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CYBER-PHYSICAL MANUFACTURING SYSTEMS – MANUFACTURING METROLOGY ASPECTS

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Abstract: *Cyber-Physical Systems (CPS) are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet. Cyber-Physical Manufacturing Systems (CPMSs), relying on the newest and foreseeable further developments of computer science, information and communication technologies on the one hand, and of manufacturing science and technology, on the other hand, may lead to the 4th Industrial Revolution, frequently noted as Industry 4.0. CPMS consist of autonomous and cooperative elements and sub-systems that are getting into connection with each other in situation dependent ways, on and across all levels of production, from processes through machines up to production and logistics networks. Modeling their operation and also forecasting their emergent behavior raise a series of basic and application-oriented research tasks, not to mention the control of any level of these systems. The fundamental question is to explore the relations of autonomy, cooperation, optimization and responsiveness. Integration of analytical and simulation-based approaches can be projected to become more significant than ever. One must face the challenges of operating sensor networks, handling big bulks of data, as well as the questions of information retrieval, representation, and interpretation, with special emphasis on security aspects. Novel modes of man-machine communication are to be realized in the course of establishing CPMS. The main goals of the paper are to discuss those approaches and milestones pointing towards the realization of Cyber-Physical Manufacturing Systems as well as to highlight some future R&D opportunities, especially in manufacturing metrology area.*

Key words: *manufacturing, ICT, modeling, simulation, manufacturing metrology*.

1. INTRODUCTION[1]

Today's business structure is much more complex and dynamic than ever before. Market demands of the industry's rapid changes in new products, which is directly reflected in the factory. On the other hand, digitization and information technology (IT) technologies provide new, unimagined possibilities, engineers in the field of design and planning. The two approaches have led to two concepts that have since emerged: digital factory and digital manufacturing. They enable to improve the engineering product development and create a new era in business and manufacturing, the sustainability of one of the most important factors of business [1]. Targets set in front of the digital factory are: to improve the technology of manufacturing, reduce costs of planning, improve the quality of production/products, and increase the flexibility of the new demands of customers and markets [2].

Developed and implement "advanced manufacturing" as a base for Cyber − Physical Manufacturing Systems (CPMSs), will be to evolve along five paths, Fig. 1. [3]: (i) On – demand manufacturing: Fast change demand from internet based customers requires mass-customized products. The increasing trend to last-minute purchases and online deals requires from European manufactures to be able to deliver products rapidly and on-demand to customers. This will only be achievable through flexible automation and effective collaboration between suppliers and customers; (ii) Optimal (and sustainable) manufacturing: Producing products with superior quality, environmental consciousness, high security and durability, competitively priced. Envisaging product lifecycle management for optimal and interoperable product design, including value added after-sales services and take-back models; (iii) Human − centric manufacturing: Moving away from a production-centric towards a human-centric activity with great emphasis on generating core value for humans and better integration with life, e.g. production and cites. Future factories have to be more accommodating towards the needs of the European workforce and facilitate real-time manufacturing based on machine data and simulation, (iv) Innovative: From laboratory prototype to full scale production – thereby giving competitors a chance to overtake European enterprises through speed,

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and (v) Green: Manufacturing 2020 needs focused initiatives to reduce energy footprints on shop floors and increase awareness of end-of-life (EoL) product use.

The digital manufacturing concept could address majority of the mentioned challenges, and it focuses on the improved automation and digitisation of the planning, design, manufacturing, inspection, management, and other activities in production system in a wider context. The digital model of a product could be used to simulate and analyse the manufacturing processes, production planning scenarios, as well as machining/tool path, inspection and resource utilisation scenarios.

