



EQUIPMENT FOR MEASURING CONICAL PARTS

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Abstract

Tapered components play numerous roles in the devices we use daily and those that surround us, sometimes performing special or even indispensable functions. The aim of this paper is to design and implement a measuring device suitable for determining the taper and taper angle of pin-type tapered components. The basic concept of the measuring instrument is inspired by the sine ruler, while effective measurement is ensured by the displacement of a digital gauge along two perpendicular axes. The data processing is performed by an Arduino microcontroller, which displays the results on an LCD screen. We measured a workpiece with a known taper. The measurement accuracy was verified using hypothesis testing.

Keywords: *rate of taper, taper angle, sine block.*

1. Introduction

In modern manufacturing, precision is essential. Parts must be within certain dimensions, known as tolerances, which are specified by the designer and recorded in the technical documentation. During the manufacturing process, the dimensions of the parts are regularly checked to ensure the required quality. For quality control, universal measuring (e.g., calipers) and/or specialized inspection tools (e.g., gauges) are used.

Tapered parts play a huge role in our daily lives and require special attention and precision in both manufacturing and quality control. This paper deals only with the latter, quality control.

Tapered parts are characterized by their taper, as defined by the international standard ISO 3040-2016. As shown in [Figure 1](#), the taper is the ratio of the difference between two different diameters measured on a length parallel to the taper axis and the length dimension.

The taper is denoted by C , which can be written mathematically as:

$$C = \frac{D-d}{L} = 2\text{tg} \frac{\alpha}{2} \quad (1)$$

The degree of taper can be given as a ratio or in percentage form, and the cone angle can also be interpreted, which is recommended to be specified in degrees.

There are several methods and measuring devices for measuring taper [\[3\]](#), which are discussed in detail in [\[2\]](#). The present paper is based on the sine bar, which is an indirect measurement method. It is preferred for its accuracy and simplicity. [Figure 2](#) illustrates the arrangement of the measuring device during measurement. The sine bar is supplemented with gauge blocks and a dial indicator.

The measured workpiece is placed on the sine bar and raised with the help of gauge blocks until it becomes parallel to the measurement base surface. The parallelism can be checked with a dial gauge. Knowing the distance between the two cylinders of the sine bar and the height of the gauge block, the cone angle of the part can be given by a trigonometric relationship:

$$\sin \alpha = \frac{H}{L} \quad (2)$$

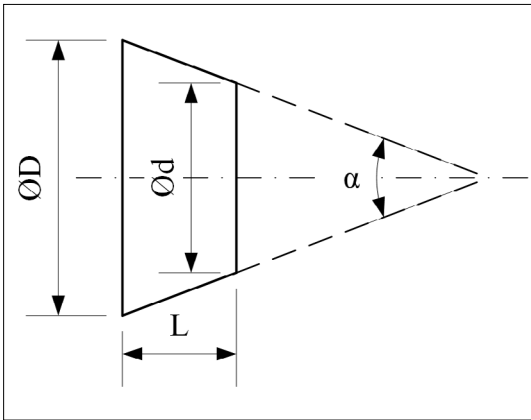


Fig. 1. Interpretation of taper according to ISO 3040-2016. [1]

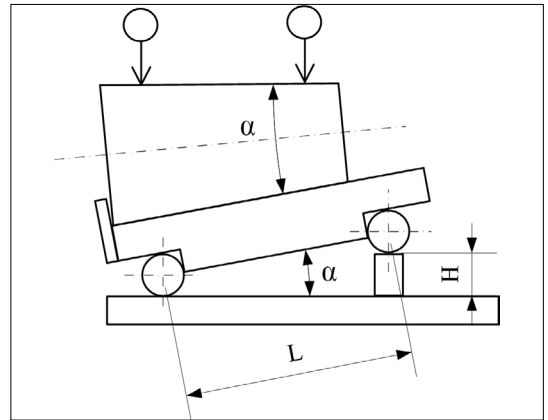


Fig. 2. The sine bar during measurement. [2]

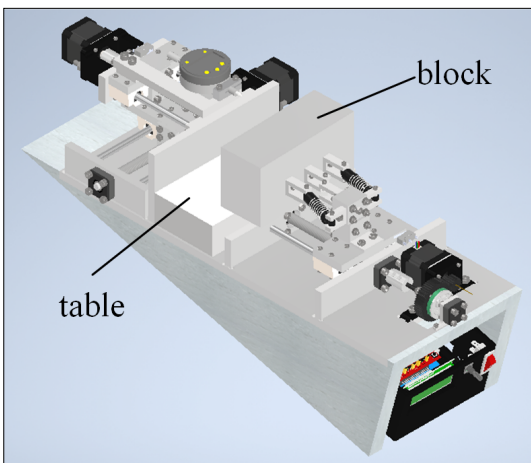


Fig. 3. The 3D model of the designed equipment.

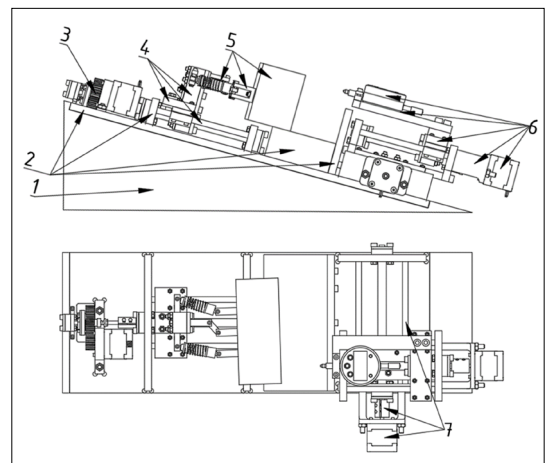


Fig. 4. The construction of the equipment.

