Automated Systems & Technologies
25-26 May 2015 • St. Petersburg, Russia

PROCESS AUTOMATION ENGINEERING WITHIN THE CONCEPT OF «INDUSTRY 4.0»

Angelina Sulerova, Vladislava Bykova, Vyacheslav Potekhin

Control Systems and Technologies Department
Peter the Great St. Petersburg Polytechnic University
Grazhdansky Pr., 28
195220, St. Petersburg, Russia

Xuan Chiem

Le Quy Don University
236 Hoang Quoc Viet – Ha Noi – Viet Nam
angelina.sulerova@gmail.com, nguyenxuanchiem83@gmail.com

Abstract

In this paper, the design of processes, as well as the problem of automating the lifecycle of the product are considered within the concept of Industry 4.0. The methods of quality control of production processes based on the optimization of control and testing and the methods of structural and parametric optimization of technological processes on the example of optimization on graphs. The example shows the use of the developed mathematical models to technological systems.

INTRODUCTION

Technological expediency, operational necessity and economic efficiency allowed wide spreading of industrial automation. The automation has passed several historical periods in the course of its development

The fourth industrial revolution, which is also called "Industry 4.0", combines all technological equipment in the production process with information networks.

Industry 4.0 is based on cyber physical systems providing M2M connectivity, planning and adaptation of personal behavior according to ambient conditions, learning of new models and ways of behavior.

This document contains the study and analysis of technological processes of foundry production, assembly of printed circuits, an example of time optimization for the assembly of phase shifters.

The concepts of integrated automated foundry and assembly process for the printed circuits have been developed within the Industry 4.0 concept. Optimization methods for technological processes and production programs have been studied.

GENERAL

Figure 1 shows the levels of the Industry 4.0 concept. The automated control and monitoring system is designed as a part of production automation project for performance improvement and increase of economic efficiency of the production line. Schematic diagram of APCS is shown in Fig. 2.

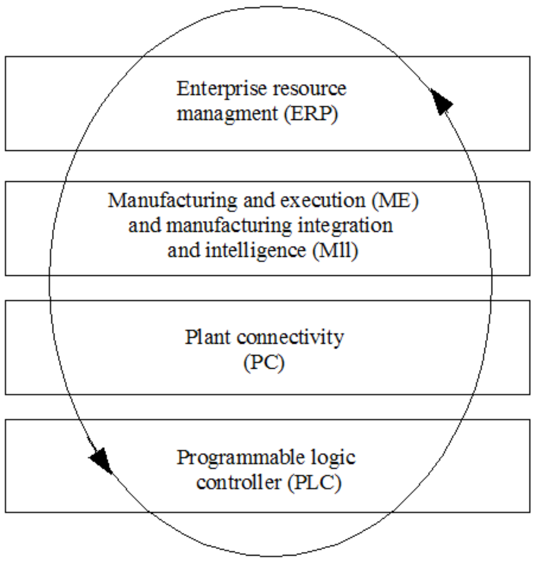

Figure 1. Schematic diagram of the Industry 4.0 concept.

The complete system has a hierarchic structure where the lower level, the PLC level, is responsible for acquisition and transmission of the information about objects and parameters of the technological process to the upper levels. Communication with the equipment recording, monitoring the readings and directly controlling the objects is provided by PLC (programmable logic controller). All sensors and execution units of the equipment involved in the technological process are connected to the PLC.

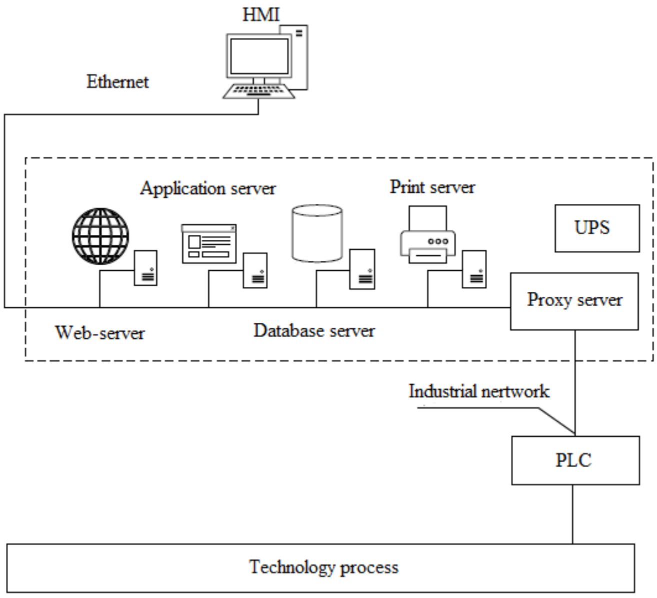

Figure 2. Schematic diagram of APCS.