For a manufacturing system with typical machining operations, factory-wide knowledge integration requires an integrated CAD-CAPP-CAM-CNC-CAI and integration with other production-related information systems such as enterprise resource planning (ERP), manufacturing execution system (MES), advanced planning and scheduling (APS), etc. A standard for the exchange of product data model (STEP), along with a STEP compliant numerical control (STEP-NC), has been developed to enable integration and exchange of design and manufacturing numerical data. STEP is based on feature technology, and it provides a neutral and interoperable format of product data, independent of any system and suitable for transfer, processing and communication among different systems. Feature technology provides us to associate not only geometric and topological information, but also form features and tolerances that could be used in CAD-CAPP-CAM-CNC-CAI chain [5, 6].

Continuously integrated product design, factory and process planning as well as factory operation and maintenance: (i) modeling, simulation, optimization and visualization of products, factories and processes, (ii) Networking and distribution of data, models, tools and computer resources with the support of grid technologies. We have next benefits: reduction of time, lowering of costs and increase of throughput and quality.

2. CYBER - PHYSICAL MANUFACTURING SYSTEMS (CPMSs)

Cyber-physical systems (CPSs) are enabling technologies which bring the virtual and physical worlds together to create a truly networked world in which intelligent objects communicate and interact with each other [7]. Together with the internet and the data and services available online, embedded systems join to form cyber-physical systems. CPSs also are a paradigm from existing business and market models, as revolutionary new applications, service providers and value chains become possible [5–7].

The merging of the virtual and the physical worlds through CPSs and the resulting fusion of manufacturing processes and business processes are leading the way to a new industrial age best defined by the INDUSTRIE 4.0 project's "smart factory" concept, Fig. 2. [6].

