An approach to complex model ECGA for the stable and unstable grinding conditions

Masar Alsigar\textsuperscript{1,2,*}, Pavel Pereverzev\textsuperscript{1}, Aziz Almawash\textsuperscript{1,3} and Mohamed Alkadhim\textsuperscript{4}

\textsuperscript{1}South Ural State University, 76, Lenin Avenue, Chelyabinsk, 454080, Russian Federation
\textsuperscript{2}Thi-Qar university, College of engineering, Thi-Qar 31, Nasiriyah 64001, Iraq
\textsuperscript{3}University of Kufa, College of engineering, Najaf 66, Republic of Iraq
\textsuperscript{4}Ulyanovsk State Technical University, Venetz str 32, Ulyanovsk 432027, Russia Federation

*masar8937@gmail.com

Abstract. In this article dedicated to the mathematical solution and analytical methods to identify the causes of low efficiency and productivity range limits of grinding machine. A major point of the paper is the development of an optimal cycles in the external cylindrical grinding with axial feed ECGA. A Classification of mathematical programming models MPM and algorithms provides general tools for engineering design optimization of grinding cycles with two feeds at radial and axial feed under different conditions of non-stochastic programming in the multi-stage zone. A related model for formation of radius on basis of experiments and calculations with a simultaneous feed to assure quality control of designing and production of grinding.

1. Introduction
At the time, in modern automated manufacturing (for example: external cylindrical grinding at computer numerical control CNC machines), since there are no models’ techniques and programming concepts for synchronous cycles used in with multi stages of workpiece M\textsubscript{1}, M\textsubscript{2} and M\textsubscript{3}. The MPM could be allowing and helping to predict to mistakes in workpiece production, leads to optimum grinding conditions of cycles design which allows for the execution in the shortest practicable period of modelling specification in terms of precision and efficiency, make absolutely sure the machining precision specified of external cylindrical grinding with axial feed ECGA at CNC machine with two feeds axial and radial of multi stages grinding cycles in different circumstances.

Automatic stage cycles control of feeds was according to the commands of the active control device, depending on the remaining stage of the allowance feeds. As a result, CNC grinding machines are used ineffectively at ECGA was ineffective due to a limited understatement by technologist of cutting conditions, because manual selection of radial and axial feed cycles. Improving efficiency of using external cylindrical grinding with axial feed ECGA by CNC machine in the territory of the Russian federation, is possible on the basis of methodology for creating mathematical programming models MPM to designing optimal grinding cycles of multi-stages with synchronous feeds to provide support for workpiece in zones M\textsubscript{1}, M\textsubscript{2} and M\textsubscript{3}.
The MPM is appropriate for numerical analyses to the fundamental concepts of the elastic deformations of technological system, actual feed, force of cutting in two direction and precision machining of treated workpiece in reverse and non-reverse zones.

2. Development of regulatory design methods for grinding cycles at ECGA

The normative method for designing cycles of external cylindrical grinding can be understood as encompassing an implicit reference to an existing Building requirements and various references of cutting conditions [1-2].

These sources mainly include recommendations for choosing cutting conditions by sets of the main parameter values, which are specified as intervals of diameters and lengths of the treated surface of workpiece, allowances and size qualification of workpiece etc. In addition, the normative method shows the characteristic features of grinding operations of typical workpieces (for example, automobile factories, equipment and modern machinery), which significantly reduces the time of works. Recommendations on the choice of cutting conditions, which are presented in different references [3-4], are based on a specific list of technological parameters (table.1).

