

UDC 621.914

V.M. Tonconogy, DEng, Prof.,
S.A. Zelinskiy, PhD, Assoc.Prof.,
V.A. Vodichev, DEng, Prof.,
V.V. Natalchishin, Senior Researcher,
A.Zh. Tkach

Odessa National Polytechnic University, 1 Shevchenko Ave., 65044 Odessa, Ukraine; e-mail: saz51@i.ua

WAYS OF IMPLEMENTATION OF VIBRATIONS SUPPRESSION METHODS AT PARTS MACHINING WITH CNC MACHINE TOOLS

В.М. Тонконогий, С.А. Зелінський, В.А. Водічев, В.В. Натальчишин, А.Ж. Ткач. Шляхи реалізації методів зниження вібрацій при механічній обробці деталей на станках з числовим програмним керуванням. Подальше підвищення ефективності механічної обробки деталей з малою жорсткістю вимагає застосування нових технологічних рішень. Концепція зниження регенеративних коливань за рахунок модуляції швидкості різання стає одним з таких напрямків. **Мета:** Метою роботи є розробка системи управління для фрезерних верстатів, яка дозволяє здійснювати модуляцію швидкості різання відповідно до періодичного закону із заданою глибиною й частотою. **Матеріали і методи:** Розробку системи управління проведено для фрезерних верстатів марки Micron OMM64SC з системою керування SINUMERIK 802D. **Результати:** Розроблено теоретичні основи нової концепції зниження регенеративних коливань, ефективність якої підтверджується проведеними дослідженнями. Розглянуто різні варіанти реалізації додаткової корегуючої ланки системи управління з функцією модуляції швидкості різання. Наведено переваги і недоліки кожного з розглянутих варіантів. Наведено блок-схему реалізації розробленої системи для фрезерних верстатів марки Micron OMM64SC з системою керування SINUMERIK 802D.

Ключові слова: програмні системи управління, вібраційна стійкість, точність обробки.

V.M. Tonconogy, S.A. Zelinskiy, V.A. Vodichev, V.V. Natalchishin, A.Zh. Tkach. Ways of implementation of vibrations suppression methods at parts machining with CNC machine tools. The further magnification of efficiency of parts machining with little inflexibility demands the machining application of new technological solutions. The concept of suppression of the regenerative oscillations at the expense of modulation of cutting speed becomes one of such directions. **Aim:** The aim of the research is the development of the control system for milling machine tool, allowing to realize modulation of cutting speed under the periodic pulsing law with the given modulating depth and frequency. **Materials and Methods:** Development of the control system is made for the machine tool Micron OMM64SC with control unit of SINUMERIK 802D. **Results:** The theoretical fundamentals of given concept of suppression of the regenerative oscillations are developed; research works have confirmed the efficiency of its applications. Various alternatives of implementation of an additional correcting link of a control system by a cutting machine with function of modulation of cutting speed are observed in the paper. Advantages and deficiencies of each of alternatives are specified. The original block diagram of the system is resulted and the exposition of its practical implementation on horizontal milling machine OMM64 with CNC system of SINUMERIK 802D is resulted.

Keywords: program control systems, vibratory steadiness, precision of machining.

Introduction. In aviation, energy and other branches of engineering industry the kind of parts of the complicated curvilinear shape, such as, mono wheels, turbine buckets, card blades etc. are applied widely enough. As a rule, they are important parts of mechanisms and consequently high demands are made to them on precision of machining and quality of a surface.

Machining of parts of this type is carried out with a method of contour milling on machine-tools with numerical control more often. In addition, contour milling by end mills usually is a finishing operation.

Efficiency of machining and quality of surface decreases because of the vibrations originating during cutting. The nature of origination of vibrations is bounded to various factors. We can specify such basic factors as the insufficient inflexibility of technological system (TS), thermomechanical appearances of cutting process and the regenerative vibrations.

Vibrations lead to origination of the regenerative oscillations that significantly reduce the machining accuracy and surface roughness, increase the rate of tool wear.

DOI 10.15276/opu.1.51.2017.07

© 2017 The Authors. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

By this time, the scientific fundamentals of dynamics of cutting machines are developed and created, great volumes of research works on raise of dynamic stability of cutting processes by raise of inflexibility and a damping capacity of the TS, using the optimum regimes and machining strategies are executed and published. The results of these studies and works have significantly expanded the boundaries of areas of optimum regimes of cutting and increasing in productivity of machining. At the same time, the possibilities of known designs are already largely exhausted that defines the necessity of searching of new paths.

