# Design and manufacture of a device for working with a portable roughness device INSIZE ISR- C002, using additive printing

*Kliment Georgiev*
*Technical University of Sofia, branch Plovdiv*
*Faculty of Mechanical Engineering; Department: Mechanical and Instrument Engineering*
*Plovdiv, Bulgaria*
k.georgiev@tu-plovdiv.bg

*Pavlina Katsarova*
*Technical University of Sofia, branch Plovdiv*
*Faculty of Mechanical Engineering; Department: Mechanical and Instrument Engineering*
*Plovdiv, Bulgaria*
p_katsarova@abv.bg

*Nikola Todorov*
*Liebherr Hausgeräte Marica EOOD*
*Plovdiv, Bulgaria*
nikolatodorov9@abv.bg

***Abstract*** — **A device for roughness tester INSIZE ISR-C002 has been designed and manufactured. It is designed to facilitate the operation of the roughness device. The developed design was designed using SolidWorks as an assembled unit and parts. To minimize the stresses received during operation, the proposed design was optimized by using SolidWorks Simulation. After the completion of the 3D model, a choice of material and technology of 3D printing was made. Then an additive 3D printing was used for its production. The developed device was used for experimental measurements in a training laboratory. Experiments prove its workability and applicability.**

***Keywords— Design, fabrication, 3d printing, 3d modelling, device, surface roughness testing;***

## I. INTRODUCTION

The roughness of the surfaces of the parts affects their performance properties. Methods for assessing the roughness of surfaces are divided into two main groups: methods for qualitative assessment and methods for quantitative assessment. Qualitative assessment methods consist of comparing roughness samples against the controlled surface. Qualitative assessment methods are divided into two types: contact and non-contact. Profilographs, profilometers are used in the contact methods. Non-contact measurements use microscopes, laser interferometers and others.

There are many surface roughness parameters that can be found. They represent the geometric characteristics of the processed detail. Those parameters are defined in many international standards such as SIST EN ISO 4287:2000/AC:2008[1]. Surface roughness profile is determined by high pass filtering with a proper selection of the filtering length (cut-off length, $l_r$). There parameters are also known as surface heights. The surface roughness parameters are calculated from the filtered roughness profile. A typical surface roughness profile is shown in figure 1. The evaluation length ln (the assessed length) usually consists of an integral multiplication of the cut-off length. The height of the assessed profile at any position x can be obtained from a general function Z(x) to mathematically describe the surface. However, surface profiles measured with a profilometer are typically digitized. Discrete points (xi, i=1, ..., n) with an equal increment Dx and the corresponding surface heights (zi, i=1, ..., n) are used instead to describe the surface profiles [2]. Commonly used surface roughness parameters are defined below. Ra is the arithmetical average of surface heights, also known as the center line average of surface heights (CLA), and can be calculated as [2]:

$$Ra = \frac{1}{lr}\int_0^{lr} |z(x)dx \qquad (1)$$

Rq(RMS) is defined as the root mean square of surface heights, i.e [2].

$$Rq = \sqrt{\frac{1}{lr}\int_0^{lr} |z(x)^2 dx} \qquad (2)$$

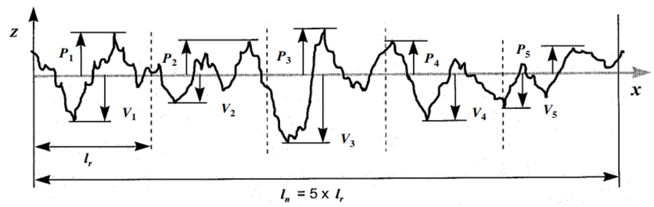



Figure 1. A typical surface roughness profile; according to Chang, W. R et al. (2001) [2].

Modern portable instruments for measuring roughness have high accuracy, can work in different production environments, but their basic devices do not allow the use of the full capacity of the instruments compared to their use in static environments. This complicates the work and requires more time for adjustment by the operator and worsens the accuracy of the results obtained.

The portable profilometer “INSIZE ISR - C002” measures the roughness of the parameters Ra, Rq, Rz, Rt, Rp, Rv, R3z, R3y, Rz (JIS), R_s, Rsk, Rp, Rsm, Rvk, Rsk, Mr1, Mr2, Ry (JIS), Rmax, range is 160µm, Speed 0.5mm / s, 1mm / s, Memory - 100 measurement results, Weight 400g, dimensions: 141x55x40mm [3].

Diagram of the device:

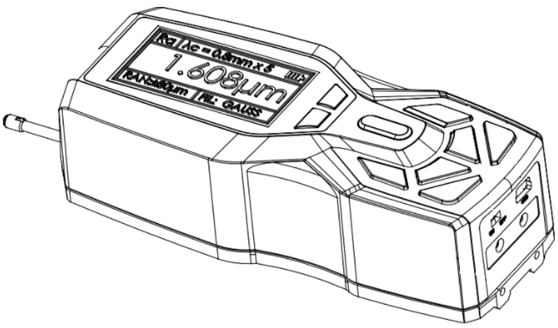



Fig 2. Portable profilometer INSIZE ISR - C002.

