Circularity Compensation by CAD Modeling in Rapid Prototyping of Cylindrical Parts

Antonio Piratelli-Filho[1], José F. Silva-Junior[2], Nabil Anwer[3], Charyar Mehdi-Souzani[4], Rosenda V. Arencibia[5] and Dianne M. Viana[6]

[1]Universidade de Brasilia, Brazil, pirateli@unb.br
[2]Universidade de Brasilia, Brazil, juniorferreiras@hotmail.com
[3]Université Paris-Saclay, France, anwer@lurpa.ens-cachan.fr
[4]Université Paris-Saclay, France, souzani@lurpa.ens-cachan.fr
[5]Universidade Federal de Uberlândia, Brazil, arvaldes@mecanica.ufu.br
[6]Universidade de Brasilia, Brazil, diannemv@unb.br

Corresponding author: Antonio Piratelli-Filho, pirateli@unb.br

ABSTRACT

This work presents an approach to error compensation in rapid prototyping of parts having circular geometries. The error compensation is carried out by correcting the circular geometry deviations in the CAD model, before sending it to the 3D printer. The experimental work was performed by manufacturing a standard part having cylinders using rapid prototyping. A first part was designed in Catia having as variables the diameter, the height and the inclination angle, settled at three levels each. Manufacturing took place with a STL file and ABS polymeric material and the part was then measured to determine the errors in diameter, height and angle, together with the circularity deviations. A revised CAD model was designed with corrections in circularity and a new part was manufactured and measured. A second part was produced extending to diameters ranging from 10 to 90 mm. Circularity deviations were determined and error compensation was applied in the redesigned part with a confirmation experiment applied. The error correction for circularity, applied over the CAD model, proved successful in conical parts of dimensions from 10 to 90 mm in diameter.

Keywords: CAD modeling, regular geometries, reverse engineering.
DOI: https://doi.org/10.14733/cadaps.2019.1063-1069

1 INTRODUCTION

Additive manufacturing is an emerging technology that has been spreading out quickly in past years and it is a promising technique for a near future. Evaluation of geometric characteristics of the produced parts has become important step to attain quality levels required by consumers. The cost reduction and increase in quality can be reached by preventing defective parts and it is effective by knowing the error profile of the 3D printer machine. A simple way to do this is by indirect error determination, e.g., by determining the error of produced artefacts.

Some researchers proposed the use of regular geometry artefacts to evaluate the quality of parts produced by additive manufacturing. Moylan et al. [5] reviewed the test parts used in additive manufacturing and proposed a new part with features observed in the previous ones. This new part was known as NIST test part [2]. Yang and Anam (2014) based their studies on dimensioning and tolerancing methods and proposed a redesigned NIST test part [7]. Islam and Sacks observed that designed flat surfaces presented a flatness error associated to z direction (height) of the 3D printer that after error correction was reduced to 25.52 % in average [3]. Martorelli et al. [3] investigated geometric errors of flatness, circularity and cylindricity in manufactured models. Medhi-Souzani et al. [4] investigated the use of artefacts with freeform surfaces to evaluate the performance of manufacturing freeform surface parts. A recent review about artefacts used to verify performance in additive manufacturing was presented by Rebaioli and Fassi [6].

This work proposes an approach to error compensation in rapid prototyping of parts having circular geometries. The error compensation is carried out by correcting the circular geometry deviations in the CAD model, before sending it to the 3D printer. The proposal follows the literature research area dedicated to verify the quality of produced parts in additive manufacturing process. The experimental work was carried out by designing and manufacturing standard parts having cylinders, developed in Catia software and produced by rapid prototyping.

A first part was designed having cylinders and changing the following variables: diameter, height and inclination angle. These variables were modified in three levels each and part was manufactured starting from a STL format file and using ABS polymer. The part was measured using a Caliper to determine the errors in diameter, height and angle, and a Coordinate Measuring Machine (CMM) to determine the circularity deviations. A new CAD model was designed with corrections in these parameters and a new part was produced and measured. Investigation was extended for other diameters by designing and producing a second part with circular steps in diameters ranging from 10 to 90 mm. Circularity was measured with a CMM and error compensation was introduced in the redesigned part.

2 EXPERIMENTAL

Two test parts were designed in Catia software to evaluate a 3D printer. The part number 1 has cylinders fixed to a squared basis, with cylindric geometry variables having different values. The diameter, the height and the angle of inclination in respect to the basis were changed in three levels each, resulting to nine cylinders distributed according to a Latin Squares design of experiment (DOE) over the basis. The Analysis of Variance (ANOVA) was additionally applied to verify the influence of these variables in diameter and height results [1]. Circularity was determined by measuring the radius deviations in respect to least squares circle diameter calculated. Figure 1 presents the designed part. Table 1 shows the designed variables with adopted levels.

