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International Symposium on ElectroChemical Machining Technology 2024

Aachen, November 18-19, 2024

Thomas Bergs, Elio Tchoupe Sambou, Timm Petersen,
Tim Herrig, Andreas Klink (Eds.)

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Editors

Thomas Bergs

Elio Tchoupe Sambou

Timm Petersen

Tim Herrig

Andreas Klink

Manufacturing Technology Institute – MTI, RWTH Aachen University

Campus-Boulevard 30

52074 Aachen

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Development and Outlook of (P)ECM-Manufacturing Applications in the Aviation Industry

*K. Bayer[a], N. Feiling[a]**

[a] MTU Aero Engines AG, Dachauer Straße 665, 80995 München

**Corresponding author:* nicole.feiling@mtu.de

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Abstract

The high-pressure compressor of the PurePower® PW1100G-JM geared turbofan for the Airbus A320neo is the first civilian compressor to be fully constructed using a blade integrated disk (Blisk) design. The compressor stages have a diameter of approximately 450 mm.

The complex airfoil design of the compressor stages poses significant challenges for manufacturing. MTU Aero Engines AG has successfully used electrochemical machining (PECM) to produce the airfoil geometry of the fifth and sixth stages of the compressor for about 10 years.

This paper outlines the success story of manufacturing complex free-form blade profiles on an industrial scale and provides insights into potential future applications of PECM technology in engine production. One such application is the use of ECM machining for manufacturing profile grooves, which offers an interesting alternative to conventional broaching.

1 Introduction

MTU Aero Engines is a prominent player in the aerospace industry, renowned for its innovation and excellence in aircraft engine technology. The company has a rich history of advancing propulsion systems, contributing significantly to both commercial and military aviation. MTU's commitment to research and development ensures continuous improvement and adaptation to the evolving demands of the aviation sector.

MTU's expertise extends across critical engine components, with a particular focus on the high-pressure compressor (HPC), the low-pressure turbine (LPT), and the turbine center frame (TCF), as illustrated in Figure 1.

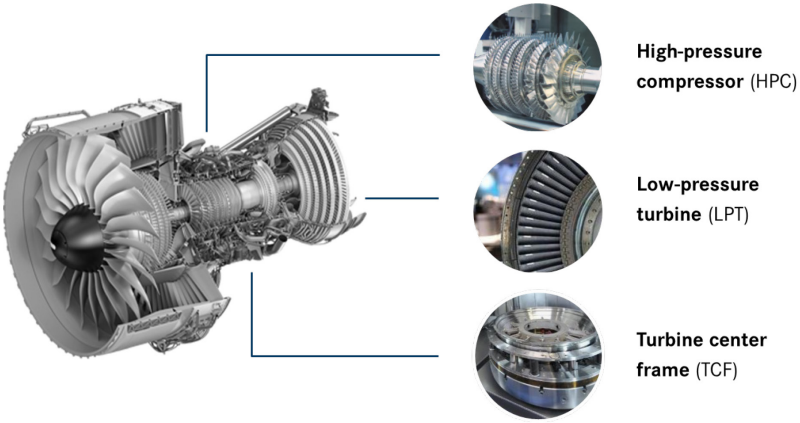


Figure 1: *Core competencies of MTU*

2 (P)ECM-Applications in aviation industry

In consideration of the requirements imposed on workpieces during flight operations, the utilization of nickel-based superalloys has become imperative for their manufacturing. However, the conventional approach of cutting-machining nickel-based superalloys proves to be prohibitively expensive. Consequently, MTU has strategically opted to produce such products through the employment of Electrochemical Machining (ECM). Within the context of MTU, ECM, alongside its variant known as Precise Electrochemical Machining (PECM), assumes a critical role in the fabrication of High-Pressure Compressor components, including Blade Integrated Disks (Blisks), and Low-Pressure Turbine components. [1, 2]

2.1 HPC Blisk manufacturing

(P)ECM Blisk manufacturing @ MTU enables the precise shaping of the entire flow channel, including the intricate curves and profiles of the blades, making it ideal for high-volume production in MTU's GTF (Geared Turbofan) engine programs (Figure 2). This ensures that Blisks are manufactured to high quality standards.

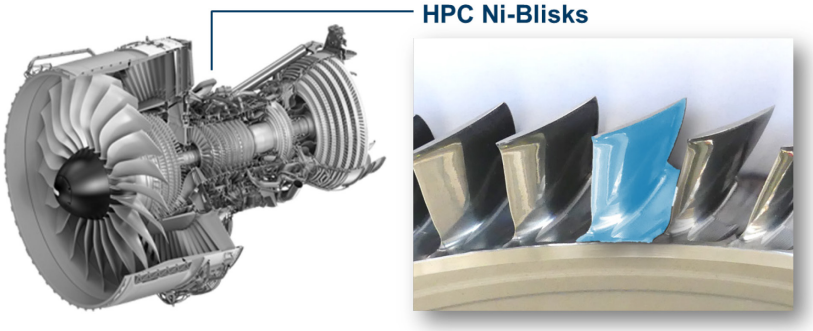


Figure 2: *(P)ECM Blisk manufacturing @ MTU for PW1000G stages 5 and 6*

The average processing time per Ni-Blisk is 24 hours. To make the process as efficient as possible, five different processing steps are used. Conventional ECM is used for roughing, intermediate, and edge machining, while pulse ECM and PECM are mainly used for the finishing touches. PECM involves the use of oscillating tool movement to improve the flushing conditions between the tool and workpiece, resulting in high geometric accuracy and surface quality.