**Advantage** of the device is that it can be connected to a computer with software and a printer to illustrate the results or stored in it [3].

**The disadvantage** is the lack of a suitable device in the kit for use in complex and inaccessible measurements in laboratory and production conditions. The presence of a device for mounting the profilometer would lead to easy positioning, increase the ability to measure and more. This would improve and facilitate the work of the operator.

The development of technology in recent decades allows the use of additive printing technologies. They allow us to quickly, easily and cheaply develop prototypes and devices of different types, shapes and sizes. The variety of materials used in these technologies allow for the selection of suitable material that meets the characteristics and requirements of the model.

The materials used in the FDM technology parts are very close to conventional engineering polymers, so the suitability of the basic materials is not a problem. The main difference between the FDM part and the 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' direction (vertically). 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 presented report has developed a device to facilitate the operation of the profilometer in a dynamic environment, using modern materials and technology for additive printing. The introduction states that there is no such device for basing and adjusting the portable roughness device, but the 3D printing technologies are sufficiently accessible and reliable for its production.

## *II.* Materials and Methods

### *A. Materials*

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

Some of the most important properties when choosing materials for 3D printing are: tensile strength, bending and tearing, modules of elasticity and flexibility, elongation, compressive strength, compressibility, moisture adsorption, thermal deformation temperature (HDT), point of Vika softening and coefficient of thermal expansion [5].

The types of materials used in 3D printing are extremely numerous, but the chosen technology for 3D printing limits us to a few. As we have no special requirements for the element itself for the initial prototype, we will use PLA filament with dimensions of 1.75 mm ± 0.03 mm as the most cost-effective material.

This material was chosen because of its less flexibility compared to other materials, the possibility of post- processing, the lack of odors when printing and the relatively low cost.

PLA - Polylactic acid - polylactide is one of the most common materials for 3D printing. It is harder than ABS, inflexible and does not require a heating platform. PLA is a biodegradable and ecological material, using cornstarch. The disadvantage is the low deformation temperature, which is 60 degrees. However, PLA is suitable for prototyping that does not have special requirements [5]. Table 1 presents the physical properties of PLA.

*Table 1*

*Physical properties of PLA*

| | |
|---|---|
| Melting temperature | 175-180 deg. |
| Working temperature (3d printer) | 190-225 °C<br>recommended 210 °C |
| Print bed temperature | 45-70°C |
| Softening point | 50-55 °C |
| Glass transition temperature | 60-70 °C |
| Minimum wall thickness (recommended) | 1.2 mm |
| Maximum layer thickness (recommended) | 80% of the nozzle diameter |
| Density | 1.24 g / s m³ |
| Tensile strength | 60 MPa |
| Bending strength | 56 MPa |
| Hardness (Rockwell) | 75-85 |
| Shrinkage | 1% |
| Turbidity (thickness 2 mm, transparent) | 3-5% |
| Glitter G, U (for all types) | 110 |
| Degrees of water absorption | 0.5-50% |

### B. *Methods*

The ISO / ASTM 52900 standard categorizes all different types of 3D printing. For the designed device a technology for 3D printing - modeling of fused deposits is chosen. It is an additive manufacturing method in which layers of materials are fused together into an object creation model. FDM is the most cost-effective way to produce custom thermoplastic parts and prototypes.

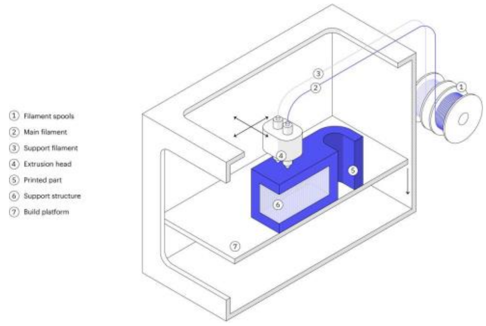
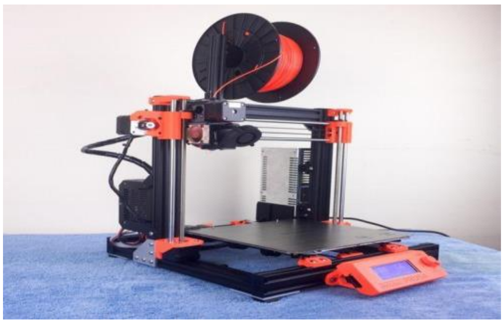



Fig. 3. Schematic diagram of FDM technology

A wide range of thermoplastic materials is available for FDM, suitable for both prototyping and some functional applications [6].