A Computer-Aided Design (CAD) model was built in Catia software using the tools available to fit regular geometries. After concluded, a mesh with 31668 triangles was fitted and the model was saved in STL file before sending to the 3D printer.

A low-cost 3D printer manufactured by Leapfrog, model Creatr, was used to produce the parts. This machine has an accuracy of 0.05 mm in x,y and z axis, according to the manufacturer. The deposition path followed the x direction with the speed set at 60 mm/s. The parts were produced in ABS (Acrylonytrile-Butadiene-Stirene) polymer.

The measurements were performed by using a Caliper and a Coordinate Measuring Machine (CMM). The Caliper used was made by Starrett, digital model, having a resolution of 0.01 mm and an standard measurement uncertainty of 0.006 mm. The circularity deviations were determined with a Mitutoyo Cantilever manual CMM, with a resolution of 0.001 mm each axis and with a standard measurement uncertainty of 0.003 mm in work volume. The circularity was determined in three cross sections of each cylinder and the mean deviation was plotted in a graph.

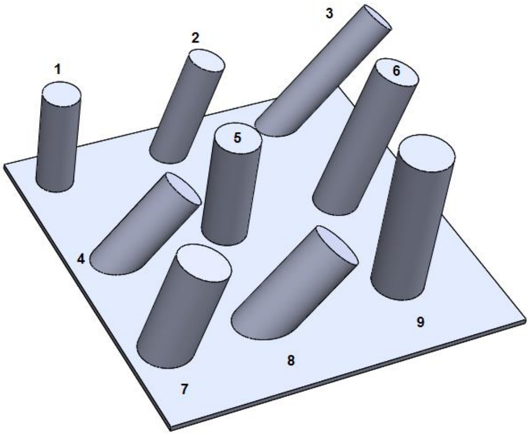


Figure 1: CAD model of part number 1.

Cylinder	Angle (°)	Diameter (mm)	Height (mm)
1	90	10	30.000
2	75	10	32.371
3	50	10	45.013
4	50	12	30.000
5	90	12	32.371
6	75	12	45.013
7	75	14	30.000
8	50	14	32.371
9	90	14	45.013

Table 1: DOE array in Latin Square, with control variables at respective levels.

After measurement of the first part, the errors found in diameter, height, inclination angle and circularity were compensated by changing these parameters in a modified new CAD model. Diameter and height were corrected by subtracting the respective systematic errors (bias) and the circularity was compensated by designing the new cylinders with error compensation in x and y axis, according to the error patterns determined, concentric to the first ones. This CAD model, presented in Figure 1, was produced and measured to compare with the designed one.

A second part was designed and manufactured with different diameters, as showed in Figure 2. The diameters were changed from 10 to 90 mm. The same conditions of material, printer and speed were adopted in this new processing. The part was measured to determine the errors in diameter and circularity and the errors found were corrected in the design of a new part. The corrected part was produced and measured to evaluate the efficiency of this proposal.

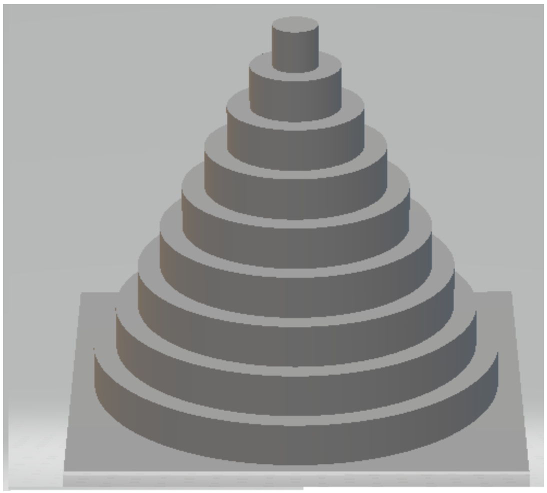


Figure 2: CAD model of part number 2, with circular steps, ranging from 10 to 90 mm in diameter.

3 RESULTS

The investigation of error compensation began with the design and fabrication of the Part 1. The produced part was measured and its circularity characteristics was measured and represented in polar graphs. It was observed a circularity deviation with similar profile for almost all cylinders, having and ellipsoid format with nearly 0.200 mm in x-axis and zero mm in y-axis, as shown in Figure 3 (previous). It was observed that the most pronounced circularity errors were determined in the x axis direction, where the printer head had a fast displacement. These errors were compensated through a new redesigned CAD model, followed by manufacturing. The residual circularity was determined and it is presented in Figure 3 (error corrected). In most cases, except cylinders 3 and 6, the error compensation proved successful to reduce the circularity to the levels of the prototyping machine resolution.