The Industry 4.0 concept requires the PC (Plant Connectivity) element for communication between the main software portion of APCS and the equipment implementing the technological process, and the data transmission server may be used for this purpose.

The upper level is used to set the general control algorithm and to arrange the high-level interface with the system users (productions engineers and service staff), it consists of AWP (automated work place) and a server providing the control and information acquisition process.

The server portion of APCS consists of several components: a web-server, an application server, a database server, a print server. The database server provides long-term storage and acquisition of production data. The application server executes the business logic related to the production processes and control processes (control algorithm), the web-server is the basis of the AWP operation.

The server portion contacts the PLC the equipment is connected to. The upper level MES subsystem functions are performed by the application server which, in turn, solves the tasks of synchronization, coordination, analysis and optimization of the product release within a certain production on a real time basis.

To coordinate the data with the external source, the thin client building principle using the web-server may be implemented.

The time-optimal selection of the technological operation sequence using the optimization search methods where each subsequent variant is more preferable than the previous one, as well as the parametric optimization by varying the transition parameters allowed to develop the technological process models providing the best combination of the quality and efficiency parameters according to the given limitations.

Production efficiency evaluation is directly expressed in the interconnected system of parameters indicating the utilization efficiency of the main production process elements.

Labour input is reduced by 49% and productivity is significantly increased due to integration of automated systems of selective laser brazing. With the existing technological process, the time for one brazing is 60 s; with the production automation, the time for one brazing will be reduced to 1.2 s.

When the foundry process is automated, operations are paralleled. The mold blow-off and lubrication are performed in parallel with the distribution manipulator traveling to the crucible furnace; and the cooling process for the parts is performed in parallel with the distribution manipulator traveling back from the furnace to the machine and with the machine operating process. Due to this fact the line productivity may be increased by 25 %.

Due to the higher level of the foundry process automation, there will be available line capacities which may generate additional profit to the production.

One the most complicated issues in production engineering is solving the task of creating an optimal route for production of parts, assembly units and the item in general considering the equipment loading, its capabilities and condition.

The system designing begins with the synthesis of the initial variant of its structure, preliminary definition of content of the technological operations by combining operations (transitions) in them as well as general sequence of the formed operations execution with the required corrections in their content. A mathematical model is created to evaluate this variant.

The technological solution with the selected physical principle of operation is searched for according to the structural synthesis method.

Figure 3 shows an example of the technological layout of the phase shifter assembly line. Definition of optimal parameter values of the technical system elements with the known structure is the task of parametric synthesis or parametric optimization.

Network diagram of the production process allows to show the technological dependence and sequence of the work package execution coordinating the schedules considering resources spent and the work cost indicating critical points. Figure 4 shows the sequence of technological operations of the phase shifter assembly process where S is the object status corresponding with the technological process at a certain moment, A is the part movement to the next position/next module.

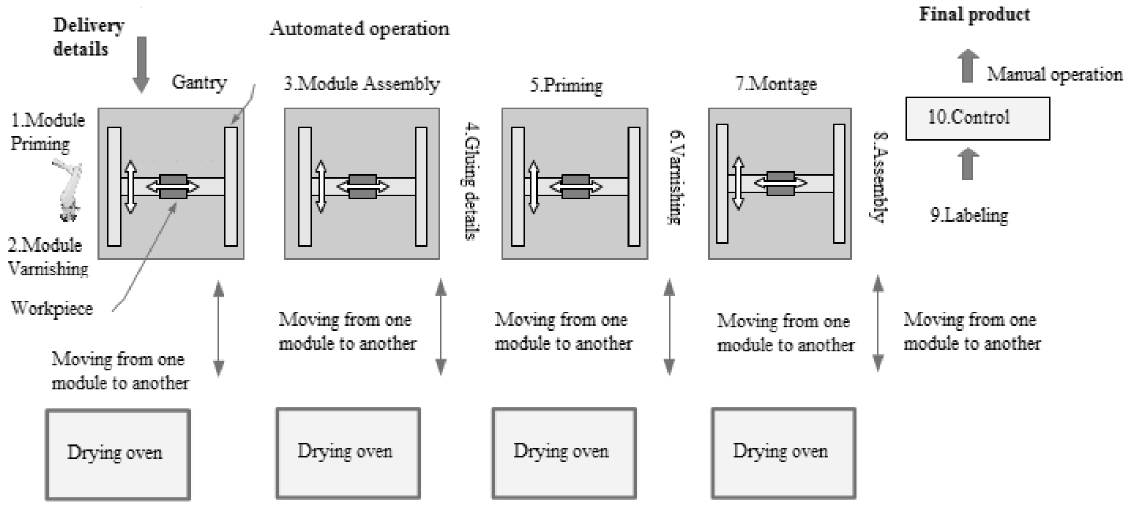

Figure 3. Technological layout of the phase shifter assembly line.

