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Control of grinding polygonal surfaces

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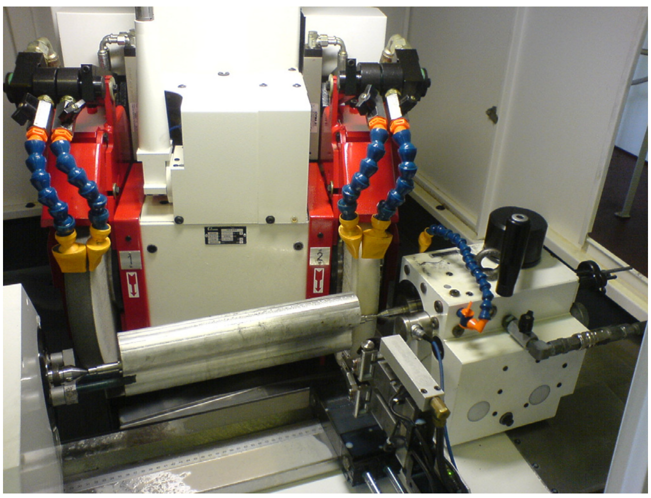
Abstract. *Grinding of non-round surfaces, in particular polygonal surfaces of dies, is characterized by substantial non stationary. At different sections of the profile, the change in the main characteristic (Material Removal Rate – MRR) process reaches tens of times. To stabilize the grinding process, it is recommended to control the spindle speed of the workpiece CNC grinding machine. Created software that allows to design the control program on the basis of mathematical model of the system. The determination of MRR is realized automatically in the simulation of the grinding process which uses the algorithm developed for solving problems in geometric interaction of the workpiece and the wheel. In forming the control program is possible takes into account the limitations on the maximum circumferential force of cutting, and the maximum allowable acceleration of the machine spindle. Practice has shown that full stabilization is not obtained, even though the performance is increased more than 2 times, while ensuring the quality of the surface. The developed block diagram of the grinding process can serve as a basis for further improvement in the solution of dynamic problems.*

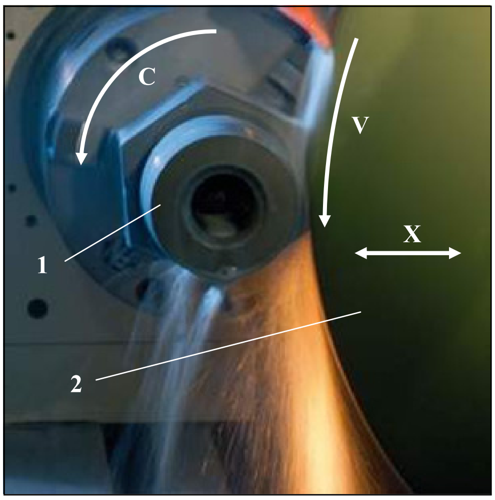
Keywords: *grinding polygonal surfaces, simulation, grinding CNC machine, stabilization MRR*

Introduction

In various areas of engineering are widely used items of a non-circular shape, which have high hardness, high accuracy and a low surface roughness. Therefore, the finish machining of such surfaces is performed on CNC grinding machines (Fig.1, a). The grinding of polygonal surface of the cutting die 1 is realized by wheel 2 with cutting speed V and movement of the forming along the axis X synchronously with the rotation of the workpiece axis C (Fig.1, b). It is also known that the grinding process of such surfaces is essentially non-stationary, making it difficult to ensure the required quality at acceptable performance. The most highly non-stationary of the grinding process is evident in the processing of polygonal surfaces of dies and molds.



a



b

Fig. 1. Working area grinding CNC machine company Studer (a) and grinding the hex stamp (b)

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Modern grinding *CNC* machines are provided with software that allows to perform the entire cycle of grinding, separating allowance for areas of assignment for each section a specific value of the cross-feed. However, the existing system, for example *StuderPunch*, though, and allows to design a control program for grinding of polygons, but do not offer specific recommendations on the choice of the values of feeds and of switch points needed to perform optimum grinding cycle. Data management frequency of spindle rotation of the workpiece to stabilize the grinding process according to its main characteristic – speed of cutting allowance (*MRR – Material Removal Rate*) is absent.

