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# Stanowisko do pomiaru objętości półfabrykatu za pomocą czujnika laserowego

## Stand for measuring the volume of the blank using a laser sensor

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**The aim of the article is to present a method of measuring the volume of a blank using a laser sensor and a complete measuring stand. In the analyzed part of the manufacturing process of water fittings, the brass rod is cut on blanks of a given weight using CNC sawing machine. Due to the applied flashless forging technology, high cutting precision is required, understood as a relative mass tolerance of the blank of less than 0.1%. In this case, it becomes important to measure the geometry of the rod to calculate its volume – to correct the length of the blank. The natural way to calculate the volume of rotational solids with complex shapes is to determine the definite integral of the curve describing the outer surface of the solid. However, in the case of solids with geometrical errors this function may vary with the angle of rotation of the solid. In the case of real systems, in which the measurement results are a discrete sequence of numbers, it is natural to choose numerical integration. The paper presents the use of a laser sensor moved around the axis and along the rod to measure its volume and the concept of a complete measuring stand.**

**KEYWORDS: volume measurement, laser sensor**

Advances in scanning techniques using laser sensors have contributed to the development of scanning systems, manufactured for the machine industry, solid state physics [1] or medicine [2-4]. The subject of this article is to measure the volume of an axisymmetrical rod made of copper alloy. This rod is a batch material for the flashless process of water fittings components intended for contact with drinking water. It is typical for this production process to cut the rod for billets, which volume tolerance - and thus the mass - allows their use in a further forging.

The methods of measuring the volume of axisymmetrical objects are based primarily on the measurement of their diameter along the main axis. In contrast to contact methods, e.g. using capacitive or eddy current sensors, non-contact methods provide great flexibility, because the measurement is not limited to electrically conductive objects [5]. The possibility of optical measurement of geometrically complex elements allows the use of these methods for quality control in accordance with ISO standards [6]. A review of vision methods and laser sensors is presented in [7].

There are also known methods based on measuring shadows cast by an object illuminated by a diverging luminous flux. The advantage of these methods is the lack of optical elements, such as the lens or mirrors [8].

Various types of machines and measuring devices for measuring axisymmetrical objects, especially those with a circular cross-section are known in commercial technology. Among the solutions available on the market, you can find contact devices, as well as contactless ones, based primarily on laser and optical sensors.

The most compact non-contact measuring devices include laser micrometers (fig. 1). They enable measurements of dimensions and shape and position errors in laboratory conditions, and thanks to the use of scanning modules - also in production conditions. Laser micrometers can be equipped with various types of feeders and supports, making it easier to take measurements.

Fig. 1. Mitutoyo laser scan micrometer [9]

Among the solutions intended for direct application in production conditions, Ultrametrix from Ultrakraft can be distinguished (fig. 2). It is a device for contactless measurements, among others outside diameter and shape errors (roundness, cylindricity) of pipes up to 1400 mm in diameter. The main element of the system is a fixed measuring head equipped with laser scanning sensors,

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distributed evenly with respect to the axis of the measured element in the radial direction. The longitudinal movement of the object is accomplished by means of powered steadies. Depending on the configuration, it is also possible to measure the length of the pipe and the internal diameter - thanks to the use of a sliding measuring head.

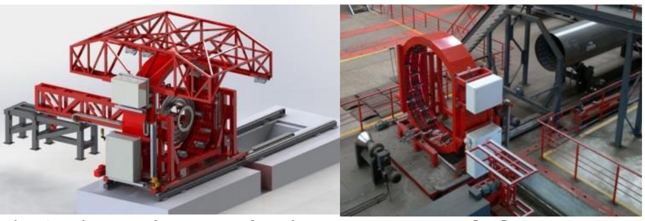

Fig. 2. Ultrametrix system for pipe measurements [10]

Also devices with vision systems are used to measure axisymmetric objects. One of them is the OpticLine revolving element scanner (fig. 3), designed for measuring lengths, diameters, angles and radii, as well as deviations of roundness, cylindricity, beating, straightness and parallelism. Cameras and light sources rotate around the axis of rotation of the measured element. The measurement range of diameters (depending on the model) is 0.2÷140 mm, the measuring range of the length - 300 mm, and the maximum weight of the measured object - 20 kg. The disadvantage of this type of devices is the inability to directly use the production lines.


