machine panel.
- In/Out of PLC unit from S7-300 series.
- 1FT6, 1FK6 and 1PH motors.
- Simodrive 611D modules.

2. Programming Methods

The selection of programming method depends on the solved problem. When selecting a programming method, it is crucial to consider whether the component can be manufactured using this method and whether the associated costs of any programming software are economically justifiable [5], [7], [8].

ISO programming and its structure: As a standard, it consists of a series of data blocks that contain enough information to perform the individual steps of the technological process on the machine tool. The blocks consist of the following components:

- Commands (words) according to DIN 66025.
- Elements of the higher language of the NC system.

Blocks are made up of one or more words that indicate that the control system will perform the operation. A word is an ordered set of characters consisting of letters and some numeric characters (Figure 1), which actuate specific actions of the machine tool [6], [16]. The first letter of the word is called the address character and it serves for identification by the control system.

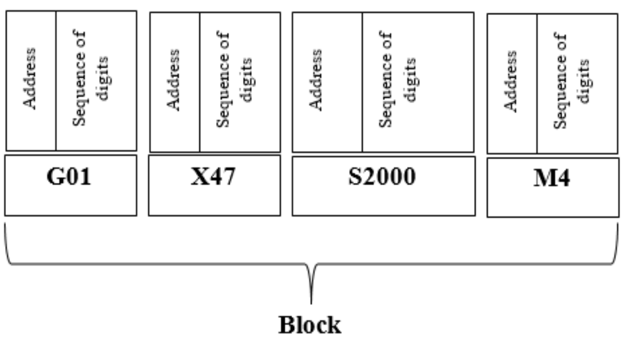


Figure 1. Programing block

The higher language elements of the NC system are used for programming complex work procedures on modern machine tools, where a set of commands according to DIN 66025 is no longer possible [10], [14], [18].

1. Higher language commands of the NC system Unlike - g-code commands, higher language commands for NC systems consist of a large number of address letters, eg:
   - OVR for speed correction (override).
   - SPOS for adjusting the spindle into a certain position.

2. Identifier:
   - System variables.
   - User-defined variables.
   - Subprograms – keywords.
   - Jump signals.
   - Macros.
   - Relational operators.
   - Logical operators.
   - Mathematical functions.
   - Managerial structures.

Commands can have modal or block validity:

1. Modal validity - commands are retained with the programmed value in all of the following blocks until:
   - The same command does not program the same value.
   - The command is programmed that cancels the effect of a valid command.
2. Block validity - commands are valid only in the block, in which they are programmed.

At the start of the program, the character '%' appears before the first row, followed by a numeric value that specifies its number [1], [8], [19]. For clarity, the blocks can be indicated by a block number at the start, where the first letter is N and is the positive integer. The end of the block ends with the character LF, but does not have to be written due to automatic insertion when moving to the next row. The maximum block length is 512 characters. In order to make the program as clear as possible, the following sequence is recommended as follows [9], [16]:

N ... G ... X ... Y ... Z ... F ... S ... T ... D ... M ... H ...,

Where:
N – Sentence number,
G – Preparatory functions,
X, Y, Z – Coordinates,
F – Feed rate,
S – Spindle speed,
T – Tool invocation,
M – Auxiliary functions,
H – Auxiliary function.

***Advanced programming methods*:** This is a method of programming that except for standard commands, allows users to program using functions. Creation of conditions together with loops leads to the possibilities of adaptive management, but its usage is also in the programming of a standard production batch. In this way, it is possible to make the machining process more effective.

Workshop programming: When using Sinumerik, the following programs, ShopTurn and ShopMill, are associated with the term workshop programming. These programs were created to simplify and accelerate the programming.

The main task of workshop-oriented programming is to create a CNC program using the control panel and graphical user interface in the shortest possible time, even during full machine operation. It is therefore the usage of a conversational CNC managerial system equipped with a workshop programming system. The conversational CNC managerial system allows to create (and subsequently to use) a managerial program using conversational instructions provided directly via the managerial screens of the CNC managerial system [2], [6], [11]. Starting the workshop programming with a PC is possible with the SinuTrain program.