The same study was carried out with the second part (part 2) having circular stairs. A previous CAD model was designed and produced. It was found a circularity deviation with similar profile for almost all cylinders, having an ellipsoid format. The mean errors in circularity, that was nearly 0.2 mm in x-axis direction and nearly zero in y-axis, were compensated in a redesigned CAD model. It was again observed that the circularity errors were determined in the x axis direction, where the printer head had the fastest displacement. A new part was produced and the residual circularity was determined. Figure 4 shows the circularity errors for the studied diameters, with previous and error corrected values. It was observed a reduction in circularity that was achieved by compensation using a constant circularity value.

Additionally, the Analysis of Variance (ANOVA) showed that, for the range of values of the studied parameters with part number 1, there were no variable that promoted significant changes in mean error in diameter and height, despite of circularity produced a regular characteristic. Table 3 presents the ANOVA results. Figure 5 presents the parts produced, the part 1 with cylinders and part 2 with cylindrical steps.

4 CONCLUSIONS

The proposed approach contributed to improve the quality of simple parts having regular geometries at reduced cost and using a simple method. The error correction for circularity, applied over the CAD model, proved successful in cylindrical parts of dimensions until 90 mm in diameter.

The ellipsoid format of the produced circular profiles was associated to the speed of the 3D printer head in the x-axis direction, close to its maximum. Besides, for small diameters and heights, the variables investigated (diameter, height and inclination angles) do not influenced the mean errors, as presented by the ANOVA results. The geometric error analysis improved the accuracy of the printed parts in the studied additive manufacturing process. This approach can be extended to other machines and parameters, to evaluate the performance of 3D printers based on a test artifact and geometric errors evaluation. Surface roughness can also be investigated as process performance parameter.

