Synthesis of self-reconfigurable manufacturing systems in engineering

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Abstract. The scientific problem of the synthesis of reconfigurable manufacturing systems is considered. Reconfigurable manufacturing systems are an integral part of self-reconfigurable factories in engineering. Self-reconfigurable plants operate on the basis of flexible and advanced lines equipped with RMS. A scheme is proposed for decomposing the requirements of the technical specifications for the design of self-reconfigurable plants in order to determine the particular requirements for individual components of the plant’s infrastructure. An algorithm for designing a different class of reconfigurable manufacturing systems is proposed.

1. Introduction

The development of software and mathematical methods to automatize project works completion created a significant technological chasm between the complicated parts 3D-modelling capabilities and the capabilities of reconfigurable manufacturing systems (RMS), which is supposed to be used to manufacture the devices [1, 2]. Automatized developing means help the designer today to create technical documentation for the device, which manufacturing complexity level is calculated under the condition of additive production [3]. Numeric control machine pool production capabilities cannot fully satisfy now the necessities of modern reconfigurable plant.

An alternative to the existing device designing companies today are the plants [4, 5], which apply the new types of flexible technologies and new types of reconfigurable manufacturing systems (RMS). Advanced RMS and new flexible lines help to create [6, 7] the hybrid line equipped with RMS, which is capable to manufacture autonomously a large bunch of parts (mass production) of high quality. Such hybrid line is known as the reconfigurable plants [8].

The best practical results of RMS implementation and flexible technologies are seen [9, 10] today in plants, which activity is in the automobile construction. The reconfigurable plant designers obtained prepared solutions how to develop automatic hybrid lines to manufacture the parts from multi-material types and the assembly of the ready for use device. Such solutions have the arrangement property and may be implemented as ready for the manufacture in many countries [11].

Despite the massive demand for products, the engineering industry as a separate area of industry today does not have solutions ready for implementation. This is due, first of all, to the lack of certain types of RMS, by their properties capable of processing of multi-materials and components used in devices [12, 13]. To create engineering enterprises in which the introduction of flexible technologies
will take precedence, it is necessary to determine the key quantitative and qualitative requirements for automatic reconfigurable plants and all its components involved in the manufacturing [14].

2. Requirements decomposition to the reconfigurable plant components

Reconfigurable plant, equipped with RMS, is a technical complex, which includes hardware, software and brainware components, that interact with each other. The design of such reconfigurable plants involves a phased solution of design problems based on the principle of decomposition of the requirements for factory as a whole, for the requirements for its elements.

The decomposition scheme of the requirements of technical specifications (TS) for the design of a reconfigurable plant to the level of private TS for plant elements is shown in figure 1.

| Industry 4.0 plant | Digital production TS requirements formation | RMS production knowledge bank |
|--------------------|----------------------------------------------|-------------------------------|
| RMS interaction options TS formation | RMS different classes private TSs formation | Company cloud resources TS formation |
| RMS mechanical interaction TS | RMS mathematical provision TS | Cloud services TS |
| RMS man-machine interaction TS | RMS software TS | Cloud applications TS |
| RMS informative interaction TS | RMS machine hardware TS | Server machine provision TS |

**Figure 1.** Decomposition scheme of TS requirements for the synthesis project reconfigurable factory for private TS to the elements of infrastructure.

The initial data for the formation of the TS on the reconfigurable plant are the requirements that determine:

- the purpose and composition of the reconfigurable plant, the RMS of which is presented in the family of industrial systems;
- technical and economic parameters characterizing the reconfigurable plant;
- requirements for the types of support for reconfigurable plants (metrological, software, mathematical, brainware, etc.);
- requirements for raw materials and components ensuring reconfigurable plants;
- requirements for industrial safety of personnel, economic and information security of plant, etc.
The set of TS requirements for a reconfigurable plant can be divided into a set of private TS for each element. In the most general case, the requirements of the original TS should be divided into three groups of private TS:

- TS requirements for the development of multifunctional RMS of various types designed to automate the manufacture of devices;
- TS requirements for the design of RMS interaction methods, the production of which in the continuous mode implements the device manufacturing route;
- TS requirements for the design of plant cloud resources, through which information support (maintenance) of the device manufacturing process is provided.

The group of requirements for the development of multifunctional RMS is detailed on the requirements for:

- mathematical support of RMS, designed to perform computational and analytical tasks that describe the sequence of operations of manufacturing products;
- RMS software designed to generate control actions on RMS instruments based on the analysis of production data received from the RMS sensor system;
- RMS hardware intended for the direct execution of operations in the chambers of the RMS.

The group of requirements for the design of RMS interaction methods is detailed on the particular requirements for:

- mechanical methods of RMS interaction, as a result of which the robot moves parts from one RMS to another RMS in accordance with the device manufacturing route;
- informational methods of RMS interaction, as a result of which the principle of RMS self-reconfigurable is implemented using artificial intelligence methods;
- man-machine methods of interaction between the operator and RMS, as a result of which commissioning, process control, etc. are carried out at the reconfigurable plant.

