ADVANCES IN MANUFACTURING SCIENCE AND TECHNOLOGY Vol. 34, No. 2, 2010

POTENTIAL FOR INCREASING THE EFFECTIVENESS OF AUTOMATED PRODUCTION SYSTEMS DUE TO APPLICATION OF SINGLE-PASS GRINDING

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Summary

In this paper the issues of improvement of the efficiency of automated production systems were analysed. The effectiveness ratios of automated production systems and the results of comparative tests in this scope concerning the single-pass internal cylindrical grinding were presented.

Keywords: production automation, efficiency, single-pass grinding

Możliwość zwiększenia efektywności zautomatyzowanych systemów produkcyjnych w wyniku zastosowania szlifowania jednoprzejściowego

Streszczenie

W artykule omówiono zagadnienia poprawy efektywności zautomatyzowanych systemów produkcyjnych. Podano wskaźniki efektywności zautomatyzowanego procesu szlifowania oraz wyniki badań porównawczych w tym zakresie, dotyczące innowacyjnej metody jednoprzejściowego szlifowania wewnętrznych powierzchni walcowych.

Słowa kluczowe: automatyzacja produkcji, efektywność, szlifowanie jednoprzejściowe

1. Introduction

Taking the decision to implement manufacturing of the specific product entails the choice of appropriate production technology. Maximum profit always adheres to the principle of economic effectiveness. Therefore, manufactures do not take any decision on selecting such the production process which could contribute to wasting even a part of outlays in the form of production means. The economic effectiveness – means such the utilisation of the production outlays that the cost of manufacture per a production unit was as low as possible. The selection of the production technology is based on the principle of minimising the costs of manufacture (expressed in monetary units).

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Today's machine-building industry is improving production efficiency by automating systems of productions. However process operations are implemented with a minimum participation of a human factor find the more and more widespread applications. The effectiveness of such systems depends in great measure on efficiency of a machine and rhythmicality. The rhythmical production is marked by exact allotments of the specific operations to relevant machine tools or production facilities and the repeatability of operation times (rhythm). The improvement in the production rhythmicality is one of the fundamental tasks of industrial engineering [1]. Thus, a timescale worked out for a repeatability period is standard production for each consecutive repetition. The higher effectiveness is an effect of rhythmical production i.e. better utilisation of production facilities and a reduction in manufacturing costs. The production repeatability requires both the precise and the clear-cut specified division of tasks to relevant devices, and also searching for methods of increasing the efficiency of these devices.

However, the issues of improvement of the efficiency one can perceive wider, not only as tendency for maximising the number of manufactured products and minimising the working time, but also as the process of technological progress [2]. The properly implemented machine process should be marked by [3]:

- *stability* – deciding on the quality of a product,
- *fluidity* – achieved by minimising the working times, eliminating the clogging, delays and bottle necks,
- *continuity* – conditioning the production rhythmicality.

These aspects mostly often derive from "a scale effect" – which results from large series production. The production of this type is usually managed at a large degree of automating of relevant operations, since each saved second is divided by thousands of manufactured products. There are no tooling setups on the stations (of machine tools or other production devices) in case of automated production systems; so in practice it is impossible to increase the effectiveness by shortening the auxiliary times. Therefore, only the machining time of a given operation is at an operator's disposal. In the paper an innovative method aimed at significant reduction of this time in operations of internal cylindrical grinding was discussed.

These experimental results represents the development of the subject matter presented in the paper entitled: „*System approach to the intensification potential for machine-production processes*", published in Advanced in Manufacturing Science and Technology no. 1/2010.

The above characterized method of grinding is an example of a radical approach to the improvement of automated production processes. Due to redesigning the process, the rough and finish grinding was substituted for one operation retaining the required accuracy of dimensions and shapes at minimum roughness of the machined surface [4, 5]. Simultaneously, the superior target could be achieved, i.e. the grinding efficiency without the need to incur additional costs [6].