Fig. 3. OpticLine Optical Scanner by Jenoptik [11]

The main idea of the presented method of measuring the volume of a blank (fig. 4) is to determine the value of the definite integral describing the rod. This method is based on the assumption that the material structure is homogeneous and that its density is known, while the blank geometry itself is subject to manufacturing errors. In principle, the rod rotates and moves relative to the sensor that creates its spatial profile. The data from the distance transducer, the encoder monitoring the relative angle of rotation and the transducer measuring the rod travel are delivered to the industrial controller, controlling the entire process. The device calculates the numerical value of the bar volume according to the following dependence:

$$V = l\sum_{1}^{m}\sum_{1}^{n}\frac{\pi}{n}r_{m,n}^{2} \quad (1)$$

where: $l$ - measured rod length; $r_{m,n}$ - radius measured at a given measurement point; $m$, $n$ - indexes of subsequent measurement points.

In order to make the results independent of systematic measurement errors resulting from the accuracy of the radial position of the measuring transducer relative to the bar, the rod is initially scanned and then weighed.

Dependence (1) has been supplemented by the correction factor $a$:

$$V = l\sum_{1}^{m}\sum_{1}^{n}\frac{\pi}{n}\left(a + r_{m,n}\right)^{2} = \frac{m}{\rho} \quad (2)$$

In this relation to the radius measured by the device a constant value a is added, calculated numerically based on the relation of volume, mass and density. In the presented case it is possible to apply the method of subsequent approximations, Newton, etc.

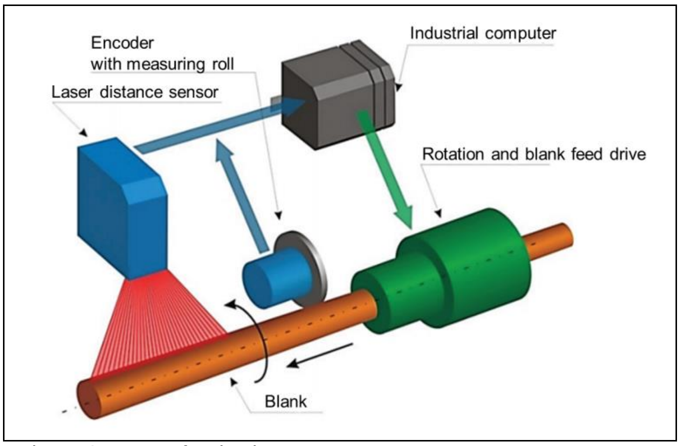


Fig. 4. Concept of rod volume measurement

**Measurement method**

The following are four different measurement methods that were used on the measuring stand.

**■ Measured with a laser point-type distance sensor.** A laser dot-type distance sensor is a measuring device in which a light beam emitted by a source reflects from the measured element and returns to a detector positioned at a certain angle. Moving the transmitter and receiver by a known angle allows tdetermination - by triangulation - the distance between the transmitter and the element being measured. Such transducers are precise and repeatable. Their disadvantages include, however, the high price and point character of the measurement, which is partly compensated by high frequency frequencies. An example of using laser point transducers to determine the bar volume is shown in fig. 5.

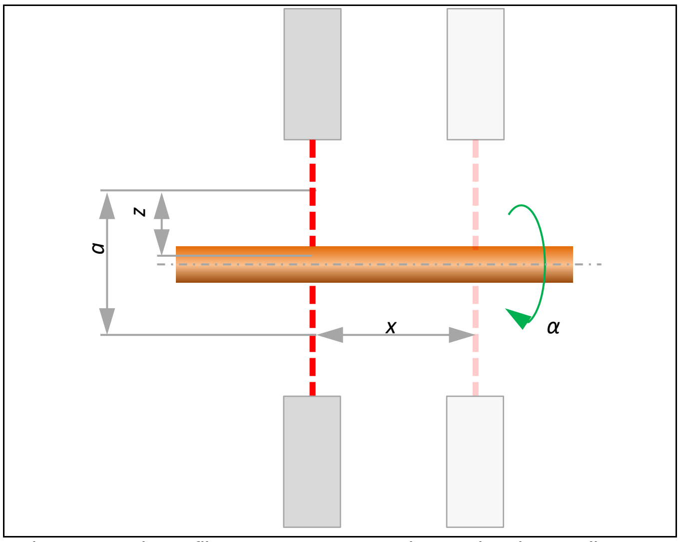


Fig. 5. Rod profile measurement using point laser distance transducers, where: $a$ - known distance of the object from the front of the transducer, $z$ - range, $x$ - linear shift of sensors, $\alpha$ - angular shift of sensors

**■ Measurement using a laser scanning distance sensor.** The laser distance scanner works on a similar principle to the point transducer, however, depending on the construction, a linear laser (spot in the form of a straight line) is used or the direction of the light beam is changed. There are available devices in 2D versions (the profile distance along the measurement line is scanned) and 3D (the distance of individual points of the measurement grid on the tested surface is scanned). The most important advantages of these devices include the speed of operation, and the disadvantages - not very reliable measurement and high cost. An example of the use of a scanning laser distance sensor to determine the bar volume is shown in fig. 6.

