IZRADA MODELA ADITIVNIM POSTUPKOM 3D PRINTANJA I DIMENZIONALNA PROVJERA NA CMM

3D PRINTING ADDITIVE PROCEDURE MODEL CREATION AND DIMENSIONAL CHECK USING CMM

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REZIME

3D printanje je tehnologija koja se sve više koristi u mnogim inženjerskim poljima i edukaciji. Ova tehnologija se prvenstveno koristi za brzo kreiranje prototipova i alata. U ovom radu je prikazana geometrijska tačnost FDM (modeliranje taložnim stapanjem) 3D printanja. Za proces dimenzionalnog ispitivanja, kreiran je 3D model, koji sadrži karakteristične geometrijske oblike i dimenzije, koje je poslužila kao referenca za mjerenje na koordinatnoj mjernoj mašini. CAD model je kreiran u softveru SolidWorks, model je printan na Ultimaker 2+ 3D printeru a mjerenje je vršeno na Zeiss Contura G2 koordinatnoj mjernoj mašini.

Professional paper

SUMMARY

3D printing is a technology that is increasingly used in many engineering fields and education. This technology is primarily used in rapid prototyping and rapid tooling. In this paper the geometrical accuracy of FDM (Fused Deposition Modelling) 3D printing is presented. For the dimensional test process, a 3D model which contains the characteristic geometrical shapes and dimensions that were used as a reference for measuring on the coordinate measurement machine, has been created. The CAD model was created in SolidWorks software, the model was printed on the Ultimaker 2+ 3D printer and the measurement has been proceeded on the Zeiss Contura G2 coordinate measuring machine

1. UVOD

3D printanje je aditivni proizvodni proces koji kreira dio direktno iz CAD modela, dodavajući sloj po sloj materijala jedan na drugi. Postoje različite komercijalne verzije printera, gdje je FDM (modeliranje taložnim stapanjem) najjeftinija verzija na tržištu. Postoje mnoga polja primjene 3D printera, uključujući brzu proizvodnju prototipova, dizajna dijelova, medicinu, edukaciju, arhitekturu i umjetnost.[1] Geometrijske karakteristike nekog dijela (tolerancije) su jedan od najvažnijih segmenata u procesu dizajna proizvoda. Koordinatna mjerna mašina je jedan od najboljih alata za dimenzionalno mjerenje. U polju prototajpinga gdje se 3D printeri najviše koriste, također su izraženi određeni geometrijski zahtjevi i postoji potreba za sve većom tačnošću izrade prototipa. Zbog prethodno navedenog razloga, 3D printanje se sve više koristi u naučnim i industrijskim studijama u svrhu povećavanja tačnosti printanja.

1. INTRODUCTION

3-D Printing is an additive manufacturing process that creates parts directly from CAD model, by adding layer by layer of material. There are different technologies commercially available, where Fused Deposition Modelling (FDM) is the cheapest one on the market. There are many fields of 3D printing application, including: rapid manufacturing and prototyping, product design, medicine, education, architecture and art. [1] Geometrical product specifications (tolerances) are very important part of product design process. Coordinate measuring machine is one of the ultimate tools for dimensional measurement. In the prototyping field where 3D printers are most used, certain geometrical requirements are expected and there is a need for ever greater prototype accuracy. Due to the foregoing reason, 3D printing is increasingly used in scientific and industrial studies in purpose of print accuracy increase.

U ovom radu je pomoću CMM-a ispitana tačnost printanja konvencionalnog 3D printera Ultimaker 2+ na modelu složene geometrije.[2]
Ovo ispitivanje ima i edukativnu svrhu, jer je ovo ispitivanje korišteno za izradu određenih završnih radova na Mašinskom fakultetu.

In this paper, CMM examines the accuracy of conventional 3D Ultimaker 2+ printer on a complex geometry model.[2]
This examination also has educational purpose as this test was used to produce specific final papers at the Faculty of Mechanical Engineering.

