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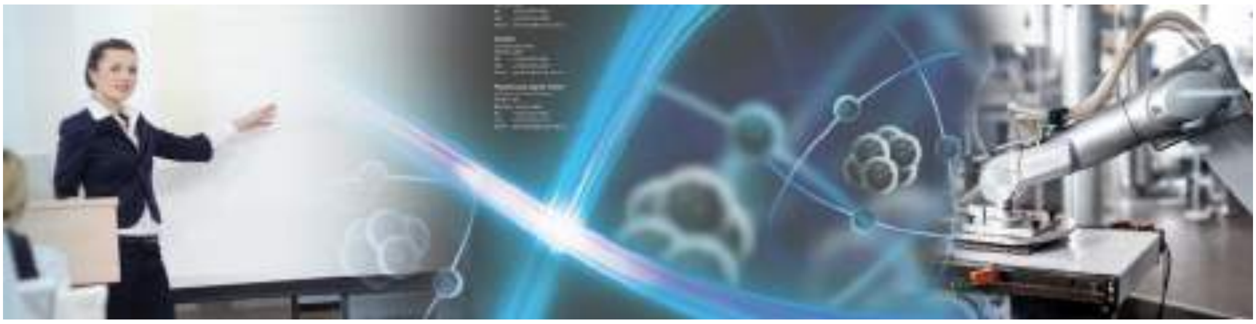

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У збірник включені тези доповідей, які присвячені сучасним тенденціям розвитку технологій та засобів виробництва та мехатронних систем, передовому досвіду та впровадженню їх в галузях систем промислової автоматизації та керування виробництвом; системній інженерії; CAD/CAM/CAE системах; мехатроніці (електро-механічних системах, електронних інструментах систем керування, механічних CAD системах); робототехніці та засобахм інтелектуалізації; MEMS (сучасних матеріалів та технологіях виготовлення MEMS) та компонентах і технологіях автоматизації видобутку, переробки та транспортування нафти та газу.

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The collection includes the thesises of reports on modern trends in the development of technologies and means of production and mechatronic systems, top experience and implementation of them in fields of: industrial automation and production management systems; systems engineering; CAD/CAM/CAE systems; mechatronics (electrical and mechanical systems, electronic control tools, mechanical CAD systems); robotics and intellectual toolls; MEMS (modern materials and manufacturing technologies MEMS) and components and technologies for the automation of oil, gas and oil extraction, processing and transportation.

ЗМІСТ

Analysis of the data collection process about products at different stages of production

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Anotation: The research is dedicated to improving the quality control system in printed circuit board manufacturing by optimizing the processes of collecting production data. Based on the analysis of modern challenges in industrial digitalization, a comprehensive approach to organizing the monitoring of technological parameters is proposed. An original conceptual model has been developed, defining the logical interconnections between data sources, methods of their acquisition, processing techniques, and the ultimate goals of production control. A systematization of data collection methods has been conducted, classified by the level of automation and the types of technologies used. The paper presents practically oriented recommendations for applying monitoring tools at various stages of the production cycle – from material preparation to the final inspection of finished products. The proposed solutions consider the criteria of technological feasibility and accuracy requirements for measurements. The implementation of the proposed approach enables full traceability of production, increases the efficiency of defect detection, and creates a foundation for building adaptive quality management systems. The research results have practical value for enterprises in the electronics industry transitioning to the principles of Industry 4.0.

***Key words*:** printed circuit board manufacturing, data collection methods, quality control, monitoring automation, traceability.

I. INTRODUCTION

In the context of modern industrial digital transformation, the collection and analysis of product data at various stages of manufacturing is becoming critically important for ensuring enterprise competitiveness [1-4]. Industry 4.0 introduces new requirements for product quality, production process efficiency, and rapid response to changing market needs.

The relevance of this research is determined by several key factors:

First, growing consumer demands for product quality and customization require detailed tracking of product characteristics at every stage of the production cycle. Traditional quality control methods based on random sampling of finished products no longer meet modern standards and fail to provide the necessary level of traceability.

Second, the implementation of the Smart Manufacturing concept requires the creation of integrated data collection and processing systems that enable real-time monitoring of production processes [5-8]. This ensures the possibility of early detection of deviations from technological standards and prompt corrective decision-making.

Third, increasing regulatory requirements for environmental safety and sustainable development compel enterprises to document the entire product lifecycle, from raw materials to waste disposal [9]. An effective data collection system is essential for ensuring compliance with these requirements.

The purpose of this work is to develop a comprehensive approach to monitoring technological parameters based on systematizing data collection methods and their alignment with production stages.

