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HYBRID MANUFACTURING SYSTEMS IN MECHANICAL ENGINEERING: INNOVATIVE APPROACHES TO INTEGRATION OF ADDITIVE AND SUBTRACTIVE METHODS.

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Abstract. This article analyses hybrid manufacturing systems that combine additive and subtractive processes in modern mechanical engineering. Hybrid manufacturing is based on the integration of 3D printing technologies and traditional machining methods such as milling, turning, drilling and grinding. Additive manufacturing provides high design freedom and enables the production of complex geometries, lightweight structures and customized parts with reduced material waste. However, it often has limitations related to surface roughness, dimensional accuracy and mechanical strength. Subtractive manufacturing, in contrast, ensures high precision, better surface quality and stable dimensional control, but it may require more material and longer processing time. By combining these two approaches, hybrid manufacturing systems make it possible to produce ready-to-use components within one technological platform. This reduces the number of machine setups, shortens production cycles and improves overall productivity. Particular attention is given to the role of hybrid systems in improving part quality, reducing manufacturing costs and increasing flexibility in production. Furthermore, the article examines the importance of hybrid manufacturing in the context of Industry 4.0. The use of digital design, automation, sensors and intelligent control systems allows enterprises to monitor and optimize production processes. Therefore, hybrid manufacturing can significantly improve the competitiveness of the mechanical engineering industry.

Keywords: hybrid manufacturing systems, productivity, mechanical engineering, additive technologies, subtractive technologies, Industry 4.0, integration.

Аннотация. В данной статье анализируются гибридные производственные системы, объединяющие аддитивные и субтрактивные процессы в современном машиностроении. Гибридное производство основано на интеграции технологий 3D-печати и традиционных методов механической обработки, таких как фрезерование, точение, сверление и шлифование.

Аддитивное производство обеспечивает высокую свободу проектирования и позволяет изготавливать сложные геометрические формы, облегчённые конструкции и индивидуализированные детали с уменьшенным расходом материала. Однако оно часто имеет ограничения, связанные с шероховатостью поверхности, размерной точностью и механической прочностью. В свою очередь, субтрактивное производство обеспечивает высокую точность, лучшее качество поверхности и стабильный размерный контроль, но может требовать большего количества материала и более длительного времени обработки. Благодаря сочетанию этих двух подходов гибридные производственные системы позволяют изготавливать готовые к использованию компоненты в рамках одной технологической платформы. Это сокращает количество переналадок оборудования, уменьшает производственный цикл и повышает общую производительность. Особое внимание уделяется роли гибридных систем в повышении качества деталей, снижении производственных затрат и увеличении гибкости производства. Кроме того, в статье рассматривается значение гибридного производства в контексте Индустрии 4.0. Использование цифрового проектирования, автоматизации, датчиков и интеллектуальных систем управления позволяет предприятиям контролировать и оптимизировать производственные процессы. Поэтому гибридное производство может значительно повысить конкурентоспособность машиностроительной отрасли.

Ключевые слова: гибридные производственные системы, производительность, машиностроение, аддитивные технологии, субтрактивные технологии, Индустрия 4.0, интеграция.

Annotatsiya. Ushbu maqolada zamonaviy mashinasozlikda additiv va subtraktiv jarayonlarni birlashtiruvchi gibrid ishlab chiqarish tizimlari tahlil qilinadi. Gibrid ishlab chiqarish 3D bosib chiqarish texnologiyalari hamda frezalash, tokarlik, parmalash va silliqlash kabi an’anaviy mexanik ishlov berish usullarining integratsiyasiga asoslanadi. Additiv ishlab chiqarish yuqori loyihalash erkinligini ta’minlaydi hamda murakkab geometrik shakllar, yengil konstruksiyalar va individual detallarni kamroq material sarfi bilan ishlab chiqarish imkonini beradi. Biroq u ko‘pincha sirt g‘adir-budurligi, o‘lcham aniqligi va mexanik mustahkamlik bilan bog‘liq cheklovlarga ega. Subtraktiv ishlab chiqarish esa, aksincha, yuqori aniqlik, yaxshi sirt sifati va barqaror o‘lcham nazoratini ta’minlaydi, ammo ko‘proq material va uzoqroq ishlov berish vaqtini talab qilishi mumkin. Ushbu ikki yondashuvni birlashtirish orqali gibrid ishlab chiqarish tizimlari tayyor holatda foydalanishga yaroqli komponentlarni bitta texnologik platformada ishlab chiqarish imkonini beradi. Bu dastgohlarni qayta sozlashlar sonini kamaytiradi, ishlab chiqarish siklini qisqartiradi va umumiy unumdorlikni