One of new paths is the concept of using of a variable cutting speed for damping of the regenerative self-excited vibrations. The concept fundamentals are stated in [1] where the theoretical justification of that fact is resulted that it is possible to achieve positive effect in suppression of the regenerative oscillations with variation of frequency and a percentage modulation of cutting speed.

In [2, 3] the concept of suppression of the regenerative oscillations at the expense of periodic or in a random way changeable cutting speed is developed.

In particular, it states that the result of a steady self-oscillation damping can be achieved by the forced creation of a variable period of waves on the surface of cut. It is determined by the oscillation frequency of the TS along the X -axis perpendicular to the cutting surface, and the speed of the latter along the axis Z , i.e. cutting speed.

Introduction of machining with a variable cutting speed in industry is restrained by that fact that up-to-date machine tools do not possess ability to modulate cutting speed, commercially available tooling and tools for such purpose does not exist. This path is universal and perspective, but demands working out of new control systems for working motions drives of machine tools or enhancements to existing systems for the purpose of implementation of a possibility of a program modulation of cutting speed in the course of machining.

The aim of the research is the development of the control system for milling machine tool, allowing to realize modulation of cutting speed under the periodic pulsing law with the given modulating depth and frequency. Development of the system is made for the machine tool Micron OMM64SC with control unit of SINUMERIK 802D.

Materials and Methods. There are various methods of vibrations level lowering. Classical solutions are based on magnification of technological system inflexibility.

However, in case of machining of the above-stated grade of workpieces, the magnification of TS inflexibility not always can be implemented for two principal causes. The first cause is that observed workpieces have low inflexibility and the complicated geometrical surface that creates difficulties of use of damping devices and as consequence, the workpiece is most unstable vibration element of the TS. In case of contour milling, the end mill with small diameter and major length of an overhang of milling cutter is the second unstable vibration element of the TS.

Besides, magnification of TS inflexibility does not eliminate a major factor of origination of vibrations – the regenerative oscillations. The regenerative oscillations as an aspect of self-excited vibrations exist constantly and do not suppress because of variable cutting force. Fluctuations of the cutting force causes such variables as the thickness of the slice, the pressure angle between the cutter and the workpiece, and the periodic appearance of built-up edge, the frequency of the formation and cleavage build-up equal to the frequency fluctuations of the cutting force.

Therefore, up-to-date methods of damping of the regenerative oscillations are based on control of a spindle rotational speed (cutting speed).

Two various ways are possible for implementation of this method:

1. Determination of the cutting speed that provides vibration-free processing based on of mathematical models embodied in machine controller and connecting the vibration parameters and modes of processing (rate) for the specific conditions of the cutting process in real time with automatic modulation (correction) of cutting speed according to model.

2. Equipping the machine tool by control system that permits modulation of the cutting speed.

The implementation of the first method is difficult due to the fact that the mathematical model has to consider a large number of interrelated variables, including random nature. Therefore, the practical realization of this method for a machine tool equipped with the most modern CNC is very laborious.

There are problems with the “incorporation” of special correction link to the program controller when implementing the second method based on the use of software modulation techniques of cutting speed in machine tools.

The analogue regulators have been developed to suppress the regenerative oscillations by controlling the rotational speed of the spindle for machine tools without CNC. However, it is impossible to use them in machine tools with CNC by placing such device in the output of program controller, which forms the signal of demanded frequency of rotation of the spindle. This is because of the CNC monitors compliance with the set speed with the actual value measured directly on the machine spindle using special sensors. If the error value is exceeded, the CNC device receives an internal signal of system malfunction, which leads to an emergency stop of the machine.

Another option involves the connection of the control input of the CNC controller of the machine tool with an external controller, which generates a signal of correction of spindle speed. Modern CNC unit allow you to analyze the state of one or more control inputs when the control program is executed (in the process of cutting). The result of this analysis is the parameter adjustment of process control program. The block diagram of such system is shown in Fig. 1.