This paper presents the design and construction of a measuring device that provides a fast and simple measurement.

2. Overview of the planned system

The main consideration in designing the device (Figure 3) is simplicity and accuracy while ensuring a stable and rigid structure.

The whole system is located on a 15° slope. The measured part is placed on the table marked in white, the principle of the sine bar is embodied in the mounting block on the table (Figure 3). The effective measurement is done with the help of a digital dial gauge, which taps the workpiece, thus ensuring the principle of the sine bar (Figure 2).

The device is divided into 7 units: 1 - the slope, 2 - the base plate and its components, 3 - the sliding clutch unit, 4 - the workpiece fixing unit, 5 - the double articulation unit, 6 - the gauge touch-securing unit, 7 - the gauge positioning unit. The device also includes an LCD display (Figure 4), which allows the user to tell how many points to taper the dial gauge, and the taper result is also displayed here.

The movement of the device is controlled by 3 stepper motors, while the associated control and transmission of the measured data is handled by an Arduino Mega and an Arduino Nano. These microcontrollers are located under the slope to be properly protected. The rigidity is provided by metal elements, which increases the accuracy of

the system. The taper gauge can measure pieces up to $\Phi 60$ mm in diameter and 160 mm in length.

3. The functioning of the measuring system

According to the purpose, the measuring device is used to determine the cone angle of the external tapered rotating surfaces. To do this, the workpiece is placed on the white marked table (Figure 3), and the user can select from the menu on the LCD display whether to measure at 4, 5, 6, 10 or 12 points. Before the measurement starts, the probe of the dial gauge is moved to position 0 by the stepping motors. The stepping motor fixes the workpiece by the 4 – fixing unit and the 5 – double articulation unit until the sliding clutch slides. At this point the effective measurement begins, during which the units that move and position the dial gauge are activated.

4. Evaluation of the results

4.1. A mérendő munkadarab

The measured workpiece is a 3D printed part with the following geometric characteristics (Figure 1):

- $D = 30$ mm
- $d = 10$ mm
- $L = 100$ mm
- $\alpha/2 = 5.711^\circ$

4.2. Determining taper with measuring microscope

The semi-cone angle of the workpiece was measured with a microscope at the Sapientia Hungarian University of Transylvania, Faculty of Technical and Human Sciences – Târgu Mureş.

The resulting semi-cone angle is 5.66° , determined by the direct method. The deviation of the measurement result from the model-determined cone angle value is negligible, 0.05° .

4.3. Determination of the taper with the implemented measuring equipment

During the measurement with the measuring device, the system stores the measured points, from which it interpolates a line. The microcontroller calculates the line's axis using the method of the least squares, which is in fact the semi-cone angle of the measured part. From the menu, 4, 5, 6, 10 and 12 measuring points were selected in order and 3 measurements were taken with each of them, summarized in Table 1.

Table 1. Summary of the results

Num. of pts.	4	5	6	10	12
Results [°]	5.06	5.35	5.61	5.65	5.7
	5.14	5.33	5.6	5.66	5.71
	5.03	5.32	5.6	5.64	5.7
Average [°]	5.07	5.33	5.6	5.65	5.7
Deviation * [°]	0.22	0.11	0.07	0.09	0.07
α	0.05				
t_{crit}	4.302653				
t	-5.091	-5.8418	-2.69087	-1.1501	-0.16818
Decision	H1	H1	H0	H0	H0

*the standard deviation values are rounded

To verify the results of the system, we also used a hypothesis test. It was checked that the deviation of the measurement results from the expected value of 5.71° was negligible at the 0.05 level. The null hypothesis: the average is equal to the expected value; the counter hypothesis: the mean is different from the expected value.

For this we use a t-test, the results of which are also shown in Table 1.

The range of acceptance is (-4.3; 4.3). Based on the actual t values, it can be concluded that the average from 4 and 5 touches is significantly different from the expected value of 5.71° , thus the counter hypothesis holds, while the average for 6, 10 and 12 touches does not differ significantly from the expected value.

Figure 5 illustrates the averages of the measurements.

A value of $R^2 = 0.69$ indicates a strong relationship between the averages and the number of touches.

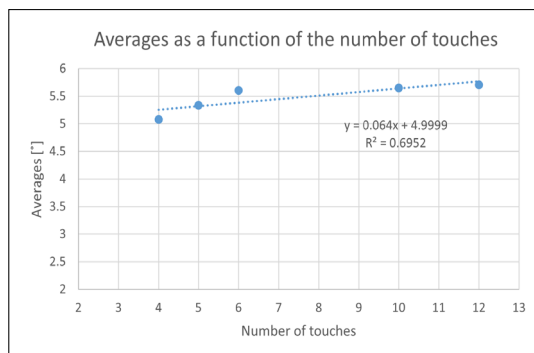


Fig. 5. The averages as a function of the number of touches

5. Conclusions

In conclusion, the designed and realized laboratory equipment shows a close and directly proportional relationship between the number of touch points and the accuracy of measurement (Figure 5).

Furthermore, a minimum of 6 probing operations is required to obtain a measurement result with an acceptable accuracy at the specified level.

It should also be noted that at 12 touch points the deviation becomes very small.

References

- [1] ISO 3040:2016 – Geometrical Product Specification (GPS) – Dimensioning and Tolerancing - Cones
- [2] Aparin G. A., Gorogyeckij I. E.: *Tűrések és műszaki mérések*. 2. kiadás. Nehézipari Könyvkiadó, Budapest, 1954. 146–161.
- [3] Curtis M., Farago F.: *Handbook of Dimensional Measurement*. Industrial Press, Norwalk (CT), 2014.