Modular architecture of cyber-physical production for Industry 4.0

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Abstract. The task is to create a digital production company equipped with cyber and physical systems. Cyber and physical transformations of productions is a direction for the industry development which is the paradigm of the Industry 4.0. The Industry 4.0 requires to implement in production autonomic production robots and advanced production technologies. The digital production main component is a production cell, production module and production system which interact in vertical and horizontal communication levels. Flexible production system control is done by the computerized control system. There is a scheme of module architecture for the Industry 4.0 cyber and physical production which functions with professionally prepared cadres.

1. Introduction
Cyber and physical transformation [1, 2] of digital production is a modern tendency for the world industry development in machine designing, item designing and other. The primary ideas how to create flexible automatic productions require the designers to know the following national programs:

- Advanced manufacturing partnership;
- The open manufacturing program;
- Digital enterprise;
- Reference architecture model RAMI 4.0 and other,

which are being realized today as the concept of the Industry 4.0.

In Russian Federation production industrializing is a part of national science and technical politics which steps are formed in a road map of the National technological initiative in the direction of “Tekhnet”.

In practice the idea of the Industry 4.0 concept [3, 4] creates the primary production structure with the nets of localized test sites which test the advanced informative technologies for automatic (automatized) project and production activity.

The test site of the Industry 4.0 is an integrated automatic production [5] equipped with flexible production systems designed with the module architecture. Test results of digital production components and technologies in the test sites are the base for digital factory and smart factory prototypes creation which functions according to the digital economy standards [6, 7]. The key role in production
Components testing is the evaluation of interaction compatibility of informative technologies as a single digital company which will ensure the production certification in a digital format [8].

Components and technologies digital certificates and flexible production system and the item itself define the properties of each object which are necessary for the stages of development, production and utilization. Each separate production technology today cannot give an Industry 4.0 company the competitive ability for the goods in the market of goods and services. Successful business solutions in production digitalizing contain the idea of cross branch technologies implementation which solve some application task and are used together in project and production activity of the company [9, 10].

Advanced informative technologies approbation in the test sites may create:

- production infrastructure of new type oriented for manufacturing of high tech goods;
- service infrastructure oriented for the item accompanying in all stages of its life cycle.

Cross branch production technologies interaction in the test sites is based on deep unification and standardization:

- digital project and production data representation formats;
- protocols and interfaces to exchange the industrial data,

which are used in physical and virtual levels of the company attention.

2. Advanced production technologies of the Industry 4.0

Advanced production technologies are a set of project procedures, processes of projection and production which correspond to modern technological level of the different difficulties items. Advanced production technologies are based on multi-disciplinary knowledge which are important for a particular industry branch.

In machine designing and item designing also the technologies are based on methods and means of digital modeling, prototyping, robotic technics, methods of industrial automatizing, additive production methods which require cyber and physical systems and other.

Implementation of new production technologies are made for transferring the company functioning from the existing concept of the Industry 3.0 to the organization of project and production activity on the base of digital factories, smart factories and virtual factories of the Industry 4.0 which provide different types of production processes.

Project and production processes of the Industry 4.0 are:

- modeling and prototyping which are parts of item projection;
- technological preparation and automatic production which are parts of item manufacturing;
- provision logistics, repairing and item servicing which are stages of item utilization.

So project and production processes are the base for the stages of item life cycle which is being produced in a digital factory in the paradigm of the Industry 4.0. Automatizing of project and production processes may significantly shorten the new equipment implementation time into use, reduce the production expenses and increase the rate of industrial intellectual ability by implementing new control mechanisms for the provision chains for item components and production assets in general.

The Industry 4.0 factories project and production activity digitalizing create the necessary conditions to develop the infrastructure company projects of physical productions, virtual environments of production companies and service centers which create eco systems of virtual factories.

Digital factories, smart factories and virtual factories of the Industry 4.0 are the project and production companies of new type oriented to manufacture competitively able high tech goods for a good consumer. A collateral task to organize digital production is a task of import exchange and tasks of high tech goods export which correspond the program of digital economy development. To solve the
task of digital production organization they use the innovation transfer technologies and methods of paperless and humanless production.