However, this possibility should be further supported by the machine manufacturer in the adaptation of the CNC to the particular machine. The control program must be designed so as to periodically review the status of the control inputs and make appropriate corrections in the course of machining. Moreover, as a rule, spindle speed can be altered only after execution of the control program frame. All this greatly limits the implementation of this option.

In [4] the alternative of a cutting speed control by means of a writing of an additional macroprogram for CNC controller is offered. The macroprogram divides linear trajectories, specified in the control program, into smaller parts and sets for them a certain spindle rotation speed. The length of the part is calculated from the magnitudes of the feed rate and the modulation period. This method is applicable only when the time duration of movement in one frame of the control program is significantly longer than the period of modulation. Otherwise, the macroprogram will not be able to divide the desired trajectory into smaller portions and change the spindle speed. It is not applicable for milling machining of workpieces with the complicated curvilinear surfaces, where all movements are divided into midget linear sections. Besides the CNC device should have possibilities of macroprogramming with implementation of mathematical calculations.

Vodichev V.A. [5] proposes to control the feed rate to use the controller connected to the CNC device instead of feed rate corrector located on the machine control panel. In the same way, you can control the modulation of the cutting speed. On the machine control panel, the machine operator can change the feed rate and spindle speed with two correctors. CNC device continuously monitors the status of these correctors and controls speed of electric drives of the feed and the primary motion depending on their position. To control the speed of the spindle according to the given parameters of cutting speed modulation instead of manually cutting speed corrector you can apply an automatic regulator, which will carry out the simulation of signals coming into the CNC controller from machine control panel. This way is simple in the practical implementation and may be easily implemented on various CNC devices. The block diagram of such system is shown in Fig. 2.

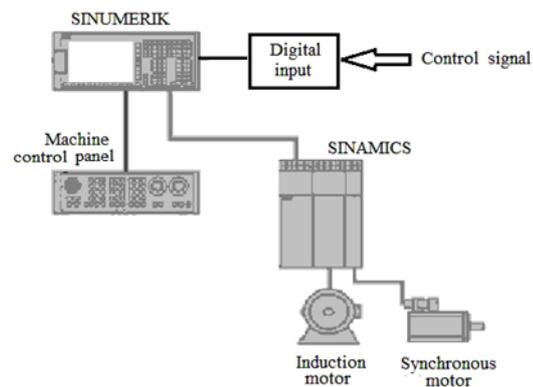


Fig. 1. The block diagram of control system with control signal from PLC

Results. The control system is designed for milling machine Micron OMM64SC with the CNC SINUMERIK 802D.

The electric SIMODRIVE is used as the primary drive of the machine. The electric drives of the machine with digital control device is connected to the CNC unit via an interface DRIVE-CLiQ. The modules of input and output signals are connected by industrial local bus PROFIBUS. Such construction ensures very simple and trusty mounting with the minimum quantity of connective cables. A wide range of control functions makes it as an ideal solution for use in standard milling machines for both simple machines, and for 3-axis machines with complex shaping.

The proposed system for modulating of rotation frequency of the spindle consists of two modules – hardware and software.

The hardware module is an input-output unit IO E14-140 connected to the unit Siemens 802D CNC and personal computer. E14-140 module is compact multifunctional USB-module: analog-to-digital and digital-to-analog converters for general use. The main purpose of the module in the system – the implementation of digital asynchronous input-output. Connecting to the CNC unit is carried out on the interface bus between the machine control panel and interface MCPA module. This connection allows the unit E14-140 to simulate the signal from the corrector of spindle speed from machine control panel. E14-140 unit is also connected via the USB interface to a PC, which directly controls the modulation process.

The software module is configured in the Labview environment. Input-output unit E14-140 has the special library that allows implementing of function for asynchronous reading and writing data to the module in LabView environment. To control the rotation speed of the spindle the upper and lower limits of the speed and frequency of its changes must be set. The speed correction signal from the machine control panel is transferred into the CNC device in the Gray code. Each of the set values of speed corresponds to a specific binary code. The range of spindle speed adjustment is in the range 50...120 % of the amount specified in the control program with discreteness from 5 to 10 %.

Necessary for imitation of signals transformation of the given decimal meaning of a percentage modulation to a binary code is carried out in the software module. The fragment of the software module is presented in Fig. 3.

