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APPLICATION OF MECHATRONIC MODULES FOR PROCESS EQUIPMENT UPDATING

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Abstract.

The paper presents the theoretical justification for process equipment updating in machinery production. Authors propose the modular approach to a workflow system on the basis of a swiss-type automatic turning lathe. It is supposed to use in the capacity of an operation unit the adaptive tool component for which authors have took out a patent. It is theoretically established that in order to avoid loss of quality of a gained surface when shaping a structural element, it is necessary to synchronize coordinate drive systems in the longitudinal and transverse direction according to a function presenting the structural element. The constructed model has allowed us to prove a necessity to use the factor which synchronizes parameters of drives by synchronization of frequencies of motor power supply voltages. The mathematical model created with the use of a special mathematical package reflects the process of cutter travel when processing a flattened surface or an unsymmetrical recess in the process of turning. Authors propose the block schematic diagram for equipment updating, and the control algorithm for a process system which involve adaptive tool components. Recommendations on assignment of cutting modes allow assessment of construction capabilities when processing structural elements of a product having a plain parallel to its axis.

Keywords. Technological system, mechatronic module, adaptive module, structural element, cutting modes, drive, algorithm.

Introduction. Changes taken place in the last decades in approaches to the design of process equipment, including machine-building facilities, allowed enterprises to expand the range of products, reduce the cost of their final product, reduce the time for preproduction engineering. These changes are associated with the use of both automated pre-production engineering systems, and with the improvement of equipment control systems [1]. Obsolete equipment held by producers is subject to a disposal or updating using the latest advances in the automation of production. Updating by embedding into a process system of mechatronic modules allows expanding the technological capabilities of the equipment at optimum cost that has already been described by the authors in the works on improvement of technological systems on the basis of the automatic bar-stock machines [2]. The use of such modules allows not only to increase the possibility of obtaining complex shaped products, but also to reduce the time for both production cycle and production preparation.

Technique. Authors consider that for processing shaped articles, in particular unconventional for lathe turning, it is necessary to solve sequentially a problem on synchronizing operation of drives upon travel of a driven element that is confirmed also by other studies executed in this area [3]. A tool or a driven element path should render the preset geometrical function. Upon that, the problem should be solved not with the use of a series axis control, as in a case with CNC equipment, and with ensuring continuous travel what allows required quality of a processed surface to attain.

Main body. The modular approach of workflow system afford an opportunity to implement adaptive control in the basic process, in the case under consideration, in stock removal operation thanks to which, in the course of further equipment operation, there would be a possibility to ensure a required quality of product at minimum expenditures, and having increased performance. Equipment control is carried out from a single controller. The number of modules depends on the forecast range of manufacture. The block diagram of proposed updating alternative on the basis of the special tool component [4] developed by authors,4 is presented in figure 1.

