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An approach to development of the digital inspection twin based on CMM

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ABSTRACT

Digital inspection twin (DIT) acting as a mirror between the physical and virtual measuring world. In this paper the measurement system with the CMMs ZEISS UMM 500 and DEA-IOTA-2203 was used as a physical twin, and a virtual machine, generated after modelling and configuring in PTC Creo software. Virtual measurement system is developed for inspection of the standard types of tolerances (concentricity, perpendicularity i.e.) and basic inspection features (IF) (plane, cylinder, truncated cone i.e.). The result of this paper is a new approach of the conceptual development of the digital inspection twin, based on CMMs - towards off-line DIT based on CMM by virtue of the control data list (CDL) and .ncl (DMIS) file.

1. Introduction

In order to realize the project vision of smart Assembly 4.0, the paper [1] specifies and highlights the infrastructure, components and data flows necessary in the Digital Twin.

A chapter of the book [2] focuses on the simulation aspects of the Digital twin, in this sense, simulation merges the physical and virtual world in all lifecycle phases.

The paper [3] gives a review of digital twin applications in manufacturing, where special focus is on the degree of integration of the proposed DT with the Manufacturing Execution Systems (MES) and practical implementation of a DT in a MES equipped assembly laboratory line.

> "Digital twin, a new emerging and fast growing technology which connects the physical and virtual world, has attracted much attention worldwide recently" [4].

The paper [5] presents a virtual replica to work parallel to an integrated inspection system (IIS) for inspection of freeform and complex surfaces based on a metric of their geometric complexity.

In line with this, and in harmonizing the protocols proposed in this paper with STEP-NC AP 238 and ISO 23247 standards, which primarily refer to manufacturing, according to Ref. [6], future research will involve the analysis of these standards application in the development of a complete DIT for CMM, as well as Quality Information Framework (QIF).

Manufacturers have to accept small-scale orders due to the limited profit margins and huge costs caused by the vacancy of production lines [7]. For this reason, it is necessary to develop a DIT that would enable the monitoring of an extremely diversified measurement needs.

The paper [8] analysed the status of digital twin research and reviewed the digital twin from the perspective of concepts, key technologies, and industrial applications. From the viewpoint of manufacturing, these authors point out that the role of digital twin is essentially to improve processing quality and reduce production cost in an efficient, dynamic, and intelligent manner, which is not available in the traditional method, as well as that the problems of data integration and complex phenomena modelling remain to be solved in future works.

From a simulation point of view, the Digital Twin approach is the next wave in modelling, simulation and optimization technology [9].

According to Ref. [10], many ways have been proposed to differentiate the digital twin from more traditional notions of modelling and simulation, such as real-time visualization as a key innovation with digital twins, while other research has focused on the digital twin as a virtual duplicate of a physical system.

The paper [11] specifies and highlights functionality and data models necessary for real-time geometry assurance.

Generation of inspection data as support to digital twin for geometry assurance, as well as an inspection strategy serving the Digital twin is given in Ref. [12].

As can be seen from literature review, DIT belongs to the field of measurement in production and its development is crucial for this field and its future development in era digitalization technologies. The basis for the development of this approach is the intelligent system [13] and the applied artificial intelligence techniques presented in Refs. [14,15].

The research problem in this paper is the development of DIT for older generations of control units of CMMs and the implementation of STEP-NC standard.

The result of this paper is a new approach of the conceptual development of the digital inspection twin, based on CMMs - towards off-line DIT based on CMM by virtue of the control data list (CDL) and .ncl (DMIS) file.

