Procedia Manufacturing

Volume 1, 2015, Pages 343–354

43rd Proceedings of the North American Manufacturing Research Institution of SME http://www.sme.org/namrc

Optimum Part Build Orientation in Additive Manufacturing for Minimizing Part Errors and Support Structures

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Abstract

Additive Manufacturing (AM) is the process of part building by stacking layers of material on top of each other. Various challenges for a metal powder based process include reducing the staircase effect which leads to poor surface finish of the part, and minimal use of support structures for regions with overhangs or internal hollow volumes. Part build orientation is a crucial process parameter which affects part quality, in particular, Geometric Dimensioning & Tolerancing (GD&T) errors on the part, the energy expended and the extent of support structures required. This paper provides an approach to identify an optimal build orientation which will minimize the volume of support structures while meeting the specified GD&T criteria of the part for a DMLS based process. Siemens PLM NX API is used to extract the GD&T callouts and associated geometric information of the CAD model. The regions requiring support structures are identified and a Quadtree decomposition is used to find the volume of support structures. The mathematical relationships between build orientation and GD&T are developed as part of a combined optimization model to identify best build orientations for minimizing support structures while meeting the design tolerances. The feasible build orientations along with the corresponding support structures are depicted using a visual model.

Keywords: Additive Manufacturing, Build Orientation, Support Structures, Geometric Tolerances, Optimization, Feasible Zone, Siemens PLM NX API, Quadtree.

1 Introduction

Metal powder based Additive Manufacturing is gaining popularity in the aerospace, medical, electronics and automobile industry, as intricate components can be built with ease. The process begins by slicing the CAD model to obtain a 2D contour at each level of the build axis, which is fixed

Peer-review under responsibility of the NAMRI Scientific Committee
doi:10.1016/j.promfg.2015.09.041

as the z-axis. Starting from the base 2D contour, a user defined slice thickness is added cumulatively at successive slicing planes. This layer by layer stacking gives rise to an error called the staircase effect which diminishes the surface finish of the part. Achieving part accuracy is currently one of the key constraints in AM. Slice thickness, part build orientation, thermal errors, support structures are a few major parameters which affect part accuracy. In this paper, the effect of part build orientation on support structures volume and part accuracy will be addressed.

Build orientation is a crucial parameter since it will affect the tolerance errors, energy expended and the volume of support structures required. Support structures are an integral part of this process as it is necessary to account for possible overhangs or internal hollow volumes which might not provide sufficient support to the overhanging layers. It is essential to minimize the use of these supports as reduced contact area between the part and these structures will result in better part quality and also reduce the post processing efforts (Dutta and Kulkarni, 2000).

This paper discusses a methodology to detect the regions requiring support and calculate the volume of these support structures at various orientations. This information is then used to find an optimal build orientation, having minimum support structures while satisfying the tolerance callouts.

The tolerances covered in this paper are Perpendicularity, Parallelism, Angularity, Total Runout, Circular Runout and Conicity. Assuming a fixed slice thickness, mathematical relations are developed between the tolerance errors and part orientation. A combined optimization model is used to obtain the optimal build angle which is then verified using the graphical representation adapted from Arni and Gupta (Arni and Gupta, 2001) and Paul and Anand (Paul and Anand, 2014). Finally, the volume of support structures at different orientations is plotted on a unit sphere depicting different build orientations which can act as a tool for visualizing and comparing extent of supports. A combined visual representation of volume of support structures and the tolerances satisfied at each orientation is also presented.

2 Literature Review

Process parameters play an important role in defining the final part quality and part accuracy of a product. In additive manufacturing, these parameters include slice thickness, build orientation, support structures and hatching pattern. Literature review on support structures, optimal part build orientation, and GD&T errors, namely, form and orientation tolerance errors and their evaluation is discussed here.

Dutta and Kulkarni (Dutta and Kulkarni, 2000) covered the various process planning parameters of AM and included part orientation and support structure among the important factors. They also enumerated the various approaches to solve the support structure and build orientation problems. Prior research includes the use of various algorithms to determine optimal part orientation with respect to build time, volumetric error, part accuracy, surface finish and build cost (Cheng et al., 1995, Thrimurthulu et al., 2004, Frank and Fadel, 1995, Rattanawong, et al., 2001, Thompson and Crawford, 1997, Pandey et al., 2004, Xu et al., 1997, Alexander et al., 1998, Lan et al., 1997 and Zhang and Li, 2013). Arni and Gupta (Arni and Gupta, 2001) investigated the effect of build orientation on flatness error and analyzed the feasibility of manufacturing the part with flatness callout. They concluded that the staircase error formed due to slice thickness and build orientation is the cause of the flatness error on the manufactured part and established a mathematical relation between them. Lynn-Charney and Rosen (Lynn-Charney and Rosen, 2000) developed an empirical model for SLA machine accuracy and established relationships among part surfaces, tolerances and process variables. Other researchers (Prakasvudhisarn and Raman, 2004, Wen et al., 2010) performed detailed analysis and evaluated conicity and cylindricity errors using different optimization techniques. Paul and Anand (Paul and Anand, 2014) analyzed the effect of build orientation on cylindricity error and developed an optimization model to obtain the part orientation while minimizing support structures and form errors. They also introduced a graphical approach to find the optimal build orientation. Allen and Dutta