

Influence of Cutting Parameters on Cylindricity Deviation by Centerless Grinding

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Grinding is one of the oldest ways of material machining operations. The requirement to produce fast and cost-effective parts in large quantities has classified the metal grinding in the engineering industry for major machining operation. The complexity of the abrasive process and the amount of abrasive tool parameters have considerable problems in the theoretical and experimental study of this process, which is machining with undefined cutting-edge tool. The submitted verifications are aimed at intensifying grinding without medium stress due to the cylindrical deviation. Also, these verifications are aimed to the adjustment of centreless grinding conditions for a given value of the geometric deviation of the shaft and the influence of the abrasive conditions on a given cylindricity deviation.

Keywords: Centreless grinding, Deviation of cylindrical, Speed

1 Grinding

Grinding is high-speed micro-cutting of the surface layers of part with very fine grain abrasives bonded to the tool. Today, grinding is one of the most important finishing operations. Improving grinding machines and tools allows to place grinding to a very productive way of precise machining of different materials. The machine parts can now be machined to an accuracy of up to one thousandth of a millimetres, which can only be achieved with very precise machines and tools. [1,2,3] The economic efficiency of the abrasive process depends on appropriate and purposeful selected technological operations, as well as on suitable machine-technology devices that enable us to obtain the desired product with the necessary properties. [1,4]

2 Centreless grinding with

Centreless grinding is that the workpiece does not set up during the grinding but is set to the outer cylindrical surface. It is inserted between the two discs (grinding and feeding) and held by the guide bar (Fig. 1).

In the case of a transverse or grooving grinding, the workpiece rests on the guide bar and rotates from the feed roller. The addition to the grinding is ensured by feeding the feed roll to the required value. After finishing the grinding, the feed wheel is removed, and the part is replaced. The axis of the feed roll is parallel to the axis of the grinding wheel. In this way, parts which cannot be grinded in a continuous manner are grinded, e.g. butt-shaped parts, conical and shape faces, and parts that do not have the centre holes. The axes of the two wheels are parallel and the parts are inserted between the wheels from the side, such as during continuous grinding or from the top to the stop. As a rule, they are rubbed into two cuts. This grinding method is mainly used in serial and mass production and can be fully automated (Fig. 1). [5,6,7]



Fig. 1 Scheme of centreless groove grinding [8]

3 Tolerance and deviation of circularity

Circularity deviation is the largest distance Δ points from the actual profile of circle. Tolerance field of circularity is a zone in a plane perpendicular to the axis of the rotating surface or passing through the centre of the sphere, bounded by two concentric circles spaced apart by an intersection width equal to the circular tolerance T (Fig. 2).

Measurement of circular variations and evaluation of measurement results are performed according to several standards. The most accurate measurements are by means of touch devices which, by means of a touching tip, capture a profile which is suitably adjusted by means of analogy or digital wave filters (e.g. the influence of surface roughness etc.) (Fig. 3). The edited profile is displayed in the shape of the polar diagrams of the profile and directly calculates the circularity parameters. The contact measuring devices may be designed so that the tip of the contact rotates around the stationary component or the component rotates about the axis and the sensor tip of the sensor does not rotate. [9,10,11]

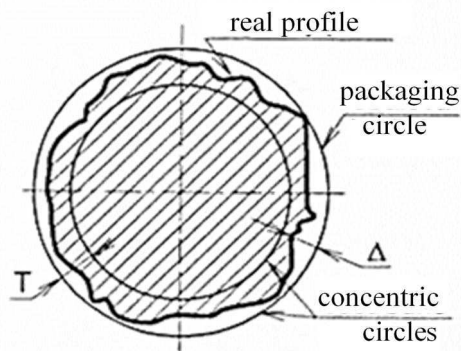


Fig. 2 Tolerance field of circularity [9]

There are several methods for evaluating deviations of circularity. The STN ISO 4291 standard from 1955 describes the deviation of circularity as the difference between the largest and smallest radius of the measured profile of the component, and the measurement can be made from any of the following centres (Fig. 3):

