**Australian Journal of Basic and Applied Sciences**, 8(4) Special 2014, Pages: 639-642

AENSI Journals
**Australian Journal of Basic and Applied Sciences**
ISSN:1991-8178

Journal home page: www.ajbasweb.com

# Dimensional Accuracy of Product Design Based on Layout Orientation

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ARTICLE INFO

***Article history:***
*Received 20 November 2013*
*Received in revised form 24 January 2014*
*Accepted 29 January 2014*
*Available online 5 April 2014*

***Key words:***
*Rapid prototyping, Part build orientation, Dimensional accuracy, Product design*

ABSTRACT

As a material-additive process, rapid prototyping (RP) has shown its capability in creating complex geometries that traditional material-removal processes cannot accomplish. One of the key factors in the determination of success of RP process is the selection of best possible layout orientation during the object building as it directly affects the part quality such as part accuracy, surface finish, built time, cost, etc. This report presents the experimental study in determination of best layout orientation angle for dimensional accuracy of product design for three dimensional printing (3DP). Product designs were manufactured by varying the x-y planes at different angles from 0-60° and build time for each orientation is taken. Results show that the dimensional accuracy for product design experienced geometric inaccuracy due to layout orientation effects and some parts tend to warp due to shrinkage.

**To Cite This Article:** R. Ummi Nazahah, C.O. Che Mohamad, S. Zainal Ariffin, B.B.T. Hang Tuah., Dimensional Accuracy of Product Design Based on Layout Orientation. ***Aust. J. Basic & Appl. Sci.,*** *8(4): 639-642, 2014*

## INTRODUCTION

Measures to improve the efficiency of production processes always include the application of new and innovative manufacturing methods. Therefore, in recent years, applications of the Rapid Technology turned out to be potentials of the modern product development process (Zhou, J.G., *et al*., 2000). Rapid Prototyping (RP) can be broadly defined as a group of technologies to fabricate a part or assembly layer by layer addition or deposition of material using its three-dimensional CAD model. Today nearly six different RP techniques exist. Common examples of RP methods are Fused Deposition Method (FDM), Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Direct Metal Deposition (DMD) and 3D printing (Pham, D.T., S.S. Demov, 2001; Kai, C.C., L.K. Fai, 2000; Hu, Z., *et al*., 2002). RP plays an important role in reducing the time required for new product development and lowering development costs. To create a physical object using RP cycle, first creation of geometric model by a Computer Aided Design (CAD) modeler is done. This is followed by determination of suitable deposition orientation, slicing, generation of material deposition paths, part deposition and post-processing operations. Many of these steps can be done automatically by RP machine, but usually part deposition orientation is selected by the user. In (Zhou, J.G., *et al*., 2000) it was proposed that orientation for part deposition on a RP machine platform has a significant effect on many key characteristics, which determine the final part quality and cost. For any RP process to produce components with high surface quality (dimensional accuracy and surface finish) and minimum build time or cost, it is essential to determine optimal orientation(s) out of infinite possibilities development costs (Chockalingam, K., *et al*., 2006). Therefore, in order to generate information on the performance of the dimensional accuracy, research should focus on finding optimal build orientations which simultaneously build time (T), for Three Dimensional Printing (3D printer).

### *Experimental Technique:*

The CAD model shown in Figure 1 provides variety of interesting geometric shapes and surfaces for experimental purpose, including planar, cylindrical, and arc and half circle surfaces with size 96 x 36 x 44 mm. Four surfaces of this CAD model are required to meet dimensional accuracy specifications. The inner cylindrical surface is Ø12 mm dimensions, the arc edges on outer side of the cylindrical surface dimension is R17 mm, the semicircle is R7 in dimension and the down facing planar surface at the base of the yoke is 96 mm length.