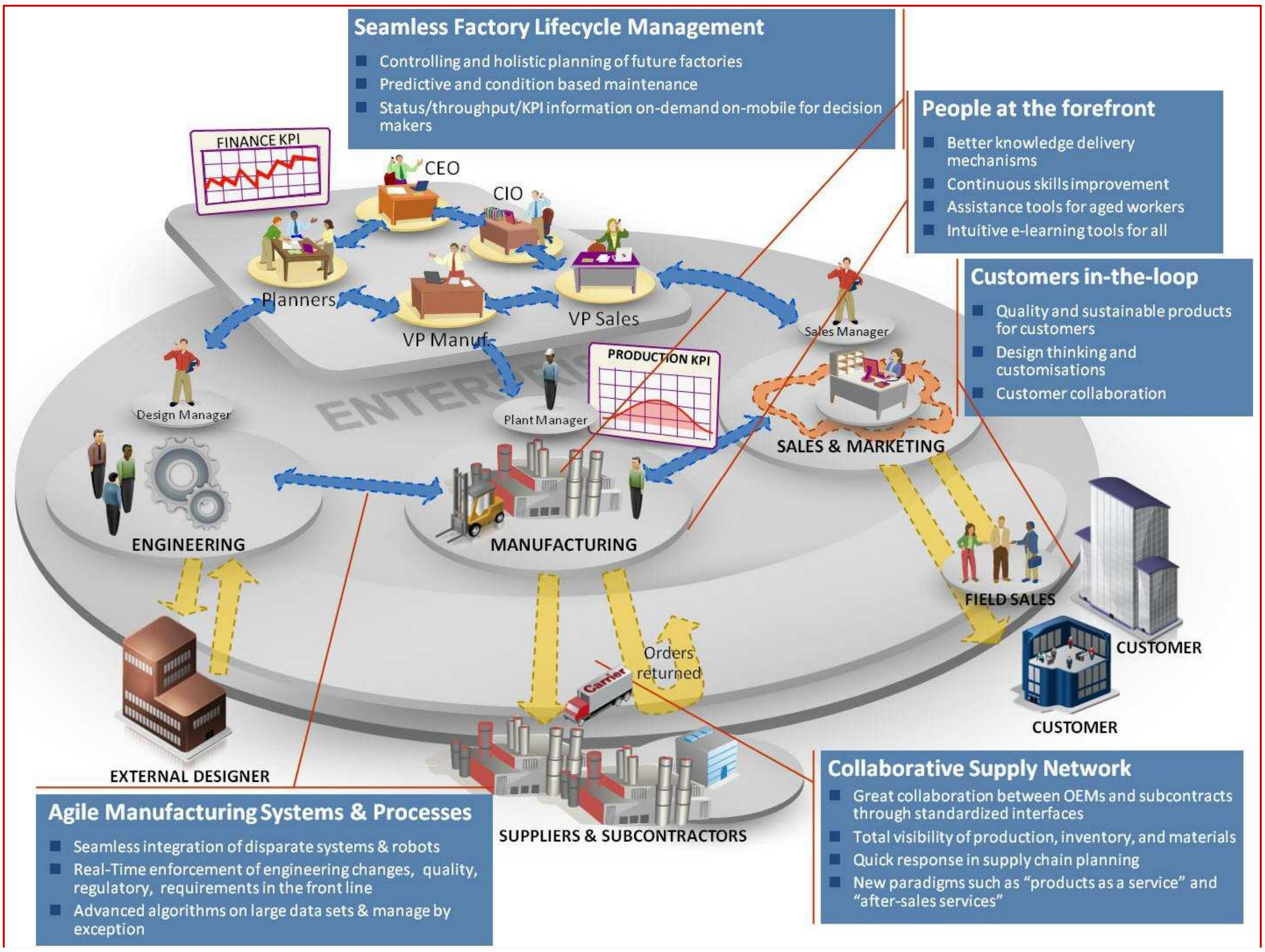

Fig. 1. A manufacturing 2020 enterprise – advanced model [3].

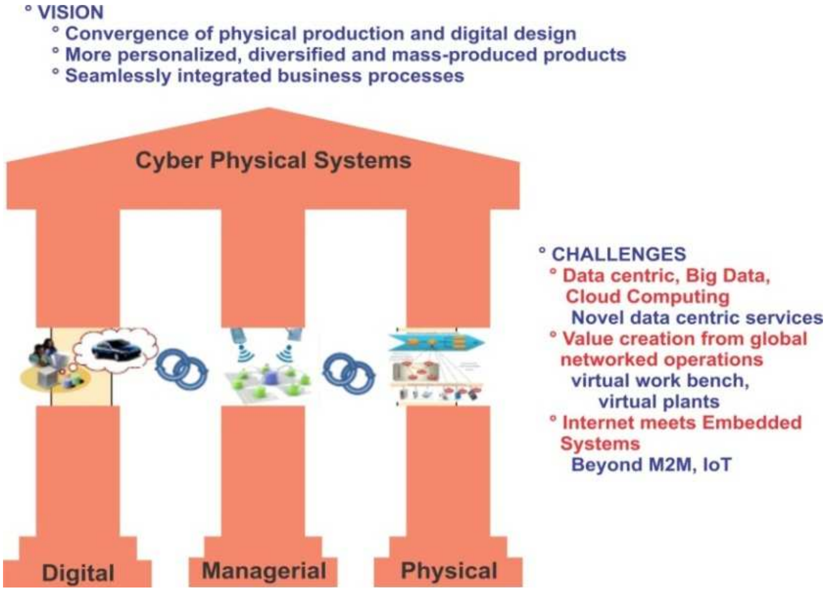

Fig. 2. CPSs – Basic facts [7].

The deployment of CPSs in manufacturing systems gives birth to the “smart factory”. Smart factory products, resources and processes are characterized by CPSs; providing significant real-time quality, time, resource, and cost advantages in comparison with classic manufacturing systems [6]. The smart factory is designed according to sustainable and service-oriented business practices. These insist upon adaptability, flexibility, self-adaptability and learning characteristics, fault tolerance, and risk management.

High levels of automation come as standard in the smart factory: this being made possible by a flexible network of CPSs - based manufacturing systems which, to a large extent, automatically supervise manufacturing processes. Flexible manufacturing systems which are able to respond in almost real-time conditions allow in-house manufacturing processes to be radically optimized [6]. Manufacturing advantages are not limited solely to one-off manufacturing conditions, but can also be optimized according to a global network of adaptive and self-organizing manufacturing units belonging to more than one operator.