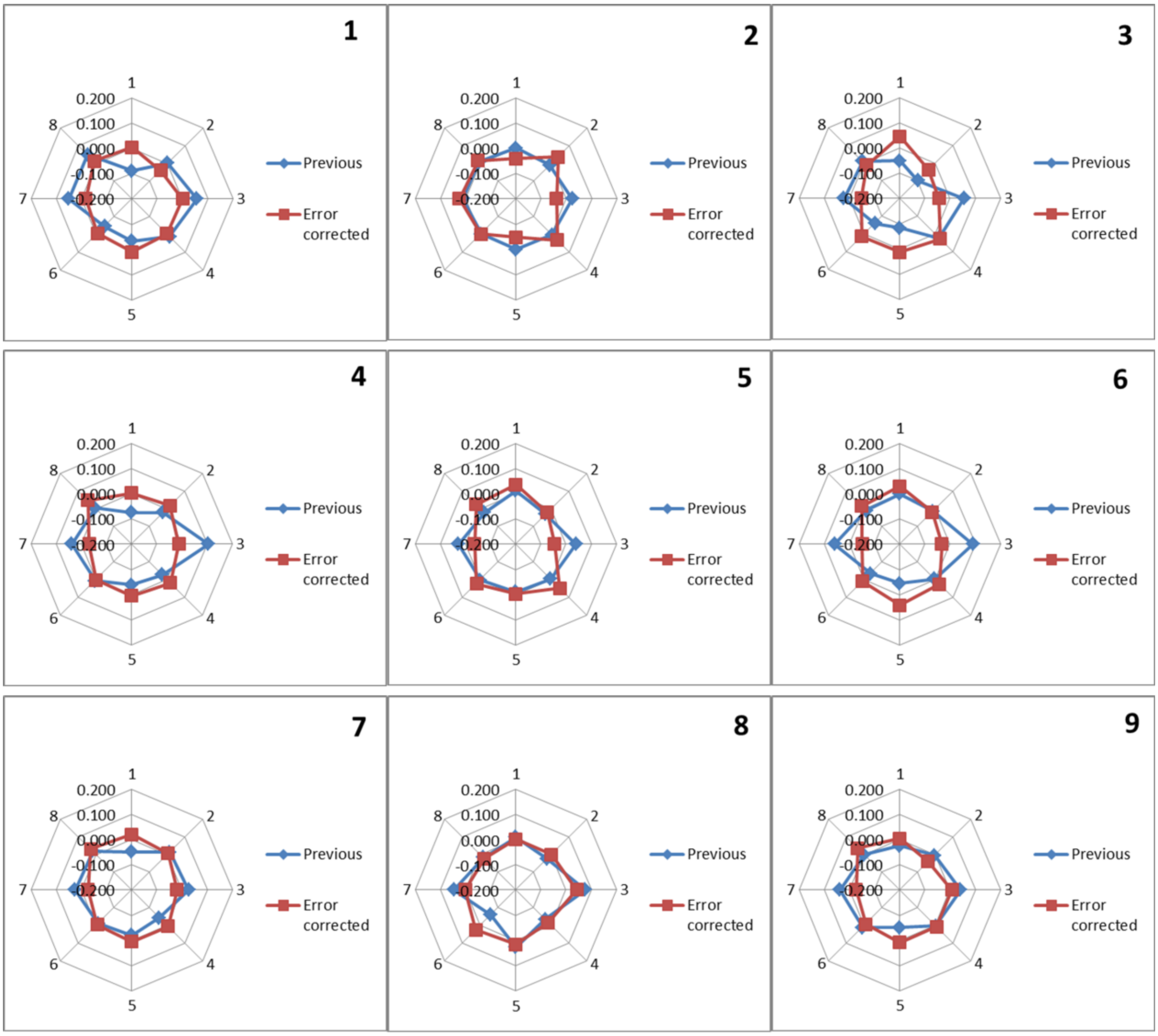


Figure 3: Circularity errors in cylinders after 1st processing (previous) compared with 2nd processing (error corrected). Part number 1, 3D printer x-axis was horizontal and y-axis was the vertical one.

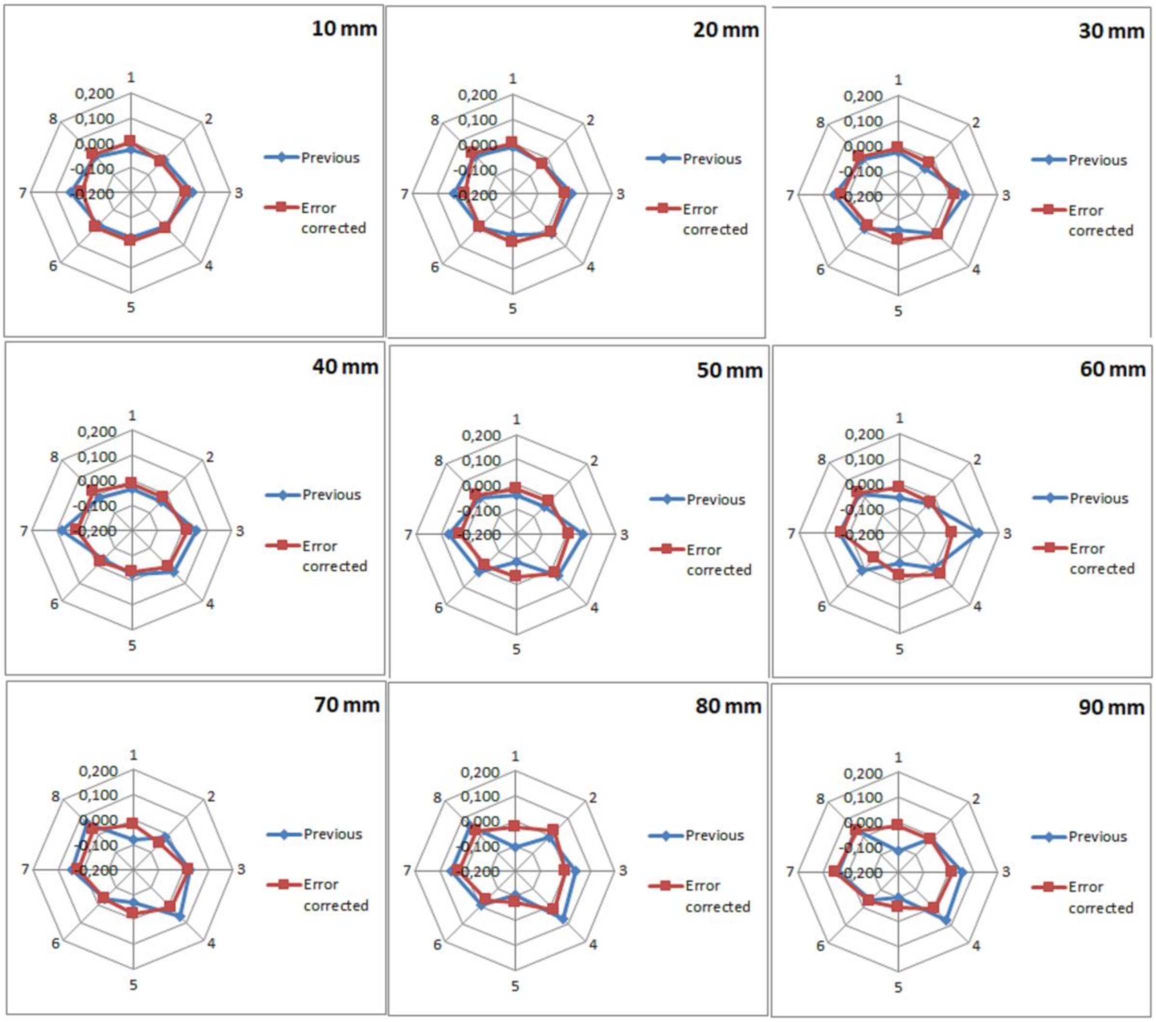
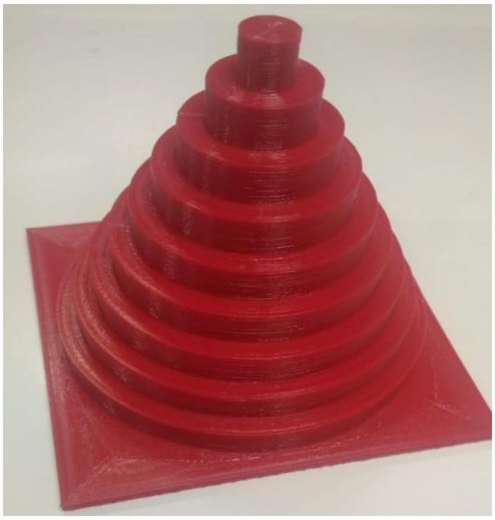