2. New concept of internal cylindrical grinding

The internal cylindrical grinding is a process of finish machining designed for final shaping the workpiece and providing the proper state of its external surface. If the high quality of surface is required, the division into two operation: rough grinding and finish grinding is mostly applied. It ensures that the required quality of dimensions and shapes is achievable in the first operation while smoothing is carried out in the second operation. One of examples of such the process is internal cylindrical grinding of bearing rings, which follows after machining and heat treating these elements. A conventional approach assumes the removal of allowance remained from earlier operations for abrasive machining in a few passes of a grinding wheel carrying out consecutively rough grinding and then finishes grinding. Grinding allowance in such process is divided into many smaller parts, being removed by a grinding wheel while performing the reciprocating motion (v_{fa}), and then after a few working passes the axis of a grinding wheel is shifted in the radial direction (v_{fr}) (Fig. 1).

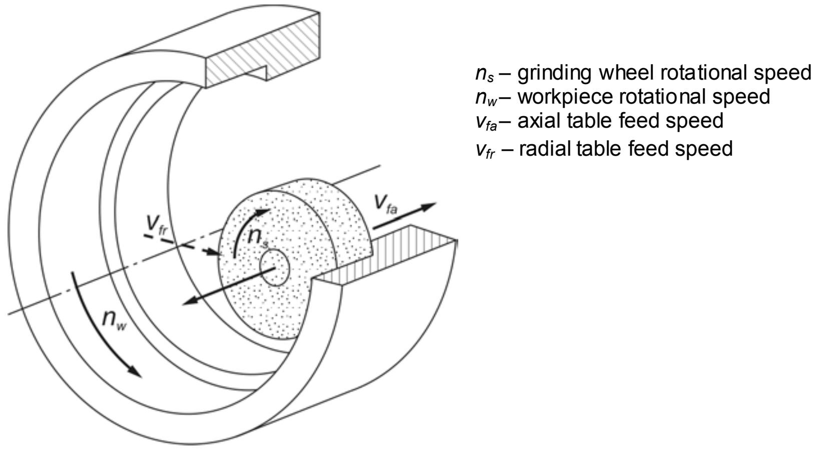

Fig. 1. Multi-pass peripheral axial internal cylindrical grinding process

However, there is the potential for radical changes in the way of this process implementation. The question was considered if generally there is the need to carry out so many passes instead of making the rough and finish grinding at the same time. The solution to this question is an innovative method of single-pass grinding. The essence of this method consists in removal of the whole allowance in one pass of a grinding wheel simultaneously preserving the required quality of machined surfaces.

To enable this kind of machining, it was necessary to work out special grinding wheels consisting of two zones having different structures (Fig. 2) [7].

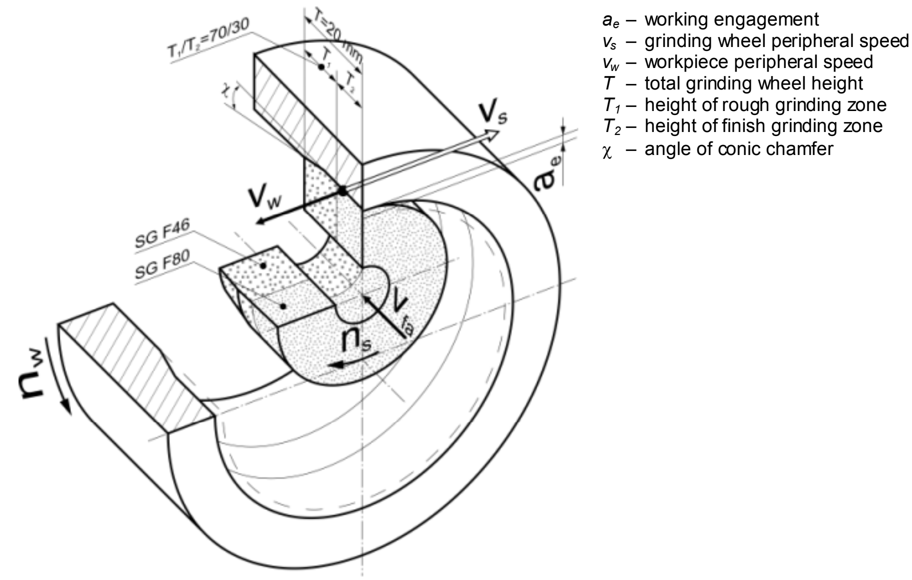

Fig. 2. Single-pass internal cylindrical grinding using grinding wheels with zone-diversified structure [4, 7]