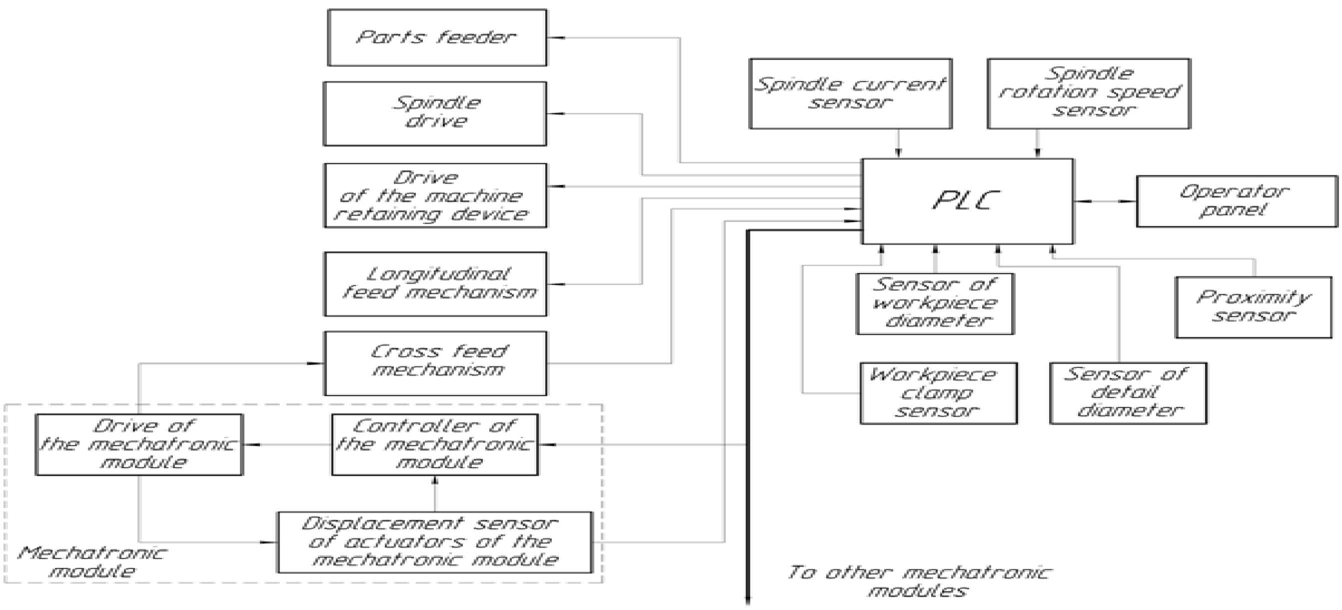


Figure 1 - Block schematic diagram of swiss-type automated turning lathe control equipped with mechatronic modules.

The programmed logical controller (PLC) collects an input information from sensing transducers about presence of an workpiece, and its fixation in a draw-in attachment. In the course of a bar feed, its diameter is monitored with the use of a special shadowgraph. When machining, the operating procedure computes a stock removal value and transmits data to executive units. During the process, PLC executes processing of the entering information on the processed item and forms drive control instructions. An operator panel (the PC with preinstalled software) represents a current condition and control command generation in PLC, such as system sensor readings recording, changing the parameters of product machining modes, turning on/off executive units. An operator also introduces in the program an information on current geometry of a product shape, settings and restrictive process parameters.

The spindle rotation speed sensor allows controlling spindle speed of a lathe. And the spindle drive current sensor is intended to correct machining modes in a case of delivery of workpieces with an uneven stock removal value. The mechatronic module controller receives a signal from PLC indicating in what direction and for what distance the executive units of lathe drives should be displaced. The controller converts these data to voltage and current values that determines a power supplied to the motor. There are sensors in the circuit in the capacity of a link between electronic and mechanical parts of the mechatronic module; they transmit into the controller the information on travel of operative parts of the equipment (which generate a pulse upon each elementary displacement. A final position is defined by count of pulses depending on a travel direction) [5]. The module can be used individually and in various combinations with other modules. The system can contain several mechatronic modules connected to one bus [6,7].

The experimental prototype of the module according to [4] has used stepping motors in the capacity of drives. Control of stepping motors was carried out with the use of interface *STEP-DIR-ENABLE*, where *ENABLE* – selection of a drive or its turning on; *DIR* – a rotor rotational direction: clockwise or counterclockwise; *STEP* – a step or a preset pulse repetition frequency ($F_{п}$)

As the pulse repetition frequency defines a rotational speed of the motor output shaft, it is directly related through the connecting gear with an operating unit travel speed. Authors had carried out research on control of stepping motor *SY*57 with the use of controlling unit *EM*705. Control was executed from PC by means of specially designed software which feature was generating of control pulses immediately from a computer clock signal generator. Research results have shown that it is possible to vary a range of a set pulse repetition frequency from 1 to 8 000 Hz what is a quite good parameter of CNC drive control depth. According to rated values for the motor *SY57STH56-2804A* [7], angular step value makes 1.8 °, the step length was not used. The module has applied as its part a lead screw on the basis of the ball screw pair with step of 4 mm that matches to travel of 0.02 mm per pulse. Hence, travel speed makes from 0.02 to 16 mm/s. Though the motor can accelerate to higher speeds, but this results in a moment loss. The drive allows smoothly to vary an output shaft rotation speed, that in turn ensures more exact path-tracing for the article produced.

