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Design and Production of a Device for Basing and Fixing Conic Details in Sine Bar Measurements

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***Abstract*. The geometric features of the conical parts measured by a sine bar requires special devices for basing and fastening. Basing and fixing conical parts on a sine bar is a problem that can lead to deviations in measurements. In the presented study, a fixture for fixing and basing conical details when measuring with a sine bar is designed and manufactured. The device is designed to facilitate the work of the operator in fixing the workpiece during the measurement, which increases the accuracy of the measurements. The developed structure is designed using SolidWorks. After the completion of the 3D model, a choice of material and technology for 3D printing is made. After that, a 3D printer is used for its production. The manufactured device is tested in laboratory studies. The designed device is installed on the sine bar without changing the measurement methodology. The conducted experiments prove its workability and applicability.**

Keywords: design, fabrication, 3d printing, 3d modelling, device, measurement, operability.

I. INTRODUCTION

In production practice, the control of conical details is one of the complex metrological tasks. The existing measurement and control methods are divided into three groups:

- qualitative assessment methods;
- Goniometric methods;
- Trigonometric methods;

In the present study trigonometric methods are used to control an external conical detail through the use of a sine bar.

A standard sine bar is a steel bar that is used with two properly spaced cylinders that may or may not be fastened to it. The axes of the cylinders are parallel to the adjacent sides of the sine bar and are located at a definite distance apart, usually 100, 200 and 300 mm. An angle is generated by putting different gauge blocks under the cylinders, as shown in “Fig. 1” [1].

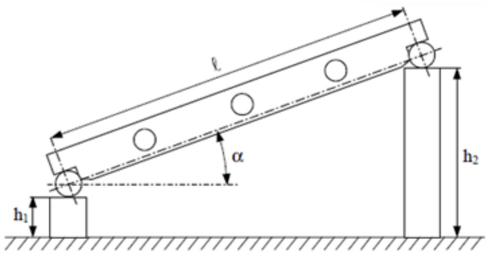

Fig 1. Standard sine bar.

$$\sin \alpha = (h_2 - h_1)/L \quad (1)$$

The most important influence on the generated angle uncertainty is parallelism deviation between the two cylinders. Too short distance between the

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cylinders are another important influence. This fact has two consequences:

- angle changes smaller than 3.3 μm/m cannot be generated;
- the uncertainty of the gauge block calibration has a significant influence on the result;

There are several measuring methods of the taper angle of the cone, such as coloring, cylinder block, two groups of cylinders with different diameters, two spheres of different diameter measurement within the taper angle of the cone, two different diameter of the ball and the gauge block measurement taper angle, sine bar measuring taper angle. The sine bar measuring the angle of the cone is commonly [2].

The sine bar is a precision measuring tool which is used for indirect measurement or machining of precision angle by the principle of sine function. The sine bar Commonly is used to measuring the taper angle of the inner and outside cone and the head diameter of the cone, and can also measuring angle block angle, the angle between hole center line and a plane, and being a machining fixture of precision parts, especially which is the most common in the measurement of the taper angle. The sine bar can measure outside taper angle, inner taper angle, taper angle of the cylindrical cone, taper angle of the synthetic cone, taper angle of the different to cone, but the formulas of gauge which we use dimension of gauge block is different. If the dimension of gauge block size is wrong and it will directly affect the accuracy of the measurement results, so we need to clear each measurement of the dimension of gauge block size [2].

The sine bar is divided into two kinds of narrow and wide, and according to the structure of each type, they are divided into three kinds of 100mm, 200mm and 300mm. As shown in "Fig. 2", we can see α=α1 by the geometrical knowledge. Based on the principle of trigonometric functions, we can see:

$$sin\alpha = \frac{CO_1}{OO_1} = \frac{BO_1 - BC}{OO_1} = \frac{h+R-R}{L} = \frac{h}{L} \tag{2}$$

So, we know that:

$$sin\alpha = \frac{h}{L} \tag{3}$$

In equation (3) α is the nominal value of the angle of the workpiece, and L is the distance between the centers of the two cylinders of the sine bar (mm)[2].

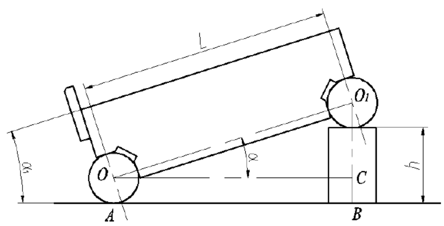

Fig. 2 Measurement principle of sine bar [2].

