



HYBRID ADDITIVE TECHNOLOGIES IN MECHANICAL ENGINEERING

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Abstract:

Hybrid additive technologies in mechanical engineering represent an innovative approach to the manufacturing process that combines traditional material processing methods with additive manufacturing (also known as 3D printing), enhanced by subtractive processes to achieve greater accuracy and desired surface roughness. This synthesis makes it possible to create complex components with a high degree of customization and material optimization - capabilities that are difficult or impossible to realize using conventional methods. Additive technologies offer significant benefits, such as reducing waste, shortening production times, and enabling the fabrication of parts with intricate geometries often unachievable through standard processes. The hybridization of these technologies increases the flexibility and efficiency of production lines while simultaneously improving the quality of the final product. In mechanical engineering, hybrid additive technologies can be applied at various stages of the manufacturing process, including design, prototyping, and the final production of components. They are particularly useful for producing tools, fixtures, and custom solutions for automation. Moreover, these technologies allow the integration of different materials into a single component, opening up new possibilities for innovation in materials science and engineering. Despite their many advantages, hybrid additive technologies still face challenges, such as high initial investments in equipment and the need for specialized personnel. Nevertheless, they continue to gain popularity in the industry due to the substantial long-term benefits and potential for innovation they offer. As these technologies evolve and costs decrease, hybrid additive solutions are expected to become more accessible and widely adopted in mechanical engineering.

1. INTRODUCTION

In recent years, a number of fundamental changes have occurred in the field of metalworking with CNC machines (computer numerical control), which have had a direct impact on the quality, accuracy and speed of production processes in mechanical engineering. The accumulated experience and the widespread introduction of automation, digitalization and modern programming environments ha-

ve made it possible to achieve increasingly high standards in this industry.

The first CNC machines appeared in the middle of the 20th century and were intended mainly for the mass production of simple parts. Over the years, their precision and functionality have developed significantly. Today, CNC machines offer high processing speeds, the ability to work with various tools and implemented automated quality control systems, as well as:

- Increased processing speed and dynamics: New servo motors and drive mechanisms allow fast but smooth movements of the spindle and work table.
- Higher rigidity and stability: The design solutions of the machine housings and the materials used (often high-strength cast iron or composite beds) ensure lower vibrations. In this way, higher accuracy is maintained in high-load operating modes.
- Automatic tool change: Integrated systems (Automatic Tool Changers – ATC) eliminate time losses and ensure parameter consistency. The high productivity of CNC machines would be impossible without the corresponding software solutions. Today’s CAM (Computer-Aided Manufacturing) systems are integrated with CAD (Computer-Aided Design) and CAE (Computer-Aided Engineering) environments, which facilitates the design, simulation and planning of the production process.
- Parametric and adaptive programming: Modern CAM systems can automatically calculate the optimal tool path and suggest appropriate cutting modes based on materials, hardness, desired speed and other factors.
- Online monitoring and control: More and more machines are being connected to the network, allowing remote access, diagnostics and analysis in real time. This leads to better management of production resources and increased efficiency.

In CNC machining of metal parts, the ultimate accuracy is determined not only by the machine, but also by a number of other factors related to the organization and methods of work.

The accuracy and roughness of the resulting surfaces, depending on the technologies used, is:

- Turning:

Roughness: Ra from 0.4 μm to 12.5 μm

Dimension accuracy: up to 0.006 mm

- Milling:

Roughness: Ra from 0.4 μm to 12.5 μm

Dimension accuracy: up to 0.003 mm

- Grinding:

Roughness: Ra from 0.025 μm to 3.2 μm

Dimension accuracy: up to 0.002 mm

- EDM: There are EDM technologies, namely:

- SINKER EDM:

Roughness: Ra from 0.1 μm to 12.5 μm

Dimension accuracy: up to 0.005 mm

- Wire EDM:

Roughness: Ra from 0.36 μm to 10.5 μm

Dimension accuracy: up to 0.003 mm.

Over the past two decades, additive manufacturing technologies (Additive Manufacturing – AM) and modern computer-controlled systems (CNC) have established themselves as fundamental building blocks of modern mechanical engineering. These two fields have developed in parallel and independently, but the possibility of their integration has led to the emergence of so-called “hybrid manufacturing systems”. Hybrid technologies combine additive methods (e.g., material deposition through laser cladding, laser sintering, or FDM) with subtractive technologies such as milling, turning, and grinding. The result is a significant reduction in the production cycle, increased precision and flexibility, and optimal material utilization.

This article will explore the fundamental concepts of hybrid technologies, as well as the key components and approaches to their implementation. It will present essential design solutions, process logic, and illustrations that contribute to a better understanding of these complex yet highly promising systems.

The table below shows the main technologies for 3D metal printing as well as the resulting printing accuracies [1].