The design of the tool cathodes for (P)ECM is challenging due to the complex removal reaction and uneven gap formation. However, advancements in simulation processes for tool design, as well as machine and process technology development, contribute to expanding the application range of ECM in the future. [3]

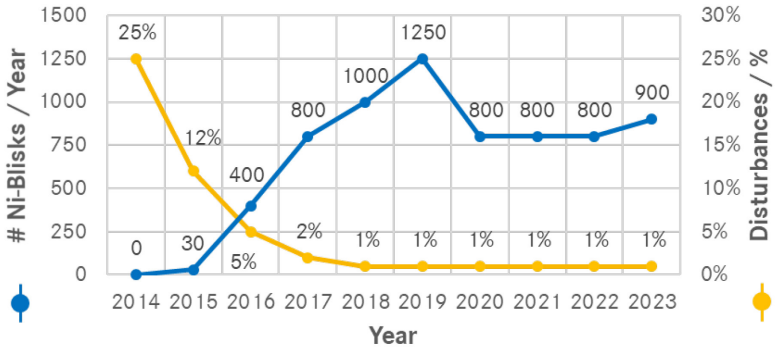


Figure 3: *Yearly production rate of Ni-Blisks including disturbances*

During the previous decade, the company has proficiently operated seven (P)ECM machines, leading to the production of more than 6,500 Blisks. Notably, the manufacturing process has showcased an impressive level of process stability, with a minimal scrap rate of less than 1%, as shown in figure 3.

This advanced technology enables to meet the demanding production of aerospace requirements. The integration of process data management has further enhanced the manufacturing process by allowing continuous monitoring and optimization of key parameters such as feed rate, current efficiency, energy consumption and rather more.

The development of the next generation of PECM systems for Blisk production represents an advancement in engine manufacturing, particularly in response to the rising demand for Ni-Blisks in upcoming engine programs. This innovative system not only secures production targets aligned with market needs but also significantly enhances component quality through revolutionary generator technology. By facilitating the production of high-quality, ECM-compatible test components, the system improves performance and reliability in aviation applications. Moreover, it achieves a remarkable increase in efficiency by a factor of 2-3 through optimized processes and strategic resource allocation, while expanded data recording capabilities enable informed decision-making and continuous improvement.

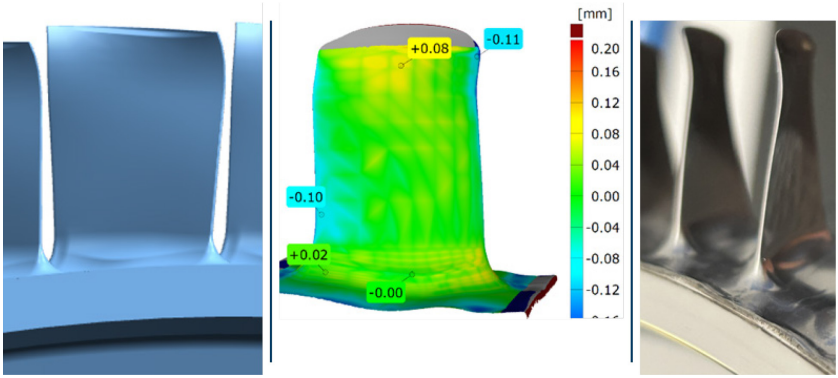


***Figure 4**: ECM manufactured demo part from CAD (left) to trial (middle) and result (right)*

The ECM process offers a decisive advantage by providing opportunities for new and innovative Blisk geometries, which have been developed and trialled by an interdisciplinary team of HPC developers and ECM process experts. The subsequent engineering of an ECM manufactured demo Blisk (Figure 4: left) further allows for the incorporation of innovative features. After first trials and

measurements (Figure 4: middle) is feedback for revolutionary and synergetic Blisks (Figure 4: right) for the next generation engine possible.

2.2 LPT Disk manufacturing

MTU is one of the world's most experienced and technologically advanced manufacturers of low-pressure turbines. The most recent development is that MTU's high-speed low-pressure turbine is a key component of the innovative geared turbofan (Figure 5). [4]

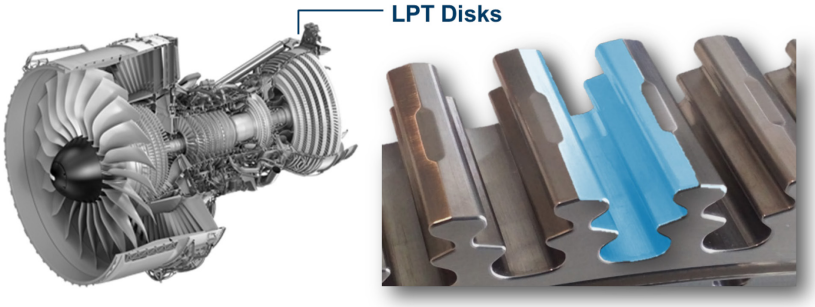


***Figure 5**: ECM Slot manufacturing in LPT Disks*

Starting in 2026, MTU also plans to use newly developed ECM equipment to machine the profile slots of low-pressure turbine disks as an alternative to the conventional broaching process (Figure 6).

In the first process step, conventional ECM is used to sink into the solid material. During this process, the slot geometry is produced with a defined oversize. In the finishing step, pulse ECM is used to produce the final geometry. This technology offers numerous advantages over conventional techniques like broaching, including improved precision and cost-effectiveness.



Figure 6: *ECM equipment for slot manufacturing with 4-fold parallel processing*

3 Conclusion

The future of aviation will be characterized by increased demand for more efficient and eco-friendly aircraft. PECM represents a significant step forward in achieving these goals by enabling the production of lightweight, high-performance components.

As a key player, MTU Aero Engines can actively contribute to the further development of PECM technology. Research and development efforts should focus on exploring new applications to fully unlock the potential of PECM in aviation.

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