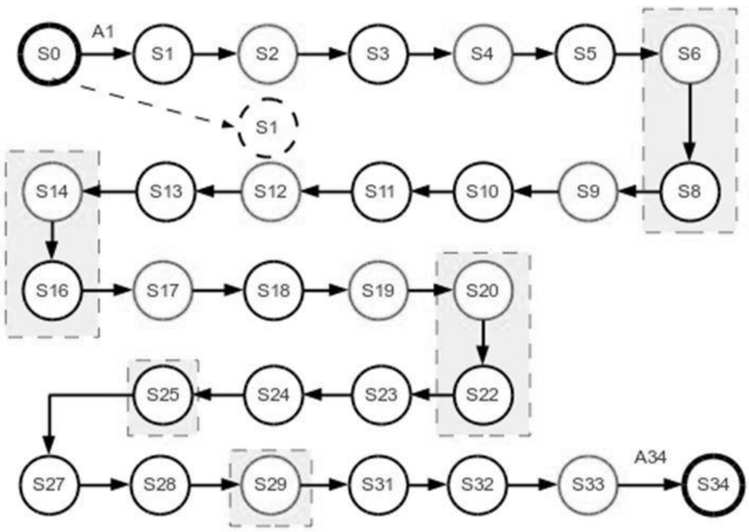

Figure 4. Technological sequence of the phase shifter assembly process.

The solution of the structural optimization tasks may be based on presentation of the structure as diagrams, comparative analysis of structures based on the limited amount of structural parameters, however, selection of the optimal variant of the designed complex technical object structure with the methods based on the exhaustive search is a rather time-consuming procedure.

Using the mathematical programming methods to solve the tasks of the structural synthesis of technical objects requires a lot of preliminary preparation for solution area study, and it is not always feasible due to the difficulty of consideration of multiple factors impacting the correctness of the task of optimal designing and due to significant calculation difficulties in solving the tasks of mathematical programming of high dimension.

Methods of parametric optimization of technological processes are based on standard patterns solving mathematical programming tasks: linear, non-linear, convex and integer-valued.

The total time of a batch assembly t(T) according to the technological process T was used as the optimization criterion during technological design of the phase shifter assembly process. The optimal T_{opt} variant is the variant of the technological process with the minimal t value:

$$t(T_{opt}) = \min t(T); \tag{1}$$

In general, when technological processes are being optimized, the optimization search methods are used for they do not impose severe restrictions on optimization criteria and solution existence domain. The principle of the optimization method is to find the sequence of the technological process variants:

$$T_1 \ldots T_i \ldots T_n,$$

where each subsequent variant is more preferable than the previous one, i.e. $C(T_i) > C(T_{i+1})$. At the extreme, the mentioned sequence must converge to a sufficiently small solution area, i.e. the variant close to optimal.

Below is an example of a mathematical model of the phase shifter assembly process allowing to make all necessary calculation for the parametric optimization where the optimization parameter is the total time of a batch assembly.

$$t_j(n)=\tilde{t}+(n-1)t_{max} \tag{2}$$

$$\tilde{t}=\sum_i t_i \tag{3}$$

$$t_{max}=\max\{t_i\} \tag{4}$$

$$T=\sum_j t_j(n)+\sum_f t^{*}_f \tag{5}$$

where T is the total time of a batch assembly, n is the number of parts in a batch, t_j is the time required for a batch assembly before the drying process starts, $\tilde{t}$ is the time required for one part treatment before the drying process starts, t_i is the time required for the technological operation i, k is the total amount of technological operations before the drying process, t^{*}_f is the time required for the drying process number f, optimization may also be based on resource intensity, power consumption, accuracy, floor space.

In the market conditions of economic management, searching for the optimal variant of solving the task related to creation of the production program of an enterprise is of great economic importance. Definition of optimal plans with the contemporary models and mathematical methods is one of the most important research areas and the subsequent use of the internal resources and the increase of the economically efficient work of the enterprise on this basis. The result of the enterprise plan (annual, quarterly, semi-annual) creation is the establishment of the set of products to be manufactured and the amount of their release as well as providing achievement of one or several goals (maximization of the gross profit, maximization of the amount of the sold products, maximization of the cultivated target market share, minimization of the total original cost of the programmed output, etc.).