In the case of a frequency regulation, travel speed of the operating unit is defined as follows:

$$V = k \cdot t \cdot f(F) \quad (1)$$

k – transmitting factor of a feeding mechanism,

$f(F)$ – motor winding supply voltage frequency function;

F - supply voltage frequency;

t - rotation to linear displacement transformation step.

Thus, knowing the operating unit path law, and using the first time derivative it is possible to define operating unit speed in each path point, and, hence, required current frequency in motor windings.

So, pulse repetition frequency changes causes changes in travel speed of the operating unit of equipment. According to the documentation for the above-specified drive [7], generation of a signal starts upon detection of a rising edge of a control pulse, and the motor rotor turns with a step strictly defined by its manufacturer – 1.8°**.** Rotor movements about its axis are executed due to impact of the magnet field generated in the motor windings, and determined by a value of a current passing through windings. In turn, the current strength is restricted by an inductive impedance of motor windings which is augmented along with frequency growth. That's what accounts for rotational moment drop upon increase in frequency of the motor winding supply voltage.

Process of control signal generation is linked with generation of control pulses. That is value of an operating unit travel depends on number of the pulses which have come to a winding what defines a travel length:

$$l = n \cdot t, mm \quad (2)$$

Where t - a pulse step value, mm.

Expression 2 allows to determine the operating unit travel speed at a known time τ:

$$V = \frac{n \cdot t}{\tau}, mm/s \quad (3)$$

Where t^i – the pulse value, mm;

τ – an operating unit travelling time, s.

As it has been noted above in the chapter, a travel speed is defined by control pulse repetition frequency. According to the manufacturing documentation [7], relative pulse duration should be not less than 50 %, that is the effective part of a pulse should be no more than a half of its period.

As is known, the period is a value reciprocal to a pulse frequency. Knowing the pulse value, it is possible to define from the expressions:

$$\tau = \sum_{i=1}^{n} T_i \, , s \qquad (4)$$

$$\tau = \sum_{i=1}^{n} \frac{1}{F_i} , s \qquad (5)$$

Where T_i – pulse duration for a step, s;

i - step number;

F_i – frequency for a step, Hz.

Thus, variation of speed is attained by variation of a pulse period at each step. As it has been noted in [8, 9]: if travels are linear, it is offered to perform them according to the linear law, alternatively to the circular law. That is there are only two types of travels: with linear and circular interpolation. Or for the swiss-type automatic turning lathe: control of a workpiece feed drive and transversal tool travel, thus, frequencies ratio can be expressed with the following expression:

$$k^F = \frac{\Delta \mathrm{x}}{\Delta z} = \frac{|x_i - x_{i-1}|}{|z_i - z_{i-1}|} \qquad (6)$$

Where x_i and z_i – co-ordinates of a section finite point;

x_{i-1} and z_{i-1} – co-ordinates of a section index point.

If to accept a longitudinal feed or workpiece feed in the capacity of "base" feed, based on which counts are made, transversal feed will be equal to:

$$S_x = S_z \cdot k^F \qquad (7)$$

Where S_z - feed in the longitudinal direction, mm/s.

As is known, an operating unit travel speed is a feed, and taking into account the connecting gear and a lead-screw pitch it is finally possible to calculate the required frequency for longitudinal feed:

$$V = \frac{k \cdot t \cdot t^{i} \cdot n}{\sum_{i=1}^{n} T_i}\ , mm/s \tag{8}$$

If T_i = *const*, then linear travel will be:

$$V = \frac{k \cdot t \cdot t^{i} \cdot n}{\sum_{i=1}^{n} \frac{1}{F}}, mm/s \tag{9}$$

