Algorithm of choosing type of mechanical assembly production of instrument making enterprises of Industry 4.0

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Abstract. The task of the algorithm of choosing the type of mechanical assembly production of instrument making enterprises of Industry 4.0 is being studied. There is a comparison of two project algorithms for Industry 3.0 and Industry 4.0. The algorithm of choosing the type of mechanical assembly production of instrument making enterprises of Industry 4.0 is based on the technological route analysis of the manufacturing process in a company equipped with cyber and physical systems. This algorithm may give some project solutions selected from the primary part or the auxiliary one of the production. The algorithm decisive rules are based on the optimal criterion.

1. Introduction

When creating new complicated technical systems, when the project object is a production section, a workshop or item designing company in general, the designer has to solve simultaneously the project optimization task with private signs of quality such as an organization component, a technological component and an economical component.

For the task of the project of the mechanical assembly production [1-3], it is necessary to develop: CD – construction, PD – program and TD – technological documentation for a production section (workshop, plant) which suits well to produce the necessary amount of the item designing component of the given nomenclature and quality level.

The organization component of the project task of mechanical assembly production is a set [4, 5] of private project quality criteria, which characterizes the production division control system, quality verification of the manufactured component, the production personnel timetable and etc.

The technological component of the project task of mechanical assembly production is a set [6-8] of private project quality criteria, which characterizes the distribution principles of production section technological equipment, the number and specialty of production sections, the total production square calculation, work capability of technological operation (machine capability), equipment load coefficient, designing components of the technological item, the rate of material consumption, etc.

The economical component of the project task of mechanical assembly production is a set [9, 10] of private project quality criteria which characterizes: the source and amount of financing project and
manufacturing works, manufacturing self-cost of the item designing component, the production utility, technological equipment repair and maintenance costs, the production personnel salary and etc.

The mechanical assembly production project task is a multi-parametrical one to solve, which requires a multi-criteria optimization mathematical apparatus, which is based on additive and multiplicative criteria.

2. The algorithm of the technological process of item designing company part manufacturing of Industry 4.0

Figure 1 shows the generalized algorithm of the technological process of item designing company part manufacturing of Industry 4.0. The functionality principle of each technological section and mechanical assembly production is the following one. The production control robotized system is a three-level information and measurement control net of the industrial Internet of Things (IoT).

The welding paste is being applied in the SMD (SMD – Surface Mounted Devices) section on the PCB (PCB – Printed Circuit Board) surface with a dispenser or using the plate printing principle, which depends on the technological equipment. The dispenser application is reasonable in the test production of Industry 4.0 company mechanical assembly. The available technological equipment maintains the dosing automatically, which makes it suitable to be applied as a part of the robotized SMD section.

Elements installation on the item designing component PCB is the most popular option today to manufacture some assembly units and is an intermediary stage of the technological process after the stage of welding paste application (printing) on the PCB and goes before the solder formation stage.

The installation is being done with the installation machines (special technological equipment with universal, carousel, ribbon and other constructions) from the package of the manufacturer plant (for example ribbon) from one or both sides. They take the components from the package with vacuum and having an intellect (to calculate the component center of gravity) holder. Installation of SMD elements

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**Figure 1.** The algorithm of the technological process of item designing company part manufacturing of Industry 4.0.
from one PCB side is being done on a special non-conductive surface (glue) after application on the PCB surface welding paste with a plate printing printer. Component installation of two sides is being conducted in several stages on one side first and then on the other one.

The soldering section is the final automatic SMD section. There is a special technological equipment - an oven for soldering. The SMD technology includes two options of soldering, which depends on the technological equipment characteristics: convection beam soldering (solder wave) and soldering of the welding paste formation method. In practice, they use the solder wave to montage the PCB with elements with packages and without packages. The solder formation method is used to montage the PCB with components without packages. There is a special law for the oven convection heating — temperature profile (temperature change curve). All PCB washing operations in the Industry 3.0 company are done with a mix of spirit and petrol. The experience of practical application of such mix in a production company shows that the liquid chemical properties are quite idle when contacting the solder, flux and other materials, which are consumable during the PCB soldering and other PCB elements left after the mounting. In addition, a spirit and petrol mix is quite flammable that is why it is unreasonable to apply such mix for the Industry 4.0 robotized production.