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 generally unsuitable for critical applications [7].

The device used is: Prusa i3 MK3S + with additional modification for better leveling of the printer bed.



*Фиг. 4. Опитна постановка*

## III. Design of a 3D Model of the Device in the SolidWorks Enviroment

### A. *The device must meet the following requirements for the appliance:*

- Do not obstruct operation during measurement
- Be able to mount on different surfaces
- Be a design suitable for 3D printing.
- To allow adjustment of the device and its stability
- To ensure the necessary accuracy

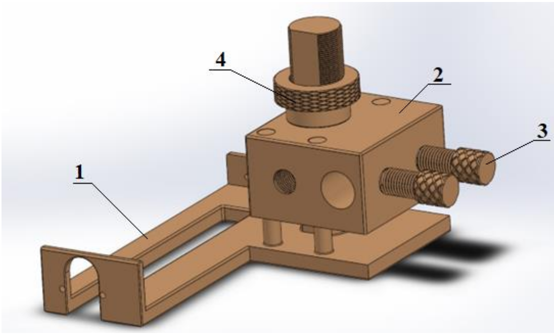



Fig 5. 3D model of the device

Fig. 5 shows a 3D model of the designed device in a SolidWorks environment. The device is designed considering the geometry of the instrument and its features, so as to facilitate the basing and bringing the instrument into readiness for measurement. The device consists of a base (1) to which the roughness tester is attached, a unit for fastening to a magnetic stand (2), locking bolts (3) and a height- adjusting nut (4). The purpose of the base is to ensure the stillness of the device without restricting the movement of the sensor. The mounting block is used to attach the appliance to a magnetic stand. The two bolts positioned in the block are used to attach the device and position it to the measuring stand. They are designed on the basis of bolt M12x1.5. The bolts are printed similar to the fixture.

### B. *Making the device*

As it’s noted, the Prusa i3MK3S+ 3D printer is used to make the device (prototype). Fig. 6 shows the positioning of the model on the printer table. The orientation of the part on the working table of the printer affects the strength of the part and obtaining 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 60 - 65˚ for PLA. The temperature of the printing table varies depending on the manufacturer of the material. The parameters set during the construction of the device are presented in Table 2.

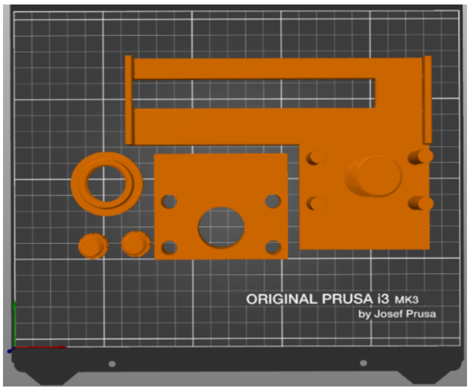



Fig. 6 - Location of the details on the printing table

*Table 2*

*Parameters of the print*

| Parameters | Value |
|---|---|
| Layer height | 0.15 mm |
| First layer height | 0.2 mm |
| Filament | Generic PLA |
| Infill density | 15% |
| Infill pattern | Gyroid |
| Top fill pattern | Monotonic |
| Bottom fill pattern | Monotonic |
| Filament diameter | 1.75 mm |
| Nozzle temperature for the first layer | 220°C |
| Nozzle temperature for the other layers | 215°C |
| Bed temperature for the first layer | 60°C |
| Bed temperature for the other layers | 60°C |
| Brim | No |

## IV. INVESTIGATION OF THREATENED CROSS SECTION AND STRESS

The study of endangered sections and stresses is performed using SolidWorks Simulation. Stress simulation - figure 7 and strain simulation – fig. 7 are presented.

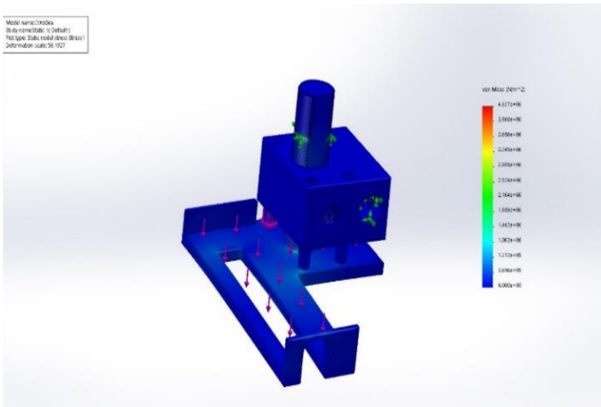


Fig. 7. Stress simulation.

The stress simulations show that the stresses in the 3D model are well distributed and no stress concentrators are observed.