| Department | Features                                                                                                                                   | Literature   | y   | Conclusions* |
|------------|-------------------------------------------------------------------------------------------------------------------------------------------|--------------|-----|--------------|
| 1 cutting forces | The general theory of encryption cycles, based on the dependence of the elastic deformations of the elements of the technological system on the radial component of the cutting force. | G.B. Lurie | № 1 2 3 4 | |
|             | Reference                                                                                                                                   | [11]         |     |              |
|             | 1960                                                                                                                                     |              |     |              |
|             | a ↑ ↑ - - -                                                                                                                                |              |     |              |
|             | b - ↑ - -                                                                                                                                  |              |     |              |
|             | c - - ↑ - -                                                                                                                                |              |     |              |
|             | d - - - -                                                                                                                                  |              |     |              |
| Department | Features                                                                                                                                   | Literature   | y   | Conclusions |
| 2 grinding time | One of the first researchers to start the study of automatic grinding cycles. Although statistical data to fully estimate and compared with the program's digital economy, these models of formation surface are absent. | S. Malkin    | № 1 2 3 4 | |
|             | Reference                                                                                                                                   | [3], [7]     |     |              |
|             | 1984                                                                                                                                     |              |     |              |
|             | a - ↑ - -                                                                                                                                  |              |     |              |
|             | b - - ↑ - -                                                                                                                                |              |     |              |
|             | c - - - -                                                                                                                                  |              |     |              |
|             | d - - - -                                                                                                                                  |              |     |              |
| Department | Features                                                                                                                                   | Literature   | y   | Conclusions |
| 3 Study on optimal cycle | A methodology for calculating optimal speed cycles is proposed, which allows for a given accuracy of the machined surface at maximum process performance grinding based on dynamic programming method and metal removal model. | P. Pereverzev | № 1 2 3 4 | |
|             | Reference                                                                                                                                   | [18]         |     |              |
|             | 2016                                                                                                                                     |              |     |              |
|             | a ↑ ↑ ↑ - -                                                                                                                                |              |     |              |
|             | b - - - -                                                                                                                                  |              |     |              |
|             | c → ↑ → - -                                                                                                                               |              |     |              |
|             | d - - - -                                                                                                                                  |              |     |              |
| Department | Features                                                                                                                                   | Literature   | y   | Conclusions |
| 4 accuracy | Performed to improve the quality of processing in automatic cycles. In modern CAM systems, there is no system for calculating the optimal cutting conditions for external cylindrical grinding ECGA with joint control of radial and axial feeds. | C. Zhang     | № 1 2 3 4 | |
|             | Reference                                                                                                                                   | [17]         |     |              |
|             | 2013                                                                                                                                     |              |     |              |
|             | a - - - -                                                                                                                                  |              |     |              |
|             | b ↑ ↑ ↑ - -                                                                                                                                |              |     |              |
|             | c - - - -                                                                                                                                  |              |     |              |
|             | d - - - -                                                                                                                                  |              |     |              |

(*) Note to table: do not use mathematical models of optimization (a); based on the data from standard reference literature or experimental data (b); model for precision processing (c); optimization of radial and axial feed cycles for external grinding with axial feed has not been considered (d); cutting forces (1); grinding time (2); Study on optimal cycle (3); accuracy (4).
Strategy stages of control parameters depends on the structure of grinding cycles synchronous, or rather, the number of steps in the cycles of reverse and non-reverse zones [5].

According to the results recorded in the table.1, we can conclude that the main drawback of the normative method of designing automatic cycles for ECGA, lies in the fact that the standards set one average value of the radial and axial feed for the basic grinding conditions. If the conditions different to the planned process from the basic ones, then using multiplied correction factors for each changed condition, we need to adjust and change feeds with time of cycle. After that we can say the conventional cycle, does not allow design of step cycles of radial and axial feeds of ECGA [6-9].

Given the complex relationship between all the technological parameters of the grinding operation, the use of correction factors in principle does not allow the design of optimal grinding cycles. Thus, in modern automated manufacturing (external cylindrical grinding at computer numerical control CNC machines), there are no regulatory methods for designing optimal control cycles at radial and axial feeds in ECGA operations [10-15]. Therefore, the graphs of the actual feeds (shown in fig.1) consist of four sections on each step of the workpiece, corresponding to the value of the actual feed on each radius of the workpiece.

3. Model for calculating values of the radius under unstable grinding conditions

To calculate the machining accuracy, a model of dimension of a machined surface of part at end of stage operation in grinding cycle is required, which is an array of radius along the entire length of the surface to be grinded in the zones M1, M2 and M3. To simulate the initial runout of the workpiece radius, the diameter profile of the workpiece being cylindrical grinding machine is adopted in the form of an ellipse inscribed in the tolerance field for the diameter of the workpiece [16-20].

The ellipse profile is divided into four evenly distributed radii. Grinding modelling begins with the largest radius (fig.1). The calculation of the actual feed (FAi) is carried out on each radius of the non-circular workpiece in all zones M1, M2 and M3 taking into account the stages and alternations of different types of external cylindrical grinding with axial feed and radial feed.