The methods shown in "Fig. 3" is a sine bar with a conical detail attached to it and placed on a test plate. One roller of the ruler rests on the table and the other on a block of gage blocks of the size ***h***. The size ***h*** of the gage block is calculated in advance so that the ruler is tilted at an angle equal to the nominal value of the measured angle - **α**. In this case, basic equipment is used to fasten the detail. The equipment for fastening the conical part is additionally made according to the views and capabilities of the operator. To achieve the required accuracy when measuring with a sine bar, it is necessary to have the measured parts fixedly attached to the sine bar[3].

Accurate and easy fixing of the controlled workpiece is one of the problems related to the operator's work when measuring with the sine bar.

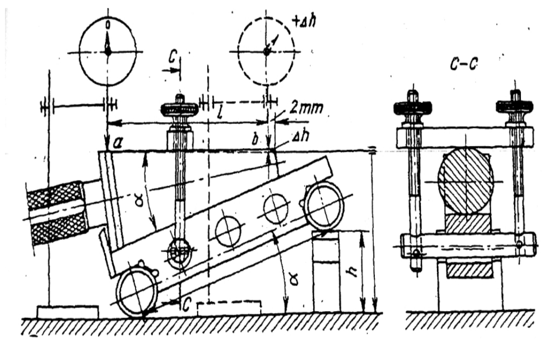

Fig. 3 principal measurement of a taper angle of outer cone with sine bar [3].

The measurement process after fixation of the workpiece follows the dependencies:

$$sin\alpha = h/L \tag{3}$$

The size of the gage block is calculated from by the formula:

$$h = L.\ sin\ \alpha \tag{4}$$

The conicity of conical detail is determined indirectly by measuring misalignment **Δh** at a certain length ***l***. For this purpose, a stand with a dial indicator is used, and the measurement is made at the two end points **a** and **b** at a on the surface of the detail. The deviation ΔC from the nominal taper angle is calculated using the formula [3]:

$$\Delta C = \Delta h/l \tag{5}$$

In „Fig. 4" shows an exemplary fastening of a conical detail measured with a sine bar. This type of attachment does not provide sufficient reliability during measurement, which increases the errors and complicates the operator's work.

Fig. 4 Basing a detail on a sine bar.

The reliable fixation of the details on the sine line is of a considerable importance for the accuracy of the measurements.

In the present work, a possible solution to the problem of fixing conical details on a sine bar is presented. A special device is designed and manufactured for fastening conical details on a sine bar. The developed device is developed using SolidWorks. After the completion of the 3D model, a choice of material and technology for 3D printing is made. After that, a 3D printing technology is used for its production. The device has a simple design, easy to make and to use, also it has a low cost due to the materials and technology used.

II. Materials and Methods

A. Materials

The materials used in FDM (fusion deposition modeling) technology parts are very close to conventional engineering polymers, so the suitability of the base materials is not an issue. The main difference between an FDM part and a molding is the fact that it is built in layers, which means that the inherent strength of the part will be slightly lower in the 'Z' (vertical) direction. The partial layers are relatively large - between 0.13 mm and 0.33 mm. This can lead to quite rough surfaces before surface treatment [4].

The selected material must meet the requirements for dimensional accuracy, minimum lead time and wall thickness of the structure.

Some of the most important properties when choosing materials for 3D printing are: Tensile, Bending and Tearing Strength, Modul of Elasticity and Flexibility, Elongation, Compressive Stiffness, Shrinkage, Moisture Adsorption, Heat Deformation Temperature (HDT), Point of Vicca softening and coefficient of thermal expansion [5].

When choosing a material, the requirements for dimensional accuracy, minimum execution time and wall thickness of the structure must be considered. The types of materials used in 3D printing are extremely numerous, but the chosen 3D printing technology limits us to a few materials. Since we have no special requirements for the device itself for the initial prototype, we will use PETG (Polyethylene Terephthalate) filament with dimensions of 1.75 mm ± 0.03 mm as the most cost-effective material.

PETG material is a thermoplastic type which has low shrinkage, strong, not brittle, and mostly layer adhesion is fantastic [6].

PETG is a polyester copolymer that has excellent technical specs like: durability, flexibility, high impact resistance, high chemical resistance, low moisture absorption and others [7]. Technical specifications of the selected material are listed in table 1 and table 2.

