Grinding Blades and Vanes with Closed-Loop Processing

Remaining Competitive in Today's Aerospace Industry

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While the MAX grounding and aftermath of the pandemic have significantly depressed the aero engine market, the current market conditions reveal that a recovery is finally on the horizon. The MAX is back in the air and vaccines are now available. As the commercial aircraft market continues its recovery, production rates will need to rise to support the growing demand.

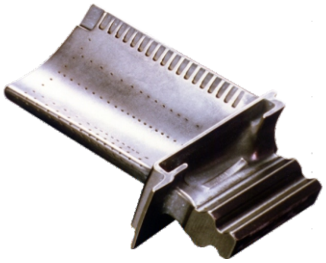
In February, during a National Aeronautic Association presentation, Richard Aboulafia, VP at Teal Group, forecast that once begun in earnest in late 2021 or early 2022, the single aisle recovery rate will occur at a very rapid pace and that by late 2022 the domestic, single aisle market will be again approaching 2018 levels. To effectively compete in this recovering marketplace, manufacturers will need to implement productive equipment and proven processes now to prepare for the anticipated rapid upturn.

As production increases, the builders—both engine and airframe—along with their suppliers, will need to produce parts as efficiently as possible. Had the market disruptions of the past few years not occurred, current production rates would already have been at record levels and increasing to even higher levels. Now it is expected that production rates may never even return to the lower "pre-disruption" levels. Manufacturers will no longer be able to rely on the unprecedented high rates to make a profit; rather, they will need to find solutions to allow a profit at lower production rates. The production processes themselves will need to change in order to be efficient at lower rates. Although this holds true for all aerospace part manufacturing, it is particularly important for the engine builders. In a relative sense, there are parts within an engine which might be considered "high volume" for aerospace parts production. Many of these are within the hot section of the engine.

Historically, the production of turbine engine hot section, components such as blades and vanes, was a complex, multi-setup process that used a combination of milling, grinding and EDM machines. As part tolerances have been tightened to improve engine performance, the need to reduce processing tolerance stack ups has become more important. In a very straight forward manner, the fewer set ups, the more dimensionally robust the process. The ability to do milling, drilling and grinding on a single, multi-axis machine platform is a key element in the reduction of part set ups.

Responding to aircraft engine manufacturers' need to produce turbine engine blades and vanes efficiently, Makino has been providing customers with robust, flexible, and productive machine platforms for more than 25 years. The current G5 and G7 iGrinders are fourth-generation machines which combine milling, drilling, and grinding capabilities on a single platform.

Although blades and vane production would be considered "low volume" in an automotive environment, in a relative sense, they are "high volume" in the jet engine business. As with all industries, when volumes increase, the advantages of automated systems become more apparent. Blade and vane processing is no different.



Closed Loop Processing

To produce these large quantities of high-quality parts with minimal scrap, manufacturers need a system that allows for more efficient production with less operator intervention.

In a closed-loop manufacturing process, the quality and accuracy of the parts being made are improved by providing correlation and feedback between the measuring device and the manufacturing device. The machines communicate and react to each other, correcting any errors and making improvements without human intervention while keeping the process on track.

At an elemental level, the closed-loop manufacturing process involves:

- Loading raw parts into the machine
- Collecting data from probing to get a best fit alignment before machining the part
- Processing it
- Checking it
- Sending it back out before loading another part

The feedback that occurs throughout the process provides the closed loop.

What to Consider When Implementing a Closed Loop Process System

- How to select the right partner and right equipment
- The importance of cell layout and automation
- Testing and process checks
- Understanding how the closed-loop process works

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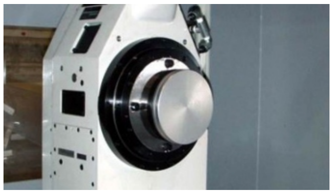
Selecting the Right Partner and Right Equipment

To implement a closed-loop manufacturing system, it's important to find the right team with closed-loop experience and who also has strong third-party supplier relationships. This partner should be able to execute a complete turnkey package; handling everything required including the automation, software, mechanical and electrical engineering, while providing local support. The right partner should be familiar not only with the machine itself, but also probing, part processing, coordinate-measure machine (CMM) integration and quality control requirements. They should be willing to set up the system/process and debug it before the machine is even delivered. The partner should also be available for post-sale technology transfer.

There are several equipment/machining features to consider when preparing for closed-loop manufacturing:

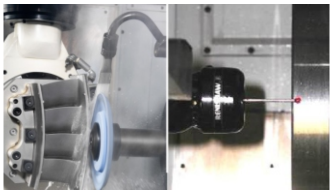


Rotary Axes

Look for a multi-axis machine with the ability to perform five-sided machining. This allows the part to be machined fully with the least possible number of setups.

ATC and Tool Storage

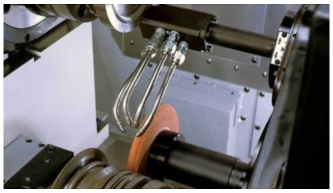
The machining platform should have the ability to quickly and easily change both the grinding wheels and other traditional cutting tools to provide a "multi-process" machining solution.