During the radial feed process, the active control device continuously measures the diameter of the surface treated (fig.1a). Upon reaching the tuning dimensions, the program feed rate is switched or the grinding wheel is retracted back into the axis, when the entire allowance is removed. In the last case, the active control device is adjusted approximately to the middle of the tolerance field (fig.1b,c and d) of the finished part (fig.1f) shows the calculated diagram of the relationship between the workpiece radii and the accumulated values of the program and actual feeds and the elastic deformations of the technological system by MPM. From dimensional relationships in fig.2 shows, that the current value of the radii of the machined surface at the i stroke of the cycle can be calculated through the difference between the current value of the radius of the workpiece at each i turn of the workpiece and the actual feed according to the following formula (parenthesis indices show the type of grinding and stage):

\[
[\Delta R_i]^{ECGA}_{radial} = \left(R_i - (\Delta FA)_{radial}\right)_{M1},
\]

\[
[\Delta R_i]^{ECGA}_{axial} = \left(R_i - (\Delta FA)_{axial}\right)_{M2}.
\]

\[
[\Delta R_i]^{ECGA}_{radial} = \left(R_i - (\Delta FA)_{radial}\right)_{M3}.
\]
Figure 1. Allowance of a non-circular workpiece at ECGA.

Figure 2 shows that the relationship between the actual and program feed after the first turn of the workpiece \( i=1 \), established through the elastic deformation of the technological system \( y' \) :

\[
\Delta F_{P1} = \Delta F_{A1} + y',
\]

(4)

During the second revolution of the workpiece \( i=2 \), the cutting edge of the wheel should move another amount in the zone of M1:

\[
\Delta F_{P2} + y = y + \Delta F_{A2},
\]

(5)

from reverse zone M1 and M3:

\[
y_{i=1} = \left( \Delta F_{P_{i=1}} - \Delta F_{A_{i=1}} \right)^{M1},
\]

(6)

\[
y_{i=2} = \left( \Delta F_{P_{i=2}} - \Delta F_{A_{i=2}} \right)^{M3},
\]

(7)

from non-reverse zone M2:

\[
\Delta y_{i=3} = \left( y_{i=2} - y_{i=1} \right)^{M2},
\]
To consider the relationship (1) – (7), elastic deformations of the technological system with programming and actual feeds at all stages of the cylindrical grinding process with axial feed in the reverse zone and non-reverse, we can be found from equality:

\[ \Delta \gamma = \gamma - \gamma_{\text{CADC}} = \frac{C_1 - \gamma_{\text{CADC}}}{1 + C_2}, \]

where \( \gamma \) = rigidity of the technological system of grinding; \( R_i \) = radius value on the i-th stroke; \( R_{i-1} \) = radius value on the i-1 the stroke; \( FP \) = programmed value; \( FA \) = actual feed; \( i \) = the sequence number of the grinding wheel stroke used a performance management cycle stage; \( y \) = elastic deformation, \( C_1 \), \( C_2 \) = the analytical coefficients characterizing ratios of external cylindrical grinding with axial feed [5].

Experiments were conducted during cylindrical external grinding with axial feed on machine model 3250CNC with an active control device 6067 at the department of engineering technology of SUSU in table.2.
Table 2. Methods MPM and results of experiments on machine model 3250-CNC of automatic cycle.

| Number of stroke | Radius value from previous revolution i-1 | Programming on all radius for synchronous cycles | Actual feed | Distribution on the radius obtained | Total of feeds |
|------------------|------------------------------------------|-----------------------------------------------|-------------|------------------------------------|----------------|
| 0                | 20.15                                    | 0                                             | 0           | 20.15                              | 0              |
| 1                | 20.15                                    | 0.014                                         | 0.00432123  | 20.14567877                        | 0.014          |
| 2                | 20.14567877                              | 0.014                                         | 0.00849318  | 20.13718559                        | 0.028          |
| 3                | 20.13718559                              | 0.014                                         | 0.01100827  | 20.12617732                        | 0.042          |
| 4                | 20.12617732                              | 0.014                                         | 0.01240444  | 20.11377287                        | 0.056          |
| 5                | 20.11377287                              | 0.014                                         | 0.01315632  | 20.10061655                        | 0.07           |
| 6                | 20.10061655                              | 0.014                                         | 0.01355578  | 20.08706077                        | 0.084          |
| 7                | 20.08706077                              | 0.014                                         | 0.01376661  | 20.07329416                        | 0.098          |
| 8                | 20.07329416                              | 0.014                                         | 0.01387751  | 20.05941665                        | 0.112          |
| 9                | 20.05941665                              | 0.014                                         | 0.01393575  | 20.04548089                        | 0.126          |
| 10               | 20.04548089                              | 0.014                                         | 0.01396631  | 20.03151458                        | 0.14           |
| 11               | 20.03151458                              | 0.014                                         | 0.01398234  | 20.01753224                        | 0.154          |
| 12               | 20.01753224                              | 0.007                                         | 0.01070593  | 20.00682631                        | 0.161          |

Cycles systems implementation been in accordance with established formulas (1-8), during the processing cycle of the values of the actual radial feed and the radial component of the cutting force at the given values of the program feed, taking into account the elastic deformation of the technological system of the workpiece in the zones M1, M2 and M3.