ULTIMAKER 2+ 3D PRINTER I TEHNOLOGIJA KORIŠTENJA PRI ISPITIVANJU

Ultimaker 2+ je široko rasprostranjen komercijalni 3D printer i korišten je za printanje referentnog modela. U tabeli 1 su prikazane specifikacije ovog modela printera kao i primjenjene opcije (označene oznakom *) koje su se koristile u ovom konkretnom slučaju (Slika 1).[3]
Postoji više aditivinih materijala 3D printanja a u ovom konkretnom slučaju je korištena PLA (polilaktidna kiselina). PLA (polilaktidna kiselina) je biorazgradivi termoplastični poliester. Ovaj materijal se dobija iz obnovljivih izvora, odnosno iz kukuruznog škroba, i iz posebne vrste krompira koji se uzgaja u Aziji. PLA je zadnjih nekoliko godina postao sve prisutniji materijal zbog svojih karakteristika, prvensteno jer su modeli sjajniji i ne krive se kao modeli napravljeni od ABS-a.

2. ULTIMAKER 2+ 3D PRINTER AND TECHNOLOGY USED IN INVESTIGATION

Ultimaker 2+ is a widely used commercial 3D printer and it is used for the reference model printing. Table 1 shows the specifications of this printer as well as the applied settings (marked with *) used in this particular case (Figure 1).[3]
There are several additional materials for 3D printing, and in this particular case, PLA (polylactic acid) is used. PLA (polylactic acid) is a biodegradable thermoplastic polyester. This material is obtained from renewable sources that is from corn glass and from a special type of potato that is grown in Asia. PLA has become more and more present in the last few years due to its characteristics, primarily because the models are glossier and do not bend as models made of ABS.

Slika 1. *Ultimaker 2+ 3D printer*
Figure 1. *Ultimaker 2+ 3D printer*

3. REFERENTNI MODEL I PRIPREMA ZA PRINTANJE

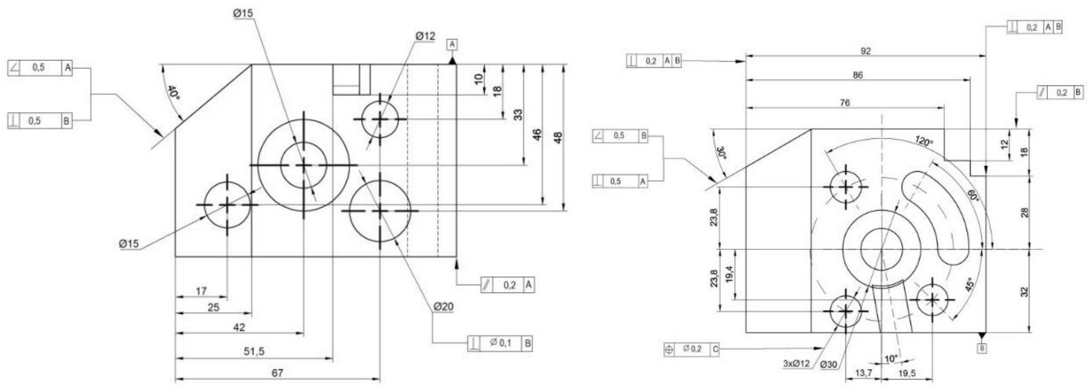
U svrhu kontrole tačnosti printanja ispitivanog 3D printera, dizajniran je originalni referentni dio koristeći komercijalni CAD softver SolidWorks. CAD model je kreiran na osnovu tehničke dokumentacije detaljnih dimenzija i tolerancija (Slika 2).[3]

3. BENCHMARK PART AND 3D PRINTING PREPARATION

For purpose of controlling the printing accuracy of investigated 3D printer an original benchmark part is designed using commercial CAD software Solidworks. CAD model is designed based on technical documentation which contains detailed dimensions and tolerances (Figure 2).[3]

Table 1. 3D printer's technical specifications and applied settings
Tabela 1. Tehničke specifikacije 3D printera i primjenjene postavke (*)

Ultimaker 2+ 3D printer	**Specifications/Karakteristike**
Print technology/ Tehnologija printanja	Fused Deposition Modeling (FDM)/ Modeliranje taložnim stapanjem
Build volume/ Radna povrština	223x223x205 mm
Nozzle diameter/ Promjer brizgalice	0.25, 0.40* , 0.60, 0.80 mm
Layer Resolution/ Popunjenost sloja	20 to 600 μm, (200 μm)*
Materials/ Materijali	Open filament system, PLA*/ Pogodan za mnoga fibrilna vlakna
Filament diameter/ Promjer vlakna	2.85 mm
Print head/ Glava za printanje	One nozzle/ Jedna mlaznica