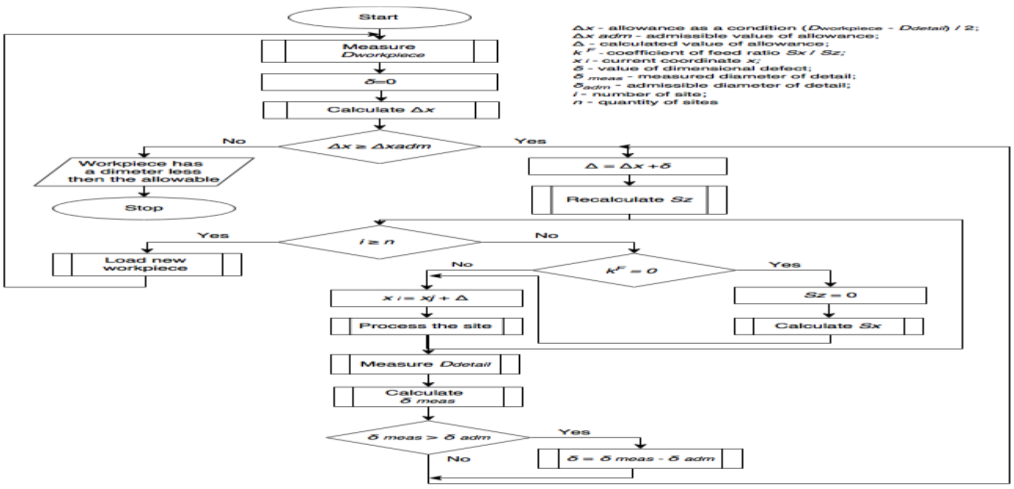
Accordingly, considering that travels are related as well as frequencies

$$k^{F} = \frac{F_x}{F_z} \tag{10}$$

Where F_x – a pulse frequency at the transversal feed drive, Hz;

F_z - a pulse frequency at the longitudinal feed drive, Hz.

It is possible to change feed direction when tracing the product profile. In the case of using a swiss-type automatic turning lathe, feed reverse is executed only in a transversal direction due to its structural features; upon that, there is a certain point of feed direction change in a path; in this point feed value becomes equal to 0, and then travel is carried out in the opposite direction. Upon a circular motion, the exit into a feed change point is performed under the circular law, and at linear interpolation under the linear law. A special case is a groove cutting and workpiece cutting off, thus feed in a transversal direction should be accepted in the capacity of base, as S_z=0, and k^F=0, accordingly. But in any case under condition of S_x=0, feed in the longitudinal direction S_z=0, that is, a travel stop in the longitudinal direction is necessary. And in the case of a groove cutting and workpiece cutting off, the condition of drive stopping to execute the operation should be observed completely.



Drawing 2 - Algorithmic diagram for the equipment control upon machining of workpieces.

The workpieces fed in the equipment are metered with the use of a special projective measuring gear (figure 2). Specially designed procedure of image processing calculates the stock removal value according to a certain algorithm. In the event if the stock removal value is equal or more than an admissible stock removal value, [Delta] being a design stock removal value should be calculated; further this value will be added to corresponding co-ordinate X on each section. In the event if the stock removal value is less; then the message is displayed that the workpiece diameter is less than the admissible one and the equipment stops. Equipment restart is possible after replacement of a workpiece. In the event if the condition on excessive stock removal is observed the design stock removal value (that is the value which should be added to the corresponding co-ordinate *X* on each section of a path) should be calculated. A [delta] should be added to this value, that is a calculated size deviation which is calculated in the course of measuring the item after machining. What is more, not an absolute value of the size, and its relative value, that is, possible co-ordinate change in a negative or positive direction. Then a longitudinal feed value is recalculated using a corresponding factor.

Machining of sections should be executed sequentially from the right back of the part, as well as it is accepted in the corresponding system of axes [10]. In the event that there would be detected a section having $k^F = 0$, or a section in which a slide transversal travel (radial turning, cutting off, groove cutting) is performed only, the feed should be calculated only in a transversal direction.

