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Estimation and Improvement of the Achievable Tolerance Interval in Material Extrusion Additive Manufacturing through a Multi-State Machine Performance Perspective

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Abstract: Dimensional quality is still a major concern in additive manufacturing (AM) processes and its improvement is key to closing the gap between prototype manufacturing and industrialized production. Mass production requires the full working space of the machine to be used, although this arrangement could lead to location-related differences in part quality. The present work proposes the application of a multi-state machine performance perspective to reduce the achievable tolerance intervals of features of linear size in material extrusion (MEX) processes. Considering aspecific dimensional parameter, the dispersion and location of the distribution of measured values between different states are analyzed to determine whether the production should be treated as single-state or multi-state. A design for additive manufacturing strategy then applies global or local size compensations to modify the 3D design file and reduce deviations between manufactured values and theoretical values. The variation in the achievable tolerance range before and after the optimization of design is evaluated by establishing a target machine performance index. This strategy has been applied to an external MEX-manufactured cylindrical surface in a case study. The results show that the multi-state perspective provides a better understanding of the sources of quality variability and allows for a significant reduction in the achievable tolerance interval. The proposed strategy could help to accelerate the industrial adoption of AM process by reducing differences in quality with respect to conventional processes.

Keywords: additive manufacturing; quality assurance; material extrusion; design for additive manufacturing; machine performance

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1. Introduction

In additive manufacturing (AM), a three-dimensional geometry is decomposed in bidimensional shapes and used to create solid parts that are built layer upon layer [1]. This basic workflow is common to different manufacturing processes, like material jetting (MJT), material extrusion (MEX), and powder bed fusion (PBF) [2]. The application of AM has evolved from prototypes to small-batches, but the objective of reaching mass production capabilities would require filling the gap between AM specification standards and the industrial needs [3]. In fact, the achievable quality is still affecting the adoption rate of AM in the consumer market [4].

Tolerance intervals (TI) are expected to be larger in AM than in traditional manufacturing processes [5], and this lack of quality has been usually addressed by adding post-processing steps [6]. Production planning in AM will require trustable information about the expected TI and the fulfillment of tolerance specifications to decide which machine or technology will be used beforehand [7].

Those works investigating dimensional quality in the AM process are frequently focused on providing a quantification of dimensional quality [8–12], analyzing the influence