3. Design of the Machined Component Production in the ShopTurn Software

The software was developed for workshop programming; its integration into the managerial system aimed to enhance work efficiency and reduce the time needed for production preparation. Shop Turn is particularly suitable for turning with one spindle operations, but also supports C-axis and counter-spindle. Its application can also be found in milling and drilling operations. The program is created using the control panel and a graphical interactive interface step by step with the possibility of possible editing (Figure 2). This allows user to program without knowledge of the G-code, but also allows user to insert program blocks in ISO/DIN. The big advantage is the possibility of using already created programs for new components.

It even allows user to build a program even with an incompletely dimensioned drawing thanks to the contour calculation function, which is the part of the system and contains up to 50 indeterminate shapes or transitions. This method of programming is especially suitable for small series production or production of individual pieces [3], [13], [15].

When designing a component, the shape of the work piece has to be adapted in the way that more of the operations, such as turning, milling, and drilling, can be performed on it. Since the production of components can be difficult to realize on a conventional machine, it was necessary to choose a machine with which the production would be possible. Another criterion was the production of a component in one clamping in order to eliminate the time associated with handling, while the final operation could be the pricking of the components. For this reason, the SP180Y machine was chosen, which has driven tools and a programmable tailstock [9], [17].

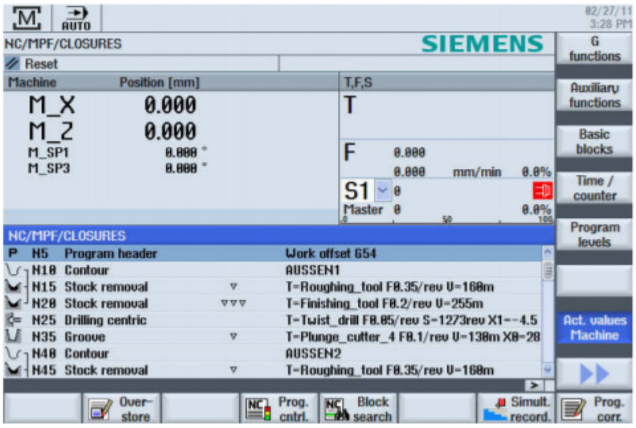


Figure 2. The screen with loaded program created in ShopTurn

The design of the sequence of operations was based on the proposed production drawing and the program was processed in the user environment ShopTurn in the training version Sinutrain Operate.

The component will be produced from a semi-finished product of rod material EN AW 6082 T6. Since the final operation performed on the machine tool will be pricking, the semi-finished product will be fed using LNS HYS 6.42 (rod with diameter 6 mm, maximal length 3000 mm). Also for this reason, the selection of rod material was preferred over the casting, because there would be a clamping problem with the casting.

4. Processing the CNC Program Using ShopTurn

The beginning of the work after the creation of the file was to fill in the basic data about the semi-finished product, including its clamping.

The diameter of the rod in our case is 32mm. Unloading has to be at least 30 mm from the axis milling to avoid a collision with collet chuck (Figure 3). The first operation is to align the work piece body completely, followed by the roughing operation of the outer sheath. Everything is done with one tool [6], [12]. The next step was the production of the Ø16 hole. This can be created either by a cycle of creating a circular pocket by milling or by central drilling using a grooving cutter. The disadvantage of drilling is that by a backward movement with the high probability arises spiral-shaped groove (Figure 4).

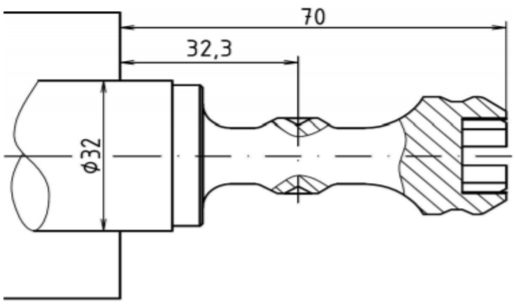


Figure 3. Displaying the offset from collet chucks

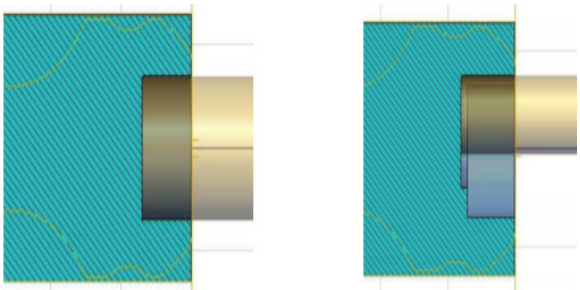


Figure 4. Creation of a hole

For roughing and subsequent finishing of the component shank we used a strategy of grooving turning and during this turning the tool moves in both the radial and axial directions, which also allows the machining of the material at the radius (Figure 5). For this type of turning, it was necessary to choose a special replaceable cutting plate. The initial design was a plate with a tip radius of 3mm.

