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# EVALUATION ON A LATHE OF CIRCULARITY DEVIATION AND FACTORS THAT COULD AFFECT ITS MEASUREMENT ACCURACY

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***Abstract:*** *The problem of complying with the prescriptions regarding the circularity deviation in certain areas of some cylindrical surfaces arises where higher values of this deviation could affect the precision of a part's rotation or other aspects related to the operation of that part. There are situations in industrial practice in which the problem arises of an operative evaluation of the deviations from the circularity of a previously processed cylindrical surface before the part is detached from the device used for its locating and clamping. As such, the problem is posed to design a device that could be mounted on a universal machine tool, and that uses a dial gauge. Consideration is given to the extent to which deviations from the positioning of the dial gauge relative to the horizontal plane of the main shaft axis of the lathe selected as a universal machine tool could affect the measured circularity deviation values. The functional requirements and design parameters are formulated following axiomatic design principles to identify a device solution to meet such conditions. Thus, a variant of the device is obtained that could be used to highlight the influence that dial positioning and, respectively, the clearance between a ring-type piece and the mandrel used to locate and grip the ring-type piece could exert on the measured values of circularity deviation.*

***Key words:*** *circularity deviation, influencing factors, lathe, dial gauge, axiomatic design, triangular matrix.*

## 1. INTRODUCTION

Turning is a machining process in which the workpiece usually rotates while the cutter performs a feed motion along a path in the plane of the rotation axis of the workpiece. By turning, it can obtain ruled surfaces, such as flat, cylindrical, or conical surfaces, but also profiled surfaces, which are determined by the trajectories of the lathe tool tips and/or the profile of the tool edge.

Circularity deviation is part of the broader group of deviations from the prescribed shape of a surface. There are several ways to define circularity deviation [1–3]. One of the definitions of the circularity deviation considers the maximum distance from the adjacent circle and the so-called true profile, the distance measured in a section perpendicular to the axis of the cylindrical surface. On the execution drawings of the parts, it is necessary to mention the value of the circularity tolerance and possibly the position in which the circularity deviation must be evaluated. The problem of evaluating the circularity deviation arises when the equipment's normal operation depends on ensuring a certain type of joint between two conjugated surfaces. In such situations, higher values of the circularity deviation could lead to improper operation of the equipment, the appearance of premature wear, etc.

Two categories of measuring methods and instruments can be used to measure the circularity deviation, namely:

a) Equipment based on the rotation of the part by using a table that rotates to a fixed coordinate system.

b) Equipment that uses the rotation of the measuring system.

When high measurement accuracy is not required and when equipment is not immediately accessible to ensure high-precision evaluation, the problem of determining the magnitude of the circularity deviation directly on the machine tool on which the cylindrical surface has been generated can be formulated and evaluated from the point of view of machining accuracy. Such a solution could be based on turning the locating and clamping the

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workpiece in the universal chuck, for example, using the main shaft of a universal lathe.

The evaluation of different methods for determining the circularity deviation has been an objective of researchers' activity in the manufacturing engineering field.

Thus, Souza et al. have appreciated that the results of measuring the circularity deviation can, in principle, be influenced by the measurement system resolution, uncertainty corresponding to the measurement system calibration, the difference from the standard measurement temperature of 20 °C, and respectively by the temperature variation during the measurement [4]. They pointed out that the mathematical models associated with measuring circularity deviations and cylindricity differ depending on their characteristics and working principles.

Sreenivasulu and SrinivasaRao developed experimental research in which they sought to highlight the influence exerted by cutting speed, feed rate, drill diameter, and some angles of the drill bit on surface roughness and circularity deviation when drilling on a machining center equipped with a numerical control system [5]. The use of Analytic hierarchy process (AHP), and Technique for order preference by similarity to ideal solution (TOPSIS) methods allowed the identification of a combination of input factor values to ensure optimal results when drilling aluminum alloy workpieces.

Korkut and Küçük studied the influence exerted by the cutting parameters, boring tool material, and tool clamping length on the circularity deviation of bored holes [6]. They used the analysis of the signal-to-noise ratio, per the Taguchi method, to establish which factors significantly influence the size of the circularity deviation.

The problem addressed in this paper was evaluating how some measurement conditions can influence the circularity deviation determined using an adaptable device on a universal lathe. Examination of the conditions under which the measurement of the circularity deviation can be carried out led to the conclusion that such a device must meet some functional requirements formulated following axiomatic design principles. In this way, it was possible to identify a device solution that would allow the study of the influence of certain factors on the results of measuring the circularity deviation.