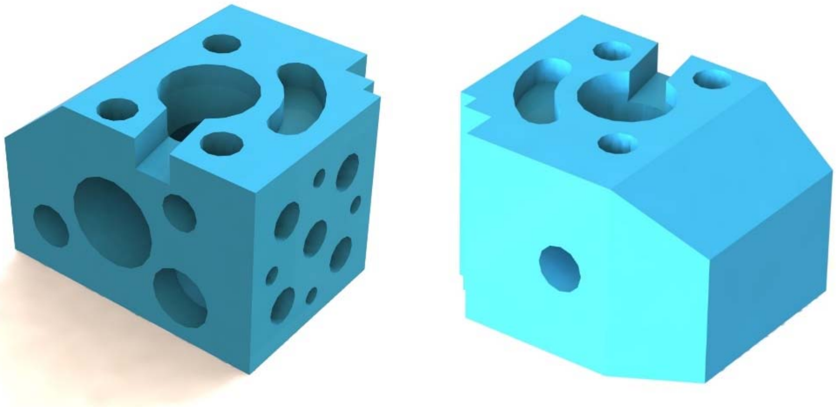
Slika 2. *Tehnička dokumentacija referentnog modela*
Figure 2. *Technical documentation of benchmark model*

Dizajn se sastoji od više ravnina, koje sadrže cilindre različitih promjera, kao i konusnu rupu, žlijeb i kanal (Slika 3). Namjera je da dizajn posjeduje takve osobine da omogući kontrolu tačnosti različitih geometrijskih karakteristika kao što su veličina, forma, orjentacija i lokacija, odnosno geometrijskih specifikacija proizvoda, a koje bi mogle biti zahtjevi tolerancija 3D printanog dijela u određenim aplikacijama.[4]

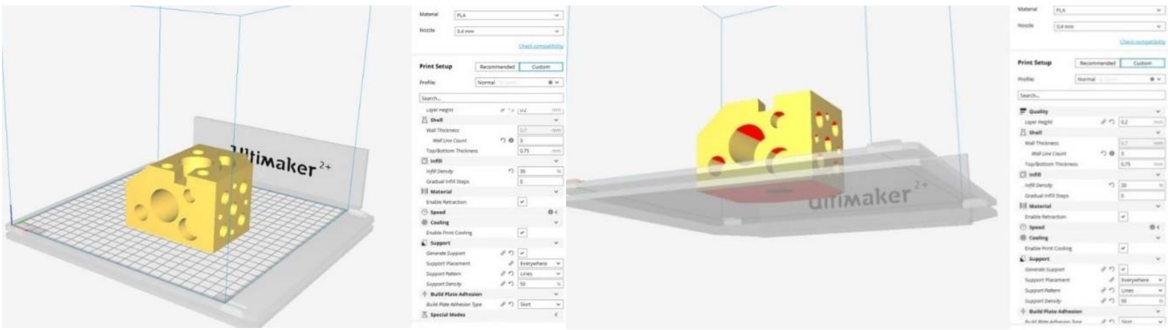
Na osnovu CAD modela, koristeći Ultimaker Cura softver, model je pripremljen za printanje. Ovaj program predstavlja poveznicu između CAD modela, 3D printera i materijala. Za ovaj rad korištena je verzija softvera Ultimaker Cura 3.1.0, u koji je ubačen STL format prethodno napravljenog modela (Slika 4).[5]

The design contains multiple planes, which contain cylinders of different diameters, as well as coned hole, shaft and channel (Figure 3). The intention of the design is to have features on the part that provide possibility of controlling accuracy of different geometrical characteristics like size, form, orientation and location, i.e. geometrical product specification, which could be tolerance requirements for the 3D printed part in some practical application.[4]

Figure 4 shows the software environment in which the necessary parameters can be set, such as injection speed, resolution, layer thickness, material, fill, position from which the print starts, support structures and many other parameters.[5]