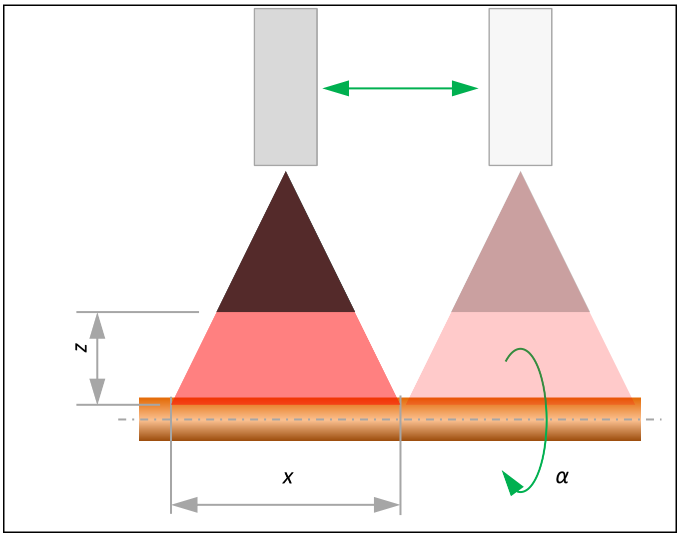


Fig. 6. Rod profile measurement using a scanning laser distance sensor, where: *z* - range, *x* - linear shift of sensors, *α* - angular shift of sensors

**■ Measured using an inductive, eddy current transducer.** Inductive distance transducers operate on the principle of changing the induction of the mutual set of coils, by introducing in their vicinity objects in which the flow of eddy currents is induced. The great advantages of these are the very low price and averaging of the results from the tested field, while the disadvantages include low measuring confidence. An example of using eddy current transducers to determine the bar volume is shown in fig. 7.

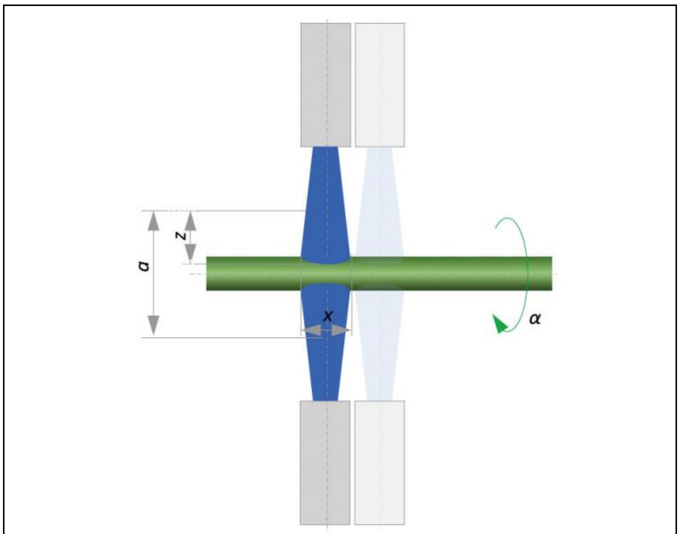


Fig. 7. Rod profile measurement using eddy current transducers, where: *a* - known distance of the object from the front of the transducer, *z* - range, *x* - linear shift of sensors, *α* - angular shift of sensors

**■ Measurement using a vision system.** Vision systems have permanently entered various industries. These devices are characterized by high flexibility and a wide range of applications, but their capabilities largely result from the creativity of programmers. As such, they do not have one purpose, thus it is difficult to precisely determine the parameters of the vision system before its construction. The proposed vision system is to register the rod so that the tangent to the circle is in the optical axis of the camera. The transducer used must have a pixel size of 2 μm, similar to the optical resolution of the used lenses. An example of using video transducers to determine the volume of a blank is presented in fig. 8.

In the examples presented above, double converters were used - monitoring the distance at points lying opposite each other. Such arrangement of the transducers allows for differential measurement, which minimizes systematic errors and limits the influence of the curvature of the examined rod on the results of the analysis.