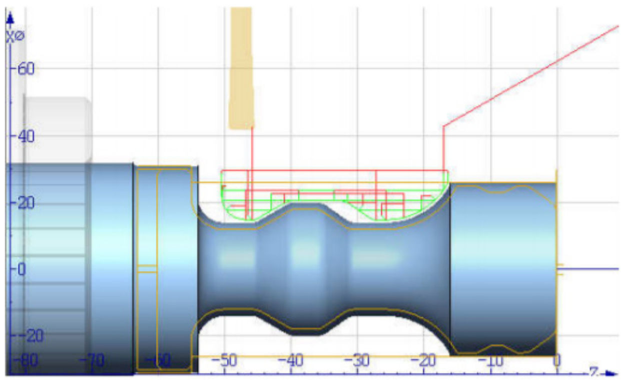


Figure 5. Roughing the shaped shaft of the tower

After simulating the machining, it was found that at the radii R3 there was a larger allowance for machining than prescribed in the program, and therefore a replaceable cutting plate with a flat cutting edge and a width of the cutting plate of 4 mm was chosen, which machined the part with the required allowance. During the final machining process, a plate with a 2 mm tip radius was used to achieve the best possible surface finish (Figure 6).

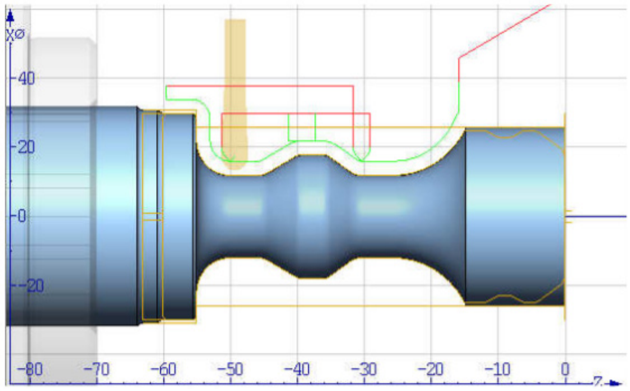


Figure 6. Turning the shaped shaft of the tower

When finishing the tower shaft, a smaller feed rate (f = 0.1mmot-1) was chosen at the radius points for better copying of the curve shape and for reducing the possibility of vibration. The next operation is to roughen the contour of the tip by immersing the tool and creating a recess on its surface. Because of the fact that the tool has to copy the shape of the recess as accurately as possible, a lower feed rate was again selected at the chamfers and the entire contour is finally machined (Figure 7).

When machining the tower head, we continue with grooves creation, which will result in a battlement. The miller path is programmed using a contour and subsequent machining is performed using a path milling cycle. In order to achieve a uniform distribution of grooves along the entire circumference of the tower head, we rotate the semi-finished product by 60 ° with a spindle by a rotation cycle of the C axis (Figure 8).

