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Design for Verification

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Abstract

Increased competition in the aerospace market has placed additional demands on aerospace manufacturers to reduce costs, increase product flexibility and improve manufacturing efficiency. There is a knowledge gap within the sphere of digital to physical dimensional verification and on how to successfully achieve dimensional specifications within real-world assembly factories that are subject to varying environmental conditions. This paper describes a novel Design for Verification (DfV) framework to be used within low rate and high value and complexity manufacturing industries to aid in achieving high productivity in assembly via the effective dimensional verification of large volume structures, during final assembly. The 'Design for Verification' framework has been developed to enable engineers to design and plan the effective dimensional verification of large volume, complex structures in order to reduce failure rates and end-product costs, improve process integrity and efficiency, optimise metrology processes, decrease tooling redundancy and increase product quality and conformance to specification. The theoretical elements of the DfV methods are outlined, together with their testing using industrial case studies of representative complexity. The industrial tests have proven that by using the new Design for Verification methods alongside the traditional 'Design for X' toolbox, resulted in improved tolerance analysis and synthesis, optimized large volume metrology and assembly processes and more cost effective tool and jig design.

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Keywords: Design for Verification; Metrology; Process Management; Product Design; Manufacturing Planning, Uncertainty Estimation

1. Introduction

The primary aim of this paper is to present a novel framework termed as "Design for Verification" (DfV) to complement the existing rules of Design for Excellence or 'X' (DfX) with a particular focus in large volume and integration processes during assembly [1]. The role of DfV is to enable and ensure paths for product conformance, with reduced manufacturing and metrology costs. This will determine the assembly and tooling philosophy, improve efficiency and increase rates of production. The secondary aim of DfV is to develop process models for analysis tools to assist designers in defining critical tolerances for large volume assemblies. This is founded upon instrument specification based algorithms for optimised measurement planning and uncertainty reduction for trade-off against cost and time. This is designed to be a four-pronged approach to cost modelling, with focus areas of tolerancing, measurement uncertainty, assembly methods and tooling methods. The achievable benefits and changes as well as the spillover effect which occurs with alterations is highlighted [2], [3].

2. Background and Structure

The proposed DfV framework assists designers for low rate high value products with a tool to optimise design for quality and cost with an improved success rate of RFT manufacturing. This depends upon the optimisation of four key areas: tolerancing, assembly, tooling and measurement.

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2.1. DfX

Success of DfX within manufacturing industries has traditionally been achieved by integrating small, focused engineering teams to ensure that parts are designed with manufacturability and ease of assembly, with interchangeable parts. Product design optimisation within a single design for 'x' parameter can cause detrimental consequences. For example, if one were to optimise a product purely for manufacture alone, the product may become significantly simplified and lose functionality. This dilemma inherently invokes a trade-off analysis between the DfX optimisation parameters and has led to various attempts at a solution to resolve the conflict between optimising parameters against other parameters. This is a well-recognised challenge, often referred to as the principle of design parameter sensitivity, further discussed by Franciosa et al.[4] [5] [6]. The traditional approach to design optimisation is a sequential method, often referred to as a Fixed Point Iteration method [4]. The challenge associated with this method is that it places heavy emphasis upon the skill set of individual designers. Franciosa et al. [6] describe the lack of effective product optimisation due to limitations imposed on product design by a prevalent feedforward approach. The DfX approach uses a feedback loop to significantly improve optimisation efforts. Attempts to overcome this challenge have been initialised through the implementation of multidisciplinary design optimisation (MDO) methods, which have aided closing the knowledge gap between distinct design sectors within large aerospace organisations. Applications of MDO have enhanced the synergy between various design disciplines, pushing for a higher level of product optimization [7]. Franciosa et al. propose a novel methodology to optimise heterogeneous design tasks with competing parameters [5].

Recent attempts to have been made to modernise DfA and DfM techniques based upon the state of the art manufacturing capabilities within aerospace facilities. The quantification of process capability for individual processes plays a significant role within the optimisation of DfA and DfM. Process capability is calculated through the dimensional analysis of repeat parts from a given manufacturing or assembly process. It provides a quantitative definition of the accuracy and precision of the particular process. It has been recognised that there is a clear knowledge gap within manufacturing and assembly process design with pre-existing process capability data. Whiteside et al. [8] produced a methodology to incorporate process capability into early stage design using historic measurement data for a given process. Measurement planning for uncertainty reduction is the means by which conformance of a product or process can be improved. It is integral within manufacturing and assembly processes, although it does not feature within DfX guidelines.

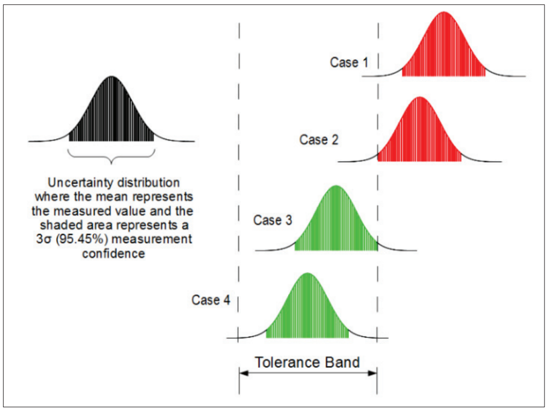

Figure 1: Measurement Uncertainty and Tolerance Bands

2.2. Metrology

The role of metrology within high value, large scale, low rate manufacturing is fundamentally crucial to the successful implementation of assembly and integration processes. There is a knowledge gap within design and manufacturing communities for large aerospace structures with respect to design for measured reality and assigning tolerances based upon estimated measurement uncertainty. This has often left metrologists at the mercy of technical drawings that demand unachievable measurements over the specified volumes.

The dominant challenges that metrologists face are due to the limitations imposed on them by their measurement hardware or by design specifications. For example, the most commonly used metrology system within aerospace for tool setting, jig verification and product conformance evaluation is the laser tracker. Specifications of different laser trackers are similar, the stated uncertainty for Hexagon's flagship laser tracker, the Absolute Tracker 901 (AT901) is stated as 15 µm + 6 µm/m at a confidence level of 2 σ [9]. Consider an assembly tolerance of +/-50 µm parallelism over 5 m. A laser tracker measuring at a distance of 5 m would typically have an MPE/uncertainty value of +/-15 µm + (6 µm multiplied by 5) = 45 µm at 2 σ, illustrated in Figure 2.

This poses a significant challenge because the laser tracker operator must achieve the parallelism requirement of +/-50 µm within a much tighter tolerance band of only +/- 5 µm to ensure that the assembly conforms to specification. Whilst this calculation gives a simplified view of the problem, it is still the most current method that a majority of technicians employ to calculate uncertainty on the shop floor. The effect of measurement uncertainty upon tolerance bands is shown in Figure 1. This image shows the effects of measurement uncertainty consuming the majority of the tolerance allocation, which subsequently allows very little room for

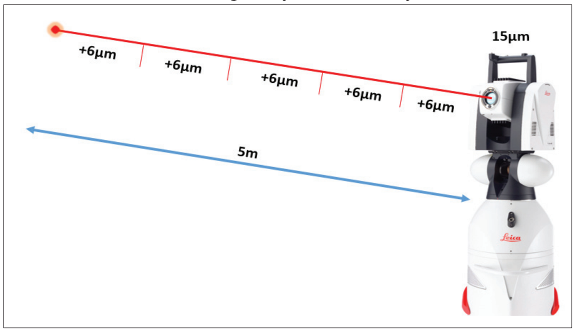

Figure 2: Laser Tracker Measurement Uncertainty