The analysis shows that the main reason for this approach to the design of control programs, is the lack of adequate mathematical models of grinding processes non-circular surfaces. Existing models calculate are based that the most important characteristics are determinates on analytical equation [8, 9, 10] and do not reflect the process of cutting removal allowance on a non-circular polygonal surface. To calculate the cutting force when grinding though, and it is proposed to use a model based on the determination of the geometric trajectories of the cutting grains, but also not taken into account peculiarities of processing a non-circular surface and, furthermore, the need for experimental determination of the three (or more) coefficients of the model hinders its practical applications [11].

Aware of the need to control the process in order stabilizing its characteristics, proposes solutions associated with the use of adaptive systems that always leads to complication of the machine [12]. All in all, today should be considered the most effective method of control which is based on a priori information using a digital process model [1]. This method is simple to realization on the grinding machine by CNC-program. Therefore, the problem of creation of means automation of designing of the control program by ensuring the stability of the cutting conditions on the main criterion is actual.

Objective

The aim of this study is the creation of adequate mathematical model of the grinding of non-circular surfaces and the automation system programming of grinding CNC machines for grinding operation of polygonal surfaces, which allows to stabilize the process according to the criterion of MRR.

Statement of the main material

Mathematical model of grinding process is developed based on the block diagram (fig. 2) that is built using systematic approach for single degree-of-freedom system. In Diagram used the following designations for signals which are applied to the structure: D_W – diameter of wheel, ω_z – velocity of rotation, $R_x(\varphi_z)$ – forming movement on X-axe, $R_z(\varphi_z)$ – contour of workpiece, $V_z(H_z)$ – crossing feed, φ_z – angle of spindle rotation, H_z – depth of cutting, s is the Laplace operator.

In consequence of the cutting process and the cutting forces occurring elastic deformation of the technological processing system, which leads to the fact that the actual cutting depth differs from the setpoint in the CNC-program. In addition, due to the accumulation of elastic strain there is a lag effect with one layer of seam allowance, which was cut in a single revolution of the workpiece is perceived at the next turnover as increasing the desired depth of cut. This effect appears in the mathematical model using delayed link with the transmission function $e^{-\tau s}$, where τ is time of one revolution. Actual cutting depth will change the shape of the workpiece that must be considered when modeling the next turn.

To solve the problem of determining the MRR in the block geometric interaction, using a technique based on the representation of the contour of the workpiece in the form of a wireframe and digital model ($R_z(\varphi_z)$ on fig. 3). At each time step of the simulation using the cyclic algorithm calculated the coordinates of the start and end points of the cutting arc. The result the cutting angle is determined as:

$$\varepsilon = \arctan\frac{y_w - y_b}{x_w - x_b} - \arctan\frac{y_w - y_a}{x_w - x_a}, \tag{1}$$