- Centre of last squares (LSC),
- Centre of minimal zone (MZC),
- Centre of minimum circumscribed circle (MCC) in outer surface,
- Centre of maximum inscribed circle (MIC) in inner surface. [12]

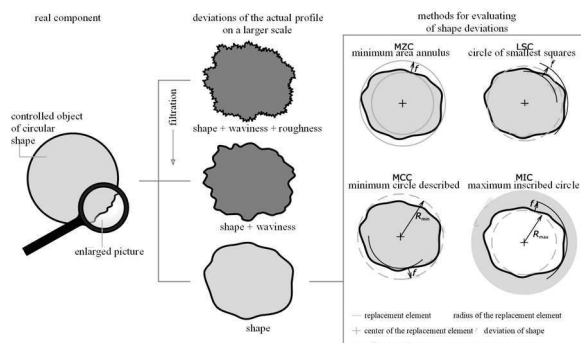


Fig. 3 Methods of circularity evaluation: LSC (Least squares circle), MCC (Minimum circumscribed circle), MIC (Maximum inscribed circle), MZC (Minimal zone circles) [12]

4 Verification of cutting conditions of the centreless grinding of the shaft

Experimental examinations are devoted to the appropriate setting of abrasive ground grinding conditions for a set value of the geometric deviation of the shaft cylindrical and the influence of the set grinding conditions on a given cylindrical deviation. The subject relates to the grinding of shafts of the 50CrMo4 steel (Fig. 4), used in the compressors in the cylinders of the lorry engines, (Fig. 5). The mechanical force of the distribution system is generally used to drive this type of compressor.

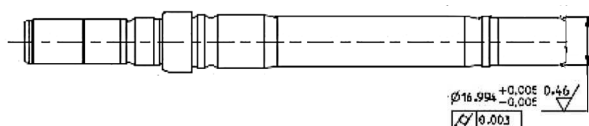


Fig. 4 Manufactured shaft

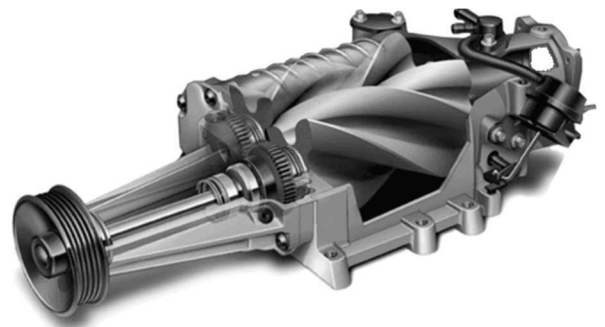


Fig. 5 A view of the turbo compressor [13]

The requirement was to adjust the geometric deviation of the cylindricity below 0.003 mm to $\varnothing 16.994 \pm 0.005$ mm after hardening of the surface layer. Under the current technological process, the required geometric deviation was not guaranteed. After the analysis of the individual stages of production, it was found that the greatest influence on the geometric deviation of the cylindricity and their possible correction was the last stage - the centreless groove grinding. The KOYO KC 300 Series CNC grinding machine with extended automatic feeding is used for grinding (Fig. 6). The shafts are automatically fed from the top to the working space between the grinding wheels and the feed roll. For better stability of the grinding process, the shafts are mounted in the sliding lugs.

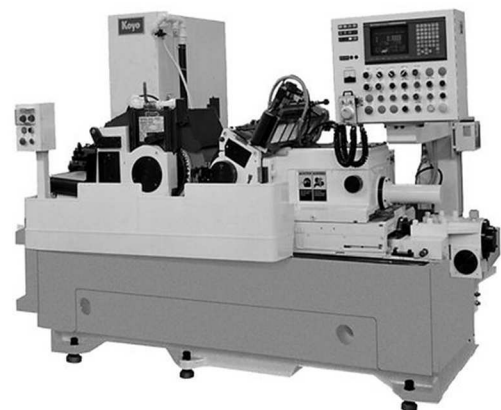


Fig. 6 CNC centreless grinding machine KOYO KC 300 [14]

After determining the order of shaft grinding, the test working conditions were determined as follows:

Centreless grinder	KOYO KC 300 Series with automatic feeder	
Grinding wheel	Norton 55A80-K8VBE - 610 x 231.3 x 304.8	
Feed wheel	Abrasive-South A100R1RS - 330x217x203.2	
Transverse feed		0.003 mm on the stroke
Process fluid		CIMSTAR 560
process fluid concentration		3 - 5 %
flow of process fluid		38 - 42 %

5 Choice of grinding conditions

Three critical factors have been identified that most influence the cylindrical deviation of the measured shaft part. During the tests we watched - *feed roller speed, grinding wheel speed, height of the guide bar.*

In the search for suitable abrasive conditions, the experience of pre-production, the characteristics of the grinding material, the possibility of setting the grinding wheel, the grinding wheel and the feeding roll, considering the possibility of a faulty measuring device and the input of human factor activity into the production process.

The grinding conditions for optimal machine setting with minimal impact on shaft cylindrical deviation are:

- revolution of the feed roll - 33,37,40,43 min^{-1} ,
- grinding wheel speed - 37, 40 43 m.s^{-1} ,
- height of the guide bar - 0, 3 mm.

By combining the observed values of process conditions, 24 experiments were obtained, from which the optimal setting of the grinding process for the further production of the shafts was determined.

6 Deviation measurement

Cylinder deviation measurement conditions:

Roundness meter	Mitutoyo RA-2100 DS
Measured diameter	$16.994 \pm 0.005 \text{ mm}$
Number of measurements per shaft	6
Measured deviation	max. $3 \mu\text{m}$
Sensor angle of inclination	90° (perpendicular to the workpiece axis)

The measurement of the cylindrical deviation was carried out by means of a method of determining the circularity deviation at six distances of the measured cross-section of 3.5 mm apart (Fig.7). For the evaluation, the least circle MCC method was used to obtain the largest measured deviations on the measured shaft cross-sections. The largest measured deviations of the circularity are in (Table 1).

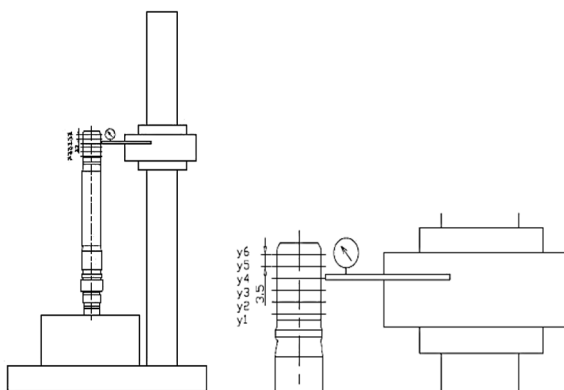


Fig. 7 Measurement of circularity deviation on six positions

Tab. 1 Results of the circularity deviation measurements

Part no.	Revolution of the feed roll [1/min]	Grinding wheel speed [m.s^{-1}]	Height of the guide bar [mm]	y_1 [μm]	y_2 [μm]	y_3 [μm]	y_4 [μm]	y_5 [μm]	y_6 [μm]	\bar{y} [μm]
1	33	37	0	1.5	1.7	2.1	2.0	1.6	2.2	1.85
2	37	37	0	2.8	2.6	2.5	2.3	2.0	2.2	2.40
3	40	37	0	1.6	1.6	1.7	1.7	1.6	1.8	1.67
4	43	37	0	1.5	1.6	1.6	1.7	1.7	1.8	1.65
5	33	40	0	2.2	2.6	3.2	1.9	2.2	2.1	2.37
6	37	40	0	2.2	2.3	1.9	1.9	1.9	1.5	1.95
7	40	40	0	2.3	2.4	2.2	2.4	2.7	2.9	2.52
8	43	40	0	1.6	1.7	1.7	1.8	1.6	1.8	1.70
9	33	43	0	2.3	2.5	2.0	2.1	2.0	1.8	2.12
10	37	43	0	1.9	1.8	1.8	2.0	1.6	2.1	1.87
11	40	43	0	2.1	1.6	2.1	2.5	1.7	1.8	1.97
12	43	43	0	2.1	2.2	2.6	2.0	2.1	1.9	2.15
13	33	37	3	2.8	1.9	1.8	3.0	2.1	3.1	2.45
14	37	37	3	2.2	2.4	2.8	1.9	2.4	2.5	2.37
15	40	37	3	1.9	2.1	1.7	1.7	1.8	1.9	1.85
16	43	37	3	2.9	3.4	3.0	2.3	2.3	2.2	2.68
17	33	40	3	2.0	2.3	2.2	2.5	2.2	2.1	2.22
18	37	40	3	1.9	1.7	2.2	1.9	2.2	1.9	1.97
19	40	40	3	2.8	2.3	2.3	2.9	2.3	2.7	2.55
20	43	40	3	2.6	2.3	2.9	2.6	2.4	2.5	2.55
21	33	43	3	2.7	2.7	2.6	3.2	2.5	3.5	2.87
22	37	43	3	2.3	2.4	2.8	2.5	2.3	3.3	2.60
23	40	43	3	2.5	2.2	2.5	2.4	2.3	2.3	2.37
24	43	43	3	2.7	2.4	2.5	2.3	2.2	2.1	2.37