The Industry 4.0 PCB washing system is ultrasonic baths, flow washing and bubbling (the process of gas or vapor penetration through the liquid) and etc. The most popular ultrasonic bathes today are the ones with the sonic frequencies vibration in the liquid cavitation where the PCB is located. The generalized washing liquid is the one with the effects of foaming and solution, which guarantee the high quality of the PCB washing. For example, flux insoluble in water during the contact with the washing liquid creates a chemical solution, which is soluble in water.

The SMD automatic section work result is a PCB with installed radio and electric elements, which will be used in the conditions when the probability of different exterior factor influences is high. To reduce the environment negative effect on a radio element, there are several measures of protection for the PCB and its conductors during the item designing component manufacturing process. One of the most popular protection methods is the item-designing component covering manually, with pulverizing or PCB immersion into the liquid filler bath. The automatic application of resistive materials, which is suitable for the Industry 4.0 technological manufacturing process, supposes the selective covering option [4-7] of the PCB with special technological equipment. Today there are several developed and successfully applied additive technologies which are being used in practice for the metal 3D printing technological equipment. Those additive technologies are based on the laser baking and the flow printing option of metallic components. The printing process base is the dosed metal layering procedure to make a component which dimensions are prescribed in the construction documentation.

A laser printing option (direct metal laser sintering) uses a powder which is being baked with a laser to create metallic components. The printing structural option supposes the technological equipment with liquid metal functionality, where the liquid metal is being extruded layer by layer on the manufacturing component surface and with a special cooling down system. But the metallic component structure and its accuracy in this case is not quite reliable so that is why this option in the due time will not be implemented in the Industry 4.0 item designing component technological manufacturing process. In the electrotyping section, there is the technological process of applying covering on the components made with 3D printing. The item designing components have some desired properties which can be achieved with the covering application. There are several methods of applying those coverings: chemical bombardment, hot metal covering, vacuum technology, metal pulverizing, diffusion method, etc. Figure 1 shows the electrotyping algorithm based on the electrolysis of the most popular electro and chemical reaction — a chemical process based on the law of Faraday under the influence of electric current in the electrolyte water environment (acid solution, salts or metal alkaline).

The Industry 4.0 technological equipment functionality faults could happen: after running some field tests; after periodical maintenance completion; after industrial data analysis, which were received in the robotized technological equipment production section control server through the Internet of
things industrial net. The device functionality control is being done after the SMD printed circuit board mounting; after the application of lacquer and anti-moisture covering on a PCB; after the product final assembly with the components made with 3D printing.

The product manufacturing final stage is a smooth work in the automatic mode of several robotic hands, which handle the step-by-step product assembly from the components from the product functionality verification section (after the application of the anti-moisture cover) and the electrotyping section. The assembly process is when the robotic hands place the components according to its documentation and fix them out with standard fixing units (which are screws, nuts and etc.).

3. The project algorithm of Industry 3.0 mechanical assembly production

Generally, it is clear that the most important stages of mechanical assembly production project are: the production primary section calculation and auxiliary sections are completed after the initial data. The initial data to project the mechanical assembly production are:

- the construction, program and technological documentation for the item designing product to be manufactured in that mechanical assembly production;
- technological processes which are necessary to manufacture the item designing component.

The primary part of the projecting mechanical assembly production requires from the designer to analyze some project solutions:

- range and the number of the primary technological equipment units engaged in the item designing component manufacturing process;
- principles and the structure of the primary manufacturing processes which are completed during the item designing component manufacturing process;
- the personnel qualification and numbers which work in the item designing component manufacturing;
- structural and planning organization principles to create production sections (workshops, production in general) and etc.

The projecting mechanical assembly production includes several designer’s solutions to analyze:

- preparation and storage system organization principles in the item designing production;
- the instrument and transport provision organization system;
- technological equipment engaged in the item designing manufacturing repairing and maintenance organization principles;
- item designing components manufacturing in the mechanical assembly quality control principles;
- security principles of personnel work of item designing mechanical assembly production;
- the basics of the construction principles of production division building and etc.