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oshiradi. Maqolada gibrid tizimlarning detal sifatini yaxshilash, ishlab chiqarish xarajatlarini kamaytirish va ishlab chiqarish moslashuvchanligini oshirishdagi roli alohida ko‘rib chiqiladi. Bundan tashqari, maqolada gibrid ishlab chiqarishning Sanoat 4.0 sharoitidagi ahamiyati ham tahlil qilinadi. Raqamli loyihalash, avtomatlashtirish, sensorlar va intellektual boshqaruv tizimlaridan foydalanish korxonalarga ishlab chiqarish jarayonlarini nazorat qilish va optimallashtirish imkonini beradi. Shu sababli, gibrid ishlab chiqarish mashinasozlik sanoatining raqobatbardoshligini sezilarli darajada oshirishi mumkin.

Kalit so‘zlar: gibrid ishlab chiqarish tizimlari, unumdorlik, mashinasozlik, additiv texnologiyalar, subtraktiv texnologiyalar, Sanoat 4.0, integratsiya.

INTRODUCTION.

Modern mechanical engineering increasingly emphasizes enhanced production efficiency and flexibility, necessitating the adoption of advanced technologies. Hybrid manufacturing systems, which integrate additive (3D printing) and subtractive (machining) processes, represent a promising solution, enabling the fabrication of high-precision components with complex geometries within a single production cycle [1]. These systems are widely applied in the aerospace, automotive and medical technology sectors, where precision, operational speed and efficient resource utilization are of critical importance. Within the framework of Industry 4.0, hybrid technologies are increasingly integrated with digital solutions, including advanced control systems and digital twins, thereby significantly enhancing their capabilities [2]. This article aims to examine the fundamental principles of hybrid manufacturing systems, analyze their advantages and limitations and evaluate their contribution to improving the productivity of mechanical engineering enterprises. Hybrid manufactural systems are founded on the sequential or concurrent integration of additive and subtractive processes within a single machine or production line. Additive technologies, such as laser cladding and selective laser melting, enable the fabrication of components with complex geometries while minimizing material waste [3]. Subtractive manufacturing methods, for instance milling and turning, achieve excellent precision and surface integrity, addressing the inherent limitations of additive processes such as surface roughness [4]. The core principle of hybrid systems lies in the synergy between processes: additive technologies are used to generate the primary geometry, while subtractive operations perform the finishing. This integrated approach reduces the number of manufacturing stages and diminish the need for transferring workpieces between different machines [5]. Technological features. Modern hybrid machines, such as CNC systems equipped with integrated laser cladding and milling capabilities, operate through unified

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software platforms for process control [6]. For instance, a component may be fabricated using metal powder-based additive techniques and subsequently machined in situ with a milling tool to achieve the required level of precision. This approach is particularly advantageous for parts featuring internal cavities or complex geometries that cannot be produced using conventional methods without additional assembly operations [7].