## 2. CONSIDERATIONS REGARDING THE CIRCULARITY DEVIATION OF A TURNING SURFACE

When turning a cylindrical surface with a circular section, some factors corresponding to the machining process or even factors outside the machining process may contribute to the generation of circularity deviations of the machined surface.

Such factors can be the clearances in the bearings of the main shaft, the vibration of the lathe tool along a direction perpendicular to the axis of rotation of the main shaft (Fig. 1), the non-uniformity of the hardness of the material of the workpiece, etc. In turn, the magnitudes of some of these factors can be influenced by the set of

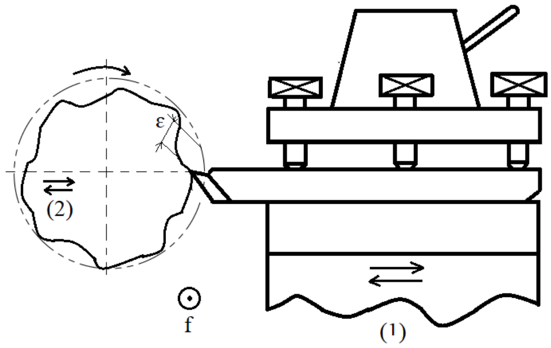


**Fig. 1.** Vibrations that can generate circularity deviations.

internal and external conditions in which the turning process takes place. For example, the amplitude and frequency of the transverse vibrations of the lathe tool or the axis of the main shaft of the lathe are quantities with a direct influence on the size of the circularity deviation of the surfaces machined on the lathes.

It is necessary to take into account the fact that the vibrations in the turning process can be generated, in turn, by the turning process itself (by the occurrence of the so-called self-vibrations), as there are situations when the vibrations are due to causes external to the turning process (for example, due to vibrations generated by the operation of the electric motor, some gears, the rotation of some components whose centers of mass are not on the axis of rotation, etc.).

Under the conditions above, circularity deviations are possible. A less precise but sometimes acceptable, assessment of the magnitude of the circularity deviation can be performed even on the lathe on which the cylindrical surface was previously made. A dial gauge can be used in this case; the axis of the probe of the gauge must be in a plane perpendicular to the axis of the cylindrical surface for which the problem of measuring the circularity deviation arises (Fig. 2). By slowly rotating the located and clamped part, for example, in the universal chuck of the lathe and following the indications given by the dial gauge, it is possible to obtain some information regarding the amount of circularity deviation.

The magnitude of the circularity deviation determined in this way will be influenced to some extent by the values of the clearances in the bearings of the main shaft of the lathe.

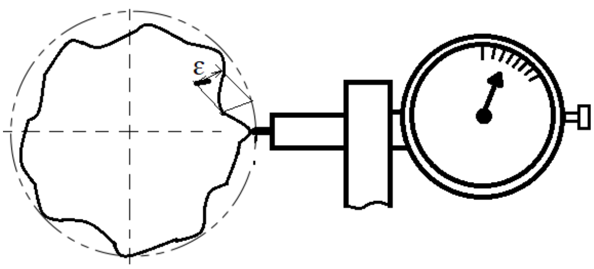


**Fig. 2.** Evaluation of the magnitude of the circularity deviation using a dial gauge.

Other factors whose variation could affect the measured values of the circularity deviation following the working scheme presented previously could be the location of the probe axis of the dial gauge above or below the horizontal plane corresponding to the axis of rotation of the main shaft of the lathe and, respectively, the inclination of the axis of the probe to the previously mentioned horizontal plane.

If the turned part is a ring-type part, fitted with clearance on a mandrel located and clamped in turn in the universal chuck or the universal chuck and chuck in the movable head, the amount of circularity deviation could also be influenced by the size of the clearance between the ring piece and the mandrel on which it is located.

## 3. REQUIREMENTS FOR A DEVICE FOR EVALUATION OF CIRCULARITY DEVIATION ON THE LATHE

Starting from the previously mentioned evaluation of the circularity deviation on the universal lathe on which the turning of a cylindrical surface was previously carried out and from the factors capable of affecting the size of the circularity deviation measured in this way, the problem of designing and making a device that ensures conditions for conducting experimental research designed to allow obtaining a mathematical model capable of highlighting the influence of some factors on the measured values of circularity deviations.

A clarification of the conditions the device must fulfill is possible by formulating the functional requirements to be fulfilled by the device.

One can note that identifying the functional requirements to which mechanical equipment or a technological process must respond constitutes a stage within the so-called *axiomatic design*.