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### *Product Design (Yoke Model):*

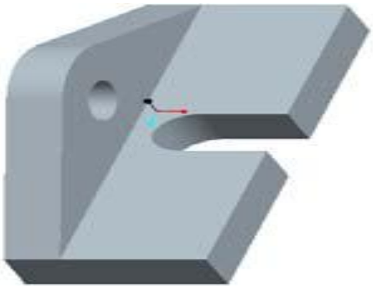


**Fig. 1:** Test part model

3D solid model of test part is modeled in Pro Engineer software and exported as STL file. STL file is imported to the three dimensional printing (3DP) software. Here, control factors (Table 1) are set as per experiment plan and other factor like layer thickness is kept at fixed level. Nine parts per experiment are fabricated using SD 3000 rapid prototyping machine. The material used for part fabrication is VisiJet SR2000 which composition of UV curable acrylic plastic and the support material is VisiJet S100 (wax). Three readings of every surface are taken per sample and mean is taken as representative value for each of these dimensions. Dimensions are measured using Mitutoyo Profile Projector of least count 0.01mm. Measured values show that there is shrinkage in length (L) and width (W).

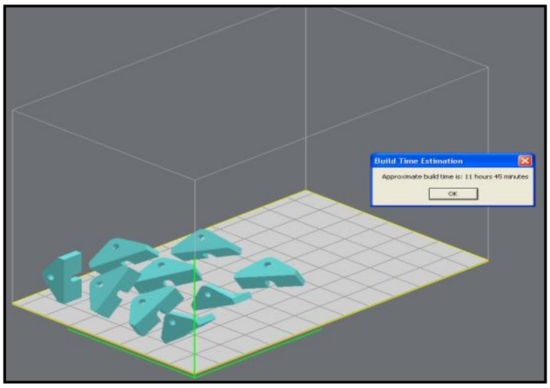
### *Design of Experiment (Part Build Orientation):*

Part building is varied to differentiate the effect on layout orientation and is set at three levels as shown table 1, which are 0°, 45°, and 60° on x-y axis.

**Table 1:** Design factors and levels for process parameters

| Parameter | Range | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| X axis | 0-60° | 0 | 45 | 60 |
| Y axis | 0-60° | 0 | 45 | 60 |

By using Taguchi method, 9 experiments as shown in Figure. 2 done based on orthogonal array L9.



Approximate build time is: 11 hours 45 minutes

**Fig. 2:** Different parts build orientation based on Orthogonal Array L9

## RESULTS AND DISCUSSION

From the graph plotted in Figure 3, the first layout orientation setting shown its dominant in determining accuracy when the x-axis and y- axis is set at 0°. 3 out of 4 geometric features shows the best accuracy value which are circle, semicircle, and planar. A reference line indicates that when the value is approaching, it gives the best value for each geometric features and percentage of accuracy can be calculated. As an inference, the layout orientation played important parameters in obtaining the best accuracy value.

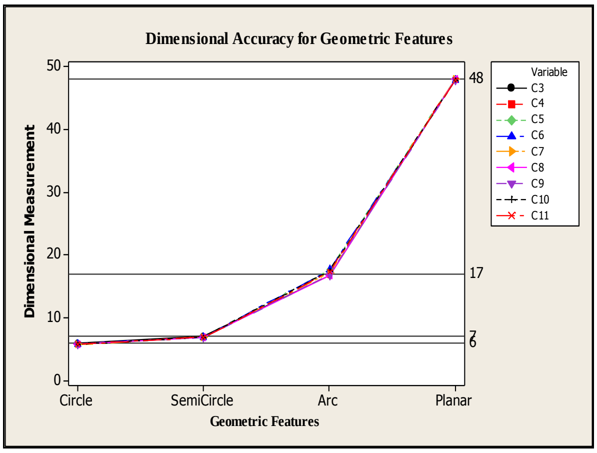


**Fig. 3:** Graph Plot of Dimensional Accuracy for geometric features

As for build time recorded, the first setting showed the highest build time where it takes 11 hours and 27 minutes to complete the prototype while the lowest build time recorded at ninth setting which takes 7 hours and 51 minutes. Overall build time is 11 hours and 45 minutes where it takes about 20 minutes to heat up the machine and layered the base printing before the actual design can be printed.