Smart factory manufacture brings with it numerous advantages over conventional manufacture, as example [5–7]: (i) CPS - optimized manufacturing processes: smart factory “units” are able to determine and identify their field(s) of activity, configuration options and manufacture conditions as well as communicate independently and wirelessly with other units; (ii) Optimized individual customer product manufacturing via intelligent compilation of ideal production system which factors account product properties, costs, logistics, security, reliability, time, and sustainability considerations; (iii) Resource efficient production; and (iv) Tailored adjustments to the human workforce so that the machine adapts to the human work cycle.

This approach as a manufacturing revolution in terms of both innovation and cost and time savings and the creation of a “bottom-up” manufacturing value creation model whose networking capacity creates new and more market opportunities.

3. OUR RESEARCH IN THE FIELD OF CYBER-PHYSICAL MANUFACTURING METROLOGY MODEL (CPM^3)

In our Laboratory for Production Metrology and TQM on Mechanical Engineering Faculty, Belgrade, now we have following researches areas: (i) Digital Manufacturing – Towards Cloud Manufacturing (base for CPMs), (ii) Intelligent model for Inspection Planning on CMM as part of CPM concept, and (iii) CPMS – CPQM our approach. In this paper we shall show some research results for third direction.

Digital quality, as a key technology for CPMs represents virtual simulation of digital inspection in digital company, based on a global model of interoperable products (GMIP). GMIP represents the integration CAD-CAM-CAI models in the digital environment. The essence of of this research is solved the concept of metrology integration into GIMP for the CMM inspection planning, based on Cyber-Physical Manufacturing Metrology Model (CPM^3) [10, 11].

Feature-based technology and STEP standard could be considered as a main integrator in terms of linking the engineering and manufacturing domain within various CAx systems. To specify the part data representation for a specific application, STEP (ISO 10303) uses Application Protocols (AP) [13]. Beside STEP APs, the following standards and interfaces are important for CAI. A vendor-independent Dimensional Measuring Interface Standard (DMIS) provides the bidirectional communication of inspection data between systems and inspection equipment, and is frequently used with CMMs. It is intermediate format between a CAD system and a CMM’s native proprietary language. Dimensional Markup Language (DML) translates the measurement data from CMMs into a standardised file that could be used for data analysis and reporting. I++ DME-Interface provides communications protocol, syntax and semantics for command and response across the interface, providing a low level inspection instructions for driving CMMs [12, 13, 15, 16], Fig. 3.