Multifunction Capability

Look for machines that will handle a variety of parts while performing multi-axis machining—including ones that can perform many types of processes such as milling, drilling, and grinding, as well as probing and in-cycle work measurement. Select machines that maintain accuracy while managing their thermal environments. This includes temperature control of the machine elements, such as ball screws, castings, spindles, etc., along with a coolant system temperature control to provide additional process thermal stability.

Selecting the Right Partner and Right Equipment

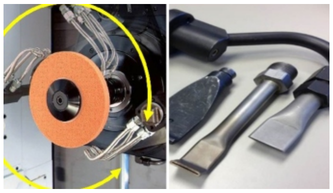


Rotary Wheel Dresser/twin-roll Dresser

To maintain efficient grinding action and maximize the grinding wheel life, a wheel dresser is needed to condition the surface of a trued wheel to expose fresh, sharp grain. The dressing process itself must be carefully considered. Machines may have single- or dual-roll dressers. These are designed to not only keep contaminants out of the work zone, but also to provide quick changeover of the dressing rolls. These designs increase the likelihood of the "first part, good part" after each part changeover.

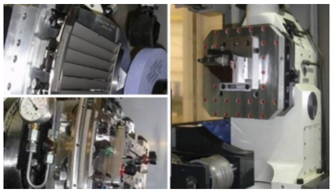
Reliable Machine Design

The platform should be both mechanically accurate, based on a robust design and appropriately thermally managed to react to a robust grinding/machining environment. The machine's heritage should come from the high volume, 24/7 automotive production environment where unplanned breakdowns are costly.



Coolant Nozzle

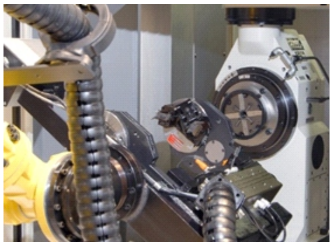
Look for a machine that can be equipped with a variety of coolant nozzles. Coolant should be delivered at high pressure and high volume directly into critical locations along the grinding wheel. Look for a dual nozzle or one with the ability to reach around the part. For example, a 360-degree NC-controlled coolant nozzle can be especially helpful for multidirectional grinding, providing flexibility with the ability to cut in multiple directions. Other features to consider include machines with no external hoses or cables, with wheel-diameter tracking and the ability to reverse directions, as well as controlled positioning of the nozzle(s) at the optimum location on the grinding wheel.



Pallet Chucks

A pallet power chuck usually comes standard on most machines, but some manufacturers also offer the option for additional chucks that accommodate greater weight or a larger pallet. Pallet systems also facilitate automation of the loading and unloading process.

Cell Layout and Automation



Initially it should be decided whether it will be best to implement a closed-loop process into an automated or non-automated cell. Automated cellular machining systems have been key to global competitiveness for many manufacturers and can be configured to meet a variety of needs across most industries. While automated systems may have a slightly higher initial cost, they can improve output. Companies use automation to increase machining efficiency and capacity to gain extra revenue potential by saving direct labor costs and setup times or to improve quality by reducing, or even eliminating, scrap.

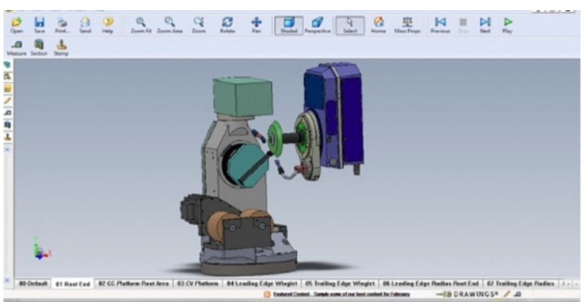
Incorporating a robot into the processing cell can help increase throughput. It enables the convenient loading of parts without stopping the machining sequence, reduces risk of incorrect loading, provides rapid loading of fixtures into the machine, helps with sequential machining, and yields higher productivity and increased efficiency. The operator loads the work-setting station while another part is in the machine, providing increased output only at a slightly higher initial cost.

In a closed-loop machining environment, it is important to choose a provider that has proven experience in automation. When it comes to machine selection, with floor space at a premium in most shops, the automation cell should be designed in a way that optimizes the use of square footage. It can be helpful to choose machines that require little area while still allowing access to the cell. Machines with stacked components can maximize floor space; yet leave room for maintenance personnel to walk between machines for servicing.

The flow of material through the cell should also be decided—such as where the raw material is introduced into the cell and the location for the finished product. Specifications for the production volumes should be known, as should requirements for additional capacity.

Testing and Process Checks

In a closed-loop environment, having the right equipment is key. However, in order to ensure quality parts, it's also equally important to select a supplier with the engineering expertise necessary to create the closed-loop processes. In addition to the pre- and post-sale support, this resource should conduct process checks during process/system design to manage the quality of the part and to make sure everything is achievable so that the manufacturer has the best machine and tooling packages. From conducting programming for coolant trajectories to engaging an in-house fixture designer, it's important to work with a provider that has the resources to predict what is going to happen and then provide and build exactly what discussed.