The diagram does not show actions in the event that a bar (workpiece) feed terminates. These actions do not refer immediately to machining control, but can be presented depending on an automaton construction. If the automaton has not a magazine, the equipment shuts down automatically upon the bar feeding termination. Operator manually loads a new workpiece and runs execution of the program. In the case of use of a raw part magazine, simultaneously with consumption of workpieces from the magazine, the automaton is charged with new in an automatic cycle and operation proceeds. With the expenditure of workpieces they are additionally charged into the magazine.

The diagram also does not show actions in the event if a cutter is worn. One of alternatives does not consist in its change, manually or by the transfer arm, but in wear monitoring. Wear monitoring can be executed by a limiting value of the magnifying of the processed diameter due to change of geometrical dimensions caused by wear of the tool cutting end. Authors consider that in order to increase a reliability of results of tool cutting end wear monitoring, it is necessary to use two ways simultaneously.

That is, if for the previous article there was a variation of the gained diameter D_{Hi}, and in the course of machining the current workpiece, there was a magnifying of a drive current in the master motor I_i in comparison with a design value for current cutting depth I_{Hi}, it is necessary to stop the automaton before machining a next workpiece and to replace the tool. The problem solution for turning the plains parallel to a workpiece rotational axis upon allows us to simplify the technological system. For the module developed by authors and presented on fig. 3, a special software [11] has been developed11 allowing synchronization of a longitudinal motion of workpiece and transversal cutter travel.

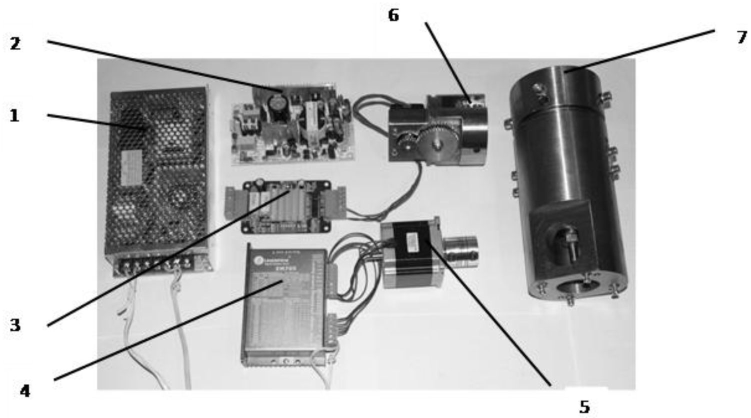


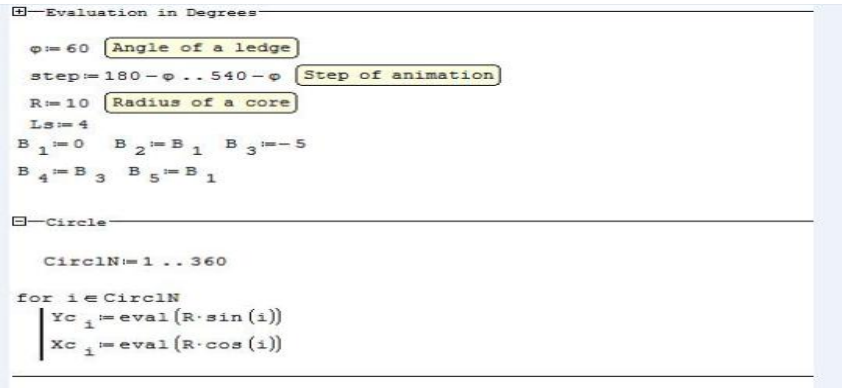
Figure 3. Experimental prototypee of the adaptive tool component

1 – 48V power module; 2 – 24V power module; 3. - tool droop drive controlling unit; 4 – transversal feed drive controlling unit; 5 – transversal feed drive; 6 - cutting end adaptation mechanism; 7 – adaptive tool component casing

The software operates on the basis of theoretical model represented in [12] and completely presenting a shape of a product processed in a swiss-type automatic turning lathe with the use of a straight turning tool. Besides theoretical study of a state-of-the-art, authors have built a virtual model with the use of software SMathStudio shown on fig. 4. The model allows us to analyze a capability of processing a flattened surface having a certain angle to a rotational axis for workpiece of preset diameter. Besides, the graphical part of the model reproduces results in dynamics upon stock removing by a cutting edge that is presented on fig. 5