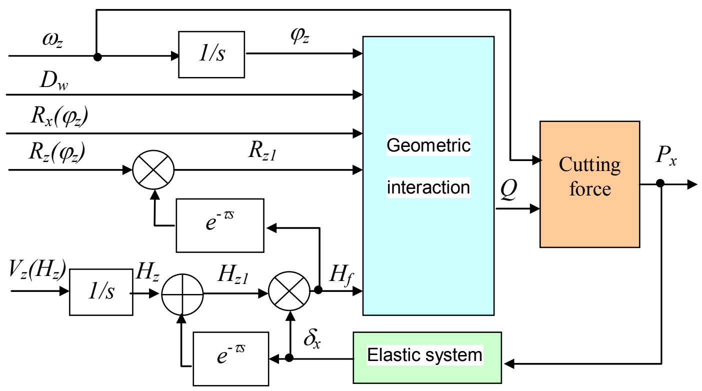

Fig. 2. Block diagram represented of the grinding process

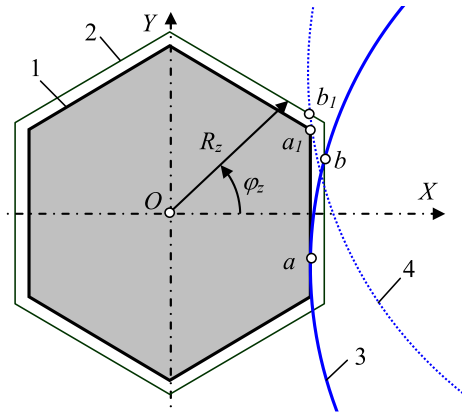

Fig. 3. Geometric interaction

where y_w, y_w – the coordinates of the wheel center, x_a, y_a – coordinates of the start point *a* of the cutting arc, x_b, y_b – coordinates of the end point *b* of the cutting arc.

As the main characteristics, which is estimated as the intensity of the cutting process and surface quality of detail is the material removal rate (MRR). At the simulation stage in accordance with the block diagram it is necessary to calculate analogue, which does not depend on the mode of grinding is determined by the geometric interaction of wheel and workpiece. Therefore the MRR analog is calculated by the formula [1]:

$$Q = 0.5(\varepsilon R_w)^2, \tag{2}$$

where R_w – is radius of wheel.

For the calculation of MRR is sufficient analogue to multiply the width (height or length) of the grinding and the speed of movement of the periphery of the tool surface to be processed of the circuit (dimension of the velocity – *rad/s*), the result is a traditional dimension mm^3/s the speed of cutting allowance:

$$MRR = Qb\omega_z, \tag{3}$$

where *b* – is height of workpiece, ω_z – is velocity of rotation.

For simulation of grinding process was created an application software which structure and the algorithm corresponds to the block diagram in Fig.2. Given the characteristics of the programming cycle control grinding machines, in particular the firm "Studer" [5], it is possible to switch of cross-feed in appropriate quantities of allowance. Whole allowance is divided into three parts: up to 0.2mm, feed of 0.03 mm/s; 0,2mm to 0.05mm, feed of 0.015 mm/s and then to zero – feed 0.005 mm/s. Law of supply control is downloaded as a text file with the button "*Ok*" in the interface window "Download file control cross-feed" (fig.4).