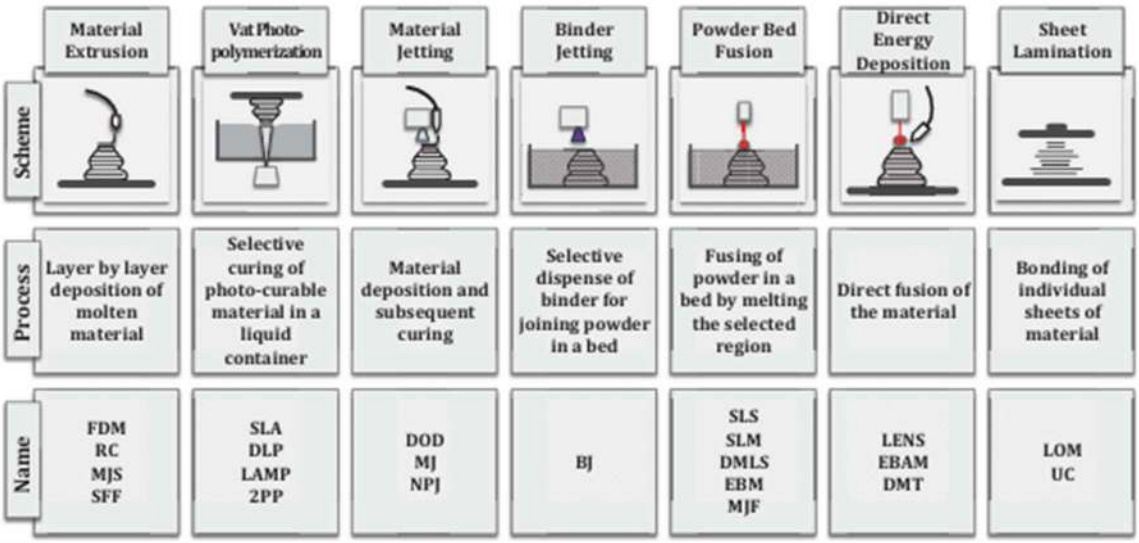


Figure 1. A current state of the art classification of additive manufacturing processes [11].

MATERIALS AND METHODS.

This study was carried out using a systematic analytical approach focused on the integration of additive and subtractive technologies in mechanical engineering. The research materials included scientific sources, technical descriptions of hybrid machines, and information related to Industry 4.0 technologies, including automation, sensors, digital twins and intelligent control systems.

The methodology consisted of three stages. First, the functional roles of additive and subtractive processes in hybrid manufacturing systems were analyzed. Second, the influence of digital technologies on process control and production stability was studied. Third, the contribution of hybrid systems to productivity, resource efficiency and manufacturing flexibility was evaluated.

The general structure of a digitally controlled hybrid manufacturing system can be expressed as:

$$HMS = AM + SM + DC$$

Where HMS is the hybrid manufacturing system, AM is additive manufacturing, SM is subtractive manufacturing, and DC is digital control.

RESULTS.

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The analysis showed that hybrid manufacturing systems improve the productivity of mechanical engineering enterprises not only by combining additive and subtractive processes, but also by integrating digital control technologies. Additive manufacturing forms the initial geometry of a part, while subtractive machining provides the required dimensional accuracy and surface quality. Digital control systems, sensors and intelligent monitoring improve the stability of these processes.

The main results are presented in Table 1.

Table 1.

Influence of hybrid manufacturing systems on production efficiency

Factor	Effect on production
Additive manufacturing	Produces complex geometry and reduces material waste
Subtractive machining	Improves surface quality and dimensional accuracy
Digital control	Stabilizes the manufacturing process
Sensors and monitoring	Detect process deviations in real time
Digital twins	Help simulate and optimize production parameters
Industry 4.0 integration	Increases automation and competitiveness
One-platform production	Reduces machine setups and production time

The results indicate that hybrid manufacturing systems can reduce production stages and improve the quality of complex parts. In comparison with traditional production, hybrid systems make it possible to perform material deposition and finishing operations within one technological platform. This reduces repositioning errors, shortens the production cycle and improves process reliability.

Another important result is that Industry 4.0 technologies increase the efficiency of hybrid systems. Sensors and digital monitoring allow real-time control of machining conditions, while intelligent control systems help optimize process parameters. As a result, hybrid manufacturing becomes more suitable for producing high-precision parts in aerospace, automotive and medical engineering.

Advantages and limitations of hybrid systems. One of the key advantages is reduced production time: integrating additive and subtractive processes within a single machine removes the need to transfer parts between separate production areas, thereby accelerating the manufacturing cycle [8].

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Quality improvement. Subtractive machining mitigates the inherent limitations of additive manufacturing, including inadequate surface finish, by enabling precision at the micrometre scale [9].

