Principles of designing cyber-physical system of producing mechanical assembly components at Industry 4.0 enterprise

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Abstract. The task of developing principles of cyber-physical system constitution at the Industry 4.0 company of the item designing components of mechanical assembly production is being studied. The task has been solved by analyzing the components and technologies, which have some practical application in the digital production organization. The list of components has been defined and the authors proposed the scheme of the components and technologies interconnection in the Industry 4.0 of mechanical assembly production to make an uninterrupted manufacturing route of the item designing components with application of some cyber-physical systems.

1. Introduction

The actual production companies do their activity today according to the technological processes of the Industry 3.0 standard. Some new technical, software and program solutions and automatizing systems are being implemented in the company project and production activity to increase the profitability of designer work and to reduce the time needed for completion of separate stages of the item life cycle.

By analyzing the ways of the company production capabilities modernization, one could clearly say that the primary tendencies which are being maintained by the companies are the expenses reduction, technological process automatizing and etc. But they also include digitalizing project procedures, the production supply process, logistics, the maintenance of the item functionality and etc.; in general it is about the item life cycle.

The optimization of item life cycle stages involves also some secondary tasks which are needed to be solved to create new approaches of production division designing at the Industry 4.0 enterprise which maintains the integrity of technological, technical, program and other means and systems which automatize the designing and production stages of the item designing components. Three types of companies can compose such «smart productions» which are «digital factory», «smart factory» and «virtual factory». The practical implementation of the item digital manufacturing technologies (without humans) are their primary purpose.

The constitution principles of manufacturing «without humans» are the conversion of science and technology into the key factor of the economy industrial sector development. Those principles are
implemented for the technological and testing equipment components application, which maintains
digital automatic manufacturing options. Such digital robotized components are cyber-physical
systems.

2. Technologies lying in the basis of project and production activity of Industry 4.0 companies

The new perspective approaches concerning the way of organizing the company production division,
which are actively developing today in Russia and being implemented abroad, were called the Industry
4.0 standard. Those approaches are based on the new digital technological processes implementation
in the item life cycle starting from its designing stage and ending at its recycling stage. The most
important technologies of the Industry 4.0 standard are [7, 8]:
- additive technologies;
- internet remote data storage technologies;
- cyber-physical systems security technologies;
- set of industrial detectors;
- augmented reality technology;
- Internet of things technology (IoT – Internet of Things);
- BigData technology of a huge amount of manufacturing data processing and others.

Generally, the Industry 4.0 is a generalized term which was used for the first time in 2011 in
Germany as a measure to implement the national development strategy of the industrial sector Hi-
Tech. The sense of the term «Industry 4.0» is a set of technical and economic solutions which are
being implemented in the company project and manufacturing activity to organize an integrated
designing environment and to manufacture the items applying digital information technologies. In
terminology [9], the term «Industry 4.0» is equal to the «fourth industrial revolution».

The primarily expected results from the implementation of the Industry 4.0 technologies in the
company project and manufacturing activity count down to the possibility of:
- constructing the production divisions which maintain the technology of manufacturing «without
humans»;
- constructing the project environment which is capable to maintain the technology of virtualization
and etc.

To implement this kind of approach, the new digital models of items, which serve as digital «twin»
of a real item after a fashion, should be developed and applied in the company project and
manufacturing environment in the field of item designing. The item digital model is something more
than a 3D geometrical description of computer models (3D - Dimension), which are prepared on the
base of computerized systems of automatic designing (CAD), because a 3D–model makes it possible
for a designer to start working on the 4D-models, for which time is an independent parameter of the
item life cycle evolution, which is important for maintaining the economy digitalization processes [11,
12].

The implementation of the item belonging to 4D-models, which is capable to evolve in time, is a
good starting point for creation of the project and manufacturing company «digital twins» in which the
greatest attention of the organization technological infrastructure is paid to the application of subject
oriented digital technologies which make it possible for the designer (manufacturer) to:
- execute some project prognostication procedures, which predict the future item, which for now
exists in the digital model format, the behavior during its exploitation;
- execute some project prognostication procedures for the item manufacturing processes to select
the most reasonable algorithms of technological processes and manufacturing routes and others.

So the companies which maintain the most important technologies of the Industry 4.0 standard
must have a computerized wireless control system which integrates technological equipment
(industrial robots), CAD program components, industrial data processing program components and
others.

To ensure the good performance of the Industry 4.0 project and manufacturing companies, it is
necessary to create item «digital twins» as well as «digital twins» of:
- item manufacturing technological processes;
- technological equipment (robotized cyber-physical systems);
- the external influence factors (environment models) and others.

Such «digital twins» which are input data for the CAD systems and systems of production automatic technological preparation in the future become the base of the new generation state standards and also define the new kinds of construction and program documents and the new order of the documentation exploitation in the production and etc.