This way of approaching design problems, namely axiomatic design, was proposed by the American professor of South Korean origin Nam Pyo Suh, in the last part of the 70s of the previous centuries. The initial objective pursued by the American professor was that of a more systematic approach to the design problems of manufacturing technologies so that aspects of technical engineering creativity are encouraged [7, 8].

As its name implies, axiomatic design requires the consideration of two axioms, namely:

a) The axiom of the independence of functional requirements, according to which the functional requirements and, respectively, the ways to formulate the answers to these requirements (design parameters) must be independent;

b) The axiom of information, which states that among several possible alternatives for solving a problem, the one that requires the least information should be selected. This last axiom must be selected as that way of solving the problem addressed, ensuring the highest probability of solving that problem.

Returning to the problem of designing a device that highlights the possible influence of various factors on the size of the circularity deviation, it is necessary first to highlight the functional requirements such a device must fulfill.

The so-called *zero-order functional requirement*, formulated according to the axiomatic design methodology, could have the form:

*FR*0: design and make a device that can be adapted to a universal machine tool and which allows highlighting the influence that the position of the dial probe axis to the horizontal plane of the main spindle axis of the lathe could have on the value of the circularity deviation of the contact point axis along a vertical direction, the inclination of the dial contact point axis to said plane and, respectively, the clearance between a ring-type piece and the mandrel on which this ring-type piece is located.

Also, following the axiomatic design methodology, after formulating the functional requirements of a certain level, it is necessary to identify the so-called *design parameters*, i.e., how to fulfill the respective functional requirement.

For the zero-order functional requirement presented previously, by effectively taking over some formulations also used in the zero-order functional requirement, it could arrive at the following:

*DP*0: Adaptable device on a universal machine tool and to allow the highlighting of the influence that the position of the point axis of dial gauge contact to the horizontal plane of the main shaft axis, along a vertical direction, the inclination could have on the value of the circularity deviation of the axis of the dial probe relative to said plane and respectively the clearance between a ring-type part and the mandrel on which this ring-type part is located.

Next, it is necessary to decompose the zero-order functional requirement into first-order functional requirements. In axiomatic design, such an action is called *mapping*.

In this regard, the following first-order functional requirements could be considered:

*FR*1: Identify a universal machine tool on which the machining of a cylindrical surface could be carried out if it is necessary to evaluate in certain areas the magnitude of the circularity deviation;

*FR*2: Identify a sub-assembly of the machine tool to which the device capable of allowing the investigation of the influence of certain factors on the results of the measurement of the circularity deviation could be attached;

*FR*3: Identify a device with which the value of the circularity deviation can be measured;

*FR*4: Provide conditions for locating and clamping the usable device for highlighting the value of the circularity deviation;

*FR*5: Provide conditions for the vertical displacement of the axis of the measuring direction of the device usable for highlighting the value of the circularity deviation when the question arises of evaluating the measure in which the position of the measuring axis of the device usable for highlighting the value of the circularity deviation is not in the axial plane of the workpiece;

*FR*6: Provide conditions for changing the angular position of the measuring axis of the device that can be used to highlight the value of the circularity deviation to the axial plane of the shaft that allows a rotational movement;

*FR*7: Ensure the existence of a part that presents a previously machined cylindrical surface and in which case the circularity deviation values could be measured;

*FR*8: Provide conditions for the locating and clamping of the workpiece on which a cylindrical surface will be machined, in which case the circularity deviation values `will be of interest;

*FR*9: Provide conditions for investigating the influence that the clearance between the part presenting a machined cylindrical surface and the component on which the workpiece has been located and clamped could exert on the measured amount of circularity deviation.

Consistent with those mentioned above first-order functional requirements, the corresponding design parameters can be identified:

*DP*1: Universal lathe on which a cylindrical surface of a workpiece could be machined;

*DP*2: Universal lathe tool holder;

*DP*3: Dial gauge;

*DP*4: Magnetic support for dial gauge;

*DP*5: Guide-sled subsystem;

*DP*6: Disc that can be rotated and immobilized in a certain angular position;

*DP*7: Ring-type part, manufactured by 3D printing, from a polymer material;

*DP*8: Mandrel on which the ring-type part can be mounted with clearance;

*DP*9: Different clearance values between the ring-type part and the mandrel used to locate and clamp the ring-type part.

Functional requirements of zero-order and first-order design parameters can be included in a table that reveals the correlations between functional requirements and *design parameters*. Correlations between *FRs* operating requirements and *DPs* design parameters have been indicated in Table 1 using "X" symbols.