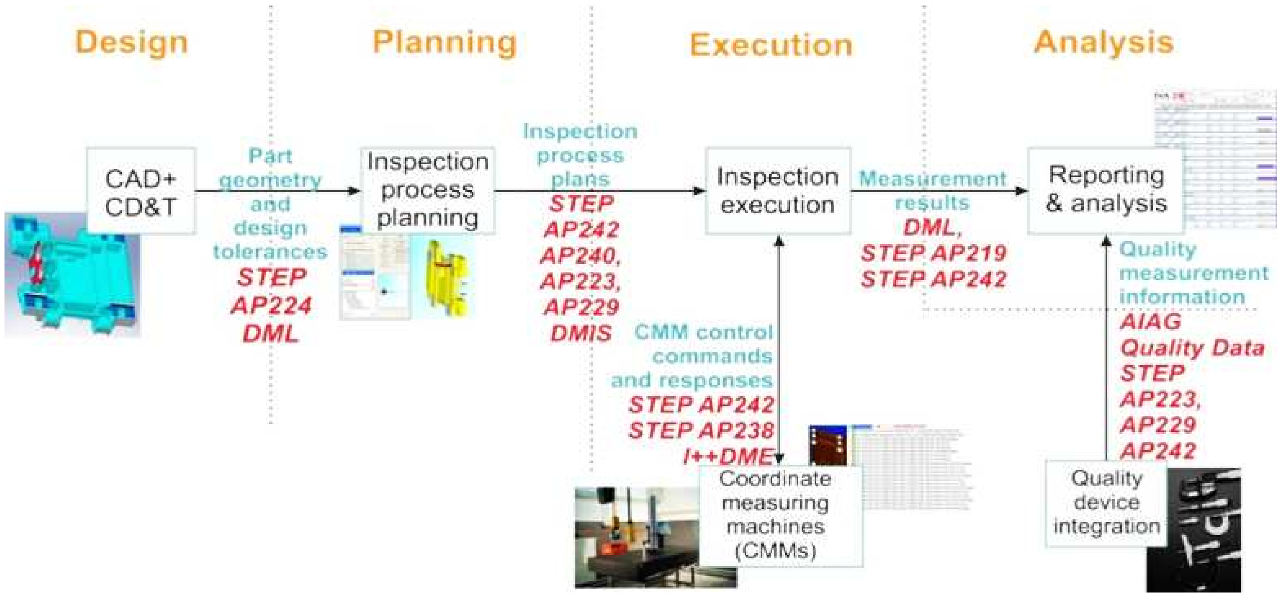

Fig. 3. CMM interoperability model [13].

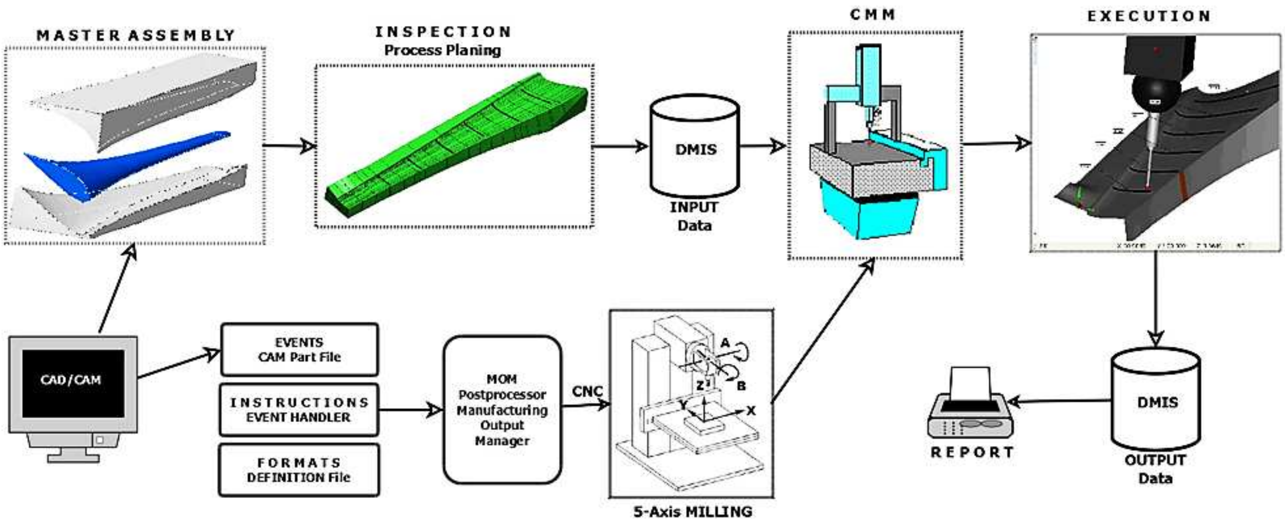

Fig. 4. Process with the integration of design, production and coordinate inspections (CAD-CAI integration).