Such grinding wheel structure makes possible the active surface to be functionally divided into a rough grinding zone (Zone A) and a finish grinding zone (Zone B). To ensure the total grinding allowance to be evenly distributed, an additional conical chamfer was formed on a larger surface of rough grinding at a small value of an χ angle that results from the given grinding thickness a_e, and the height of a rough grinding zone T_1 (Fig. 3) [7].

A rough grinding zone of such the grinding wheels (Zone A) is composed of grains of larger size ensuring the high material removal rate of the process to be achieved. A respectively lower roughness of the work surface was obtained by introducing the finer abrasive grains to Zone B, where finish grinding and sparking out were carried out. Grinding wheels composed from super-hard abrasive grains, such as CBN (Cubic Boron Nitride), found application to the processes of this type [8-11].

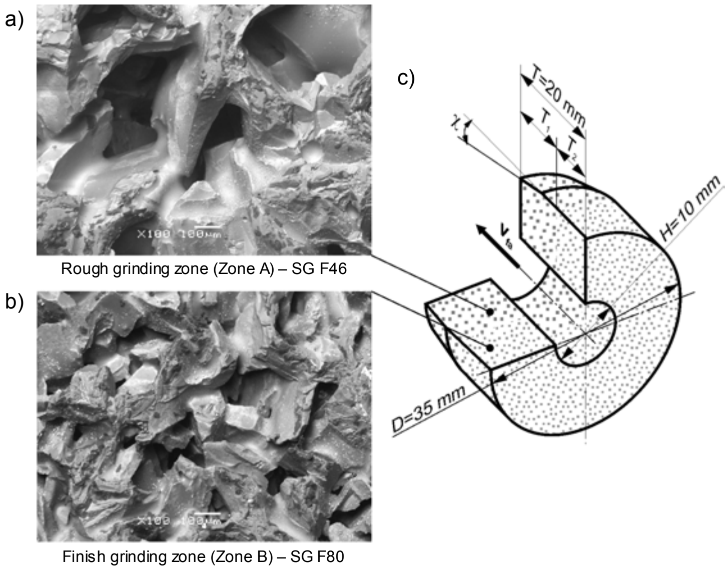

Fig. 3. The example of structure of grinding wheel for single-pass internal cylindrical grinding: a) overall scheme, b) photomicrography of rough grinding zone (Zone A), c) photomicrography of finish grinding zone (Zone B) [7]

Experimental investigations conducted in Koszalin University of Technology have been focused on the application of low-cost (in comparison with CBN) grains of white alundum and SG (Seeded Gel) microcrystalline sintered corundum to the structure of grinding wheels. The application of this type of abrasive materials to advanced grinding wheels, allowed the material removal rate comparable with CBN to be achieved.

To determine the most favourable structure of such the innovative grinding wheels, the methods for efficiency evaluation that were used for experimental tests on internal cylindrical grinding of bearing rings have been worked out [4, 6].

3. Criteria of effectiveness evaluation of a grinding method under test

The effectiveness evaluations are based on judging propositions. They are clear-cut proposition following the process of human's cognition, mainly comparative in character. These propositions describe real events. Thus, they try to prove that the application of a given method – compared with the other – results in a higher degree of the target accomplishment [3]. The effectiveness of the test method for single-pass grinding in such the presentation is determined by the ratio of the really obtained effects to the expenditures incurred for their achievement. The effects initially include the quality of the machined surface and the achieved material removal rate. Whereas, the most important factors describing the outlays are: grinding power and working time [4].