2. Method and data model

This method starts from modelling of the prismatic workpiece (PW) with predefined tolerances, then modelling of the CMMs UMM500 and DEA-IOTA-2203 components, fixture clamps, as well as probe design in CAD system PTC Creo and Autodesk Inventor, Fig. 1. By setting the coordinate systems and selecting the corresponding kinematic links of

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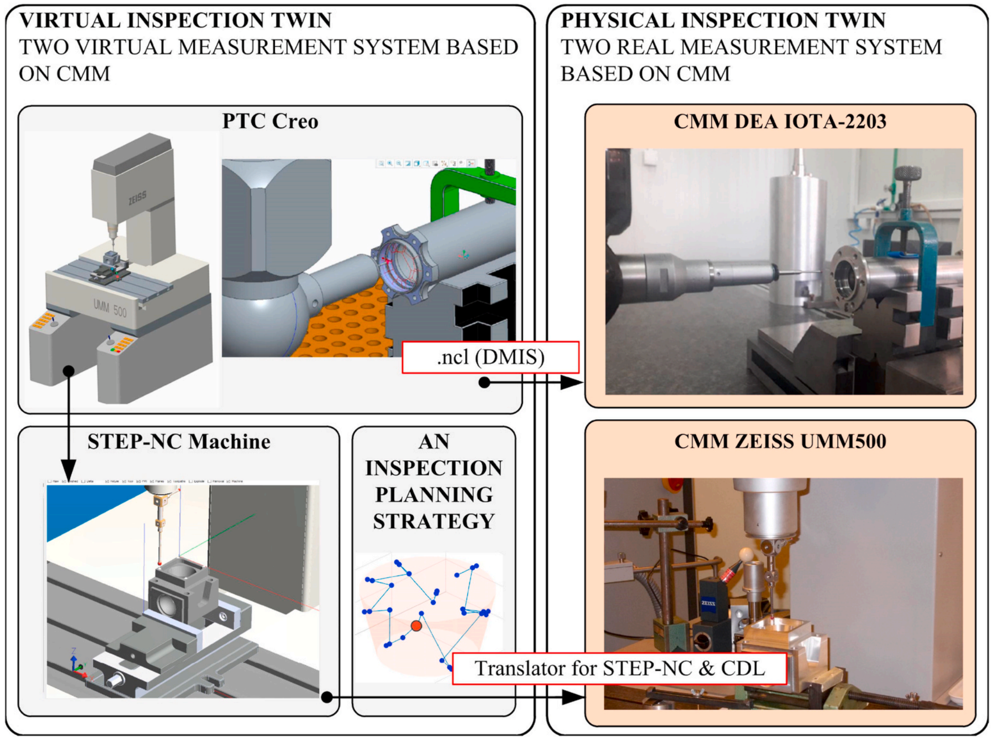

Fig. 1. Outline of the concept - DIT based on two types of CMMs.

the machine CAD components, virtual CMMs was configured in a software system PTC Creo. Import of a modelled configuration of CAD measuring probes in the software STEP-NC Machine is also performed, as well as import of a CAD model of PW and fixture within the framework of virtually created UMM500 generates a virtual measurement system.

STEP-NC file was generated by programming and simulating a measuring path for standard types of tolerances, and associated Ifs (plane, cylinder, truncated cone, i.e.). The developed translator converts STEP-NC file to CDL instructions for machine UMM 500 thus enabling the execution of measurement on a real machine. This pairing of the virtual and physical measurement system allows DIT, that is, analysis of control data and monitoring of overall measuring systems, collision avoidance between PW and probes, prevention of errors and problems in inspection planning.

In simulation and generation of the STEP-NC file, STEP-NC Machine software uses its measurement strategy (measuring points distribution, choice of databases and sequence of features, etc.), which cannot be affected from user's viewpoint. In parallel with STEP-NC measurement strategy, the paper considers a novel strategy of measuring path generation. This strategy, Fig. 1, consists of inspection planning model that includes a modified Hammersley's algorithm, accessibility analysis and collision avoidance principle, whose aim is the generation of a measuring path of the point-to-point shape and visualization in software for collision check. The generation of the measuring path for Inspection planning of modelled PW consists of two sets of points. Those points necessary for inspection, generated for the features of the PW, are sorted with the purpose to generate a unique sequence for the needs of loading the path in the translator and conversion to CDL.

