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# Toward a Digital Twin for real-time geometry assurance in individualized production

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ABSTRACT

Simulations of products and production processes are extensively used in the engineering phase. To secure good geometrical quality in the final product, tolerances, locator positions, clamping strategies, welding sequence, etc. are optimized during design and pre-production. Faster optimization algorithms, increased computer power and amount of available data, can leverage the area of simulation toward real-time control and optimization of products and production systems – a concept often referred to as a Digital Twin. This paper specifies and highlights functionality and data models necessary for real-time geometry assurance and how this concept allows moving from mass production to more individualized production.

## 1. Introduction

A highly automated production factory for complex assembled products is a huge investment and return on investment requires high product quality, factory throughput, equipment utilization, and flexibility as well as low energy consumption. Geometry related problems, resulting in late changes and delays, usually constitute a significant part of the total cost for poor quality.

### 1.1. Geometry assurance

Geometry assurance can be described as set of activities that contributes to minimizing the effect of geometrical variation in the final product. Activities take place in all phases of the product realization loop, see Fig. 1.

*The design phase*: Here, concepts are analyzed and optimized to withstand manufacturing variation. Product requirements are defined and decomposed into locator positions and tolerances on pars and subassemblies.

*The pre-production phase*: Here, the product and the production system are verified physically. Adjustments are made to correct initial errors and prepare for full production. Inspection preparation and off-line programming of coordinate measurement machines and scanners are performed and all inspection strategies and inspection routines are decided.

*The production phase*: Here, all initial production process adjustments are completed and the product is running in full production. Inspection data from parts and subassemblies are used to control production and to detect and correct errors.

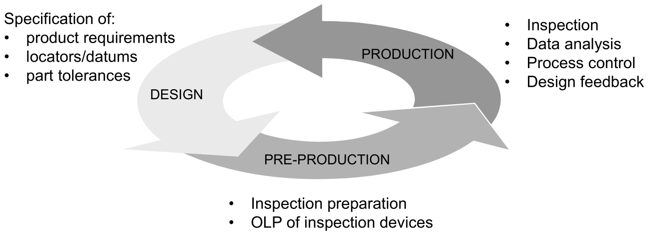

**Fig. 1.** The geometry assurance process.

Most companies today are fully aware of the fact that a change is costlier in production than in the design phase. An effective digital geometry assurances process has the potential to drastically reduced costs and adjustments in production [1].

### 1.2. Digital Twins

The area of virtual/digital development of products and production systems has grown extensively the last 20 years. Simulation and optimization are today used for a variety of different products and development tasks. Simulation has been an important tool for shifting expensive product changes, often discovered during production start, to earlier design phases where cost for change is low. Increased number of model programs with shorter intervals drive the needs for simulation. The ability to simulate production ramp-up therefore becomes increasingly important [2].

Increased computer power, faster algorithms and more efficient optimization routines have made simulation and optimization an everyday tool for engineers. Calculation time has gone from weeks

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to hours and minutes which have made it possible to, not only verify solutions, but also to explore the solution space, searching for the global optimum. Increased focus on sustainability, with reduced waste, is also a driver for a more global view on optimization of design and manufacture [3].

Traditionally, simulation has been used in the design phase with estimated or historical data as input. Increased use of sensors and in-line measuring equipment are making it possible to use (and reuse) simulation models created during product development also in production, now with real data as input. This will allow for adjustment of machine settings for the next product in line based on simulations in the virtual world before the physical changeover, reducing machine setup times and increasing quality. The ability to link large amounts of data to fast simulation makes it possible to perform real-time optimization of products and production processes. The concept of using a digital copy of the physical system to perform real-time optimization is often referred to as a Digital Twin. The concept of a Digital Twin was adopted by NASA for safety and reliability optimizations in [4] and [5]. With an aggressive push toward “Internet of Things”, data has become more accessible and ubiquitous which necessitates the right approach and tools to convert data into useful, actionable information [6]. The vision of the Digital Twin itself refers to a comprehensive physical and functional description of a component, product or system, which includes more or less all information which could be useful in the current and subsequent lifecycle phases [7,8]. Simulation and seamless transfer of data from one life cycle phase to the subsequent phase are central for the concept of the Digital Twin.

The digital development advancements allow sensors, machines, workpieces, and IT systems to be connected along the value chain beyond a single enterprise. These connected systems (also referred to as cyber-physical systems) can interact with one another using standard Internet-based protocols [9] and analyze data to predict failure, configure themselves, and adapt to changes. Increased availability of data will also open up new possibilities for better maintenance and related service systems [10].