In general this effectiveness can be evaluated according to criteria (indices) divided into five groups: (1) qualitative, (2) productive, (3) costs of grinding, (4) course of grinding and (5) associated indices, also called synthetic. Therefore, for the evaluation of the process under consideration the specific indices from these five basic groups were marked out (in addition, the standardisation of given parameter was assumed as a criterion for the selection). So, the following indices of the effectiveness evaluation were used:

- roughness of the workpiece surface Ra, μm,
- material removal rate Q_w, mm³/s,
- grinding power P_c, W,
- specific grinding power P'_{sc}, W·s/mm²,
- grinding ratio $G = V_w/V_s$, where: V_w – material removal in mm³ and V_s – volumetric grinding wheel wear in mm³.

Moreover, this set was supplemented with a grinding cost index, expressed by the formula [12]:

$$\frac{C_O}{V_w} = \frac{C_S}{Q_w} + \frac{C_W}{G} + \frac{C_d}{\Delta V_w}, \quad €/\text{mm}^3 \tag{1}$$

where: C_O – overall cost of grinding, €; C_S – constant costs of grinder service, €; C_W – costs of grinding wheel generating relate to its usable volume, €/mm³; C_d – costs of single cycle of dressing, €; ΔV_w – material removal in period of durability of grinding wheel, mm³.

Additionally two synthetic criteria presenting the basic output quantities of the single-pass internal cylindrical grinding process, such as V_s, V_w, P_c, Q_w and Ra, were assumed for the evaluation of the effectiveness of grinding wheels put to the tests. They are as follows:

- the effectiveness of grinding E_s [13]

$$E_S = \frac{G}{P'_{sc}}, \quad \text{mm}^3/\text{W·s} \tag{2}$$

- the index K [4]

$$K = \frac{Q_w}{P_c \cdot Ra}, \quad \text{mm}^2/\text{W·s} \tag{3}$$

The relations defining the relevant criteria and their connections with each other within the framework of a single-pass grinding process being investigated are presented in the diagram (Fig. 4) [6].