When the assortment is formed in unstable demand conditions, the machine building enterprises need the improved calculation and budgeting tools aimed at efficient solutions to control expenses, profit and market value of the company

The specialists have previously considered separate methods of the assortment formation, the conventional approach to the assortment optimization. The conventional approach is based on the target gross profit maximization function and distribution of indirect expenses according to one or two indirect expense distribution bases (material costs or salaries of the main production workers). However, the development of new technologies assists the indirect expenses increase and reduction of the portion of material expenses and expenses fir the salaries of the main production worker in general expenses. Thus, using the sum of material expenses or the paid salary of the main production workers as the only basis for distribution of indirect expenses may provide the false information about the product profitability. Moreover, such a pressing issue as formation of the optimal product assortment of the machine building enterprises is not developed to the sufficient extent. The well-known literature does not pay sufficient attention to the assortment formation methods, their classification, optimization methods of the product assortment of the machine building enterprise aimed at maximization of the financial results of its activity.

The study is based on the methodology involving the systematic approach to solving the problem of assortment optimization for the planned production program of a machine building enterprise. The systematic analysis methods were used in the course of work as well as the methods of linear programming and mathematical modeling of economic processes.

It is necessary to distinguish the following levels of accounting the indirect expenses when the ABC-method is used for the assortment optimization: the level of the unit of product, batch, workshop providing more independent accounting of indirect expenses in comparison with the conventional method. It allowed to add the "cost distribution base" classification feature for indirect expenses at the level of the enterprise, divisions and operations to the classification of the expense accounting and original product cost calculation methods.

The ABC-method may be used during formation of the product assortment for the planned production program of the enterprise for it allows to optimize the assortment selecting the gross profit maximization as the optimization criterion. The optimized assortment may be included in the system of planned tasks of the product release. The ABC-method considers that the enterprise deals with various operations related to the product release. The ABC-method considers the expenses for a particular operation and thus optimizing the processes involved in this operation provides independent accounting and reduction of expenses in the future in the course of the corresponding events aimed at the system debottlenecking. Moreover, the ABC-method allows to pay the required attention to indirect expenses, thus, the cost management becomes more flexible. To introduce the ABC-method, it is necessary to:

- divide the production processes in the enterprise into the main operations;
- set the cost object (action causing the expenses) evaluated in physical terms of measurement for each operation;
- define the cost of the cost object unit (quotient of the sum of indirect expenses for each operation and the values of the corresponding cost object);
- calculate the original product cost (the cost of the cost object unit multiplied by their amount for a particular operation).

Selecting the operation as the expense accounting item allows to reflect the actual production correlations and causes of the expenses and, eventually, define the indirect expenses using the actual and not artificial bases of allocation. Thus, the original product cost with the ABC-method is not changed. But it should noted that introduction of the ABC-method is rather expensive. Nevertheless, due to the fact that the expenses for the calculation technologies are gradually being reduced, the cost of ABC-method introduction is also being reduced. The companies that are not capable of accurate evaluation of the expenses gradually lose their clients due to incorrectly assessed products.

CONCLUSIONS

Models of flexible intelligent production technological processes which advantages are described in [6] were created within this project.

The merits of the developed concept are increased production flexibility and mobility, reduced time of the production cycle. General control functions integrated in a single user interface and interaction of the lower and upper levels with a data transmission server and application server allow to minimize the intervention of the service staff to control the technological process, to record the system events in order to analyze them and involve the operator in due time, if necessary. The integrated industry development will allow to exceed the scope of a certain production and to use the infrastructure and data of several enterprises altogether.

REFERENCES

[1] Prof. Dr. Henning Kagermann, Prof. Dr. Wahlster, Dr. Johannes Helbig. Final report of the Industrie 4.0 Working Group «Recommendations for implementing the strategic initiative Industrie 4.0», 2013. 80 p.
[2] GOST 18169-86. Foundry technological processes. Terminology and definitions.
[3] GOST P 53432-2009. Printed circuit boards. General productional requirements.
[4] «PLCs and ERP/APS+MES+ACS integration», Rational Enterprise Management — information and analytical magazine for IT managers and experts of industrial enterprises, research and design organizations, 2009, No.2, p. 50 – 51.
[5] S. A. Polyakov. Mathematical models and engineering production facilities modeling: textbook – M.: Moscow state university publisher, 2011. 104 p.
[6] V. Y. Shishmarev. Automation of production processes in mechanical engineering: textbook. – M.: Academy, 2007. 368 p.
[7] A. Y. Krukov. Mathematical modeling of processes in mechanical engineering. – Perm: Perm State Technical University Publisher, 2007. 322 p