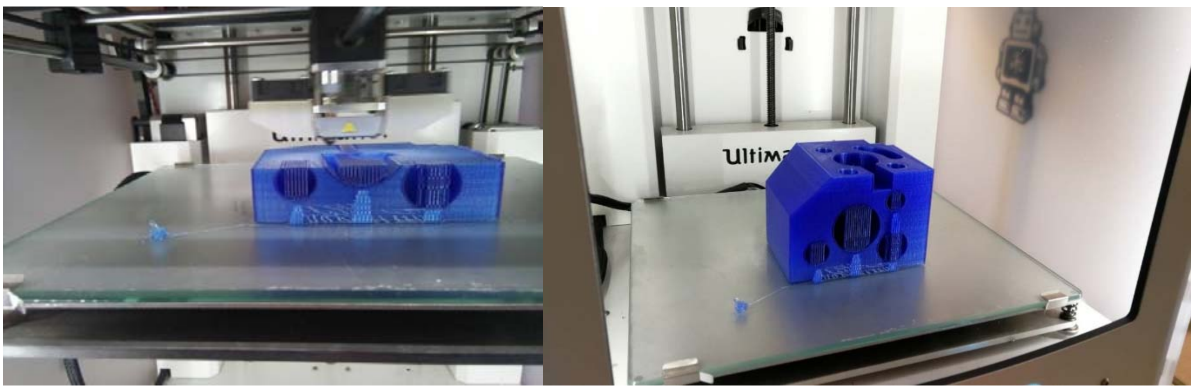
Slika 3. *Benchmark part CAD model*
Figure 3. *CAD model referentnog dijela*



Slika 4. *Ultimaker Cura softver za pripremu printanja*
Figure 4. *Ultimaker Cura software for printing preparation*

Na slici 4 je prikazano okruženje softvera u kome se mogu podesiti potrebni parametri, kao što su brzina brizganja, rezolucija, debljina sloja, materijal, popunjenost, pozicija iz koje počinje print, potporne strukture i mnogi drugi parametri.
Nakon ubacivanja odgovarajućeg materijala u printer, G koda (instrukcija za printenje) sa modelom i parametrima, nakon 13 sati printanja, dobijen je vjerodostojan realni dio (Slika 5).[6]

Figure 4 shows the software environment in which the necessary parameters can be set, such as injection speed, resolution, layer thickness, material, fill, position from which the print starts, support structures and many other parameters.
After inserting the appropriate material into the printer and G code (printing instructions) with the model and parameters, after 13 hours of printing, a reliable realistic part was obtained (Figure 5).[6]



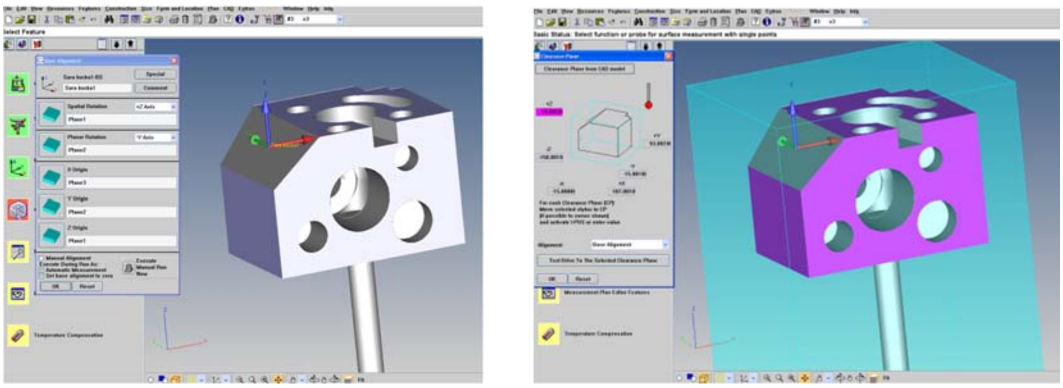
Slika 5. *Odgovarajući realni printani dio*
Figure 5. *Reliable realistic printed part*