From the measured circle variance values, the mean deviation values for the cross sections y_1 to y_6 for each measured shaft were calculated. Optimum grinding conditions were then those that showed the best average results of circular variations for each critical factor value separately.

7 Evaluation of the influence of grinding conditions on the deviation of the shaft cylindricity

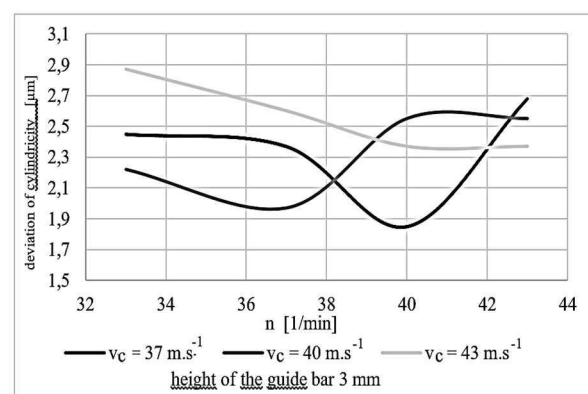
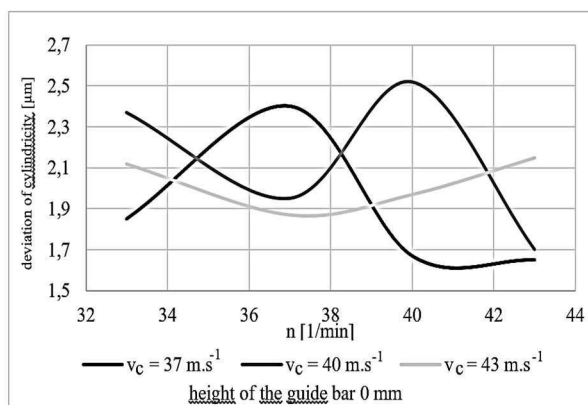


Fig. 8 Deviation of cylindrical deviation from the revolution of the feed roll.

For revolution of the feed roll, an optimal speed of 40 - 43 min^{-1} was determined. For the grinding wheel speed, the optimal speed values were 37-40 m.s^{-1} and the height of the guide bar at 0 mm. However, we only talk about the height of the pad under the guide bar at the guide bar. With this test, we did not only monitor the optimum setting of abrasive parameters for the grinding of the shaft, but also the cylindricity dependence on these abrasive conditions. The test did not show that the cylindricity linear dependence on the revolution speed of the feed roller in the case of smooth grinding on a given diameter of the shaft (Fig. 8). We achieved the best results at 40 min^{-1} . The reduction of the feed spindle and the increase of the speed of the feed spindle from 40 min^{-1} speed also increased the cylindricity deviation.