Economy industrial sector uniting the branches of machine designing and item designing is a driver for industrial advanced technologies and innovations development which significantly increase the added value of high tech goods being manufactured.

3. **Module architecture of digital company**

Module architecture of digital production company is given in figure 1. Digital production company division base is a flexible production module — an elementary cyber and physical system (CPS). Flexible production module in the National technological initiative «Tekhnet» terminology is a unit of technological equipment arranged on the base of item automatic assembly unit (parts). Flexible production module is for autonomous functioning as a part of flexible production cells and flexible production systems.

![Diagram of the Industry 4.0 digital production company module architecture.](image)

**Figure 1.** The Industry 4.0 digital production company module architecture.

A flexible production cell is a set of flexible production modules which are controlled by a computerized informative system of a digital company. Flexible production cell makes a closed cycle of item manufacturing technological operations completion by means of flexible production cells which include the machines of automatic assembly and machines of conveyor systems which is a part of robotized transport infrastructure of the company. The conveyor systems provide in production blank transferring among work stations of cyber and physical system including loading and unloading of production machines with materials and components by the production tasks which are in the routes of item manufacturing.

A flexible production system is a set of flexible production modules and flexible production cells which are controlled by a computerized informative system. Flexible production system is for organization of humanless production on the base of technological equipment being used in the Industry 4.0.

Flexible production systems in the types of flexibility could be classified as:

- the flexibility of which is an ability to adapt to the necessities of multi-nomenclature production (the flexibility of cyber and physical system) when the necessary self-organization of cyber and physical system to organize the item manufacturing of new type;
the flexibility of which is an ability to adapt to volumes production alteration of the items being manufactured in a digital company (operational flexibility of production);

the flexibility of which is an ability to adapt to the non-correct behavior which could happen in cyber and physical systems, robotized transport system and other components of digital production (production control system flexibility).

So a flexible production cell, flexible production module and flexible production system is an element of digital production module architecture equipped with the components providing the advantages of high tech goods mass production. The flexibility of such a production is an ability to quickly re-arrange a cyber and physical system and systems of production control when the item manufacturing organizing task is changed.

Within the flexible production system the interaction of production cells is done in the direction of vertical and horizontal connections. A vertical connection is realized by wireless communication nets and provide informative data exchange among cyber and physical systems and between cyber and physical systems and computerized control system. Data processing being circulated in the level of vertical connection is done in the digital company cloud environment.

Horizontal connections are done in production among cyber and physical systems by the sequence transferring of materials and parts (components) by a robotized transport system among work stations of production machines (cells) which function autonomously.

In practice the interaction of components in the vertical and horizontal levels of connection is done by:

- physical machine of cyber and physical system which support the technologies inter-machines Machine-to-Machine (M2M) and inter-system Systems-to-Systems, and also man-machines Humane-to-Machine (H2M) interaction;
- communication nets of wireless data exchange provide information exchange among cyber and physical systems using the protocols of industrial Internet of Things;
- cloud services from the digital company cloud environment and which supports the technologies of virtualization and technologies of augmented reality in production;
- program applications to automatize project and production activity in the company and to process industrial data using the technologies of BigData.

Those components of a digital production together form the hierarchy levels of infrastructure research of the Industry 4.0 company.

4. Conclusion

Designing digital manufacturing enterprises of Industry 4.0 is a multifactor scientific problem, the solution of which is based on mathematical optimization criteria. The modular principle of constructing the cyber-physical production architecture allows the introduction of particular quality criteria that numerically characterize each flexible production module, flexible cell and flexible production system. In the case of choosing numerical characteristics for each flexible production component in the class of additive-separable mathematical criteria, the scientific problem of designing digital production can be solved by the Volkovich method [6, 7].

The primary flexible production systems designed for digital enterprises should be:

- automatically technologically plot surface mounting elements in which the installation of radio parts on printed circuit boards;
- automatic technological section of additive printing, in which the manufacture of items using additive technologies;
- automatic technological section of humidity protection, in which all-climate performance of manufactured products is ensured;
• automatic technological section of electroplating in which special anti-corrosion materials are applied to metal parts;
• automatic technological section of the functional control, in which the procedures for checking the manufactured products are performed.

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