Presented approach for development of DIT in this paper refers to already machined prismatic parts (post-processing measurements), that is to say, the chain of measurement data retrieved ends with data on measured value generated by software CMMs UMM500 and DEA-IOTA-2203 after statistical data processing. The chain of retrieved machine data, the primary goal of this work, ends by generating CDL for CMM UMM500 and .ncl (DMIS) for DEA-IOTA-2203.

Presented approach leaves the possibility of using Web interface and server, because it affords DIT simulation and is accessible to participating clients on a cloud platform. On this way, DIT allows the activities to be implemented wherever there is an end-client.

The physical components are two CMMs, as it is shown on Fig. 1.

3. Towards the digital inspection twin

DIT and its approach to development in this chapter encompass the flow of data between physical and digital twin in one direction. From the standpoint manufacturing data the inspection process is specific because that consists from post-process as the final process and in - process inspection. Therefore, the measurement data report for post-process inspection is a final-output document and no further return (bi-directional flow of information) to the manufacturing is required.

3.1. Physical twin

As it is mentioned as the physical twin are used CMMs ZEISS UMM 500 and DEA-IOTA-2203. The reasons for using both of the CMMs are interoperability problem between different softwares which using CMMs in this paper and different of protocol for information flow. Namely, as the main data formats, one machine uses a CDL and the other a DMIS file.

3.2. Virtual twin

A measuring path was programmed, a virtual inspection systems based on a virtual CMM UMM 500 and IOTA-2203 was simulated for standard types of tolerances of PW, as well in STEP-NC Machine software was generated.

In the absence of CMM control unit that can interpret STEP-NC programme, STEP-NC Machine software provides the possibility to simulate a measuring path using the configured measuring machine UMM500. Using STEP-NC makes possible to have an integrated process planning system for both machining and inspection processes. STEP-NC

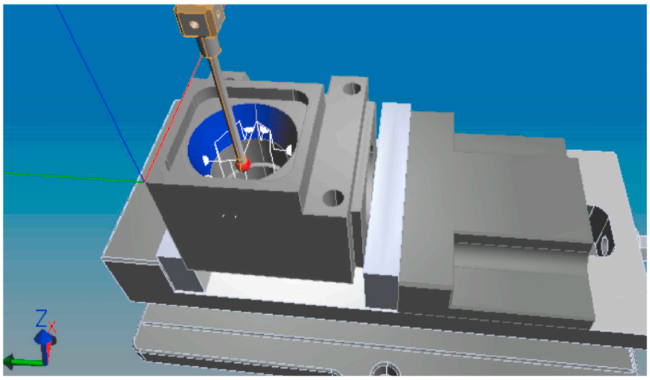

Fig. 2. A STEP-NC Machine simulation view (inspection of cone).

Machine software can provide two types of inspection: on-machine inspection, and inspection on a separate CMM. This approach considers off-line programming method, based on the standard ISO 10303–238, using developed module for CMM control data list generation. The module converts STEP-NC file in P21 format to CMM control data list with instructions for the CMM axes movement. Segment of the inspection path for cone inspection is shown in Fig. 2.

Detailed virtual CMM with all kinematic relation between moving components created in PTC Creo software shown in Fig. 3. Slider connection is used for the all translatory movement. Simulation of measuring path allows motion of movable segments of virtual CMM, with the probe. Matching the coordinate system of PW and coordinate system on working table enables the setting of the PW on the configured virtual inspection system based on CMM during the measuring simulation. Also, during the path simulation on virtual CMM, Fig. 3c, and d) besides PW and probe that moves through measuring path, it is possible to create and load fixture that is of importance in verification of measuring path and detection of the possible collisions. After the simulation on virtual CMM generated measuring path that is saved in CL file (DMIS program) is verified.