Metal AM Process	Typical XY resolution, μm	Typical Z resolution, μm
Binder Jetting	20÷65	50÷100
PBF	20÷200	20÷200
Powder DED	100÷1000	100÷1000
Joule printing	500÷1000	500÷1000
Wire DED	2000÷50000	1000÷10000

It is evident that the disadvantage of additive technologies is the low accuracy on one side and on the other hand the difference in accuracy in the horizontal and vertical directions. To overcome this, hybrid technologies were born. They combine the advantages of additive technologies, in which the

material consumption is practically the same as the product itself with an addition for the finishing operations using modern technologies.

2. FUNDAMENTAL PRINCIPLES OF HYBRID TECHNOLOGIES

Hybrid manufacturing systems combine two core processes: additive and subtractive, **Fig. 1**. The additive phase allows for the rapid layering of volumes, complex shapes, and internal structures with minimal waste. The subtractive phase subsequently refines surfaces with precision, ensuring accurate dimensions and smooth finishes. This approach achieves the best of both worlds-geometric freedom and precision.

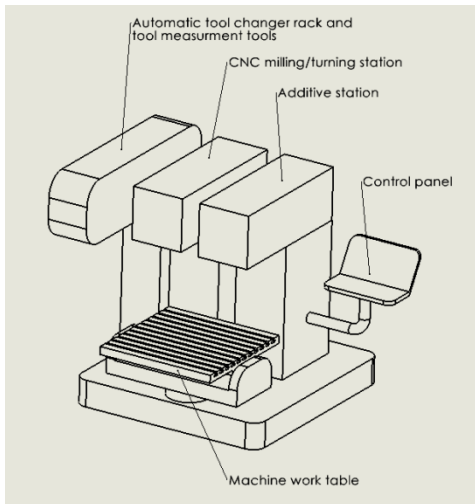


Fig. 1 Schematic layout of modules in a hybrid machine.

Key advantages:

- **Reduction in production time:** Transitioning between additive and subtractive operations within a single machine eliminates the need for moving the part.
- **Optimal material usage:** The additive process ensures precise material addition, while the subtractive process provides economical fine machining.
- **Enhanced accuracy and quality:** Precise machining following additive layering leads to geometric and dimensional accuracy typical of CNC technologies.

The schematic representations of hybrid technologies can generally be illustrated through block diagrams that describe the sequence of operations,

as well as structural diagrams of the machines themselves, **Fig. 2**.

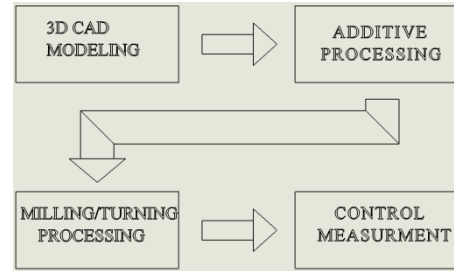


Fig. 2 Block diagram of a hybrid manufacturing process.

A hybrid machine typically integrates several key technological modules:

- **Additive Module:** Laser source (laser cladding, laser sintering) or electron beam head (EBM).
- **Subtractive Module:** Milling or turning spindle, tools for mechanical processing.
- **Workpiece Fixing and Positioning System:** Precision rotary/tilting worktable (5-axis kinematics) or standard 3-axis configuration.
- **Control System:** Software, integrated CNC controller, and interface for managing laser parameters (power, deposition speed) and cutting tool trajectories.
- **Measuring and Monitoring Equipment:** Laser sensors, optical measurement systems, or contact probes for feedback, **Fig. 3**.

The process of hybrid manufacturing can be divided into several main stages:

1. **Preparation of the CAD Model:** Initially, engineers prepare a 3D model and determine which sections will be built additively and which will undergo subtractive actions.
2. **Additive Layering:** The machine applies layer after layer of material, which may consist of metal powder or filament, and different types of materials can be used. This allows for the use of cheaper material for non-critical sections of the 3D model, while higher-quality, more expensive materials with superior physical and mechanical properties can be applied where necessary. Additionally, sections with varying hardness levels can be realized.

3. **Intermediate Metrology and Control:** After key stages of additive building, measurements may be performed. If deviations are identified, parameters are corrected in real time.
4. **Subtractive Processing:** In the second stage, the machine transitions to CNC processing. Through milling, turning, or grinding, precise shaping, dimension compliance, and required surface smoothness are achieved.
5. **Final Inspection and Finishing Operations:** After the final geometry is achieved, a comprehensive inspection is conducted. Additional procedures such as polishing, thermal treatment, or coatings can be applied.

Different conceptual schemes exist depending on the specific technology and material. Two main approaches are:

- **Hybrid Center with Integrated Laser Metal Deposition (LMD):** In this case, a spindle is equipped with a laser head that delivers metal powder and sinters the layer. The same machine can then switch tools and transition to milling.
- **Hybrid System with Integrated Polymer Extruder (FDM) and CNC Spindle:** Here, 3D printing with a polymer filament is combined with subsequent milling to achieve precise surfaces and functional dimensions.



Fig. 3 Measurement Directly On CNC Machine [2].