Figure 4: Circularity errors for part with circular steps, for diameters ranging from 10 to 90 mm, manufactured without (previous) and with (error corrected) circularity compensation. Part number 2, 3D printer x-axis was horizontal and y-axis was the vertical one.

FV	SQ	GL	QM	Fc	p
Diameter	6.66667E-05	2	3.33E-05	0.08	0.92
Height	0.000866667	2	0.000433	1.08	0.48
Angle	0.003466667	2	0.001733	4.33	0.19
Residual	0.0008	2	0.0004		
Total	0.00520	8			

Table 3: ANOVA results of mean variation in diameter.



(a) (b)

Figure 5: Parts produced: a) part 1 with cylinders; b) part 2 with cylindrical steps.

5 ACKNOWLEDGEMENTS

The authors would like to acknowledge the Fundação de Apoio à Pesquisa do Distrito Federal (FAPDF) for financing this research.

Antonio Piratelli-Filho, https://orcid.org/0000-0002-7773-3187

REFERENCES

[1] Box, G.E.P.; Hunter, W.; Hunter, J.S.: Statistics for experimenters, 2nd Ed., John Wiley & Sons, New York, 2005.

[2] Islam, M. N.; Sacks, S.: An experimental investigation into the dimensional error of powder binder three dimensional printing, The International Journal of Advanced Manufacturing Technology, 82(5), 2016, 1371-1380. https://doi.org/10.1007/s00170-015-7482-7.

[3] Martorelli, M.; Gerbino, S.; Lanzotti, A.; Patalano, S.; Vitolo, F.: Flatness, circularity and cylindricity errors in 3D printed models associated to size and position of the working plane, In: International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing (JCM 2016), 2016, Catania, Italy. https://doi.org/10.1007/978-3-319-45781-9_21

[4] Medhi-Souzani, C.; Piratelli-Filho, A.; Anwer, N.: Comparative Study for the Metrological Characterization of Additive Manufacturing artefacts, In: International Joint Conference on Mechanics, Design Engineering & Advanced Manufacturing (JCM 2016), 2016, Catania, Italy. https://doi.org/10.1007/978-3-319-45781-9_20.

[5] Moylan, S.; Slotwinski, J.; Cooke, A.; Jurrens, K.; Donmez, M.A.: Proposal for a Standardized Test Artefact for Additive Manufacturing Machines and Processes, Proceedings of the Solid Free Form Fabrication Symposium, August 6-8, Austin, Texas, USA, 2012.

[6] Rebaioli, L; Fassi, I.: A review on benchmark artifacts for evaluating the geometrical performance of additive manufacturing processes, The International Journal of Advanced Manufacturing Technology, 93(5-8), 2017, 2571-2598. https://doi.org/10.1007/s00170-017-0570-0

[7] Yang, L.; Anam, M.A.: An investigation of standard test part design for additive manufacturing. Proceedings of the Solid Free Form Fabrication Symposium, Austin, Texas, USA, 2014.