4. Conclusions

1- The model of the metal removal process during external grinding: allows to take control cycles at radial and axial feeds with various technological conditions of grinding operation to calculate the current values of the actual feeds, time and cutting forces in different zones.

2- A unified generalized model of shaping the grinding surface has been developed, which allows calculating the depth of cut and the current values of the radius in any section of the machined surface of grinding cycles for given processing conditions.

3- The MPM is obtained on the basis of experimental data and mathematical relationship of cutting force, elastic deformations of the technological system, cutting depth, program and actual feeds and the sizes of the radius in any section of the machined surface of grinding cycles.

References

[1] S. Bratan, S. Roshchupkin 2017 Identification of removal parameters at combined grinding of conductive ceramic materials, MATEC Web of Conferences, V. 129, 01079.

[2] Hahn R 1964 On the nature of the grinding process. In : Proceeding of the international machine tool design and research conference, p 129–154

[3] S. Malkin 1984 Grinding Technology: Optimal infed control for accelerated spark-out in plunge grinding. Industrial Press, New York, USA. ASME J Ind 106(1) : 70–74.

[4] Moerlein AW (2009) In-process force measurement for diameter control in presion cylindrical grinding. Int J Adv Manuf Technol 42(1) : 93–101.

[5] M. Alsigar, P. Pereverzev et al 2019 Designing optimal automatic cycles of round grinding based on the synthesis of digital twin technologies and dynamic programming method. Mech. Sci. 10 :331–341.
[6] R. Sones, J. Peters, A. Decneut 1974 The significance of chip thickness in grinding. Ann CIRP 23(2) :227–237.

[7] A. Deshunukh, S. Malkin, 2004 Continuous optimal in feed control for cylindrical plunge grinding. Part I. Methodology, J. Manuf. Sci. Eng., Trans. ASME, v. 126 (2), pp. 327–333.

[8] Y.K. Novoselov 2012 Dynamics of surface formation during abrasive processing.

[9] Korchak S.N. 1974 The Productivity of the Grinding of Steel Parts (Mashinostroenie, Moscow).

[10] P.P. Pereverzev, M.K. Alsigar 2018 Model of removal in reverse and not reverse zones for round grinding operations with longitudinal feed, Journal « METALLOOBRABOTKA » v. 3, 105.

[11] G.B. Lurie 1960 The theory of the working cycle during circular grinding and its automation, Mashinostroitel, v. 2, pp.87-108.

[12] J. Couey, E. Marsh 2005 Monitoring force in precision cylindrical grinding. Precis Eng 29(3) :307–314.

[13] P.P. Pereverzev, M.K. Alsigar 2017 V International Correspondence Scientific and Practical Conference « Automates Design in Mechanical Engineering » 29, 42.

[14] W.B. Rowe, M.N. Morgan 1995 CIRP Ann Manuf-Technol 44 (1), 329.

[15] A.V. Akintseva, M.K. Alsigar 2017 the future of machine building in Russia: conf. young scientists and specialists. 17, 19.

[16] Cutting modes for work carried out on grinding and lapping Machines with manual control and semi-automatic (Publishing house АТКОСО, Chelyabinsk, 2007)

[17] C. Zhang 2013 Experimental and numerical studies on the temperature field in precision grinding of SiCp/Al composites. Int J Adv Manuf Technol 67(8):1007–1014.

[18] P.P. Pereverzev, A.V. Akintseva 2016 Model of Cutting Force While Managing Two Regime Parameters in the Process of Internal Grinding, Procedia Engineerin. v. 150, pp. 1113-117.

[19] Snoeys R, Peters J, Decneut A (1974) The significance of chip thickness in grinding. Ann CIRP 23(2) :227–237.

[20] P.P. Pereverzev, M.K. Alsigar 2018 II International Scientific and Practical Conference «Mechatronics, Automation and Robotiques » 22, 124.