Changing the speed of the spindle is carried out under the periodic pulsing law: in the first half of the period the lower limit of the speed is set, in the second half of the period – the upper limit is set. Consequently, software module at predetermined time intervals vary binary value input to the hardware module E14-140. The corresponding binary value is set at the digital outputs of the hardware module. The CNC controller reads this binary code and in real-time mode makes adjustments of spindle speed. Thus, the implementation of the control program is not interrupted. The software module changes the value of the code at the digital outputs of the hardware module E14-140 at intervals equal to half of the modulation period T_{mod} . Appropriately, the CNC device changes the desired signal to control the spindle speed.

The minimum and maximum values of cutting speeds and modulation period are specified on the control panel of the software module (Fig. 4).

Fig. 5 shows the change of the spindle speed N in the time range equal to the modulation period T_{mod} . The following parameters of cutting speed modulation are set: the modulation period $T_{mod} = 1$ s, the modulation depth is 10%, spindle speed set in the program of the CNC – $N = 1000 \text{ min}^{-1}$. Fixing the value of spindle speed implemented with rotary encoder HONTKO HTR-5B, we obtain the resolution of 100 pulses/rotation.

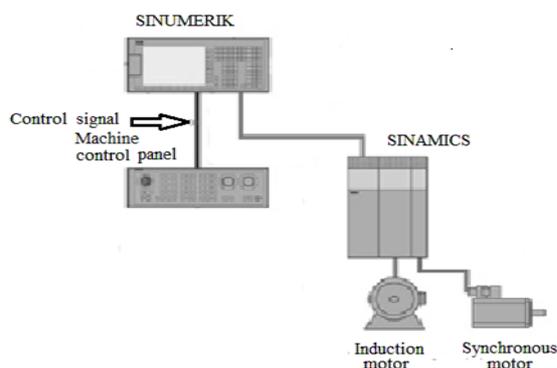


Fig. 2. The block diagram of control system with correction signal imitation

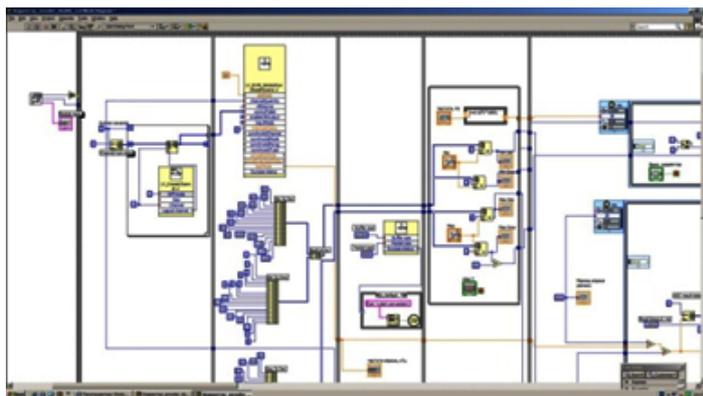


Fig. 3. Implementation of the software module in LabView environment



Fig. 4. The control panel of the software module

There are two zones in the graph of spindle speed. The first is a zone of transients of deceleration and acceleration of the electric drive of primary motion, the duration of which is about 0.1 s. The second is a zone of steady motion in which the spindle speed fluctuation caused by dynamic overshoot of the primary motion motor speed due to periodic changes in its load caused by beating of the milling cutter.

With a decrease in the modulation period T_{mod} duration of transients, the zone (zone 1) remains unchanged. The duration of the steady motion zone (zone 2) is reduced to its complete disappearance. Graph of modulation of spindle speed takes the form shown in Fig. 6. Thus, the law of the speed modulation control changes, from the periodic pulse it will turn into a harmonic.

It can be concluded (using the analysis of the study results) that the minimum value of the cutting speed modulation period T_{mod} is determined by the dynamic characteristics of primary motion electric drive. In particular, it depends on the bandwidth of the speed control loop of the electric drive.

The proposed implementation of the system that controls the rotational speed of the spindle has a number of advantages:

- simplicity of regulator incorporation in the machine tool with CNC;
- system with the regulator can work with different devices without CNC substantial revision and modernization;
- system can be upgraded to change the spindle speed under other laws – pulse (short-term change in the rate), triangular and short spindle stop.