Flexibility by utilizing combination of additive and milling machining process for 3D-parts in finished, offered by one of the leading companies DMG MORI have the following technological capabilities, **Fig. 4:**

- The laser head is handled by a fully automatic shuttle - without manual intervention;

- 5-axis material deposition by coaxial nozzle for homogeneous powder distribution, independent from direction of laser deposition welding;
- Full 5-axis milling machine in rigid mono BLOCK-design with < 129.2 ft² footprint;
- Process monitoring and adaptive process-control (Closed Loop);
- User friendly and specifically developed software with operator-orientated user interface and CELOS integration.

Completely new product design potential:

- 5-axis controlled laser deposition welding in machining centers makes new products possible;
- New part features possible due to alternating material deposition and machining strategies;
- Improved part performance by utilizing new material combinations (e.g. Copper + Inconel);
- Parts with inner channels for innovative, improved cooling, **Fig. 4.**



Fig. 4 DMG MORI LASERTEC 65 DED [3].

There are two options for using finishing operations in additive technologies:

- applying an entire thickness and then finishing milling, turning or grinding is performed. This is used when repairing parts, **Fig. 5;**
- printing a certain thickness and then finishing milling is performed. This is followed by a new level and subsequent milling or turning.

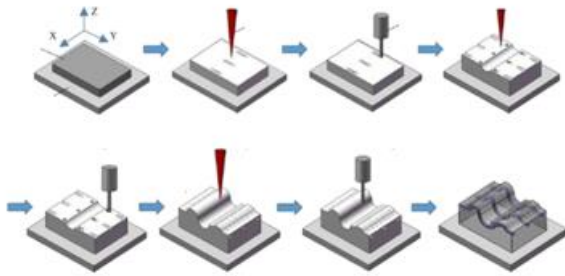


Fig. 5 Hybrid manufacturing processes.

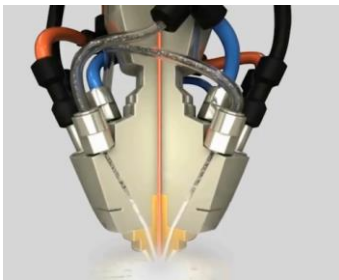


Fig. 6 Powder-based directed energy deposition (DED).

Powder-based Directed Energy Deposition (DED) (Fig. 6), such as Laser Engineered Net Shaping (LENS) or Laser Metal Deposition (LMD) involves feeding powder material into the deposition area, where it is melted by a heat source such as a laser or electron beam.

This method is prized for its high precision and suitability for repairing and adding features to existing parts. Companies like Optomec and BeAM are notable players in this field. Metals and alloys, including titanium, cobalt-chrome, and stainless steel, are commonly used. The method offers advantages such as high precision, material choice flexibility, and effectiveness in complex repairs. However, it also presents challenges, such as the high cost of powder materials and potential issues related to powder handling.

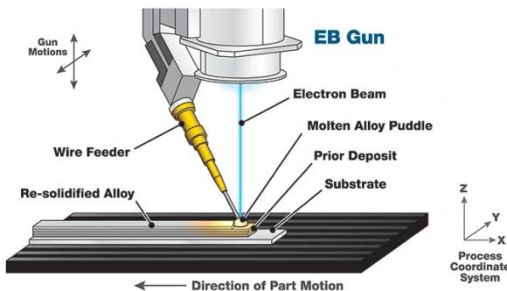


Fig. 7 Wire-based directed energy deposition (DED) [5].

Wire-based Directed Energy Deposition (DED), **Fig. 7**, utilizes a metal wire as the feedstock, which is melted by a heat source and deposited layer by layer. This method stands out for its efficiency and economy, especially for constructing large structures. Companies like Gefertec and Sciaky, Inc. are notable players in this field. Materials commonly used include titanium, aluminium, and stainless steel. The method offers advantages such as high material utilization and lower costs than powder-based alternatives, making it particularly suitable for large parts. However, it does have drawbacks, including lower precision compared to powder-based methods and being limited to wire feedstock [4].

3. CONCLUSIONS

Hybrid manufacturing technologies are a key element of the future of mechanical engineering and precision manufacturing. Their potential to combine the flexibility of additive technologies with the accuracy of subtractive machining enables the reduction of production costs, the improvement of quality and the shortening of time to market for new products.

The schematic diagrams presented here are only a basis for understanding the concept. In real practice, these systems are developing dynamically, incorporating more advanced sensor systems, more intelligent control and optimization software, as well as increasingly diverse and innovative production methods. It is expected that in the coming years, hybrid technologies will continue to be integrated and improved, providing sustainable, high-tech and efficient solutions for industry.

REFERENCES

- [1] <https://manufactur3dmag.com/surface-roughness-a-guide-to-metal-additive-manufacturing-by-digital-alloys/>
- [2] <https://metrology.news/solution-puts-part-measurement-directly-on-cnc-machine-tools/>
- [3] <https://en.dmgmori.com/products/machines/additive-manufacturing/powder-nozzle/lasertec-65-ded-hybrid>
- [4] <https://engineeringproductdesign.com/knowledge-base/direct-energy->

deposition/?utm_source=youtube&utm_medium=video

- [5] <https://engineeringproductdesign.com/knowledge-base/direct-energy-deposition/>