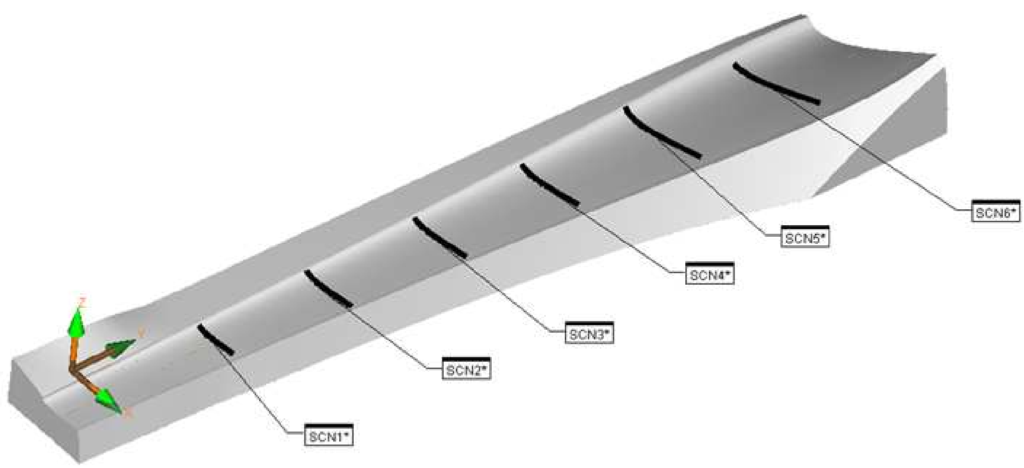

Fig. 5. Bottom of the tool for wind turbine with inspection plan.

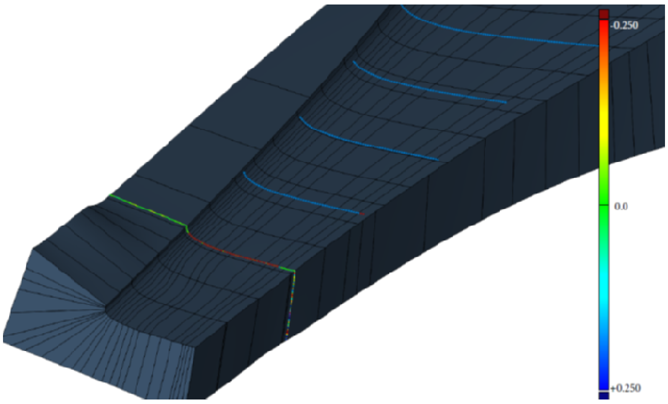

Fig. 6. STEP loaded in coordinate system for inspection.

Fig. 7. DMIS file for inspection turbine blade.

Fig. 4. shows the working process with the integration of design, production and coordinate inspections. Master Assembly represents the mechanical assembly with all associated parts. This assembly consists upper and lower tools and wind turbine. The experiment was done on the bottom of the tool (Fig. 5).

Computer aided manufacturing (CAM) or Computer aided inspection (CAI) is executed in a separate part-file that consists the original geometry of the part [14]. Only this way it is possible to make changes on the original geometry that can reflect on some of the engineering activities.

Part file CAD/CAM is usually obtained as STEP AP203 or AP214. It represents the basis for the preparation of manufacturing technology. At the same time a geometry inspection is being prepared so that when a part is manufactured, its inspection can be implemented on the numerical measurement machine (CMM).

As an output from CAD/CAM, STEP AP203/214 is obtained which is the input for PC-DMIS Wilcox. S/W Wilcox PC-DMIS uses its integrated translator to convert it into DMIS format. At this stage GD&T and the motion of measurement probe are defined. Based on the acquired measurements, "DMIS output" was generated which can be a printed report or STEP too, but now with measured geometry. This STEP can be loaded again into a CAD/CAM system or some other coordinate system for inspection (Fig. 6), and contents for the same part of DMIS file (Fig. 7), give procedure CMM inspection.

4. CONCLUSIONS

In the above presented of SPMSs for quality as a CAI model, it is important to consider the newly developed AP242 that is designed to improve the interoperability in STEP, support model-based GD&T and allows for CMM programming based on the inspection features. AP242 enables 3D product manufacturing information (PMI) with semantic representation and 3D model-based design and data sharing on service-oriented architecture (SOA).

The adoption of AP242 will further enhance interoperability among different information systems and data exchange along the supply chain. This could be of paramount importance for SMEs, since it could allow usage of lower cost software based on standard interfaces which should lead to a cost reduction [13]. On the other hand this concept (CPM3), will integrated in CPMSs model in our future researches [11].

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