According to the requirements of axiomatic design, a design is decoupled when the symbols that highlight the correlation between the functional requirements and the design parameters are inscribed, in Table 1, along a descending diagonal [7, 8]. As can be seen in Table 1, the "X" symbols were inscribed both along the descending diagonal and in some niches below the descending diagonal. A situation of this type corresponds to a so-called *triangular matrix*, also considered acceptable from the point of view of axiomatic design. In such a situation, the requirement formulated by the first axiom of axiomatic design is fulfilled, according to which each functional requirement *FR* is fulfilled by a single design parameter *DP*.

## 4. PRINCIPLE SOLUTION FOR A DEVICE FOR ASSESSING CIRCULAR SHAPE DEVIATION ON LATHE

Starting from the functional requirements and design parameters mentioned previously, the constructive solution shown in Figs. 3, 4 and 5 was gradually arrived at.

Thus, it can be seen that a metal part of parallelepipedal shape was taken into account, by means of which the device was located and clamped in one of the slots of the universal lathe's tool holder support.

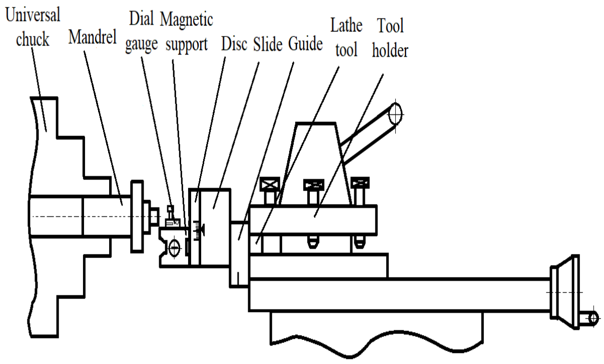


**Fig. 3.** Front view of the device for measuring the circularity deviation on the lathe.

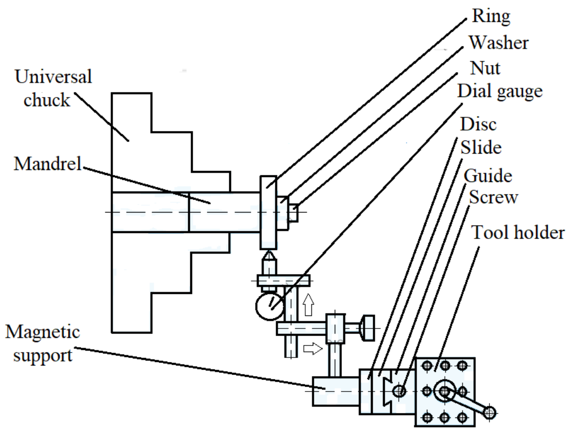


**Fig. 4.** Top view of the proposed device for measuring the circularity deviation.

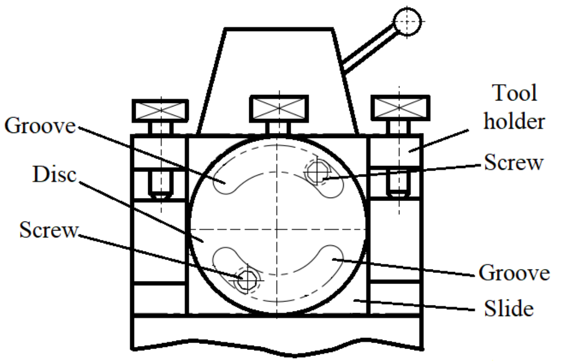


**Fig. 5.** View of the disc used to tilt the axis of the dial gauge contact point.

Tools from the category of lathe tools or some special tool holders are usually placed in these slots.

A dovetail-shaped guide, in which a sled can be moved, was attached to the parallelepipedic part by means of screws. This movement is achieved by acting on a screw solidarized with the guide, while a nut solidarized with the slide makes it possible to move it.

A disc having a pin by means of which the disc can be rotated about its axis of symmetry was bolted to the aforementioned slide. The disc has two channels in the shape of a circular arc, through which two immobilizing screws pass in a certain position of the disc on the sled.

The angle of rotation of the disc can be highlighted using an angular graduation on the disc and a mark on the sled.

A magnetic support for a dial gauge was attached to the flat surface of the disc which could be rotated and locked in a certain position.

The probe tip of the dial gauge can come into contact with the cylindrical surface of a ring-type part by proper handling of the lathe cross slide.

The ring part can be located and clamped on a fixed mandrel, in turn, in the universal chuck of the lathe. The ring-type part is immobilized on the mandrel using a washer and a nut that will be screwed onto the free end of the mandrel.