The advanced research results in the field of the digital designing and item manufacturing perspective technologies development belong today to the leading technology companies, in particular to company Siemens. In company Siemens, they created the designing instrument Digital Enterprise Software Suite (DESS) which is capable to maintain option preparation and analysis automatizing procedures of modelling project solutions for technological processes imitation of the industrial application automatic lines. The DESS software includes:
- the instruments of designing subsystem CAD NX;
- the instruments of planification subsystem Teamcenter;
- the instruments of subsystem Tecnomatix and others.

These instruments are used to model and analyze options of the item solution at different stages of its life cycle including the possibility to make documentation of designing results which are formed automatically.

3. Mechanical assembly production cyber-physical system components
The base of perspective mechanical assembly productions of Industry 4.0 for the field of item designing is the technologies and components (Figure 1) oriented to the application in the digital economy environment and forming a part of a cyber-physical system. The technologies of a cyber-physical system are [1, 2]: remote storage data technologies, additive technologies, the Internet of Things technology (IoT – Internet of Things), the BigData technology to process a large quantity of data, the set of industrial detectors technology and others.

The components of the digital cyber-physical systems are [3, 4] automatic robots (testing and technological equipment) — cyber-physical machines which make in the production in the automatic mode one or several technological operations of item designing component manufacturing. The cyber-physical units servicing requires from the production additional personnel to make routine and preventive works. When the personnel role in the Industry 3.0 production was included to make some production operations in the automatic mode with the technological equipment, an integrated controller automatically controls a cyber-physical equipment in the Industry 4.0. The sequence of the technological operations and its content can be defined with the technological route, which is unique for each item designing a component and is prepared at the stage of technological preparation of production.

Each digital cyber-physical component in the Industry 4.0 production contains:
- a set of detectors (in English «cyber-physical sensitive system» [3, 5]) which shows the state of equipment and status of item manufacturing technological operation completion;
- a set of gears — automatic robot executive elements which are applied to make some item manufacturing technological operations;
- an automatic controller which functions according to the programmed algorithms to produce the item designing component;
- a working chamber where they perform each manufacturing technological operation of the item designing of a component.
Figure 1. Cyber-physical system components of mechanical assembly production of the item designing of a component in the Industry 4.0 company.

4. Cyber-physical system interaction technology of mechanical assembly production

Cyber-physical units assembled together to make a particular item, manufacturing a technological process algorithm of a piece for example in sealant application and lacquering division or in SMD montage division, forms a cyber-physical system. The cyber-physical units’ interaction is described as a mathematical apparatus of a specialized technology [5, 6], which used to have in English the collective term “M2M” (Machine-to-Machine). The cyber-physical systems which interact between each other at the level of production sections or in separate technological lines can be described with the mathematical apparatus technology “S2S” (System-of-Systems).

Technologies M2M and S2S of interaction of the cyber-physical system components are built on the controlling laws theory of the digital automatic system with a random delay value [7]. Any delay in the cyber-physical system, controlling channel, can be explained with temporal characteristics of the IoT protocols with guaranteed message delivery and temporal characteristics of the production data processing algorithm completion in the environment of the remote data storage and access. Physically, technologies M2M and S2S are based on the wireless IoT channel, which grants access for the Industry 4.0 cyber-physical units to the services of remote data storage and access. Such cyber-physical system of remote data storage and access could be [8-13]:

- the automatic computer control algorithms for technological lines and production sections, which include the organized collection of production data (technological processes monitoring) and the forming of cyber-physical units control commands;
- the construction, program and technological documentation for the item designing component, which must be manufactured;
- the routing and protocolling algorithms for interaction of the cyber-physical units which maintains the specifications of the connection of wireless channel IoT for example, which is based on
a single-rank scheme with a gate topology (the simplest way is connection channel IoT based on the Bluetooth technology);

- an ontological glossary of the digital mechanical assembly production, which is a «bridge» after a fashion between the «physical world» of cyber-physical units and the «cyber-world» of the services of remote data storage and access;
- the production data processing algorithms based on the BigData technology (the production data are a collection of the information received from the cyber-physical sensitive system and includes the stochastic destructive factors, influencing the item manufacturing processes — instrument breakdown, equipment breakdown and other factors);
- 3D (Dimension)-models of the item designing components, working layers with 3D-printers additive technologies — a cyber-physical unit, applied in the manufacturing process of the item designing of a component;
- a set of State and branch (international) standards (norm and technical documentation) which prescribe the technological process content (operations) and the quality control of the item designing component manufacturing in the production and other things.

5. Conclusion
The Industry 4.0 production division arrangement is a complicated multi-factorial task, which includes the formal technical and economical indications of the company activity and quality criteria of the future mechanical assembly project and several issues:

- the preparation of qualified personnel which is capable to apply digital and intellectual production technologies in the field of cyber-physical system components exploitation;
- the preparation of standards in the field of machine and item designing of new generation and amendments of the laws, adapting them to the conditions of the digital economy, which regulates the company activity.

To solve this project task and to formalize the parametric space of those project solutions, it is necessary to create and successfully develop the new kinds of educational and professional standards in the close cooperation of creative groups of science education and industry representatives.

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