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CURRENT STATE AND PROSPECTS OF TOOL PRODUCTION: TRENDS, INNOVATIONS, AND CHALLENGES FOR MECHANICAL ENGINEERING

Tool production occupies a key position within the structure of modern mechanical engineering, as it provides the creation and improvement of cutting, measuring, stamping, and specialized tools, without which the functioning of any manufacturing system is impossible. The tool base essentially serves as the foundation for technological development in industry, since the level of its quality determines the precision, productivity, and economic efficiency of production processes. The quality of tools directly affects the quality of finished products, the costs of their manufacturing, and the competitiveness of enterprises in the global economic space. The use of modern tools allows for high-precision material processing, reduces the duration of production cycles, and optimizes the consumption of energy resources and raw materials. At the same time, outdated or low-quality tool infrastructure becomes a factor that restrains innovative development in production and limits its capabilities in international markets [1].

The strategic significance of tool production is manifested in its multiplicative effect: the development of the industry stimulates progress in machine tool building, materials science, automation, robotics, and additive technologies. A high level of tool support creates conditions for the implementation of complex technological processes and the production of innovative products with high added value. In this context, tool production is an integral element of the industrial base of any country, determining its capacity for modernization, integration into the global market, and the formation of competitive advantages in mechanical engineering [2].

At the present stage, tool production worldwide is undergoing profound modernization and digital transformation, driven by the needs of high-tech mechanical engineering and increasing competition. One of the leading directions of development is the implementation of integrated CAD/CAM/CAE systems, which allow not only the creation of high-precision tools but also the virtual modeling of their operational characteristics at the design stage. This significantly reduces the development time of new solutions and lowers research and design costs. Production increasingly relies on the use of high-precision CNC machines, which ensure the manufacturing of tools with complex geometry and minimal deviations, high product quality, and flexibility of production processes. Automation of technological operations, in turn, reduces the impact of human factors and improves reproducibility of results [3; 4].

The materials science aspect is also of great importance. Modern tool production extensively employs cemented carbide composites, superhard materials based on polycrystalline diamond (PCD) and cubic boron nitride (CBN), ceramics, and tools with multilayer composite coatings. The use of such materials provides enhanced wear resistance, heat resistance, and durability of tools, which is critically important for high-speed processing and operation in challenging manufacturing conditions.

In Ukraine, the tool industry is undergoing gradual modernization. Despite the implementation of modern software systems and high-precision technologies at certain enterprises, the sector largely depends on imports of both materials and equipment. This limits its development and creates risks for the country's industrial security. At the same time, positive trends are observed, including the integration of Ukrainian enterprises into global production chains, which contributes to the renewal of the technological base and the gradual increase of competitiveness.

The further development of tool production is directly associated with the introduction of innovative technologies. Promising directions include the application of additive technologies (3D printing with metals and composites), which enable the creation of tools with complex internal structures, including cooling channels of unconventional configurations that improve heat dissipation and extend tool life [5; 6]. Another important innovation is the development of "smart tools," equipped with sensor systems for monitoring technological parameters in real time. Data on temperature, wear, or vibration is transmitted to automated control systems, allowing for prompt adjustment of processing modes and prevention of failures. The use of digital twins is also increasingly widespread, providing the possibility to model tool operation processes, predict its service life, and optimize production costs [4; 7].

At the same time, modern composite materials and nanocoatings enhance hardness, wear resistance, and thermal stability of working surfaces, improving machining efficiency and tool durability.

However, the development of the sector is accompanied by a number of challenges. Major issues include high production costs due to the expense of specialized materials and equipment, insufficient levels of automation and digitalization at many enterprises, and a shortage of highly qualified engineers and technologists with modern digital competencies. Additional challenges arise from increasing requirements for energy efficiency and environmental sustainability, as well as global competition from leading countries such as Germany, Japan, China, and the USA, which possess significant scientific and technological potential and well-developed production cluster systems.

The prospects for the development of tool production will be determined by the integration of advanced technologies, digitalization of processes, and orientation towards sustainable development. Further automation and robotization will reduce costs, increase precision, and ensure product quality stability. The widespread implementation of Industry 4.0 technologies – Internet of Things, artificial intelligence, and big data analytics – will contribute to the optimization of production processes and prediction of tool condition [3]. In the long term, a transition to the concept of Industry 5.0 is expected, which implies harmonization of technologies and

human factors, as well as a focus on environmental sustainability and production personalization. For Ukraine, a strategic direction is the development of domestic production of tool materials, which will reduce import dependency and ensure industrial security. Another key task is the creation of high-tech clusters that unite manufacturing enterprises, research institutions, and educational establishments, promoting technology transfer and increasing global competitiveness.

Thus, tool production is a key component of technological development in mechanical engineering and industry as a whole. Its current state is characterized by active digitalization and the implementation of innovations, while the sector faces numerous economic, technological, and personnel challenges. Overcoming these issues and implementing prospective directions will allow the formation of an efficient, flexible, and competitive tool industry capable of meeting the needs of modern mechanical engineering and contributing to the country's economic growth.

References:

1. Абушов Теймур. Стан машинобудування в Україні через призму управління ресурсами // *Herald of Khmelnytskyi National University. Economic sciences*. – 2024. – № 5(334). – С. 21-35. – DOI: https://doi.org/10.31891/2307-5740-2024-334-20

2. Бурбурська Світлана В., Пасічник Віталій А. Можливості адитивних технологій у виготовленні високотехнологічної продукції машинобудування та біомедичної інженерії // *Технічна інженерія*. – 2022. – Вип. 1(89). – С. 21-26. – DOI: https://doi.org/10.26642/ten-2022-1(89)-21-26

3. State Statistics Service of Ukraine. Statistical Yearbook of Ukraine for 2023. – Київ, 2024. – Режим доступу: https://www.ukrstat.gov.ua

4. Export.gov.ua. Machinery & Engineering — Trade with Ukraine. – Режим доступу: https://export.gov.ua/directory/industry/machinery

5. ResearchGate. Potentials of Additive Manufacturing of Cutting Tools (оглядові публікації). – Режим доступу: https://www.researchgate.net

6. Сапон С. П., Дзюба Д. І. Цифрові двійники шпиндельних вузлів. Огляд // *Вісник Херсонського національного технічного університету*. – 2023. – № 4. – С. 17-27. – DOI: https://doi.org/10.35546/kntu2078-4481.2023.4.17

7. Гужва Володимир Михайлович. Технологічні драйвери цифрової трансформації: цифрові двійники // *IPSPR*. – 2023. – № 3-23. – С. 46-57. – Київський національний економічний університет імені Вадима Гетьмана