The experimental prototype of the module was tested under control from PC LPT-port with the use of the program developed by authors [11] in the MSVisualStudio environment. Feature of the program is that frequency of a control signal applied to stepping motors is changed not by means of a procedure, by variation of a time of signal output to the corresponding port pin, but its synchronization with a computer clock signal generator that has allowed us to ensure a considerable motor shaft rotation speed control band. The fragment of the program with access to data of a computer clock signal generator with the use of QueryPerformanceFrequency procedure is shown below.

```
Private Sub Command2_Click ()

 Rem KeyPress

 Dim Ctr1 As Currency, Ctr2 As Currency, Freq As Currency

Rem Start pulse

QueryPerformanceFrequencyFreq

QueryPerformanceCounter Ctr1

Label2.Caption = 1 / (Freq * 10000)

Label3.Caption = Ctr1 * 10000

Out &H378, 1 * 128 + 0 * 64 + 0 * 32 + 0 * 16 + 0 * 8 + 0 * 4 + 0 * 2 + 0

QueryPerformanceCounter Ctr2

Out &H378, 0 * 128 + 1 * 64 + 0 * 32 + 0 * 16 + 0 * 8 + 0 * 4 + 0 * 2 + 0

Label4.Caption = 1 / ((Ctr2 * 10000 - Ctr1 * 10000) * (1 / (Freq * 10000))) * 1000000

Label6.Caption = 0.001 / ((Ctr2 * 10000 - Ctr1 * 10000) * (1 / (Freq * 10000))) * 1000000

RemEndPulse

EndSub
```



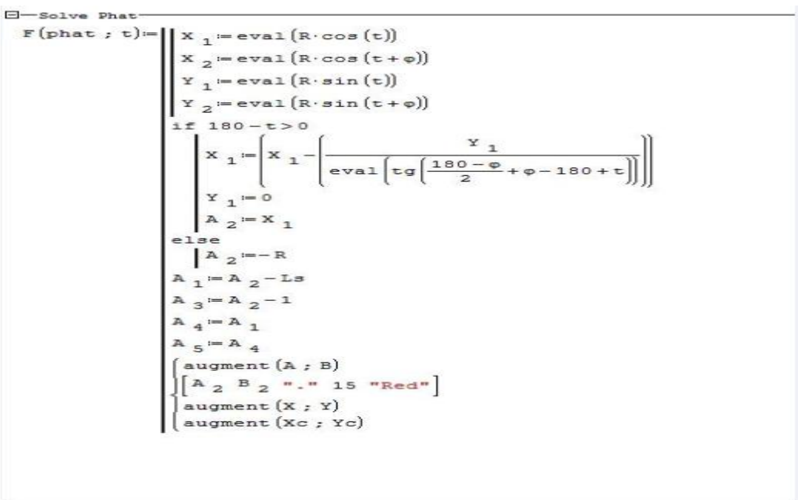


Figure 4 – SMathStudio program sheet with calculation by means of model for processing a flattened surface.

The chosen approach to algorithm implementation by a stepping motor of the adaptive tool component has allowed us to ensure high speeds of operating unit travel and exactitude of its positioning.