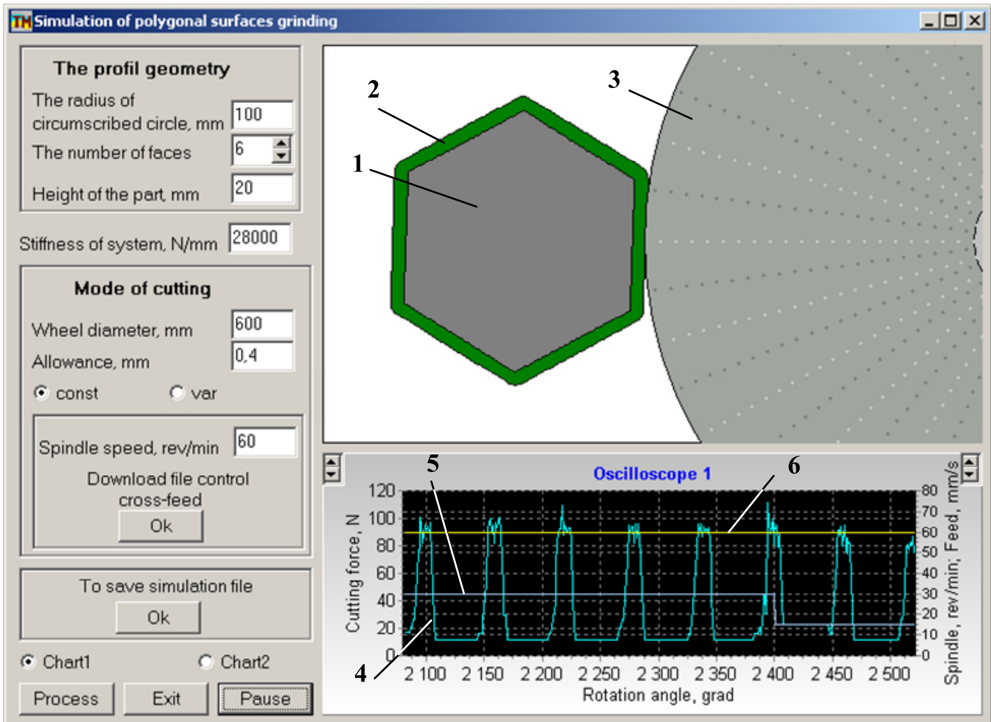

Fig. 4. Interface of the created software

In the simulation, which is triggered when you click "process", in animation window shows the motion of the workpiece 1 with an allowance of 2 and grinding wheel 3, which represents removal of allowance. In the window of the oscilloscope 1 displays the characteristics of the process: line 4 – peripheral cutting force, line 5 – cross-feed, line 6 – spindle speed. On the oscilloscope the time of switch of cross-feed is observed (line 5 for rotation angle 2400 grad.).

The peripheral cutting force is calculated according to the formula [7]:

$$P_c = C_p (MRR)^{\alpha}, \tag{4}$$

where C_p and α – is an empirical coefficient and the exponent.

It is seen that the cutting process is essentially non-stationary: cutting force changes to each face in the range from 10 N to 110 N. This provokes changes in the surface roughness of the face may cause changes in the structure of the material and even the appearance of cracks in hardened parts. Obviously, such a machining process is in need of stabilization. In accordance with the cutting data for the entire cycle of grinding ends 27s.

The actual change in the MRR and peripheral cutting force over the entire cycle of grinding can be saved to a file when you click “Ok” in the window “To save simulation file” on Interface (fig.4). The saved file contains a digital array of large dimension, so to design a control file was created by an application software interface which is shown in Fig.5.