4. CMM MJERENJE

Referentni model je mjeren na koordinatnoj mjernoj mašini Zeiss Contura G2 (opsega mjerenja: 700x1000x600 mm, mjerene nesigurnosti na osnovu ISO 10360-2: MPE_E=(1,8+L/350) µm, MPE_P=1,8 µm) opremljenom sa ZEIS VAST XT skenirajućom sondom i Calypso 4.8 softverom za mjeriteljstvo.[7] Plan mjerenja na CMM softveru je napravljen CAD programiranjem koristeći importovani CAD model. Nakon importovanja modela, bitno je definisati koordinatni sistem, domen unutar kojeg se kreće mjerna sonda i izvršiti mjerenje tri referentne ravnine na modelu.[8] Usklađivanje koordinatnog sistema radnog komada sa koordinatnim sistemom mašine vrši se ručnim skeniranjem ravnina 1, 2 i 3. Nakon poravnanja radnog komada, mjerenje svih definisanih dijelova se vrši CMM skeniranjem u jednom ciklusu mjerenja u CNC režimu rada. Strategije mjerenja za površinske karakteristike definišu se sa ručno kreiranim poligonom linija, imajući u vidu odgovarajuću površinsku pokrivenost; Karakteristike cilindra su definisane sa jednim ili dva kruga, ravnomjerno raspoređena. Algoritmi generisanja su zasnovani na principu najmanjih kvadrata i ta (Gausova) metoda se koristi u CMM mjerenjima (Slika 6).

4. CMM MEASUREMENT

The benchmark part is measured on Coordinate measuring machine Zeiss Contura G2 (measurement range: 700x1000x600 mm, measurement uncertainty according to ISO 10360-2: MPE_E=(1,8+L/350) µm, MPE_P=1,8 µm) equipped with ZEIS VAST XT scanning probe and Calypso 4.8 measurement software.[7] The measurement plan in CMM software is made by CAD programming, using imported 3D model. After importing the model, it is necessary to define coordinate system, domain of measurement probe movement and measure three referent planes on the model.[8] Alignment of the work piece coordinate system in the machine coordinate system is done by manual probing of the planes 1, 2 and 3. After the work piece alignment, measurement of all defined features is performed by CMM scanning in one measurement cycle in CNC mode. Measurement strategies for plane features are defined with polylines, manually created, aiming for appropriate surface coverage; the cylinder features measurement strategies are defined with one or two circles, uniformly distributed. Fitting algorithms based on the principle of the least squares (Gaussian) method are used in CMM measurement (Figure 6).



Slika 6. *Importovanje modela i početne postavke mjerenja*

Figure 6. *Import of the model and basic applied measurement settings*

Kreiranje strategija mjerenja podrazumijeva definisanje kretanja sonde i mjerenja određene površine modela. Definisane su 32 mjerne strategije za 14 ravnih i 18 cilindričnih površina (Slika 7).

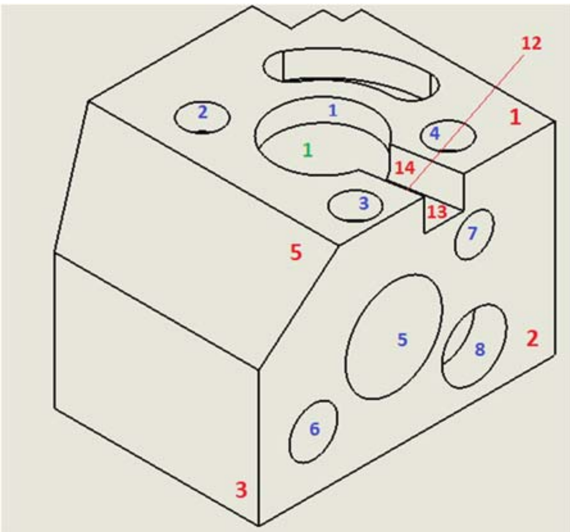
Za ravne površine definisane su konture kretanja nepravilnog oblika, gdje se mjerilo 600 tačaka pri brzini od 5 mm/s. Za cilindrične površine mjerilo se 200 tačaka pri brzini od 5 mm/s. Za otvore većeg prečnika definisane su dvije kružnice mjerenja, a za otvore manjeg prečnika definisana je jedna kružnica mjerenja.[9]

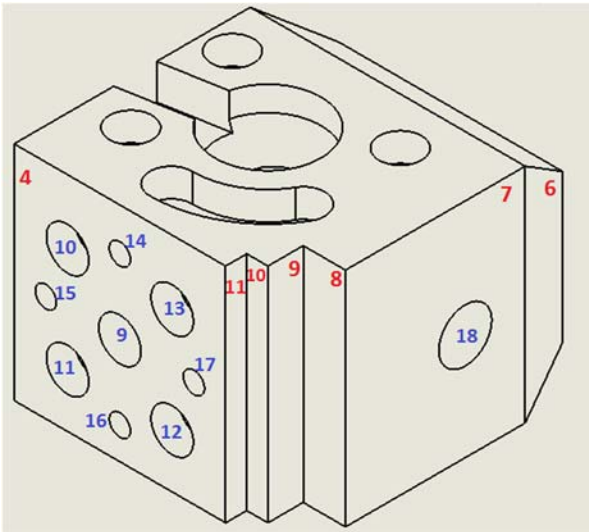
Creating measurement strategies involves defining the probe movement and measuring the specific surface of the model. 32 measurement strategies were defined for 14 flat and 18 cylindrical surfaces (Figure 7).