The group of requirements for the design of cloud resources of the reconfigurable plant is detailed on the requirements for:

- the composition and types of cloud services that support the manufacturing processes of devices;
- the purpose and functions of cloud applications that allow RMS to perform one or more operations;
- server hardware, on the basis of which cloud services and applications are remotely created and run.

The numerical values of the requirements of the general TS and private TS for individual elements correspond to the current level of industry and flexible technologies, determined by the knowledge base on production.

### 3. RMS system designing algorithm

Multifunctional RMSs are the main technological unit of automatic reconfigurable plants. Today, RMS of various classes have been developed and are successfully used, performing complex operations in production in automatic or semi-automatic mode. The creation of flexible production lines in the area of engineering making will require the design of such technologies (methods, tools, RMS, etc.) developers that will provide the industry with a wide range of RMS for various purposes.

Figure 2 shows the route of the system design of RMS for various purposes using automation tools for design work.

At the system level of designing the RMS, it is advisable to solve the design problem in stages. The first stage of the synthesis of RMS involves the creation of a classification system of RMS, which should be based on essentially common types of manufacture operations carried out in production for the classes...
of the same name. For engineering enterprises, such RMS classes may include: solder reflow units, additive 3D-printers, moisture protective coating plants, etc. Such a RMS classification system can be created on the basis of specialized knowledge base and database on reconfigurable technologies.

The second stage of the system design of RMS is based on the introduction within each separate class of different brands of RMS, performing the same manufacture operations using different technologies. An example of such production machines is PCB washing baths using ultrasonic, inkjet, and other principles of cleaning an assembly unit from industrial pollution.

The third stage of the RMS system design is based on the introduction of different RMS models within each brand of RMS, i.e. physical RMS, performing manufacture operations in production with various technical and economic indicators. These can be automatic installers of SMD (Surface Mounted Device) components, BGA (Ball Grid Array) components on printed circuit boards, which have various accuracy characteristics.

![RMS system designing algorithm](image)

**Figure 2.** RMS system designing algorithm.

The fourth stage of the system design of RMS is based on the development of mathematical and software components of the RMS, forming a digital twins of the RMS. The digital twin of RMS is a way of describing a production machine in the cloud. A digital twin of RMS at the parametric level describes the principle of RMS operation and the manufacture operations carried out in its chamber.
The nomenclatures of RMS classes, RMS brands, RMS models and digital twins of the RMS form the corresponding libraries of reconfigurable manufacturing systems, developing and supplementing the existing RMS databases that are used today by plants developers to determine the structure of the create automatic production facilities.

4. Conclusion
The reconfigurable plant as a design object is characterized by the signs of a complex system:

- multidimensionality of the space of design decisions on the choice of the plant;
- hierarchy of the structure of the RMS, communication environment, virtual environment, etc.;
- RMS multi-connectivity based on the methods of RMS interaction in the process of equipment self-reconfiguration;
- the variety of RMS, focused on the implementation of various manufacture operations;
- multi-mode functioning of the RMS in the process of completing manufacture tasks;
- multichannel communication environment combining RMS, operators and distributed control system;
- multi-criteria, due to the space of indicators characterizing the reconfigurable plant.

The solution of the reconfigurable plant design problem is systemic in nature and is based on general scientific knowledge bases and databases of flexible technologies. A systematic approach to the design of the reconfigurable plant is to implement the following design procedures by the developer:

- study of the reconfigurable plant as a single design object with its inherent performance indicators;
- designing the structure and composition of the reconfigurable plant, identifying the relationships between RMS and their presentation at the level of analytical models;
- assessment of private parameters of the quality of functioning for each RMS;
- coordination of functional and parametric requirements global for the reconfigurable plant and local for RMS performance criteria.

References
[1] Kolberg D, Berger C, Pirvu B-C, Franke M and Michniewicz J 2016 Procedia CIRP 57 32-7
[2] Oks S J, Jalowski M, Fritzsche A and Moslein K M 2019 Procedia CIRP 84 257-64
[3] Bogatyrev V A, Bogatyrev S V, Derkach A N 2019 CEUR Workshop proceedings 2522 26-36
[4] Graessler I, Poehler A 2019 Procedia CIRP 84 251-6
[5] Singh I, Centea D, Elbestawi M 2019 Procedia manufacturing 31 116-22
[6] Chen J-Y, Tai K-C, Chen G-C 2017 Procedia CIRP 63 150-5
[7] Mehami J, Nawi M, Zhong R 2018 Procedia manufacturing 26 1077-86
[8] Oks S J, Fritzsche A, Moslein K M 2018 Procedia CIRP 72 456-61
[9] Bauernhansl T, Tzempetionidou M, Rossmeissl T, Groß E and Siegert J 2018 Procedia manufacturing 23 201-6
[10] Berger C, Zipfel A, Braunreuther S and Reinhart G 2019 Procedia CIRP 79 349-54
[11] Komenda T, Reisinger G and Sihn W 2019 Procedia manufacturing 31 296-301
[12] Stern H and Becker T 2017 Procedia manufacturing 9 151-8
[13] Francalanza E, Mercieca M and Fenech A 2018 Procedia CIRP 72 486-491
[14] Galaske N and Anderl R 2016 Procedia CIRP 50 442-7