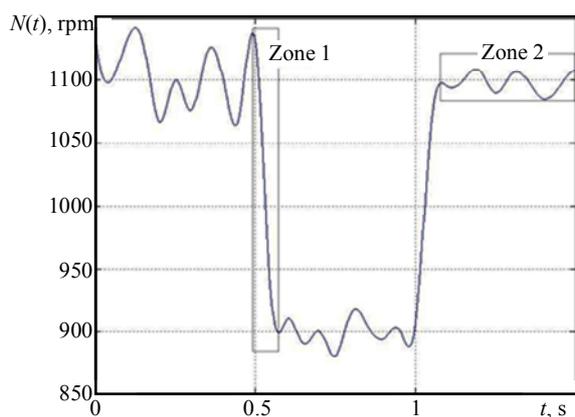


Fig. 5. Graph of spindle speed modulation

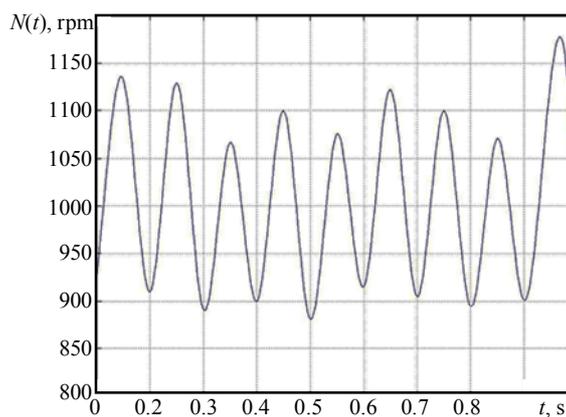


Fig. 6. Graph of spindle speed modulation under the harmonic law

Conclusions. Implemented on a milling machine Micron OMM64SC control system can be used to perform research works to suppress regenerative oscillations by modulating cutting speed. Further modernization of the proposed system will implement other control algorithms of cutting speed modulation: triangle, harmonic, random and others. Developed principles of build-up of the system with special corrective element can be successfully implemented in other machine tools with other models of CNC devices.

As a result of research work, the principles of appending of special correction link in the CNC system with the possibility of the spindle speed varying on the periodic law with a given pulse depth and modulation frequency are developed. Constructive solutions for the implementation of these principles are presented.

Література

1. Свинин, В.М. Фрезерование с модулированной скоростью резания: монография / В.М. Свинин; под ред. А.И. Промптова. – Иркутск: Изд-во ИрГТУ, 2007. – 304 с.
2. Жарков, И.Г. Вибрации при обработке лезвийным инструментом / И.Г. Жарков. – М.: Машиностроение, 1986. – 184 с.
3. On the stability of high-speed milling with spindle speed variation / S. Seguy, T. Insperger, L. Arnaud, etc. // *The International Journal of Advanced Manufacturing Technology*. – 2010. – Vol. 48, Issue 9. – PP. 883-895. DOI:10.1007/s00170-009-2336-9
4. Трунов, С.Н. Управление частотой вращения привода главного движения станка с ЧПУ с использованием макропрограммирования / С.Н. Трунов // *Известия ТулГУ. Технические науки*. – 2013. – № 12, Ч. 1. – С. 109–114.
5. Водичев, В.А. Аналого-цифровой регулятор режима металлообработки для верстатів з числовим програмним керуванням // *Автоматика. Автоматизация. Электротехнические комплексы и системы*. – 2003. – № 1(11). – С. 86–91.

References

1. Svinin, V.M. (2007). *The Milling with the Cutting Speed Modulation*. Irkutsk: IrGTU.
2. Zharkov, I.G. (1986). *Vibrations in Edge Tool Treatment*. Moscow: Mashinostroenie.
3. Seguy, S., Insperger, T., Arnaud, L., Dessein, G., & Peigné, G. (2010). On the stability of high-speed milling with spindle speed variation. *The International Journal of Advanced Manufacturing Technology*, 48(9), 883-895. DOI:10.1007/s00170-009-2336-9
4. Trunov, S.N. (2013). Rotating speed control of main drive CNC machine using macro programming. *Proceedings of the Tula State University: Technical Sciences*, 12(1), 109–114.
5. Vodichev, V.A. (2003). Analog-digital regulator of the metal cutting process for machine-tools with computer numerical control system. *Automatics. Automation. Electrotechnical Complexes and Systems*, 1, 86–91.

Received November 28, 2016

Accepted January 15, 2017