TABLE 1 TECHNICAL SPECIFICATION OF PETG [8]

Chemical name	**Polyethylene Terephthalate Glycol Copolymer**
Melting temperature	210-260 °C
Working temperature (3d printer)	250 ±10 °C
Print bed temperature	80 ±10 °C
Print speed	up to 200 mm/s
Moisture Absorption in 24 hours	0.07 %
Moisture Absorption in 7 days	0.10 %
Heat Deflection Temperature (0.45 MPa)	68 °C
Heat Deflection Temperature (1.80 MPa)	68 °C
Density	1.2 g/cm³
Tensile strength	46 ±1 MPa
Interlayer Adhesion	18 ± 4 MPa
Hardness – Shore D	74

TABLE 2 MECHANICAL PROPERTIES OF 3D PRINTED SPECIMENS [8]

Property\Print Direction	**Horizontal**	**Vertical xz**	**Method**
Tensile Yield Strength [MPa]	47 ± 2	50 ± 1	ISO 527 - 1
Tensile Modulus [GPa]	1.5 ± 0.1	1.6 ± 0.1	ISO 527 - 1
Elongation at Yield Point [%]	5.1 ± 0.1	5.1 ± 0.1	ISO 527 - 1
Flexural Strength [MPa]	66 ± 2	70 ± 1	ISO 178
Flexural Modulus [GPa]	1.7 ± 0.1	1.6 ± 0.1	ISO 178
Deflection at Flexural Strength [mm]	9.0 ± 0.1	9.3 ± 0.2	ISO 178
Impact Strength Charpy [kJ/m2]	No break	No break	ISO 179 – 1
Impact Strength Charpy Notched [kJ/m2]	6 ± 1	3 ± 1	ISO 179 – 1

B. Methods

The ISO / ASTM 52900 standard categorizes all the different types of 3D printing. The 3D printing technology chosen for the designed device is fused deposition modeling (FDM) "Fig 5". It is an additive manufacturing method where layers of materials are fused together in a pattern to create an object. FDM is the most cost-effective way to produce custom thermoplastic parts and prototypes.

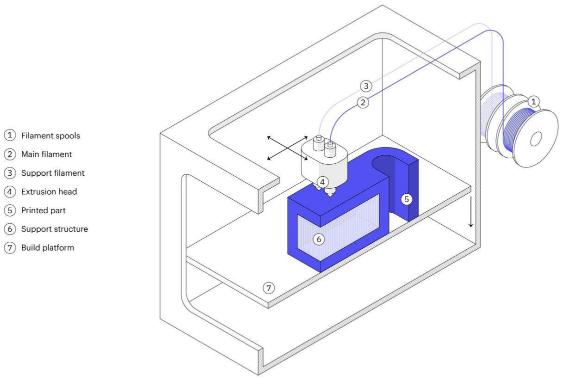

Fig 5. Schematic diagram of FDM technology.

A wide range of thermoplastic materials is available for FDM, suitable for both prototyping and some functional applications [9].

As a limitation, FDM has the lowest dimensional accuracy and resolution compared to other 3D printing technologies. FDM parts have visible lines, so for treatment on a smooth surface, subsequent treatment is often required. In addition, the adhesion mechanism of the layer makes FDM particles inherently anisotropic. They are weaker in one direction and are unsuitable for critical applications [10].

The device used is: Prusa i3 MK3S + with additional modification for better levelling of the printer bed is shown at “Fig. 6”.

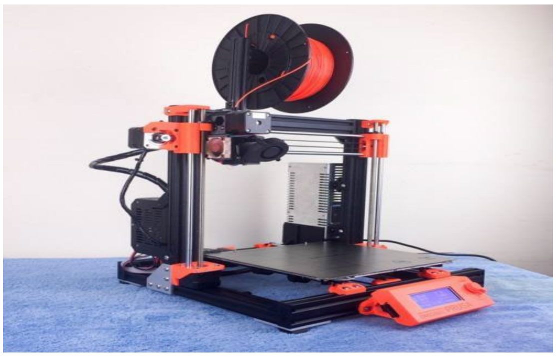

Fig. 6. Prusa i3 MK3S+.