In order to realize DIT, it is necessary to harmonize the output-input files of the two programs PC-DMIS and PTC Creo. The PC-Dmis software allows the import of a .ncl (dmis) file, previously generated and tested in the PTC Creo software using the standard import → dmis command block. Previously, a .ncl (dmis) file was generated in PTC Creo to verify the inspection plan procedure on the virtual CMM. Fig. 4 shows an illustration of an imported virtual measuring machine in the PC-Dmis program. The machine in the functional sense completely coincides with the real measuring machine DEA-IOTA 2203, and on which the plan of inspection of the part - bearing carrier was performed.

The final representation of the developed DIT is shown in Fig. 5. CMM UMM500 is shown in Fig. 5a) and b), while CMM DEA-IOTA-2203 is shown in Fig. 5c) and d). Communication between physical (Fig. 5b) and Fig. c)) and digital twin (Fig. 5a) and c)) is done with unidirectional data flow via a CDL and .ncl (dmis) file.

4. Conclusions

DIT presents a bridge between the physical and virtual inspecting world and has a significant impact on inspection planning through increasing the efficiency of processes. This paper proposes a novel DIT approach of the development for CMMs. The inspection systems with the CMMs UMM 500 and DEA-IOTA-2203 was used as a physical twin, and as a virtual twin that same machine, but a virtual one, was modelled and configured in software PTC Creo, as well as CAD model PW and fixture

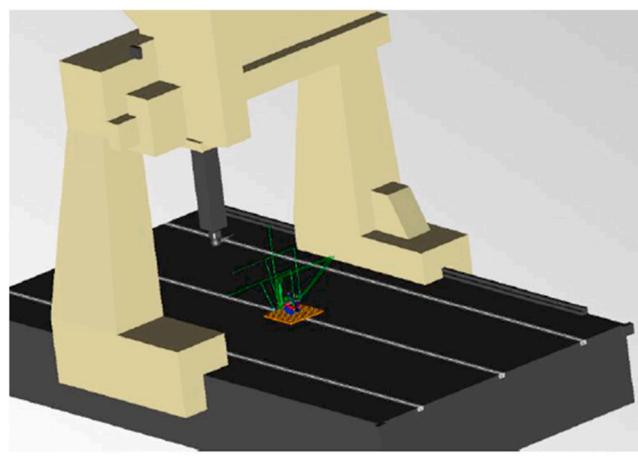

Fig. 4. PC-DMIS simulation view.

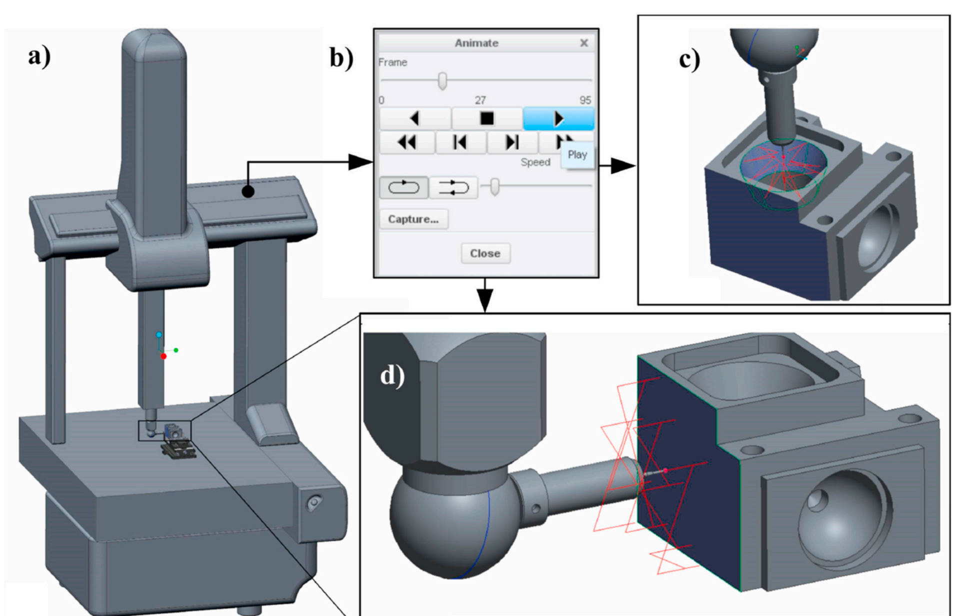

Fig. 3. A PTC Creo simulation view: a) virtual inspection system based on CMM, b) play options, c) inspection of cone, d) inspection of plane.