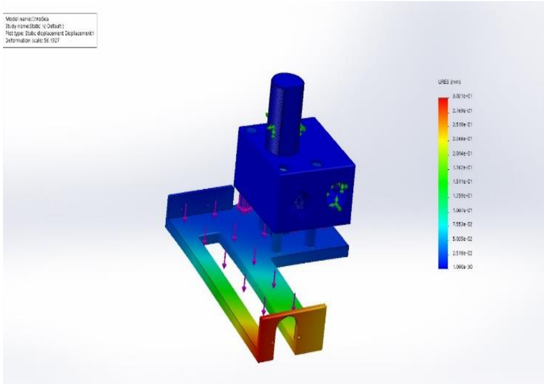


*Fig. 8. Deformation simulation.*

The deformation simulation in the 3D model shows the endangered areas. Bending at the front of the fixture is expected. The expected bending can be compensated by the way the profilometer is attached to the device through the designed bolts, which are part of the original equipment of the roughness tester.

## V. EXPERIMENTAL USE OF THE MANUFACTURED DEVICE IN A LABORATORY INVIROMENT

Fig. 9 shows the assembled device

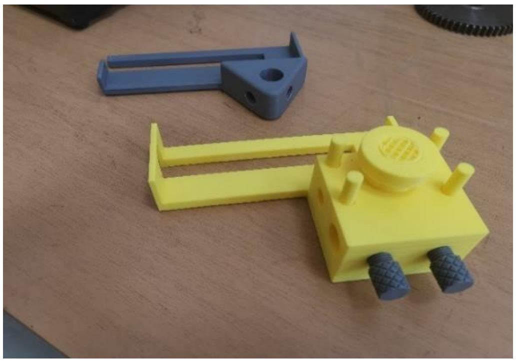


Fig. 9. Portable profilometer device.

It is easily mounted on the stand together with the device. As this determines the first requirement to be met. The screws hold it firmly to the object stand and hold the weight of the appliance.


Fig. 10 Measuring a reference with the device

Attaching the device itself to the magnetic stand, as well as leveling the appropriate height is much faster than the before. The designed screw gives a good result as the discrepancy is only -0.078 μm relative to the zero point of the device – fig. 11.

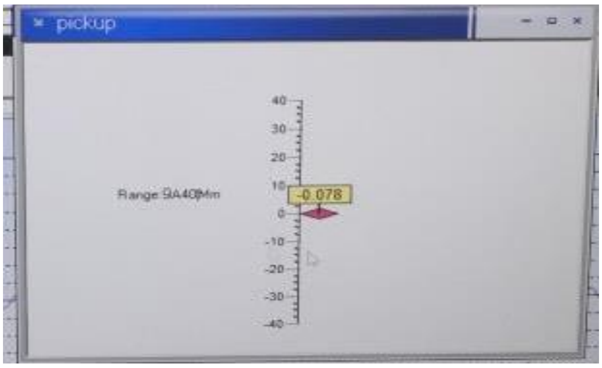



Fig. 11. Sensor positioning scale

After the preparation of the device, a test with reference roughness Ra = 1.20μm is performed, the device shows a value Ra = 1.264 μm which is about 6% error at the factory set to 10% at λc = 0.8mm x3. Fig. 10 shows a visualization of the results of the test, using software to connect and control the profilometer with a computer.

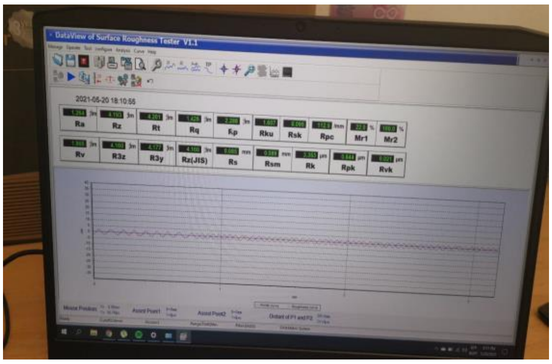


Fig. 12. Test results

As the step λc = 0.8mm x5 increases, the measurement error decreases. The device is firmly fixed and stable, it steps entirely on the platform, and there is no contact of the diamond needle with the hole of the platform. Bending during fastening is avoided by designing an arch above the channel for the diamond needle which does not allow bending of the platform by the fastening forces of the two screws diagonally with which the device is fastened to the device. The results of the measurement are shown in Fig 12. For this purpose, special software is used with which the device for measuring roughness works.

## VI. Conclusions

1) The designed device facilitates the work of the operator and increases the possibilities for measurement
2) The tests performed in laboratory conditions prove its indisputable operability
3) Additive printing technology can be used for fast and cheap production of functional prototypes and devices.
4) The accuracy and quality of the manufactured devices does not affect the accuracy of the obtained results.

## Acknowledgment

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