The design of the device is done using SolidWorks. A three-dimensional model- “Fig. 7” of the Sine bar with the optimization is created - the new device /prototype/, which consists of 6 elements:

- COVER, tightly enveloping the walls of the sine bar, attached to it by PINS /1 large and 2 pcs. small pins/ snug fit in the matching process holes of the casing and the sine bar.
- STOPPER COMB, attached to the cover, in the recesses of which comb rests the so-called STOPPER.
- ARC WITH GUIDES, moving along guide channels located on both sides of the cover, which serves to fix the measuring cone to the face of the sine bar.
-

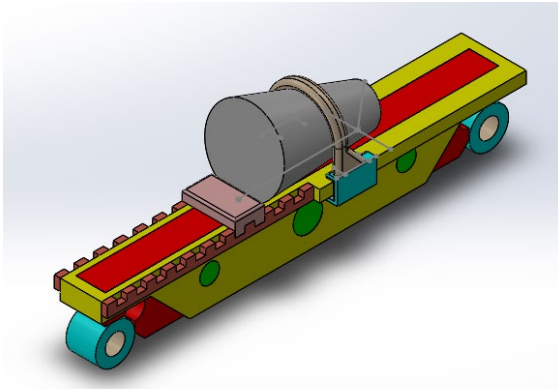

Fig. 7 3D model of the device.

“Fig.8” shows the positioning of the model on the printer table. The position of the workpiece on the printer table influences the strength of the workpiece and obtains good adhesion. Good adhesion plays an important role in the construction of the first layer. This can be improved by using a heating plate heated to 95˚ for PETG.

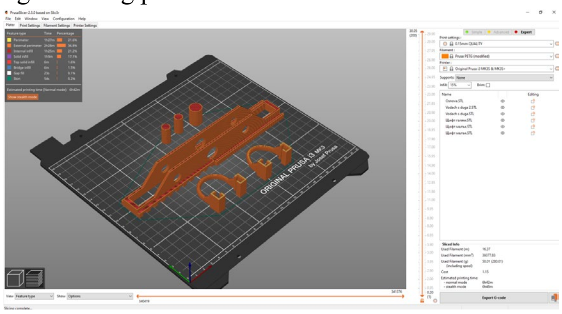

Fig .8 Details positioned on the print bed.

Setup and calibration of the printer is done immediately before starting the manufacturing process.

The purpose of the X/Y/Z calibration procedure is to measure the misalignment of the X/Y/Z axes and find the position of the 4 calibration points on the print bed for proper bed alignment. XYZ calibration can be started from the Calibration menu on the LCD panel.

The initiation of this established order performs a series of measurements in three rounds: In the first round, without the steel sheet installed, 4-sensor points on the print bed are carefully searched so as not to touch the print bed with the nozzle. In the second round, the points are improved. In the last round, with the steel sheet on, the height over 9 sensor points is measured and stored in non-volatile memory for reference. This completes the Z-axis calibration.

Mesh bed alignment can be found in LCD Menu - Calibration. This procedure is performed before each print.

During the design, all the elements of the device were made separately, but subsequently the Cover "Fig. 9" and the stopper comb as well as the Arc with the guides "Fig. 10" are assembled for easier and faster 3D printing.

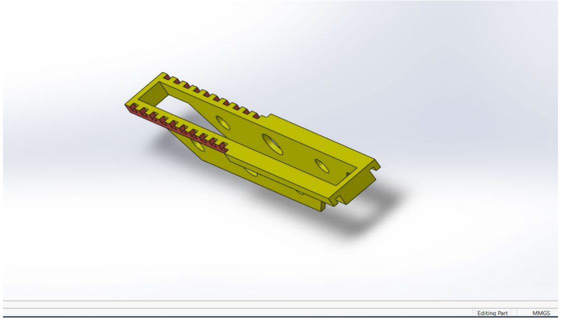

Fig.9 Cover.

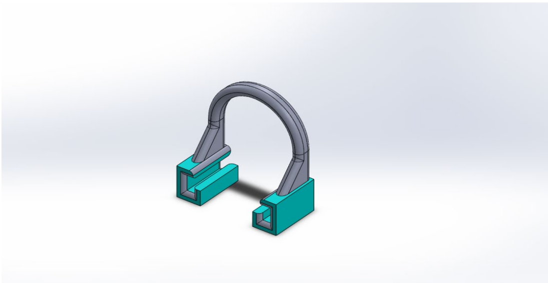

Fig. 10 Arc with guides.

In "Fig. 11" shows a manufactured device mounted on the sine bar. The fixture rests firmly on the sine bar and no clearance is observed between the sine bar and the device.

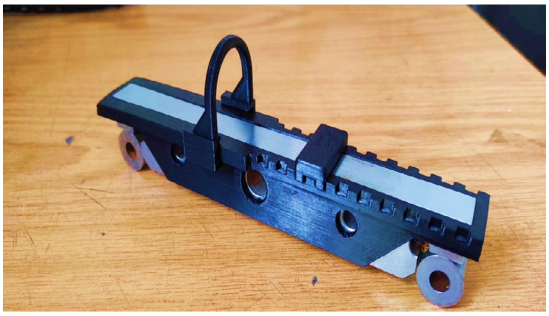

Fig.11 The device mounted on a 200mm sine bar.