For flat surfaces, contours of irregular shaped movement are defined, where the measured number of points is 600 at a speed of 5 mm/s. For cylindrical surfaces, 200 points were measured at a speed of 5 mm/s. For larger holes, two measuring circles are defined, and one circle of measurement is defined for smaller diameter holes. [9]

Šezdeset različitih mjernih karakteristika dijela definisane su u CMM planu mjerenja za kontrolu tačnosti printanja na referentnom dijelu. Karakteristike u CMM softveru se koriste za definisanje geometrijskih dimenzija i tolerancija kontrolisanih dijelova i mogući rezultat CNC mjernog programa. Karakteristike su grupisane u šest grupa, a to su: ravnost, okomitost, ugao, paralelnost, cilindričnost i prečnik cilindra.[10]

Sixty different part measurement characteristics are defined in CMM measurement plan for controlling printing accuracy on the benchmark part. The characteristics in CMM software are used for definition of controlled work piece geometrical dimensions and tolerances and are possible output of a CNC measurement program. Part features are used for definition, and features measurement results for calculation of characteristics measurement results. The characteristics are grouped in six groups, and those are: flatness, perpendicularity, angularity, parallelism, cylindricity and diameter cylinder.[10]





Slika 7. *Definisane ravne i cilindrične površine modela*
Figure 7. *Defined flat and cylindrical model planes*

5. REZULTATI MJERENJA

Izmjereni rezultati za sve karakteristike dijela printanog na Ultimaker 2+ 3D printeru su dati u tabeli 2. U tabeli su prikazane nominalne i izmjerene vrijednosti, kao i odstupanja kod prethodno navedenih karakteristika od interesa. Odstupanja pri mjerenju ravnosti površina ne prelaze 0,15mm, a u nekim slučajevima su vrijednosti ispod 0,1mm. Odstupanja za mjerenje okomitosti, ugla i paralelnosti ne prelaze 0,35mm. Vrijednosti cilindričnosti su unutar 0,8mm odstupanja. Bitno je naglasiti da su izmjerene vrijednosti promjera cilindara u svim slučajevima manje od nominalne vrijednosti i odstupanja pri mjerenju ne iznose više od 0,5mm. Maksimalno odstupanje posmatrajući sva mjerenja je 0,789mm, a minimalno 0,017mm.

5. MEASUREMENT RESULTS

The measured results for all the characteristics of the printed part on the Ultimaker 2+ 3D printer are given in Table 2. The table shows the nominal and measured values, as well as the deviations of the above mentioned characteristics of interest. Deviations for flatness measurement do not exceed 0.15mm, and in some cases values are below 0.1mm. Deviations for perpendicularity measurement, angle and parallelism do not exceed 0,35mm. The cylindrical values are within the 0.8mm deviation. It is important to note that the measured cylinder diameter values are in all cases less than the nominal values and the deviations in the measurement are not greater than 0.5mm. The maximum deviation considering all measurements is 0,789 mm and minimum is 0,017 mm.

Značajna činjenica koja je primjećena prilikom obrade rezultata je ta da su kod mjerenja cilindričnosti na datom modelu, značajne razlike u odstupanju kod onih cilindara koji se nalaze na gornjoj strani dijela u odnosu na one koji se nalaze na bočnim stranama. Maksimalno odstupanje cilindričnosti izmjerene na gornjoj strani dijela je 0,119mm a na bočnoj strani 0,789mm. Pretpostavlja se da je ovo posljedica karakteristike tehnologije izrade modela, gdje se u obzir trebaju uzeti činjenice da se materijal termički obrađuje i da je prilično porozan, a da kao posljedicu slijeganja materijala daje devijacije na bočnim stranama i ta činjenica bi trebala biti razmatrana u nekim budućim istraživanjima.