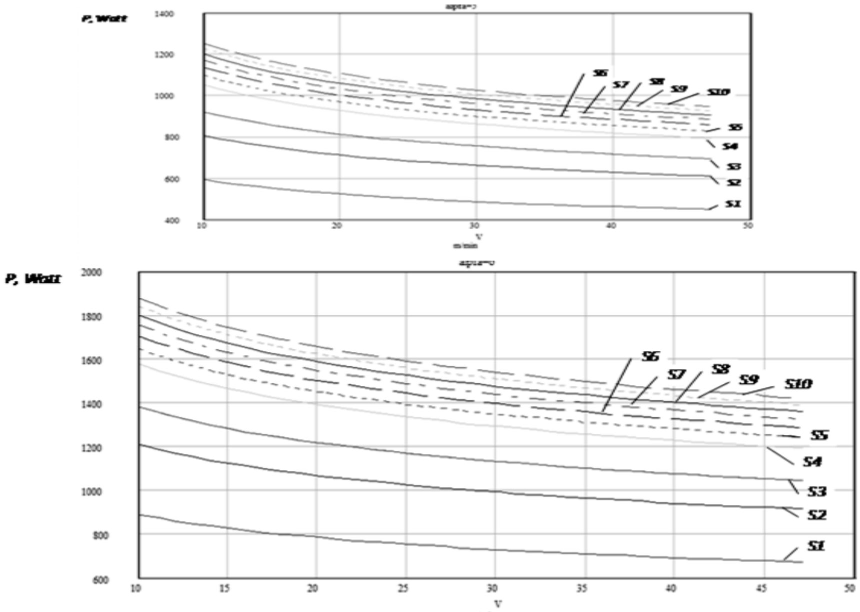
Resume. If a possibility to process a shape of the structural element can be proved theoretically with the use of model presented in fig. 4 and fig. 5, the assigned modes are determined experimentally. Authors have obtained nomograms (fig. 6) for assignment of cutting modes upon machining a carbon fine-machining tool steel by a straight-turning tool with cutting end made from HSSCo5, and with an end-clearance angle [alfa] 5 ° and 6 °.

The feed values presented in fig. 6 in the form of variables S1, S2 … were assigned according to table 1.

Table 1. The table of transversal feed values

No.	1	2	3	4	5	6	7	8	9	10
Feed value, mm/rev.	0.01	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45

The nomograms presented on fig. 6, *a*, show that at the angle [alfa] =5 ° effect of cutting rate is insignificant what additionally proves operation capability at high speeds. The basic effect on power consumed by the drive is caused by a longitudinal feed value. The considerable forces arising in the course of cutting increase a drive power input, but power limits at this angle do not exceed maximum permissible values that allows varying modes within considerable speed and feed range, thus ensuring high efficiency under condition of maintaining the quality of a processed surface.



Drawing 6 – Nomographs for assignment of regimes of cutting at deriving of ledges by the adaptive tool component

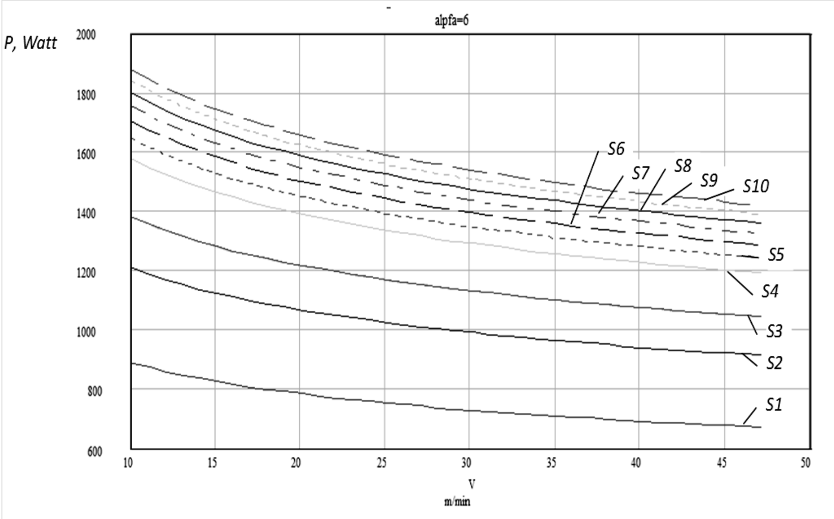


Figure 6 - The nomograms for assignment of cutting modes when processing recesses by an adaptive tool component

The nomograms presented in figure 6, *b* show that at angle [alfa] =6° effect of cutting rate is also insignificant, as well as at angle [alfa] =5° what additionally prove operation capability at high speeds. The main effect on the power consumed by the drive is caused by a longitudinal feed value. But upon that, the drive power input has increased though it does not exceed maximum permissible values. It is necessary to select cutting modes in a narrower range. Thus, with magnifying a primary back clearance angle value, decline in productivity is possible under condition of maintaining the quality of a processed surface. In the case of further magnifying the value [alfa] there will be a cutting power surge, so the occurring modes will lead to breakage of the adaptive tool component and, hence, cannot be recommended.