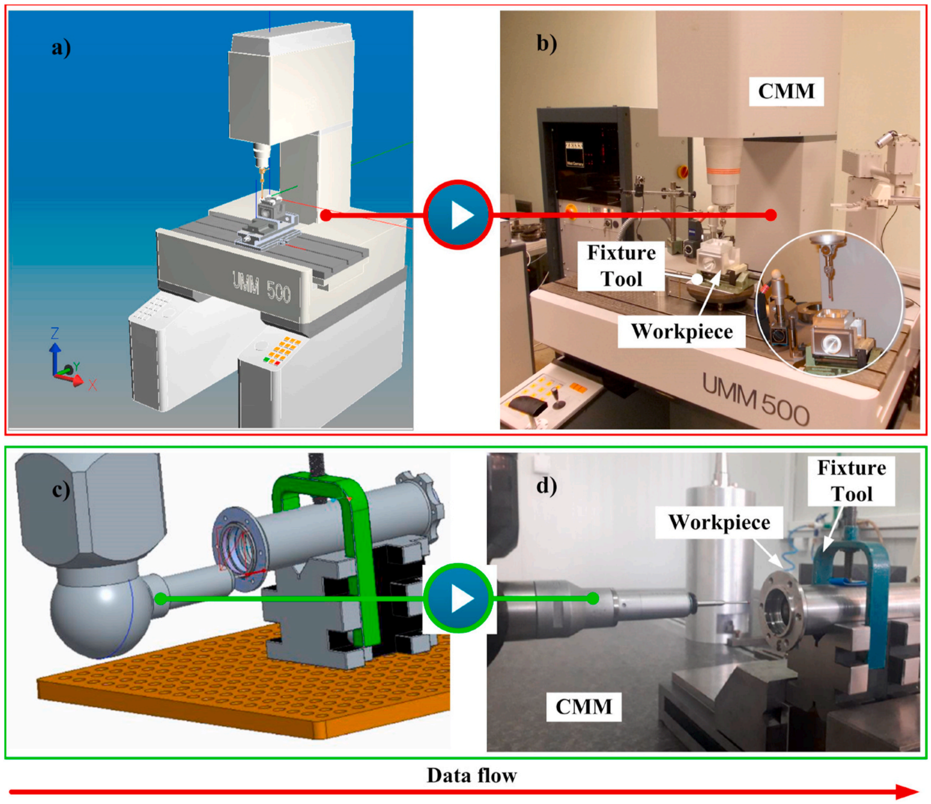

Fig. 5. DIT based on CMMs.

clamps as component parts of a virtual inspection systems.

A measuring path was programmed, a virtual inspection systems operation based on a virtual CMMs. This approach of the development DIT presents indirect programming method or off-line DIT with one-direction of data flow. The result of this paper is a new approach of the conceptual development of the digital inspection twin, based on CMMs - towards off-line DIT based on CMM by virtue of the control data list (CDL) and .ncl (DMIS) file.

Besides the to-date developed off-line DIT, future research will also include DIT development with bi-directional data flow between physical and virtual CMMs, In addition to developing DIT, the paper provides an overview of the possibilities of applying STEP-NC standard with the aim of generating CDL for available CMM UMM500, that is, the development of CDL for CMM whose control units do not support the programme written based on standards STEP-NC and QIF. One of the development directions is the extension of this concept to CMMs of other manufacturers, and thereby harmonization of STEP-NC in the application for programming CMMs of various manufacturers (software).

On the basis of proposed methodology, the directions of future research would embrace extension to non-prismatic machine parts and development of digital thread for measurements on a CMM.

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