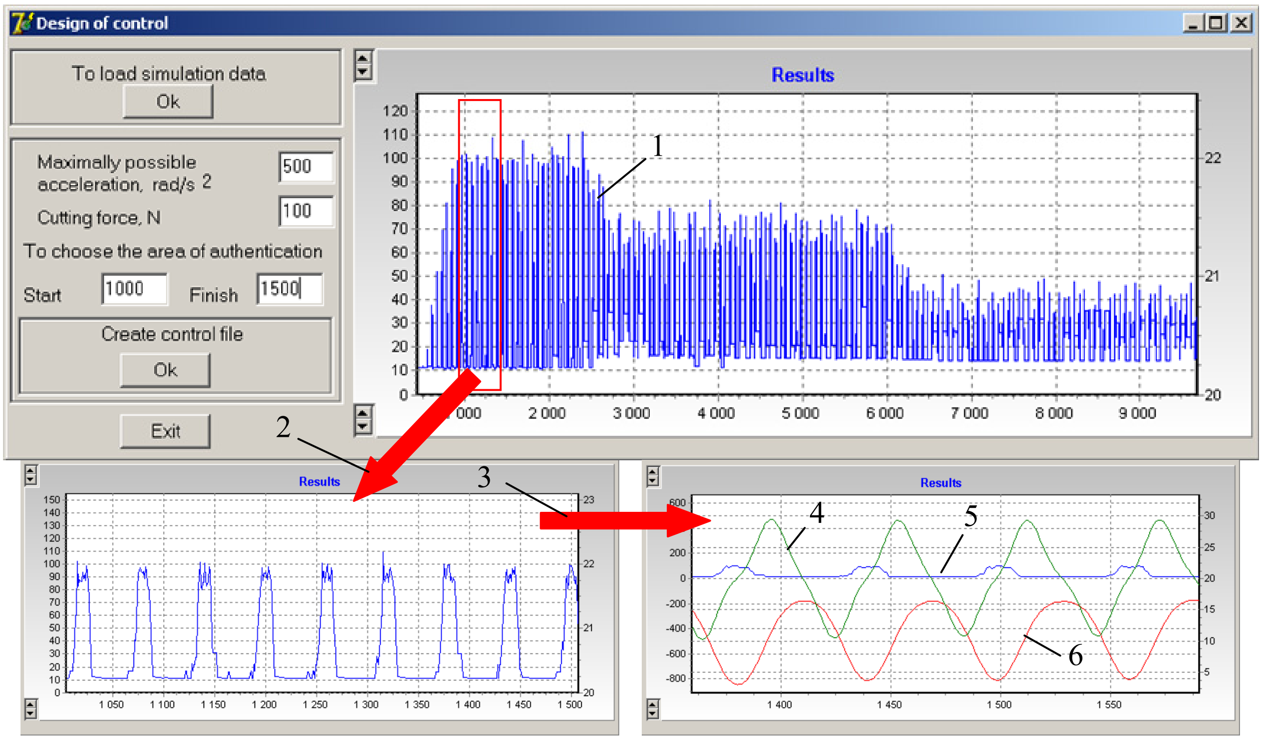

Fig. 5. Stages of creation of a control file

After downloading the file formed in the simulation, it graphically appears in the output window interface application software – line 1 on Fig.5. Because the entire grinding cycle is present, the stages of which are characterized by different intensity, for future designing, it should select the site with the highest values of peripheral cutting forces. The boundaries of the area are written in the corresponding windows interface, and this digital data array for subsequent analysis and transformation appears in the same window (see arrow 2 on Fig.5). The next stage designing consist in creation the control file – arrow 3 on Fig.5.

Smoothing of the original file in the selected range is performed by the iteration method using the interpolation polynomial of Lagrange. This tests on the maximum allowable acceleration so the number of iterations is determined by the performance of the specified conditions.

The results of the transformations are shown in the interface window: line 4 – schedule created control spindle speed, line 5 – schedule acceleration, line 6 – schedule of cutting force reference. It is seen that the control law is smooth, and acceleration never exceeds the limits $500 rad/s^2$, which is recorded in the window of software interface. These conditions allow to implement the control on the CNC machine. When the moment of inertia of the spindle $I \approx 0.08 kgm^2$ this mode of operation requires the maximum torque $T_{\max} = 0.08 \cdot 500 = 40 Nm$, which is provided by a drive motor. For stable operation in this mode for a long period of time, it is desirable to perform a thermal calculation of engine.

Because the control file is different from the discrete and continuous optimal, there is a need to monitor its operation according to the simulation results and, if necessary, return to the program the design of optimal control law to correct the number of switching points and the magnitudes of the corresponding coordinates.

In Fig.6 shows the interface of the simulation software, while downloading the created control file. The designed control law is designated line 1, and the corresponding graph of the changes of the circumferential force of the cutting line 2. It is seen that the designed control law does not provide a complete stabilization process due to restrictions, but allows to reduce the cycle time of grinding in 2.25 times (up to 12s). The maximum value of the cutting force does not exceed the maximum cutting forces when cutting without control spindle speed (compare with Fig.4).