Resource conservation. Hybrid manufacturing systems reduce material waste, as additive processes utilize only the necessary amount of raw material, while subtractive operations remove only a minimal excess of material [10].

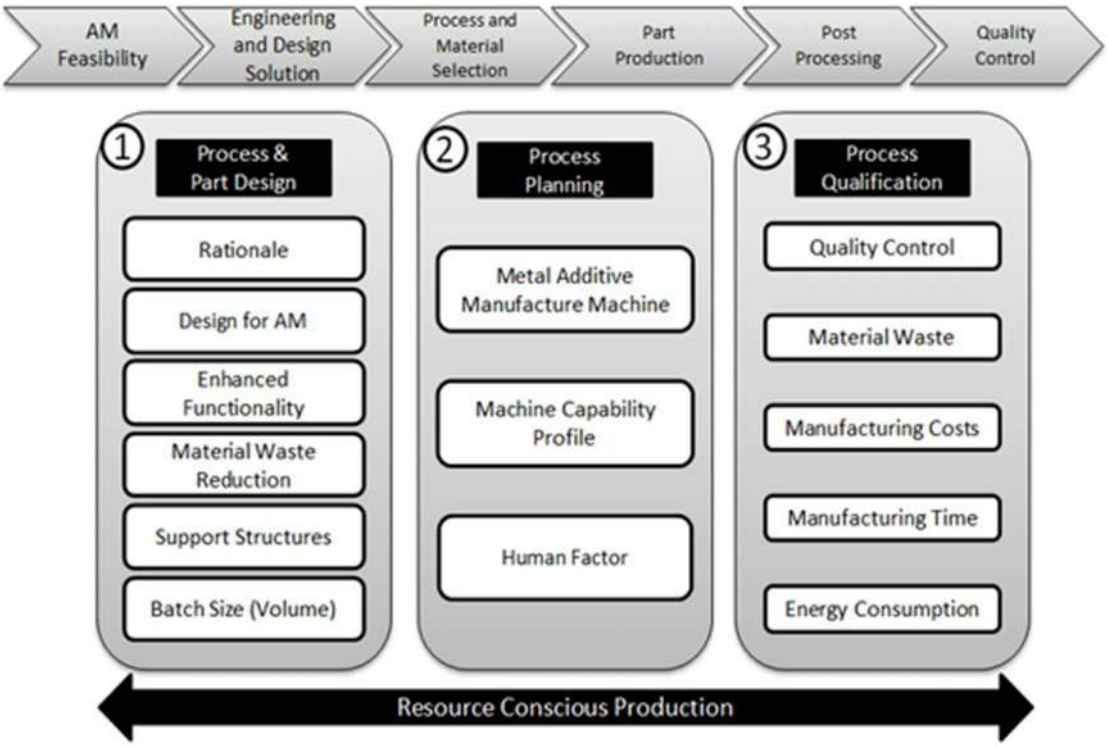


Figure 2. A framework outlining the factors that influence resource efficiency in metal additive manufacturing.

Design flexibility. The capability to produce complex geometries with optimized topology improves component functionality, especially in the in the aerospace sector and medical technology applications.

DISCUSSION.

The obtained results show that the effectiveness of hybrid manufacturing systems depends not only on the mechanical combination of additive and subtractive methods, but also on the level of digital integration. In conventional hybrid systems, additive manufacturing and CNC machining are used mainly to improve geometry and surface quality. However, in modern Industry 4.0-based systems, sensors, digital twins and intelligent control methods make the process more stable and predictable.

This is the main difference between ordinary hybrid manufacturing and advanced hybrid manufacturing. Ordinary systems focus on physical production, while digitally integrated systems focus on production control, data collection and

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real-time optimization. Therefore, modern hybrid systems can reduce not only material waste and machining time, but also process errors and equipment downtime.

However, several limitations remain. Hybrid machines require high initial investment, advanced software and qualified specialists. In addition, the use of sensors, AI-based control and digital twin technologies increases the complexity of the system. For small and medium-sized enterprises, these factors may limit the practical implementation of hybrid manufacturing technologies.