Figure 2 shows the iterative project algorithm of the Industry 3.0 mechanical assembly production. The project algorithm of Industry 3.0 mechanical assembly production contains the subsequent changes of each project solution to get the optimal criteria of the result project quality. The quality criteria of the project algorithm of mechanical assembly production could be for example the list of annual expenses to manufacture the item designing components. The coefficient value should be minimized when the initially given program of the product manufacturing in the company and can be determined with the formula:

\[
E_m = \sum_{j=1}^{N} N_j (\delta + \beta) S_{sw} \sum_{i=1}^{M} \left( T_j + \frac{(E_{\mu} + \alpha F)}{F_e} \right) \sum_{i=1}^{M} A_j a_j \right] \rightarrow \min,
\]

where \(j\) – the product ordinary number; \(N\) – the number of products in the company manufacturing nomenclature; \(N_j\) – the annual number of manufactured products of \(j\) type; \(\delta\) – the coefficient which depends on the personnel salary; \(\beta\) – the amount of expenses which include the repair and maintenance of the technological equipment; \(S_{sw}\) – the amount of the personnel salary; \(i\) – the ordinary number of the \(M\) technological operation which is being done when a \(j\) series product is manufactured;
$T_g = T_g^{ct} / k_m$ – labor capacity to complete an $i$ technological operation to manufacture a $j$ product; $T_g^{ct}$ – machine capacity of the $i$ technological operation or the time to manufacture the $j$ product expressed in the machine work hours of this equipment in the company; $k_m$ – the service coefficient to determine the number of machines where one worker works; $E_n$ – the efficiency coefficient to characterize the company capital expenses; $\alpha$ – the coefficient to characterize the company cushion expenses; $F_i$ – a time period which is necessary to complete technological operation; $F_e$ – the annual amount of time in the company; $A_{ij}$ – the cost of technological equipment used in the $i$ technological operation to manufacture the $j$ product; $a_i$ – the number of equipment of the $i$ technological operation.

Figure 2. The project algorithm of Industry 3.0 mechanical assembly production.

4. The project algorithm of Industry 4.0 mechanical assembly production
The features of the project algorithm of item designing company mechanical assembly production shown in figure 3 are:
- rearrangement (compared with the Industry 3.0 algorithm) of several company production structure components between the primary and the auxiliary parts (including the role of personnel);
- the appearance of new digital information and production technologies, new technological equipment as a part of the manufacturing process of item designing components.

The project quality criterion of Industry 4.0 mechanical assembly production, based on the digital project and manufacturing, could be criterion $f (W_1, W_2) \rightarrow ext$ based on some private indications where $W_1$ – the cargo flow (a particular amount of products which is being transported in a particular direction per unit of time) of a production line, $W_2$ – the given efficiency of the item designing components manufacturing:

$$
W_1 = \sum_{j=1}^{M} \sum_{i=1}^{g_j} g_j l_{ab} \rightarrow min,
$$

$$
W_2 = N/V \rightarrow max
$$

where $N$ – the annual amount of the transporting number of products in a production line; $M$ – the number of technological operation which robots complete to manufacture the product $j$; $g_j$ – the annual amount of components being transported in a production line; $l_{ab}$ – the distance between work points $a$ and $b$ of the section (workshop) work space in which the component transportation is conducted.
after the completion of the technological operation $i$; $V$ – the work space volume in the section.

![Project Algorithm](image)

**Figure 3.** The project algorithm of Industry 4.0 mechanical assembly production.

5. Conclusion

The direct implementation of the new digital information technologies in the item designing components manufacturing processes affects directly the mechanical and assembly production project methods. The methods of the previous decades today are unacceptable to create the projects of manufacturing sections because the section of cutting, perforation and other not included technological equipment can be changed with 3D-printing capable of additive technologies when the part is being printed with a step-by-step volume printing method.

Such equipment can work successfully today with polymer and metallic materials which gives the new perspective to create the robotized production in the field of the item designing. To create such production they need new methods and project algorithms based on the several stages of mathematical formalization of several stages of the component manufacturing with the application of progressive technologies.

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