A significant fact observed in the results obtained is that when measuring the cylinders on a given model, significant differences in deviation is between those cylinders located on the upper side of the part and those on the sides. The maximum cylindrical deviation measured on the upper side of the part is 0.119 mm and on the sides is 0.789 mm. It is assumed that this is a consequence of the printing technology characteristics, where it should be considered the fact that the material is thermally treated and material is quite porous. Deviation on the part sides is consequence of the leakage of the material and this fact should be investigated in some future studies.

Tabela 2. *Rezultati mjerenja*
Table 2. *Measurement results*

RAVNOST/FLATNESS			
Pozicija/Position	Izmjerena vrijednost/ Evaluated value (mm)	Nominalna vrijednost/ Nominal value (mm)	Odstupanje/ Deviation (mm)
Flatness 1	0.1206	—	0.1206
Flatness 2	0.10892	—	0.10892
Flatness 3	0.13937	—	0.13937
Flatness 4	0.10413	—	0.10413
Flatness 5	0.08288	—	0.08288
Flatness 6	0.13399	—	0.13399
Flatness 7	0.11733	—	0.11733
Flatness 8	0.12164	—	0.12164
Flatness 9	0.09883	—	0.09883
Flatness 10	0.10858	—	0.10858
Flatness 11	0.13033	—	0.13033
Flatness 12	0.04002	—	0.04002
Flatness 13	0.01737	—	0.01737
Flatness 14	0.03073	—	0.03073
OKOMITOST, UGAO I PARALENOST/ PERPENDICULARITY, ANGULARITY AND PARALLELISM			
Perpendicularity 1	0.17821	—	0.17821
Perpendicularity 2	0.14803	—	0.14803
Perpendicularity 3	0.10213	—	0.10213
Perpendicularity 4	0.18491	—	0.18491
Perpendicularity 5	0.328	—	0.328
Perpendicularity 6	0.11676	—	0.11676
Angularity 1	0.09063	—	0.09063
Angularity 2	0.15933	—	0.15933
Parallelism 1	0.12626	—	0.12626
Parallelism 2	0.21044	—	0.21044

CILINDRIČNOST/CYLINDRICITY			
Cylindricity 1	0.11599	—	0.11599
Cylindricity 2	0.10172	—	0.10172
Cylindricity 3	0.11153	—	0.11153
Cylindricity 4	0.11924	—	0.11924
Cylindricity 5	0.44483	—	0.44483
Cylindricity 6	0.27296	—	0.27296
Cylindricity 7	0.25013	—	0.25013
Cylindricity 8	0.27827	—	0.27827
Cylindricity 9	0.13131	—	0.13131
Cylindricity 11	0.30086	—	0.30086
Cylindricity 12	0.33606	—	0.33606
Cylindricity 13	0.20137	—	0.20137
Cylindricity 14	0.34087	—	0.34087
Cylindricity 15	0.14739	—	0.14739
Cylindricity 16	0.14004	—	0.14004
Cylindricity 17	0.10077	—	0.10077
Cylindricity 18	0.78927	—	0.78927
PREČNIK CILINDRA/DIAMETER CYLINDER			
Diameter Cylinder 1	29.78794	30	-0.21206
Diameter Cylinder 7	11.76409	12	-0.23591
Diameter Cylinder 8	19.7386	20	-0.2614
Diameter Cylinder 18	14.57327	15	-0.42673
Diameter Cylinder 10	11.79975	12	-0.20025
Diameter Cylinder 11	11.81108	12	-0.18892
Diameter Cylinder 12	11.87925	12	-0.12075
Diameter Cylinder 13	11.87039	12	-0.12961
Diameter Cylinder 14	5.81512	6	-0.18488
Diameter Cylinder 15	5.79232	6	-0.20768
Diameter Cylinder 16	5.83786	6	-0.16214
Diameter Cylinder 17	5.84552	6	-0.15448
Diameter Cylinder 3	11.85945	12	-0.14055
Diameter Cylinder 9	11.77889	12	-0.22111
Diameter Cylinder 2	11.9046	12	-0.0954
Diameter Cylinder 4	11.79275	12	-0.20725
Diameter Cylinder 5	29.68299	30	-0.31701
Diameter Cylinder 6	14.73846	15	-0.26154

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