In the case if the primary back clearance angle [alfa] =5 ° maximum cutting power would not exceed 1.5 kW that is quite comprehensible to the equipment. Thus it is possible to consider the most preferable modes when cutting speeds are over the range of 30 … 45 m/min; transversal feeds – 0.1 … 0.3 mm/rev; cutting power - 0.5 … 0.6 kW.

Conclusions

Use of an adaptive mechatronic module when updating of Swiss-type automatic turning lathes allows technological possibilities of the equipment to expand, in particular, for processing structural elements parallel to an item rotational axis. Updating of the existing equipment assumes the use of ready adaptive tool components with synchronization of their operation with the equipment with application of an integrated control system.

It is proved that frequency ratios for control of longitudinal and transversal feed drives should match up as well as feed values when moving according to a prescribed function presenting a structural element that allows discreteness to avoid when shaping the element.

We have determined power limit values for machining by the adaptive tool component that makes it possible to process various structural elements and assign operating unit travel modes.

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References

1. Ding S.L., J.Mo, D. Yang, 2010. HSM strategies of CAD/CAM SYSTEMS - part I operating unit path generation. Key Engineering Materials, #426: 520-524.
2. Chepchurov, M.S., A.V. Tyurin, 2013. Technological systems based on swiss-type automatic lather using the modular configuration of the equipment. Journal «Manufacturing Engineering» [Journal “Tekhnologiya Mashinostroyeniya”].-Moscow, Russia, #7: 64-69.
3. Ilyukhin Yu V., Yu V. Poduraev, A.V. Tatarintseva, 2015. Nonlinear adaptive correction of continuous path operating unit speed for high efficiency robotic machining. Procedia Engineering, #100: 994-1002.
4. Chepchurov, M.S., A.V. Tyurin, 2013. RF Patent # 126274, Adaptive tool component [Adaptivnyy operating unital'nyy modul '].
5. Chepchurov, M.S., A.V. Tyurin, 2013. Technological systems based on swiss-type automatic lather using the modular configuration of the equipment. Journal «Manufacturing Engineering» [Journal “Tekhnologiya Mashinostroyeniya”].-Moscow, Russia, #7: 64-69.
6. Chepchurov, M.S., N.A. Tabekina, 2016. Reduction of time expenditure in obtaining details on swiss-type automatic lathes with the sorting device. Journal «Proceedings of Irkutsk State Technical University» [Vestnik Irkutskogo gosudarstvennogo tehnicheskogo universiteta]. - Irkutsk, Russia, #6 (113: 64-72).
7. SongYong Hybrid Stepping Motor. General Specification for High Torque Hybrid Stepping Motor Date Views 16.10.16: http://www.kosmodrom.com.ua/pdf/SongyangPdf.pdf
8. Neugebauer R., B.Denkena, K. Wegener, 2007. Mechatronic systems for machine operating units. CIRP Annals - ManufacturingTechnology, #56 (2: 657-686).

9. Kudoyarov R.G., E.M. Durko, D.V. Ivanov, 2008.Design of mechatronic machine-operating unit equipment. Russian Engineering Research, #28 (1: 74-78).
10. KudoyarovR.G., E.M. Durko, R.R. Kadyrov, 2009. Automatic development of the structure of mechatronic machine-operating unit modules. Russian Engineering Research, #29 (12: 1271-1274).
11. Tyurin, A.V., M.S. Chepchurov and E.M. Zhukov, 2015. RF Software patent # 2015616431. Control program of adaptive tool component [Programma upravleniya adaptivnym operating unital'nym modulem].
12. Chepchurov M.S., A.V. Tyurin, E.M. Zhukov, 2014. Getting flat surfaces in turning. Journal World Applied Sciences, #30 (10: 1208-1213).