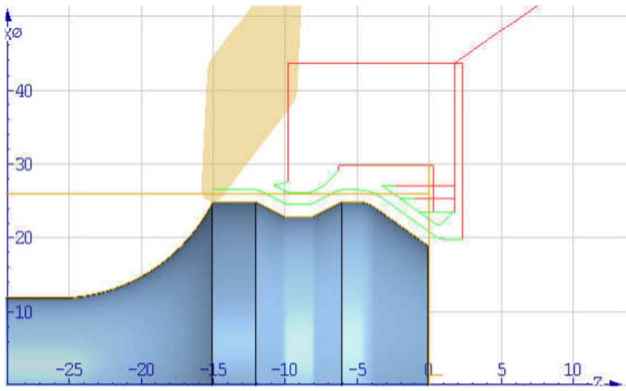


Figure 7. Roughing and finishing the tower head

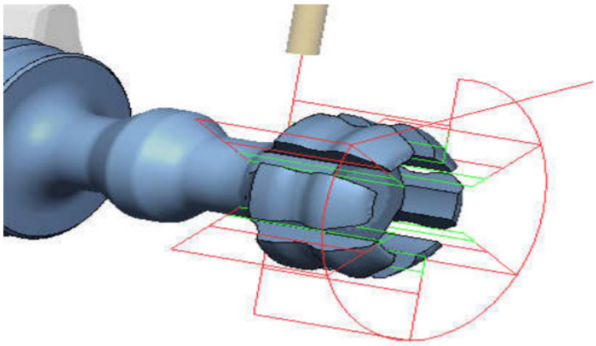


Figure 8. Creation of grooves

Similarly, multi-edge machining on the tower shaft is programmed. Prior to machining, the C axis is rotated 30 °. The tool path is programmed in the Y-axis direction using a path milling cycle (Figure 9).

The last operation is pricking, during which a chamfer is formed. When using the left plate, no protrusion will form on the bottom of the part after pricking. The disadvantage is the higher tool load compared to case when using a neutral plate and the lower life cycle. When using such a plate, care must also be taken to reduce the feed rate during cutting (25%) in order to reduce vibrations. It is also suitable to reduce the cutting speed. The resulting part after machining looks as shown in Figure 10.

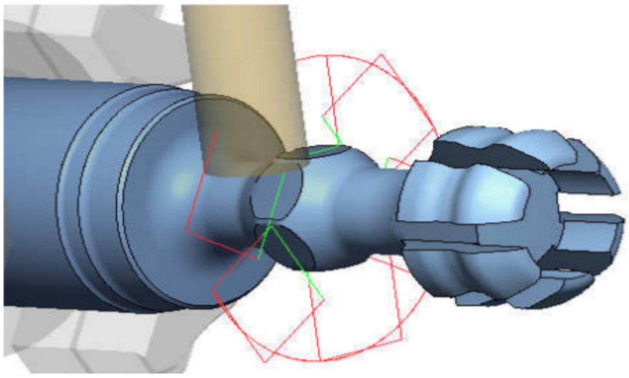


Figure 9. Creation of multi-edge

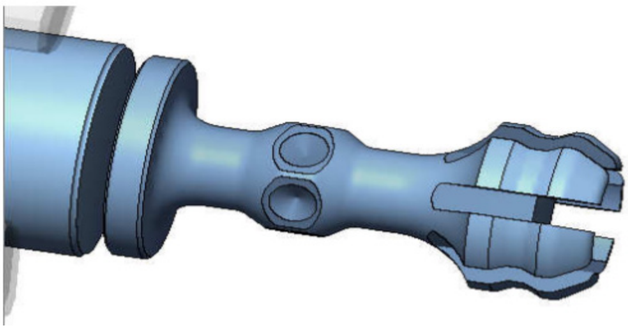
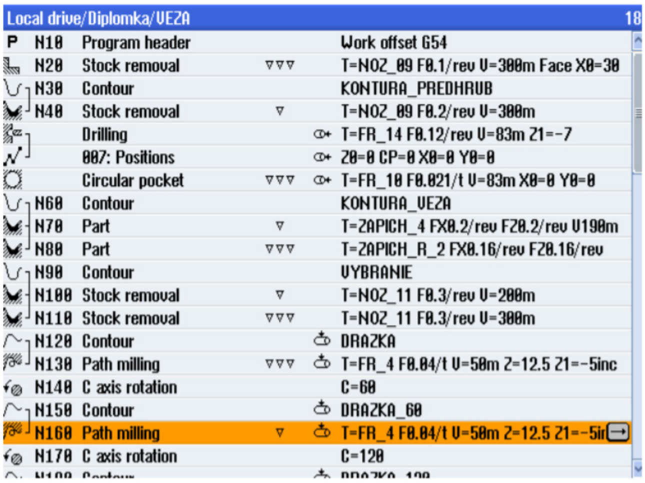


Figure 10. Example of a machined component – Tower

This production variant was made without the support of a tailstock.