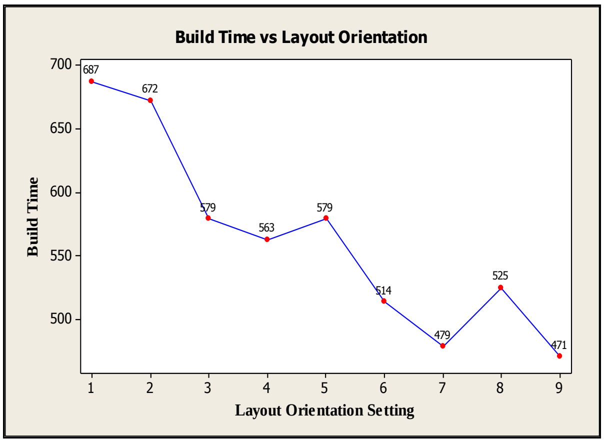


**Fig. 4:** Time Series for Build Time versus Layout Orientation

Researcher (Alexander, S., D. Allen, Dutta, 1998) states that a preferred orientation can be obtained by considering only two geometric features. Although a resolution may be possible for more than two geometric features, it is not as clear that it will work in the majority of cases. The orientation of these two geometric features can be parallel (0 ° and180°), perpendicular (90 ° or 270 °) or at an angle (all other cases). There are also some rules developed to handle such case:

(1) *If the feature axes of two surfaces of revolution are parallel, orient the feature axes in the z direction.*

For a parallel orientation of the feature axes of two surfaces of revolution; both of the axes should be in the z direction. However, the rules draw attention to a possible trapped volume.

(2) *If the feature axes of a hole and a free-form surface are perpendicular, or at an angle, the orientation of the feature axes is not clear* (stair stepping).

The orientation of the feature axes is perpendicular or at some angle, so one of the geometric features will have a stair stepping effect. In this case, to resolve the preferred orientation, the program needs additional information, such as the relative importance of the geometric features. With this information, the rules consider the priority of one geometric feature and allow the stair stepping effect on the second feature. The rules consider how many similar features with the same axis there are in the part as well as the different feature diameters. If the part has only one occurrence of the primary feature, but the secondary feature is repeated several times in parallel orientations, the system must take into account the quality of the secondary feature, and will recommend the orientation of the secondary feature axis in the z direction. However, if this additional information does not help to recommend a preferred direction to build, and then we have has to choose one of two different orientations.

(3) *If the feature axes of a surface of revolution and an inclined plane are perpendicular, orient the feature axis of the surface of revolution in the z direction and orient the feature axis of the plane perpendicular to the z axis.*

Therefore, the definitions of rules for a preferred orientation take all variety of shapes into account.

Scaling Process

Scale process is the most important parameter that significantly affects the fidelity, quality, strength, and cost of the physical prototypes to be fabricated. For this project, the original dimension is scaled down to 50% to reduce the build time and also amount of material used. Previous research (Kulkarni, P., *et al*., 2000) states that, scaling process has definitely improved the accuracy by reducing the probability of shrinkage in product design.

### *Shrinkage & Warpage:*

A consistent problem with 3D printing is part distortion and dimensional inaccuracy. Shrinkage caused by resin-curing unsymmetrically relative to the mid-plane of the strands, layers, and part is the principal cause of warpage. As the resin cures, material properties and shrinkage change with time. Consequently, the order in which the vectors or strands are drawn relative to one another, which is a time-dependent process, affects warpage (Lee, C.S., *et al*., 2007) where warpage is a distortion where the surfaces of the produce part do not follow the intended shape of the design.

### *Conclusion:*

The concept presented for the optimization of part orientation includes a multitude of influencing factor and can supply a number of proposed solutions to aid in the choice of orientation. Apart from the dependencies presented here, there exist further effects which need to be taken into account in future developments and thereby increase the validity of the calculation. Due to the complexity of the orientation selection, knowledge of decisive effects and interdependencies are of fundamental importance. The part has been manufactured on a three dimensional printing (3DP) machine and additionally compared with the calculated solution. Both parts showed nearly the same value with minor deviations of just a few mm. Error between predicted data and observed values varies between 0 to 1.2%. The suggested orientation is a compromise between quality and efficiency. Part height is considerably bigger than the minimum height but leads to less supports and less stair casing. A vertical orientation would result in good part quality except the holes but also in a high number of layers and therefore in long build time. An angle orientation would lead to a cost-effective build time but also to insufficient dimensional accuracy due to warping. However, it is important to note that the identified orientations only act as suggestions and aids for supporting a decision-making process and not to be considered as fixed results. As long as design intentions, functional surfaces or special design features are not stored in a corresponding data interface (Danjou, S., P. Köhler, 2008) and thus prevent an automatic analysis, knowledge of an experienced user is pivotal in the final definition of part orientation.

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