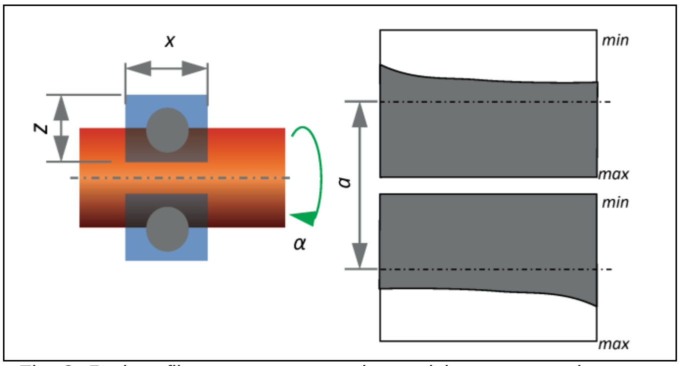


Fig. 8. Rod profile measurement using a vision system, where: *a* - known distance of the object from the front of the transducer, *z* - range, *x* - linear shift of sensors, *α* - angular shift of sensors

### Measuring stand

Due to the high cost of the devices discussed above, as well as due to the extremely difficult or even impossible application in the case of precise cutting of rods, the construction of a special measuring device was developed (fig. 9 and fig. 10).

The main elements of the bar measuring station are the drive module, the measurement module and the components responsible for supporting and receiving the rod.

For the needs of tests, the device was mounted on a steel table with *T*-slots, which ensures precise positioning of individual elements of the station with respect to the plane passing through the axis of the measured rod perpendicular to the base.

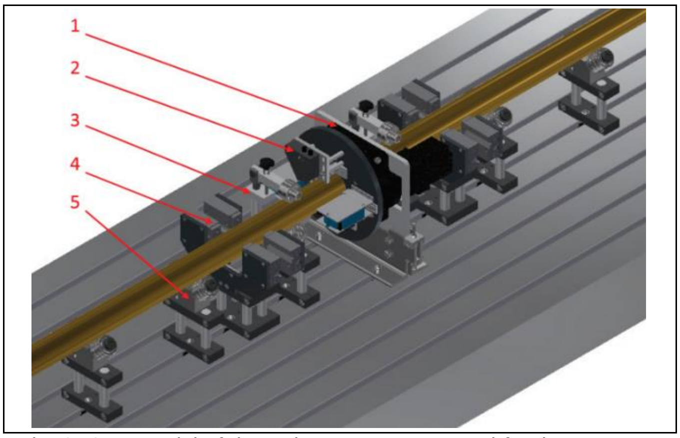


Fig. 9. CAD model of the rod measurement stand for the purposes of flashless forging of drinking water fittings elements: 1 - drive module with indexing gear, 2 - measurement module, 3 - tip, 4 - bar feeder, 5 - steady rest

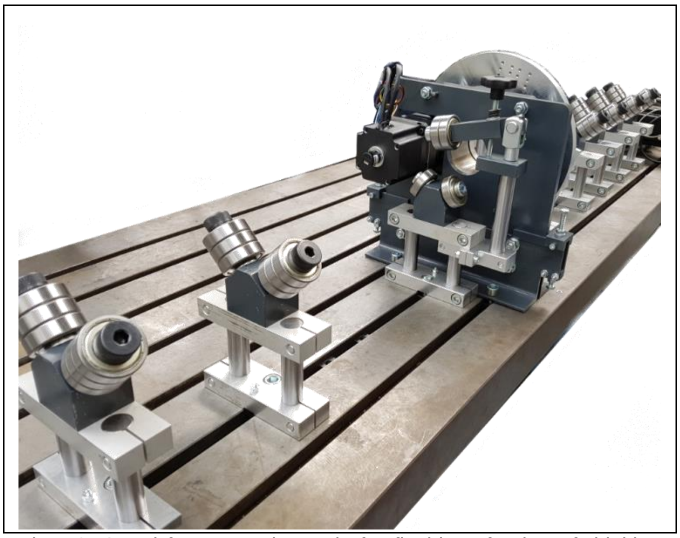

Fig. 10. Stand for measuring rods for flashless forging of drinking water fittings

The drive module (fig. 11) consists of a steel plate placed in the holders to which the indexing gear with a reduction ratio of 1:10 is attached. The drive is provided by a stepper motor with an encoder, which makes it possible to indirectly measure the angular position of the measuring module. The stand has been adapted to measure rods with a maximum diameter of 70 mm, and its design allows for infinitely variable adjustment of the position of the measurement module relative to the base - necessary due to the variable range of the measured diameters.