If the vibrations occur during production process that would degrade the tool or work piece, a tailstock must be used to increase the clamping rigidity. In this case, the production technology will also change. First, the front of the part is aligned, then the centre hole is drilled and the part is supported by the tip. Another operation is the machining of the contour, while at the end of the turning operation the tailstock is released and is continued by drilling a hole and milling a pocket on the front of the part. Gradually, grooves are formed on the head [4], [16]. The whole program is in Figure 11.



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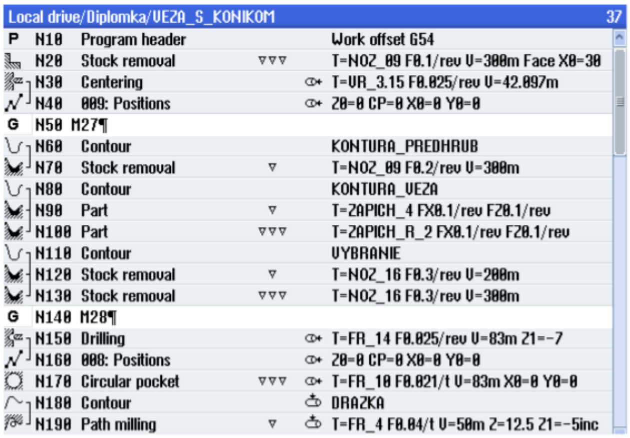
P	N10	Program header			Work offset G54
	N20	Stock removal	▽▽▽		T=NOZ_09 F0.1/rev V=300m Face X0=30
	N30	Contour			KONTURA_PREDHRUB
	N40	Stock removal	▽		T=NOZ_09 F0.2/rev V=300m
		Drilling			T=FR_14 F0.12/rev V=83m Z1=-7
		007: Positions			Z0=0 CP=0 X0=0 Y0=0
		Circular pocket	▽▽▽		T=FR_10 F0.021/t V=83m X0=0 Y0=0
	N60	Contour			KONTURA_VEZA
	N70	Part	▽		T=ZAPICH_4 FX0.2/rev FZ0.2/rev V190m
	N80	Part	▽▽▽		T=ZAPICH_R_2 FX0.16/rev FZ0.16/rev
	N90	Contour			VYBRANIE
	N100	Stock removal	▽		T=NOZ_11 F0.3/rev V=200m
	N110	Stock removal	▽▽▽		T=NOZ_11 F0.3/rev V=300m
	N120	Contour			DRAZKA
	N130	Path milling	▽▽▽		T=FR_4 F0.04/t V=50m Z=12.5 Z1=-5inc
	N140	C axis rotation			C=60
	N150	Contour			DRAZKA_60
	N160	Path milling	▽		T=FR_4 F0.04/t V=50m Z=12.5 Z1=-5ir
	N170	C axis rotation			C=120

Figure 11. The sample of program – Component

This is followed by milling multiple edges and drilling holes on the shank and parting the part. The program supplemented by the tailstock programming is in Figure 12.



Local drive/Diplomka/VEZA_S_KONIKOM 37

P	N10	Program header		Work offset G54
	N20	Stock removal	▽▽▽	T=NOZ_09 F0.1/rev V=300m Face X0=30
	N30	Centering		T=VR_3.15 F0.025/rev V=42.097m
	N40	009: Positions		Z0=0 CP=0 X0=0 Y0=0
G	N50 M27¶			
	N60	Contour		KONTURA_PREDHRUB
	N70	Stock removal	▽	T=NOZ_09 F0.2/rev V=300m
	N80	Contour		KONTURA_VEZA
	N90	Part	▽	T=ZAPICH_4 FX0.1/rev FZ0.1/rev
	N100	Part	▽▽▽	T=ZAPICH_R_2 FX0.1/rev FZ0.1/rev
	N110	Contour		VYBRANIE
	N120	Stock removal	▽	T=NOZ_16 F0.3/rev V=200m
	N130	Stock removal	▽▽▽	T=NOZ_16 F0.3/rev V=300m
G	N140 M28¶			
	N150	Drilling		T=FR_14 F0.025/rev V=83m Z1=-7
	N160	008: Positions		Z0=0 CP=0 X0=0 Y0=0
	N170	Circular pocket	▽▽▽	T=FR_10 F0.021/t V=83m X0=0 Y0=0
	N180	Contour		DRAZKA
	N190	Path milling	▽	T=FR_4 F0.04/t V=50m Z=12.5 Z1=-5inc

Figure 12. The sample of program – Component – with programmed tailstock

To program the tailstock M-functions were used. After drilling the centering hole, the program is interrupted and in the manual mode, the part is supported by the tailstock using the foot controller and then released again.