The importance of automation lies in its ability to ensure measurement stability and repeatability, reduce human factor influence, and enable real-time integration of control into the production process. Automation is a necessary condition for implementing Smart Manufacturing and Industry 4.0 concepts, as it creates the foundation for scalability, rapid response to deviations, and complete traceability of production data [10-14].

Thus, analyzing the process of collecting product data at various manufacturing stages is not only theoretically important but also a practical necessity for enterprises seeking to maintain their competitiveness in the digital economy.

II. BASICS OF DATA COLLECTION IN MANUFACTURING

The data collection stage is crucial as it lays the foundation for the method's effectiveness: the higher the accuracy and completeness of the information, the better results can be expected [15, 16]. This study focuses on printed circuit board manufacturing, therefore the analysis of data collection methods is centered on the specifics and requirements of the PCB production technological process.

To systematize the fundamentals of data collection in manufacturing, it is appropriate to consider this process as a sequential flow of information from sources to the final result. This logic allows for clear structuring of all system components and determination of their interrelationships.

Figure 1 presents a conceptual model of data collection in manufacturing, based on the principle of logical data flow sequence.

Particular attention in the model is paid to the issue of the targeted collection of data, as a clear understanding of the ultimate goals allows for the optimization of all previous stages and avoids the collection of excessive or irrelevant information. This increases the efficiency of resource use and reduces the burden on the enterprise's information system.

Integrating feedback into the model architecture creates a dynamic system capable of self-improvement and adaptation to changing production conditions. This approach ensures continuous improvement in data quality and an increase in the accuracy of analytical conclusions, which is the basis for making informed management decisions.

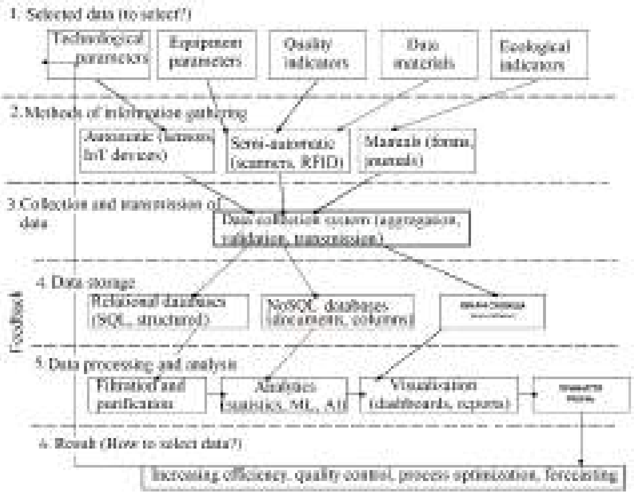

Fig. 1. Conceptual model of data collection in manufacturing

The diagram represents six main levels, each addressing a specific question about the information collection and processing process:

- «What do we collect?» – defines the types of data that serve as information sources;
- «How do we collect?» – describes the methods and technologies of collection;
- «Where do we store?» – characterizes data storage and management systems;
- «How do we process?» – details the analysis and interpretation processes;
- «Why do we collect?» – formulates the ultimate goals and results.

A key feature of this model is the feedback loop, which demonstrates how analysis results influence the optimization of data collection processes at all previous levels. This reflects the iterative nature of improving the data collection system in manufacturing.

The presence of feedback in the model enables rapid adjustment of the technological process when deviations are detected, increasing the overall responsiveness of the quality control system.

III. DATA COLLECTION METHODS FOR PRODUCTS AT DIFFERENT MANUFACTURING STAGES

According to the proposed conceptual model (Fig. 1), the "How do we collect?" level is central to the practical implementation of the monitoring system. In the context of printed circuit board (PCB) manufacturing, data collection methods are classified according to two main criteria: the degree of automation and the technology used. The generalized classification of data collection methods in PCB manufacturing is presented in Table 1.

The accuracy level of data collection methods varies depending on the technology and degree of automation.

The highest accuracy is provided by automated optical inspection (AOI) systems, capable of detecting defects as small as 1 micron, which is critically important for controlling conductor topology on modern printed circuit boards.

Table 1. GENERALIZED CLASSIFICATION OF DATA COLLECTION METHODS IN PRINTED CIRCUIT BOARD MANUFACTURING

Classification criterion	Category	Description of the method	Technologies and tools
Degree of automation	Automatic	Data collection without operator involvement	Automatic optical control systems (AOCS), IoT sensors
	Semi-automatic	The combination of automation and operator involvement	Digital measuring instruments, scanners
	Manual	Full operator control	Loupes, micrometers, visual inspection
Collection technology	Optical	Visual analysis of images	Cameras, specialized software
	Touch	Physical measurements of parameters	Temperature, pressure, humidity sensors
	Radio frequency	Contactless identification	RFID, NFC tags
	Electric	Measurement of electrical parameters	Multimeters, oscilloscopes

Electrical measurement methods are also characterized by high accuracy (±0,01-0,1 %), enabling reliable monitoring of insulation resistance parameters and circuit integrity.