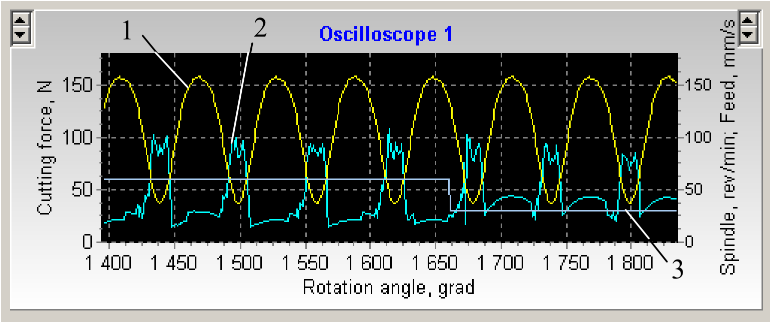

Fig. 6. Stages of creation of a control file

Conclusions

1. Grinding of non-round surfaces, in particular polygonal surfaces of dies, is characterized by substantial non stationary. At different sections of the profile, the change in the main characteristic (Material Removal Rate) process reaches tens of times. This causes the appearance of various defects and causes the cutting mode to be reduced. The existing CAM systems of CNC grinding machines do not provide for the design of a control program for stabilizing the cutting conditions.
2. The design of the spindle speed control program must be carried out on the basis of simulation of the cut-off process using the results of solving the task of geometric interaction within the framework of the created block diagram of the process. The developed block diagram can serve as a basis for solving dynamical problems when adding an even one-mass model to the elastic system.
3. The created application software allows automatized the design of the spindle speed control program taking into account the limitations on the maximum permissible acceleration and power of the spindle drive motor. Practice showed the effectiveness of the developed methodology, which allowed to increase the productivity more than 2 times when grinding the hexagonal stamp with assure the quality requirements.

Управление шлифовальными полигональными поверхностями

Ю.В. Петраков

Аннотация. *Шлифования некруглых поверхностей, в частности полигональных поверхностей штампов, характеризуется существенной нестационарностью. На различных участках профиля, изменение основной характеристики (Material Removal Rate – MRR) достигает десятков раз. Для стабилизации процесса шлифования, рекомендуется управлять скоростью шпинделя заготовки станка с ЧПУ. Создано программное обеспечение, которое позволяет разработать программу управления на основе математической модели системы. Определение MRR выполняется автоматически при моделировании процесса шлифования где используется разработанный алгоритм решения задачи геометрического взаимодействия заготовки и круга. При формировании программы управления возможно учитывать ограничение на максимальное окружное усилие резания и максимально допустимое ускорение шпинделя станка. Практика показала, что полная стабилизация не обеспечивается, хотя производительность увеличилась более чем в 2 раза, в то время как обеспечено требуемое качество поверхности. Разработанная блок-схема процесса шлифования может служить основой для дальнейшего совершенствования в решении динамических задач.*

Ключевые слова: *шлифование полигональных поверхностей, моделирование, шлифовальный станок с ЧПУ, стабилизация MRR.*

Контроль шліфування полігональних поверхонь

Ю.В. Петраков

Анотація. *Шліфування некруглих поверхонь, зокрема полігональних поверхонь штампів, характеризується суттєвою нестаціонарністю. На різних дільницях профілю, зміна основної характеристики (Material Removal Rate – MRR) достигає десятків раз. Для стабілізації процесу шліфування, рекомендується управляти швидкістю шпинделя заготовки верстата з ЧПК. Створено програмне забезпечення, котре дозволяє спроектувати управляючу програму на основі математичної моделі системи. Визначення MRR виконується автоматично при моделюванні процесу шліфування, де використовується розроблений алгоритм вирішення задачі геометричної взаємодії заготовки і круга. При формуванні програми управління можливо враховувати обмеження на максимальне окружне зусилля різання і максимально допустиме прискорення шпинделя верстата. Практика показала, що повна стабілізація не забезпечується, хоча продуктивність збільшується*

більш ніж у 2 рази, при забезпеченні якості оброблення поверхні деталі. Розроблена блок-схема процесу шліфування може слугувати основою для подальшого вдосконалення при розв'язанні динамічних задач.

Ключові слова: *шліфування полігональних поверхонь, моделювання, шліфувальний верстат з ЧПК, стабілізація MRR.*

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