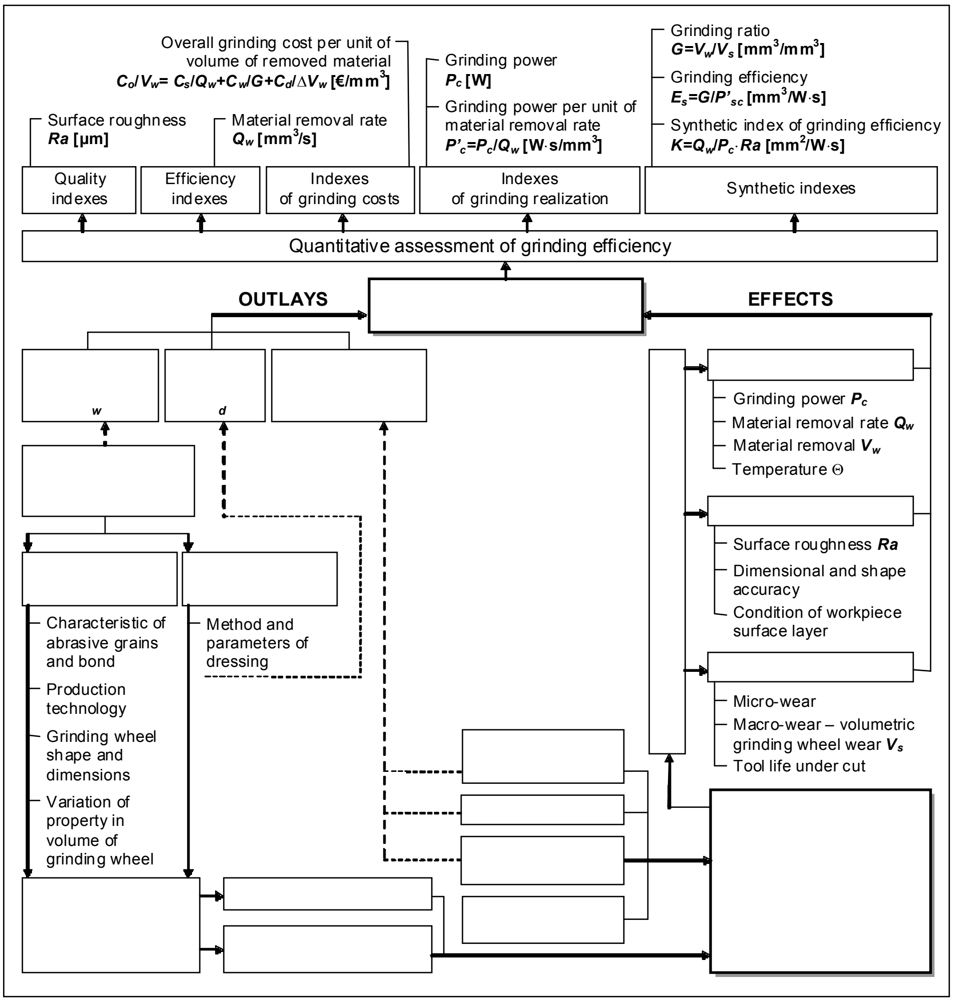

Fig. 4. Scheme describing costs and results of single-pass internal cylindrical grinding and quantity evaluation of efficiency in that process [6]

4. Experimental results

Experimental investigations of a single-pass grinding process were carried out on an experimental setup affixed to a RUP 28 internal grinder equipped with a high-speed electro-spindle (Fischer EV-70/70-2WB) of the power 5.2 kW and the max rate of rotation 60000 rpm. The process of grinding was carried out on the internal cylindrical surfaces of bearing rings of 100Cr6 steel at the hardness of 63±2 HRC.

Experiments were aimed to investigate an influence of various grain size in the finish grinding zone (grains of size 60 and 80 were tested) and the amount of a T_2 zone part in a T total height of a grinding wheel (systems under test: $T_2 = 20\%T$ and $T_2 = 30\%T$) on the effectiveness of grinding. Structures of grinding wheels tested and their characteristics were compiled in Tab. 1.

To simplify the presentation and the specification of experimental results, the short names of grinding wheels in Tab. 1 were applied. They include information on the abrasive grain size in zones of rough grinding and finish grinding (e.g. 46/80) and the number defining the percentage fraction in the second zone (e.g. 30%). As reference to the results obtained with grinding wheels of layered structure, the grinding wheels composed totally from SG grains of size 46 (symbol 46-100%) were also prepared.

From among indices marked out for evaluation of the effectiveness of the process under investigation, the synthetic index K was the most sensitive to changes in the structure of grinding wheels.

The lowest value of this criterion was obtained for a 46-100% grinding wheel (Fig. 5). The other grinding wheels marked by zone diversified structure produced better results within the scope: from 9 to 55%. The best result was obtained (in case of a 46/80-30% grinding wheel) at the same material removal rate, where the work surface roughness was reduced by 24% on average at a slight drop (3%) in power consumption. In consequence the index K was as much as higher by 55% compared to a uniform grinding wheel (totally composed from SG grains) of size 46 (Fig. 5).

