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Realization of Industry 4.0 with high speed CT in high volume production

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A B S T R A C T

Industry 4.0 is taking process information to the next level with improved exchange of data, analytics and relevant feedback regarding the process, equipment health and dynamics. Quality Control needs to adapt to new requirements of 100% inspection and additive manufacturing (AM) to enable high-speed inspection of internal and external features, rapidly accommodate part design changes, tie results to unique part numbers, perform automated metrology and make a final decision on the condition of a measured part. All of this must happen at a rapid pace, permitting inspection of internal and external features simultaneously. Computed tomography (CT) offers needed flexibility and, with recent technological advancement, part throughput of a few seconds is possible, even while performing complex metrology and inspection tasks simultaneously. With defect analysis and feedback, virtually defect-free production is achievable. In this paper, authors will discuss implementation of complete solutions enabling greater process control, digital part tracking as well as flexibility and throughput of parallel metrology with industrial CT.

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Introduction

Over the past two centuries, industry has shifted from unique manufacturing of single items to mass production and is now driven towards mass production of customized individual components while still maintaining the economy of scale [1]. Massive customization and high speed of product development require increased flexibility of manufacturing and quality control solutions [2]. To realize this goal industry has to evolve and take advantage of available modern computing, communication and automation under the umbrella of Industry 4.0 which, step by step, is defining the future direction of manufacturing [3–5]. Over the past decade, focused discussions and intense development have driven results towards modern and agile manufacturing processes. [6,7]. The main design principles of the Industry 4.0 are: interoperability, information transparency, technical assistance and decentralized decisions [8]. These principles, coupled with massive customization, provide new requirements for manufacturing and quality inspection capabilities. This demand can be realized with flexible manufacturing based on subtractive and additive manufacturing methods. Additive manufacturing (AM), especially, offers unprecedented freedom of design bounded by selection of materials [9] and manufacturing techniques [10]. New complex designs require inspection methods, such as x-ray computed tomography (CT) which can non-destructively measure internal and external features of metallic and non-metallic AM parts [11,12]. Usability of CT for metrological applications has been intensively researched over the past decade, and has resulted in many publications [13–23]. In general, CT offers unprecedented data analysis possibilities due to the collection of the complete volumetric data set. CT also provides an unprecedented level of flexibility and speed for parallel metrology tasks that is unmatched by classic methods, which collect data feature by feature. The distinction between CT and classic methods stems directly from how the data is collected, and this difference offers possibilities for measurement parallelization.

Implementation

To enable Industry 4.0, a quality control group must be prepared for high volume production and be capable of measuring 100% of parts produced with cycle times better than 4 s per part. The measurement results must be attached to unique serial numbers and decisions about part condition have to be made automatically. Optimally, the part data also should be available as feedback to the manufacturing line.

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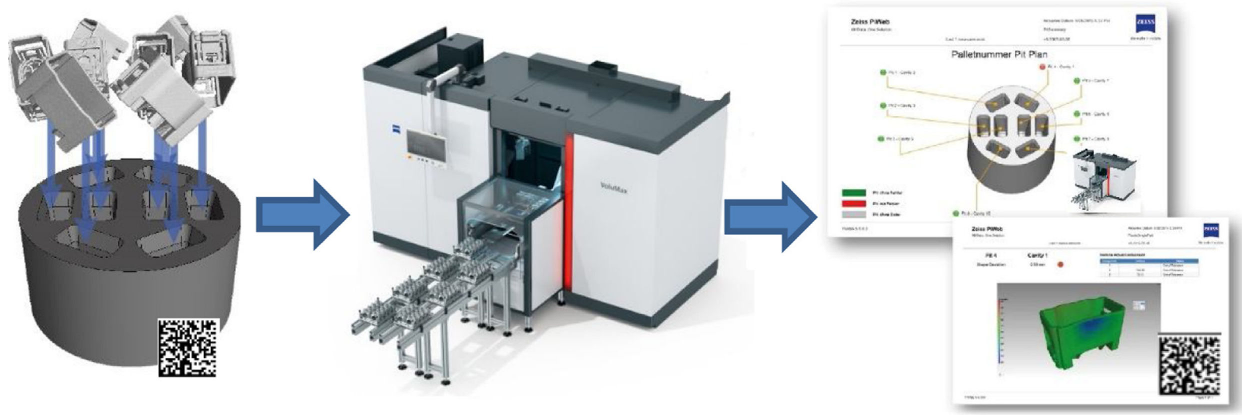

Fig. 1. Schematic showing sample part flow and results tracking by serial numbers.