*Table 1*

**Design matrix for a device adaptable to a universal machine tool and that allows highlighting the influence of different factors on the circularity deviation**

| Line No. 1 | **Design parameters (*DP*s)** | | **Design parameters of zero order** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | | | *DP*0: Device adaptable to a universal machine tool that allows highlighting the influence of different factors on the circularity deviation | | | | | | | | | |
| 3 | | | **Design parameters of the first order** | | | | | | | | | |
| 4 | **Functional requirements (*FR*s)** | | *DP*1: Universal lathe | *DP*2: Universal lathe tool holder | *DP*3: Dial gauge | *DP*4: Magnetic support | *DP*5: Guide-sled sub-system | *DP*6: Disc that can be rotated | *DP*7: Ring-type part, manufactured by 3D printing | *DP*8: Mandrel on which the ring-type part can be mounted with clearance | *DP*9: Different clearance values |
| Col. 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 7 | Functional requirements of zero order | Functional requirements of the first order | **Design parameters of the first order** | | | | | | | | |
| 8 | *FR*0: Design and make a device that can be adapted to a universal machine tool and that allows highlighting the influence of different factors on the circularity deviation | *FR*1 Identify a universal machine tool | ■ | | | | | | | | |
| 9 | | *FR*2: Identify a sub-assembly of the machine tool | ■ | ■ | | | | | | | |
| 10 | | *FR*3: Identify a device with which the value of the circularity deviation can be measured | ■ | ■ | ■ | | | | | | |
| 11 | | *FR*4: Provide conditions for the locating of the device | ■ | ■ | ■ | ■ | | | | | |
| 12 | | *FR*5: Provide conditions for the vertical displacement of the axis of the measuring direction of the device | ■ | ■ | ■ | ■ | ■ | | | | |
| 13 | | *FR*6: Provide conditions for changing the angular position of the measuring axis of the device | ■ | ■ | ■ | ■ | ■ | ■ | | | |
| 14 | | *FR*7: Ensure the existence of a part with a previously machined cylindrical surface | ■ | | | | | | ■ | | |
| 15 | | *FR*8: Provide conditions for the locating and clamping the workpiece | ■ | | | | | | ■ | ■ | |
| 16 | | *FR*9: Provide conditions for investigating the influence that the clearance between the part presenting a cylindrical surface and the component on which the workpiece was located and clamped | ■ | | | | | | ■ | ■ | ■ |

To avoid the situation where the coaxiality deviation of the main shaft of the lathe, together with the universal chuck and the mandrel, to the bore corresponding to the bearings of the main shaft of the lathe, it is necessary that the final turning of the cylindrical surface of the mandrel was carried out on the lathe on which the circularity deviation the cylindrical surface of the ring-type part is to be evaluated.

The magnetic support provides conditions for placing the dial gauge so that the axis of its contact point is initially in the horizontal plane of the main shaft axis and perpendicular to this axis. Positioning the dial gauge contact point's axis to meet the previously mentioned condition can also be done by moving the slide in the dovetail guide.

Highlighting the influence that the positioning of the of dial gauge to the the horizontal plane of the axis of rotation of the main shaft of the lathe exerted on the circularity deviation is possible by carrying out experimental tests in which the position of dial gauge will be adequately changed along a vertical direction, by turning the screw that causes the sled to move in the vertical plane.

When the problem of researching the influence that the angle positioning of the probe axis of the dial gauge exerts on the measured values of the circularity deviation of the cylindrical surface of the ring-type part will resort to the rotation of the disc at previously established values of the angle relative to the horizontal plane of the axis of rotation of the main shaft. In this sense, it is necessary to unscrew and then screw the two screws fixing the disk on the slide whose position can be changed along a vertical direction.

## 2. CONCLUSIONS

This paper addressed the problem of designing a device that allows studying the influence that certain factors can exert on the measured values of the circularity deviation. The possibility of using such a device even on the lathe on which the turning of a cylindrical surface was previously carried out was considered. As factors with a possible influence on the value of the circularity deviation, the possible location of the probe axis of the dial gauge above or below the position of the horizontal plane of the axis of rotation of the main shaft of the lathe, the possible inclination of the axis of the probe to the previously mentioned plane, the value of the clearance between the ring-type part in which the evaluation of the size of the circularity deviation is aimed, and, respectively, the mandrel used for the locating and clamping the ring-type part. Principles from axiomatic design were used to formulate the requirements that the tracked device must meet. It is appreciated that using a factorial experiment in which the input factors are those previously mentioned, it is possible to identify an empirical mathematical model that highlights the influence exerted by the input factors on the value of the circularity deviation. In this way, a constructive solution for the tracked device was gradually outlined. It is planned to make and experiment using this device in the future.

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