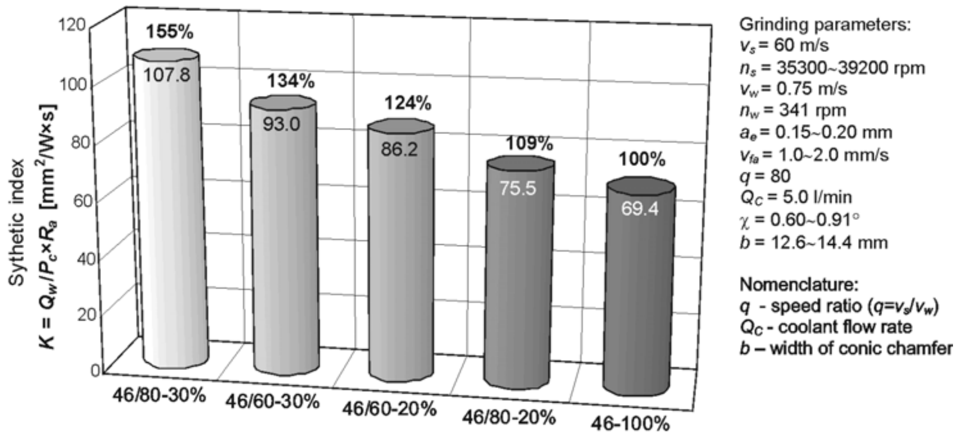

Fig. 5. Average values of synthetic index of grinding wheels abrasive ability

If finish grinding zone B was decreased by 20%, the index of effectiveness *K* was also went down (10-40%). It mainly resulted from deterioration of the work surface roughness.

Additionally the material removal rates Q_w obtained in a single-pass process were compared to data obtained from two producers of rolling bearings (marked here as manufacturer X and manufacturer Y). These manufacturers employed the classical method for reciprocating grinding of bearing rings of the same inside diameter (40 mm) and made of the same material (100Cr6 at hardness of 63±2 HRC) as the workpieces under investigations. Comparison of two processes revealed that the substitution of the classical multi-pass grinding, where at $Q_w \approx 8.5\text{-}13.6$ mm^3/s the machining time $t_m \approx 30\text{-}48$ s/ring was obtained, with the innovative single-pass grinding allowed the material removal rate to be increased by 76% to the value $Q_w \approx 24$ mm^3/s, and consequently the machining time was reduced to $t_m = 19$ s/ring (Fig. 6).

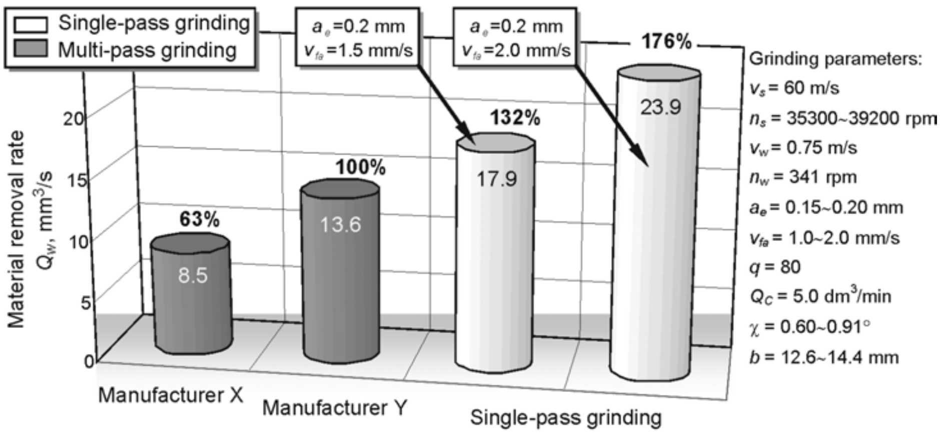

Fig. 6. Comparison of material removal rate in single-pass internal cylindrical grinding with grinding wheels whose structure is zonally diversified and in industry multi-pass grinding

It follows that due to the application of this innovative method of single-pass grinding using grinding wheels with a specific conical chamfer and zone-diversified structure it was possible to achieve 2.5-tuple reduction of the machining time per bearing ring, which means a significant increase in the effectiveness in case of automated manufacturing systems.

5. Conclusions

The process of single-pass internal cylindrical grinding using grinding wheels of zone-diversified structure discussed in this paper provides a viable alternative for a universally used method of multi-pass abrasive machining. New-developed grinding wheels due to their optimised structure enable the material removal rates to be increased up to 24 mm^3/s. It means that one can achieve the 2.5-tuple reduction of machining time required for this operation compared to the previous production technology. However it should be mentioned that single-pass processes impose higher requirements for grinding machines, especially regarding their stiffness. Additionally, in case of using the grinding wheels with conical chamfers it is necessary to apply special instrumentation for fast and precise shaping the active surface geometry of grinding wheels in the course of their dressing. However, despite these limitations the present grinding method provides the potential for a very significant increase in the effectiveness of automated production systems.

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Received in February 2010