Experimental setup

The complete solution is defined by the following part flow:

1. A part's serial number is read and stored in a database (this step can be moved to step #5; however, this possibility is dependent on the ability to read the 2D code directly from the CT data).
2. Next, a part is inserted into a designated location of multi part fixture and its position is stored into the database.
3. The fully loaded fixture is moved into the VoluMax 800 225 kV x-ray CT machine. The fixture capacity is designed to hold 36 parts scanned in 3 batches of 12 parts each, yielding 3.9 s of throughput per part.
4. After the scan has completed the fixture is removed and replaced with a new fixture holding the next batch of 36 parts.
5. While the second fixture is being scanned the first fixture is being evaluated in parallel and complete results are available within one cycle time of the machine. During this time each part volume is separated and measured independently. All measurements are performed in parallel. This parallelization is done not only on a single PC but can also be spread across multiple PCs/computing nodes as necessary.
6. All results are matched with the unique part serial numbers.
7. Parts can be sorted by robotic system or humans equipped with barcode readers. By reading the serial number, the measurement results as well as the decision as to whether the part passed or failed the test is provided.
8. More detailed information is available as manufacturing feedback, allowing quick diagnostics and understanding of production performance to help facilitate any necessary adjustments. If the part number is tracked with manufacturing centers, a clear map of individual manufacturing cell performance can be created (Fig. 1).

Experimental results

Test part

To demonstrate the process, 36 parts have been machined out of Aluminium with nominal dimensions as shown in Fig. 2. The part was designed with holes, as well as larger and smaller openings to simulate components available in today's high volume and quickly changing consumer electronics market as good representation of the early adopter of the Industry 4.0 concept.

Fixture

As stated above, a total of 36 parts have been produced. A custom fixture was created to hold all 36 parts at once and is shown in Fig. 3.

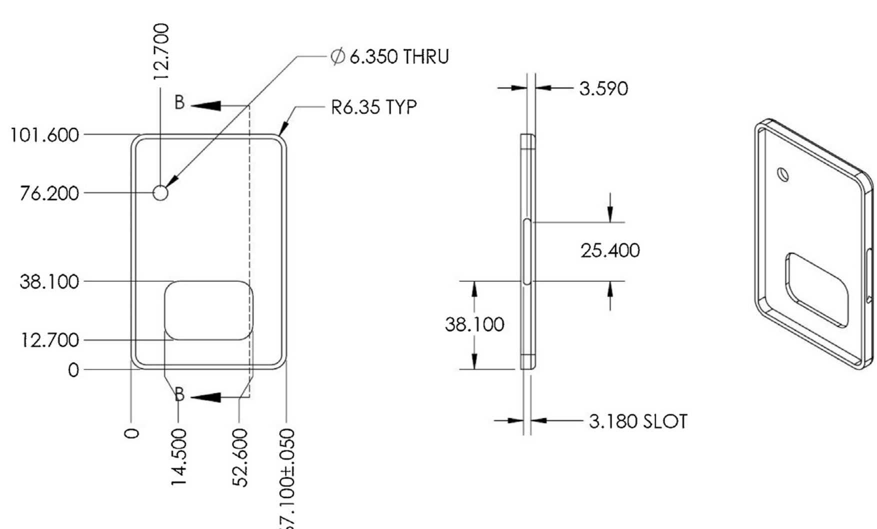

Fig. 2. Test part machined out of Al.

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