### 1.3. *Scope of the paper*

This paper proposes the concept of a Digital Twin for geometry assurance. The paper combines research within variation simulation and quality control to an autonomous self-adjusting system that optimizes quality and allows for individual production. The Digital Twin is developed and used for product and production system design in the concept phase and later on inherited for inspection preparation and process control. Functionality and information needed in each phase/step are specified. How the concept of the Digital Twin allows moving from mass production to more individualized production is discussed, as well as future research challenges.

## 2. The Digital Twin in the design phase

In the design phase, different product concepts are developed and optimized to withstand the effect of manufacturing variation. From a geometry assurance perspective, three basic activities are performed:

- Specification of product requirements/tolerances.
- Specification of locating schemes.
- Specification of part tolerances.

A Digital Twin, supporting robustness and tolerance analysis in the design phase, uses geometry representations of the parts, kinematic relations (locating schemes and transformation matrixes) in combination with FEA to perform sensitivity and variation analysis. The Digital Twin is fed with variation data for parts and fixtures, normally gained from similar earlier projects.

### 2.1. *Functionality: locating scheme optimization*

Locating scheme optimization is a critical step in geometry assurance. Variation propagates through the physical contacts (locating schemes) between parts and fixtures in an assembly. Locating schemes can be seen as representing the transfer functions between input and output variation and controls the robustness of a mechanical assembly. The stability analysis evaluates the geometrical robustness of a concept and shows how variation, introduced by the locators and the additional clamps, propagates and affects critical features and dimensions [11]. Fig. 2 shows variation for two different locating schemes (Concept 1 and Concept 2) used for joining before and after spot welding and release from the fixture. Only the master location schemes are shown. Additional clamp locations can be included in the same way.

### 2.2. *Functionality: statistical variation simulation*

Variation simulation can be performed by utilizing transformation matrices to calculate how part variation propagates in the assembly. The method is often combined with Monte Carlo (MC) simulation. For non-rigid variation simulation, finite element analysis (FEA) is included. The method allows over-constrained locating schemes that result in bending during assembly due to variation in parts and fixtures. The method of influence coefficient (MIC) [12] is used to reduce computational time. Contact modeling prevent penetration due to bending and deformation during assembly, see [13] and [14]. Fig. 2 shows non-rigid variation simulation in the software RD&T, where the color coding indicates the expected variation.

Lately, new materials with tougher requirements on bending, deformation and stress are introduced in aerospace and automotive industry. Variation simulation to verify geometrical deformation and stress criteria and to support shimming strategies are treated in [15]. A future challenge is how variation simulation can be performed fast enough for in-line use.

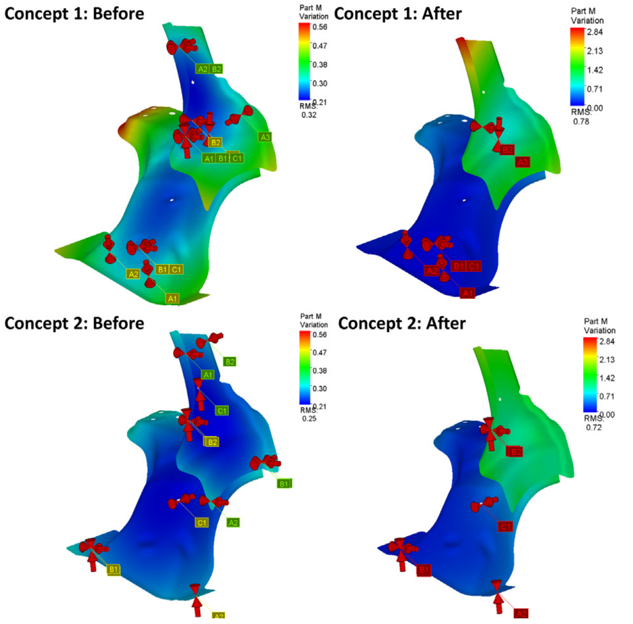

**Fig. 2.** Variation simulation of a two-part assembly.

## 3. The Digital Twin in the pre-production phase

In the pre-production phase, the Digital Twin is used as a basis for inspection preparation and off-line programming (OLP) of coordinate measure machines (CMMs) and scanners. It also contains the definition of the final inspection points and a link to the inspection database.

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