The linear dependence of the grinding wheel speed on the cylindrical deviation was found. The higher the speed of the grinding wheel, the deviation of the cylindricity of the measured section of the shaft also increased. Therefore, we achieved the best results with the grinding wheel velocity of 37 m.s^{-1} (Fig. 9). Linear dependence was also demonstrated when the guide bar was set.

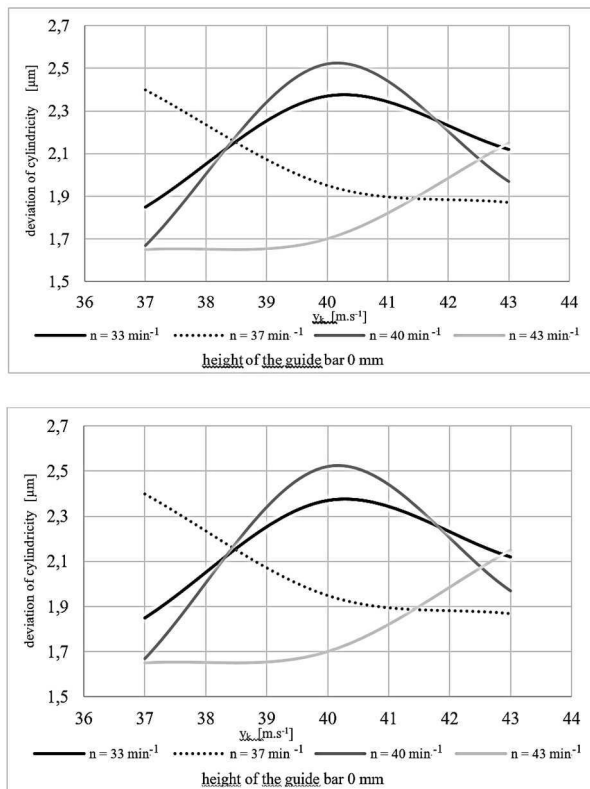


Fig. 9 Deviation of cylindrical deviation from grinding wheel speed.

By raising the guide bar by 3 mm, the cylindricity value increased. For safety reasons, we did not lift the guide bar any further, as the grinding wheel and guide bar could collide. On the three shafts (3, 4 and 8) with the best results of the cylindricity deviation, the full pitch deflection was then measured as the shafts do not have the same diameter over their entire length. The result of the measurement was very good, confirming the accuracy of the choice of abrasive parameters

of the 24 tested shafts, only in five cases of cutting setting, the cylindrical tolerance to customer requirements was not respected. These are the grinding conditions of shafts number 5, 13, 16, 21, and 22. Since with these shafts the deviation of circularity at all measured sections increased, we can say that the observed parameters of the shafts are unsatisfactory. The most satisfactory results have achieved the settings of the grinding conditions observed for shafts 3, 4 and 8.

8 Conclusion

The task of experimental verification was to find suitable abrasive parameters for the centreless grinding of the shaft and to determine the effect of these parameters on the cylindricity deviation of a given section of the shaft.

By summarizing all the results of the measurements of cylindricity deviations, it has been found that the smallest impact on the cylindricity deviation of the measured section of the shaft has a grinding wheel speed of 37 m.s^{-1} , a feed wheel speed of 40 rev.min^{-1} and a height of the guide bar at a basic position of 0 mm.

Since the shafts do not have the same diameter over their entire length, the full throttling variance measurement was performed on the three best-result shafts of the cylindrical deviation of the measured section. The result of the measurements was very good, which confirmed the correctness of the choice of grinding parameters.

These optimal parameters in the next practice will ensure maximum process stability for the measured shaft characteristic and will reduce the produced wasters, which will ultimately reduce the cost of manufacturing of the shafts. These optimum grinding parameters may also be used for other similar products of the tested material of a similar diameter and a cylindrical deviation of not more than 0.003 μm .

The handling of the problem cannot be considered as final with regards to the range of the problem, including examining the temperatures in the grinding, replacing the grinding and feeding rolls with other types, using another grinding machine and examining the impact of machine oscillation on the stability of the process. It is only about obtaining the maximum stability of the centreless grinding process with respect to the measured geometric characteristic of the shaft.

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