The clamping position for automatic mode for the M27 function is automatically written. Then the program starts again in automatic mode. To release the tailstock in automatic mode, we can use the command M28 (release the tailstock) or M25 (release the tailstock to the extreme clamping position). The program was also programmed using ISO code in the Sinutrain Operate 2.6.1 [16]. The main advantage of such programming is a more detailed description of the tool path. This allows the programmer to reduce time and increase the efficiency of the production. Reduction of the production time in series production, even by just a few seconds, can ultimately lead to large savings.

Preview of the whole program:

```
N10 G54 G18 G90 DIAMON
N20 G0 X200 Z10 N30 M6 T1 D1;
SIDE CUTTER
N40 G96 S280 M4
N50 LIMS=5000
N60 G0 X34 Z1
N70 G1 Z0 F0.1 M8;
FRONT ALIGNMENT
N80 G1 X-1.6
N90 G0 Z1
N100 X31;
ROUGHING A PLASTIC
 N110 G96 S380 F0.2
N120 G1 Z-63
N130 G0 X32 N140 Z1
 N150 X26
N160 G1 Z-54
N170 G0 X32 M9
N180 X200 Z10;
MILLER FI 14
N190 M6 T6 D1
N200 G96 S138 F0.13
N210 G0 X0 Z3 M8;
HOLE DRILLING
N220 CYCLE82(3,0,1,-8,,0,0,1,12)
N230 X200 Z10 M9;
MILLER FI 10
N240 M6 T7 D1
N250 G96 S83 M8
N260POCKET4(3,0,1,8,16,0,0,8,0.01,0.01,0.029,0.0
29,0,12,40,9,8,0,2,0,1,2,1 0100,111,110)
N270 G0 X200 Z10 M9;
GROOVING CUTTER
N280 M6 T3 D1
N290 G96 S190 F0.2
N300 G0 X27 Z-15 M8;
TURNING STREAM CONTOURS
N310CYCLE952("STREAM",,"",101311,0.1,0.2,0,2
,0.1,0.1,1,1,0.1,1,1,26,1,,,,,2,2,1,30,
0,1,0,,32,1000110) N320 X200 Z10 M9 ;
GROOVING CUTTER R2
N330 M6 T4 D1
N340 G96 S180 F0.2
N350 G0 X27 Z-15 M8;
FINAL TURNING STREAM CONTOURS
N360
CYCLE952("STREAM",,"",101321,0.1,0.16,0,1.5,0.
1,0.1,1,1,0.1,1,1,26,0,,,,,2,2,1,30,0,1,,0,32,1000110)
N370 X200 Z10 ;
COPY CUTTER
380 M6 T2 D1
N390 G96 S200 M8
N400 G0 X26 Z2
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5. Conclusion

The paper's objective was to address the complexities of programming with the Sinumerik system. Given the breadth of this topic, the paper aimed to succinctly outline the fundamental principles and methods of programming. For the implementation, a complex shaped component was designed, for which the cycles included in the ShopTurn system were used. The output is a dynamic simulation in the tutorial Sinutrain Operate 2.6.1, which is practically identical to the control panel of the machine tool. Production processes on machine tools are influenced by the requirements for shorter time-to-market and increasing individualization of products. For machine producers and their users, high productivity is now the most important factor. Simultaneously, it is crucial to ensure optimal collaboration between solutions for automatic and CNC control, sophisticated technology, and the efficient integration of digital solutions. This is related to all areas: from the design and production of the machine to its operation and service.

The management is based on an open architecture and this allows the maximally adaption to the machine. The operating system can be supplemented and adapted to the specific operation. It is even possible to integrate robots and other handling systems into the system. The model is adapted for the control of turning, milling and grinding machines, machines for the production of gears, machines for cutting material by water jet, plasma and laser, but also for the management of multifunctional machining centers. The management is also used in progressive production methods, such as combined erosive and additive technologies.

Acknowledgements

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