Despite these limitations, hybrid manufacturing systems have strong potential for future mechanical engineering. Their integration with Industry 4.0 technologies can improve productivity, increase product quality and support the digital transformation of manufacturing enterprises.

A significant limitation of hybrid systems is their high initial cost. The acquisition of hybrid machines requires substantial investment, which may pose a barrier, particularly for small and medium-sized enterprises. In addition, the operational complexity of such systems necessitates highly qualified operators and programmers. Another constraint is the limited range of materials compatible with additive manufacturing, which can restrict the application of hybrid technologies in high-load or high-stress components.

CONCLUSION. Hybrid manufacturing systems enhance productivity in mechanical engineering enterprises for several reasons. Firstly, they shorten production cycles, which is especially critical for small-batch and customized manufacturing. Secondly, the integration of digital technologies, such as AI-driven control systems and digital twins, enables real-time optimization of machining parameters, thereby reducing errors and improving process accuracy. Practical applications demonstrate the effectiveness of these systems. For example, in the aerospace industry, hybrid machines are employed in the production of turbine blades. In this case, additive processes form complex internal surfaces. This combination reduces component weight and enhances mechanical strength, which directly contributes to lower fuel consumption and improved operational efficiency. Within the framework of Industry 4.0, hybrid systems are emerging as a crucial component in the digital transformation of manufacturing. Progress in artificial intelligence enables automated configuration of hybrid machine parameters, while the Internet of Things (IoT) facilitates real-time system monitoring, thereby improving reliability and reducing downtime. In addition, ongoing research into advanced materials, such as high-strength alloys and composite structures, is broadening the range of potential applications for hybrid technologies. Future developments are expected to focus on reducing equipment costs and simplifying system management. The implementation of

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standardized software platforms and modular machine architectures is likely to make hybrid manufacturing solutions accessible to a broader range of enterprises.

Hybrid manufacturing systems, integrating additive and subtractive processes, constitute an innovative approach that is transforming mechanical engineering. Their core principles rely on the synergy between these technologies, enabling the production of complex components with high precision and reduced cost. Despite certain limitations, such as high capital investment and complex control requirements, these systems substantially enhance industrial productivity by shortening production times and optimizing resource utilization.

REFERENCES

1. Иванов А.В. Гибридные технологии в машиностроении. – М.: Машино строение, 2023. – 180 с.
2. Петров В. И. Индустрия 4.0: цифровые технологии в производстве. – СПб.: Питер, 2022. – 200 с.
3. Смирнов Д. Г. Аддитивное производство: теория и практика. – М.: Тех носфера, 2024. – 150 с.
4. Кузнецов П. А. Субтрактивная обработка в гибридных системах. – Ка зань: КГТУ, 2023. – 120 с.
5. Егоров Р. С. Экономические аспекты гибридных технологий. – М.: Эко номика и промышленность, 2022. – 160 с.
6. Сидоров М. Н. Управление гибридными станками: современные под ходы. – Новосибирск: НГТУ, 2023. – 140 с.
7. Григорьев А. И. Технологии производства сложных деталей. – М.: Ин фра-М, 2024. – 180 с.
8. Васильев С. А. Интеграция аддитивных и субтрактивных методов. – СПб.: Политехника, 2023. – 200 с.
9. Козлов Д. А. Качество поверхности в гибридном производстве. – М.: Техносфера, 2022. – 150 с.
10. Николаев Д. В. Экологичные технологии в машиностроении. – Екате ринбург: УГТУ, 2023. – 170 с.
11. Dilberoglu, U. M., Gharehpapagh, B., Yaman, U., & Dolen, M. (2017). The role of additive manufacturing in the era of industry 4.0. Procedia manufacturing, 11, 545-554.
12. Girdwood, R., Bezuidenhout, M., Hugo, P., Conradie, P., Oosthuizen, G., & Dimitrov, D. (2017). Investigating components affecting the resource efficiency of incorporating metal additive manufacturing in process chains. Procedia Manufacturing, 8, 52-58.

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