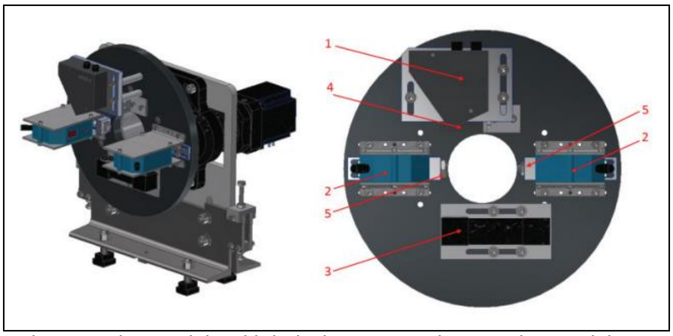


Fig. 11. Drive module with indexing gear and measuring module: 1 - laser scanning distance sensor; 2 - laser, point distance transducer; 3 - vision transducer; 4 - mirror; 5 - eddy current transducer

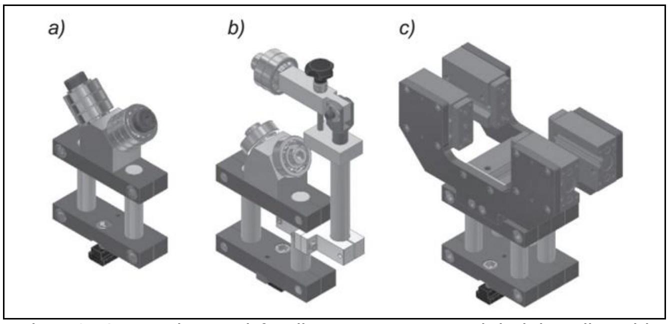


Fig. 12. Supporting and feeding components: a) height-adjustable support, b) fixed-height support with a pressure-back, c) pneumatic feeder of the rod

The indexing module is attached to the indexing gear (fig. 11), consisting of a disc, to which a set of measuring transducers has been attached via special sliding holders. The first of these is a laser scanning distance sensor 1 with a resolution of 3 μm and a measuring range of 5.9 mm. In the plane perpendicular to the scanner axis, laser point distance transducers 2 with a measuring range of 12.7 mm and a resolution of 0.64 μm were attached. Below them is an inductive eddy current sensor 5. The measuring unit is complemented by: camera 3 (equipped with an angular lens) and mirror 4.

Extremely important from the point of view of the accuracy of measurements is to limit the influence of rod deflection on the obtained results. For this reason, the measuring stand has been equipped with several steady rests (fig. 12a), enabling precise support of the rod due to the height adjustment. In addition, two steadies, closest to the measurement module, have been equipped with wrappers (fig. 12b), whose task is to ensure that the rod is correctly guided in the measuring zone. In order to be able to carry out the measurements in an automatic cycle, special pneumatic feeders have been designed, which construction is based on compact cylinders with guides with a stroke of 50 mm. The feeders were placed on both sides of the measuring zone to ensure the continuity of the station work. During work, one of the feeders moves the rod, while the other acts as a clamp, limiting the risk of errors related to the axial positioning of the rod being measured.

The device control system has been designed on the basis of an industrial controller, which at the same time is responsible for data acquisition and performs tasks related to the relative displacement of transducers and the measured object. Considering the required computing power, it is necessary to use an industrial controller with an Intel i7 or higher class processor. The high computational power required is due to the vision system software. The device has been retrofitted with digital and analogue input modules, digital output modules and communication interfaces. Analog inputs will be used for reading signals from sensors with such outputs, communication interfaces - for exchanging information with the engine controller and scanning laser distance sensor, while digital outputs - for displaying the device status and controlling the pneumatic valves of the linear drive actuators. A USB port, mounted directly in the CPU, will be used to connect the video sensor.

## Conclusions

The article presents a summary of currently known methods for measuring the volume of axisymmetric elements. The subject of the research was the method of measuring the volume of a rod made of brass, which is a batch material for the precise die forging process. The bar's volume is important due to the designation of the pre-cut lines, whose volume (and mass) tolerance must guarantee flashless forging.

The article analyzes four different measurement methods using laser distance transducers, eddy current transducers and a vision system. A research stand was designed and made, which will allow to determine which of these sensors provides the measurement with the required accuracy.

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