III. RESULTS AND DISCUSSION

While conducting the laboratory experiments, a sine bar with the length of 200 mm is used.

Three conical details with a nominal angle α = 5° are measured. The data of the measured cones are listed in table 3

TABLE 3 CONE PARAMETERS

Cone №	Angle, [°]	Length, [mm]	min diameter, [mm]	max diameter, [mm]	Calculated angle, [°]
1	5°	80.00 mm	22.61 mm	29.91 mm	5° 13` 1``
2	5°	79.56 mm	22.55 mm	29.75 mm	5° 10` 48``
3	5°	79.90 mm	22.55 mm	29.82 mm	5° 12` 36``

For the laboratory experiment, a test plate with a dial indicator placed on it is used.

The sine bar with a workpiece attached to it is placed on the test plate. One roller of the ruler rests on the test plate and the other on a block of gage blocks of the size *h*. The size *h* of the gage block is calculated, so that the ruler tilts at an angle equal to the nominal value of the measured angle <α. If the angle being checked is equal to the nominal one, the conical part will be parallel to the test plate on which the ruler is located.

Dependency is used for this purpose:

$$\sin \alpha = h/L \tag{3}$$

Where,

$$h = L.\, \sin \alpha \tag{4}$$

Where L is the distance between the axes of the two rollers on the sine bar,

$$h = 200.\, \sin 5 \tag{4}$$

h = 17.43 mm is the gage block size that needs to be made.

The conicity of conical parts is determined indirectly by measuring misalignment Δ**h** of a certain length ℓ. For this purpose, a stand with a dial indicator is used and the measurement is made at two endpoints **a** and **b**, which are 2mm apart from the workpiece faces. The distance ℓ is between the two points a and b is obtained – the length of the cone minus 4 mm. The deviation from parallelism is measured with a dial indicator attached to a stand which is moved on the test table.

The measurement of the workpiece begins by placing the dial indicator in contact along the axis of the cone 2 mm from its major diameter. Then the dial indicator resets. After that, the sine bar is rotated, so dial indicator is located on the surface of the small diameter of the cone "Fig. 12", and the value of Δh is measured.

The deviation ΔC from the nominal taper angle is calculated according to the formula:

$$\Delta C = \Delta h / \ell \qquad (5)$$

$$\Delta\alpha = \frac{\Delta h}{l}.3438\ [\text{min}] \qquad (6)$$

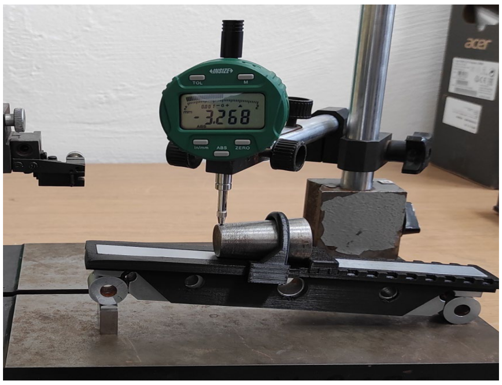

Fig.12 Measurement setup.

The results of the measurements and deviations **ΔC** and **Δα** are presented in table 4.

TABLE 4 RESULTS

Cone №	Δh, [mm]	ΔC , [mm]	Δα, [°]	Calculated angle, [°]	Actual angle, [°]
1	0.146 mm	0.0019 mm	6.53 °	5° 13\` 12\`\`	5° 6\` 38\`\`
2	0.208 mm	0.0028 mm	9.63 °	5° 10\` 48\`\`	5° 9\` 27\`\`
3	0.153 mm	0.0020 mm	6.88 °	5° 12\` 36\`\`	5° 6\` 55\`\`

The conducted experiments confirm the operability of the designed device. It is easy to use and improves the accuracy of measurements.

IV. CONCLUSIONS

1) The designed fixture significantly improves the operation of the device and allows the measurement of parts of various sizes.
2) The technology of additive printing and materials used improves the fast and cheap production of functional prototypes and devices.
3) The accuracy and quality of the manufactured device increases the accuracy of the results.
4) The manufactured device ensures immobility when measuring the controlled cone, facilitates the operator's work and reduces measurement errors.
5) Experiments carried out in real laboratory conditions confirm the functionality of the device.

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