Sensor technologies provide measurement accuracy of physical parameters at the level of ±0,1-1,0 %, which is sufficient for monitoring soldering temperature regimes and parameters of layered package pressing.

Semi-automatic methods typically have a medium accuracy level (±0,01-0,1 mm), which is determined by the influence of the human factor during measurements.

Manual control methods have the lowest accuracy, where the error can reach ±0,1-1,0 mm, limiting their application to operations that do not require high precision. However, they remain indispensable for quick visual inspection and control of dimensional parameters.

Analysis of Table 1 allows us to formulate key conclusions:

1. The most effective results are achieved by combining methods of different technologies and automation levels, which compensates for the limitations of individual approaches.
2. The choice of specific method depends on several factors, with the key ones being: production stage, type of controlled parameters, accuracy and speed requirements, as well as economic feasibility.
3. The current trend is directed toward integrating different data collection technologies into a unified quality information system, ensuring complete product traceability and improving production management efficiency.

Thus, the classification creates a basis for justified selection of monitoring methods according to the specifics of the printed circuit board manufacturing technological process.

The application of automatic methods, such as AOCS, enables real-time defect detection directly on the production line, significantly increasing efficiency compared to selective manual control.

IV. RECOMMENDATIONS FOR APPLICATION OF DATA COLLECTION METHODS AT DIFFERENT STAGES OF PCB MANUFACTURING

Effective quality management in printed circuit board manufacturing requires a strategic approach to selecting data collection methods. Based on the analysis of the technological features of different stages of the production process, practical recommendations for the application of monitoring methods have been developed.

Table 2. RECOMMENDATIONS FOR APPLICATION OF DATA COLLECTION METHODS AT DIFFERENT STAGES OF PCB MANUFACTURING

Stage of printed circuit board production	Recommended methods	Justification	Controlled parameters
Preparation of materials	RFID/semi-automatic	It is economically feasible for tracing batches of materials	Quality of foil, dielectric, certification
Formation of layered packages	Touch (automatic)	The criticality of temperature-pressure regimes	Temperature, pressure, lamination time
Drilling	Optical (automatic AOI)	The need for rapid monitoring of a large number of openings	Diameter, location, quality of holes
Metallization	Electrical (automatic)	Objectivity of the control of electrophysical parameters	Resistance, coating thickness, contact quality
Photolithography	Optical (automatic AOCS) + semi-automatic	High precision in controlling the geometry of conductors	Width of lines, presence of breaks/short circuits
Soldering components	Optical (AOCS) + sensor (thermographic)	Comprehensive quality control of connections and modes	Soldering quality, temperature profiles
Final control	Combined (automatic + manual)	Comprehensive assessment before shipment	Functionality, appearance, compliance with technical specifications

Method selection criteria:

1. Parameter criticality – automatic methods are used for key characteristics.
2. Production volume – mass production requires automation.
3. Economic feasibility – implementation costs must be justified.
4. Required accuracy – critical tolerances require high-precision methods.
5. Control speed – compliance with production line pace.

The optimal strategy is combining methods of different automation levels, which enables creating an effective multi-level quality control system.

V. CONCLUSIONS

The conducted research proves the critical importance of a systematic approach to organizing data collection in printed circuit board manufacturing.

As a result of the research, a comprehensive approach to monitoring organization has been proposed, which includes a conceptual model, method classification, and practical recommendations for their application.

The developed conceptual data collection model, based on the principle of sequential information flow, provides a comprehensive understanding of the interrelationships between data types, their collection methods, processing technologies, and monitoring objectives. The inclusion of feedback in the model reflects the iterative nature of quality control system improvement.

The systematization of data collection methods by automation level and technology used confirmed the necessity of a differentiated approach to selecting monitoring tools. The classification demonstrates that the most effective results are achieved by combining automatic, semi-automatic, and manual methods while considering the specifics of technological operations.

The practical recommendations for applying data collection methods at different stages of PCB manufacturing take into account the technological specifics of each stage and economic feasibility criteria. The proposed approach enables optimization of quality control costs while ensuring high monitoring accuracy and efficiency.

Implementation of an integrated data collection system based on the proposed solutions ensures complete product traceability, enhances production management efficiency, and creates a foundation for transitioning to Industry 4.0 principles.

Future research prospects lie in developing defect prediction algorithms based on monitoring data and creating adaptive quality management systems using artificial intelligence.

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