It is important to perform fixture testing prior to running production on the system. Finite element analysis (FEA) studies compare test loads and ensure that a stable fixture is built in to achieve reliable results. In essence, it compares what finite element analysis indicated it would be versus what was actually measured. It is helpful to work with a provider that models everything in 3-D, proving it out in SolidWorks or another similar program before building it.

Conducting a time study as part of the product package can also help to ensure a robust process from the start. This study provides an estimate of the cycle time that should be achieved and where processes can be improved. It essentially helps manufacturers better understand the process—such as the tools needed, the machining parameters and the cut/non-cut time. Inspecting design CAM, programming, simulation, feedback, and wheel tracking all helps to predict cycle time.

The cut strategy makes use of the time study and plans the cuts in more detail to ensure a robust process from the start. It examines the individual sequences of all the cuts needed, determining how to best approach the part so that the machine can get to all the features. It details the individual attributes that contribute to cycle time and it determines the types and shapes of wheels needed as well as wheel usage.

These studies may show that the part needs to be approached from a different angle or side. And the Vericut simulation proves out the part path and ensures that all features have a robust process. It also ensures that the nozzle path is clear.

The Closed-Loop Process

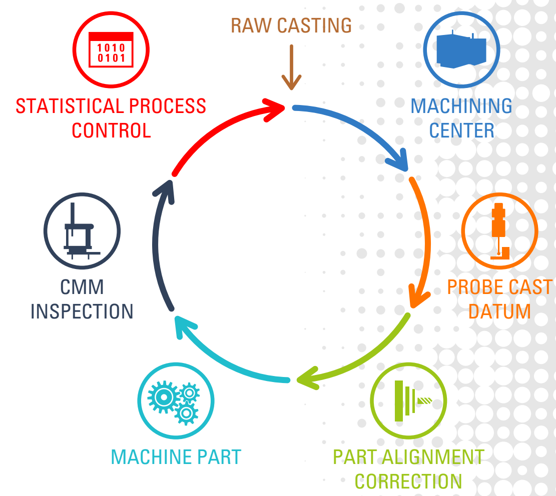
MACHINE	• Raw casting is loaded in fixture • Fixture is loaded into Makino 5-axis chuck
PROBING	• Fixture pallet probed for ID (optional) ID chips can be used • Initial alignment (I/A) is obtained by probing cast datum points. Iteration after every cycle determines best fit for gas path
PART MACHINING	• Using I/A, NC path is automatically modified, placing machined surfaces relative to gas path • KPV monitoring
CMM	• Path inspection
QUALITY CONTROL	• CMM inspection data archiving • SPC - Serialized recording/reporting/archiving • KPV - Serialized recording/reporting/archiving • Feature Compensation (F/C) - Automatic Individual characteristic offset adjustment feedback to machine based on selectable FI/FO sample size

In the closed-loop process, the casting is loaded into the fixture and the fixture is loaded into the machine. The next piece of the process—probing—is optional. However, manufacturers should correlate between the machine and probe, machine to machine, or the CMM on which the part is ultimately measured. Initial alignment is obtained by probing cast datum points. Probing can be completed in the machine or outside the machine in a CMM or other measurement device. That data can be stored or passed to the machine program to compensate the cut path.

The next step of the process is part machining. Beginning with the initial offsets, the NC code is modified automatically making the actual path match the adjusted alignment based on the probed datum values. During part machining, key process variable (KPV) monitoring is also conducted. These KPVs will include coolant pressure, volume, and temperature. These are critical items to monitor as a drop in pressure could lead to scrapped parts. Other KPVs to observe include spindle rpm, dresser rpm and tooling data. For tool monitoring, there are checks on how often the tool has been in the spindle and how accurate it is. The KPV data is usually kept for each part so that the manufacturer can review the historical data of how a part was produced.

After machining, part inspection data is fed back to the machine to determine whether adjustments are needed. Corrections can then be made for slight part misalignments.

To have a capable production process, typically the part is tracked along with the offset for the fixtures, the part, and the tool.



In a highly automated cell, some closed-loop providers have software with a graphics panel that displays CMM results and helps the operator monitor the machines. They are able to review robot speed control, cell sequencing, KPV reporting, feature correction and coolant monitoring. This information is valuable as it can quickly show that the closed-loop process is performing properly.

Conclusions

Ultimately, using closed-loop manufacturing technology not only reduces overall machining time but increases accuracy and quality. This is essential for today's global environment, where manufacturers must gain every competitive advantage available.

Although the closed-loop process can be complicated, it doesn't have to be if the right system supplier is selected. When implementing a closed-loop manufacturing process, it's essential that companies thoroughly evaluate suppliers based on these criteria:

- A single-source provider with a complete engineering staff and the commitment to the planning and execution of the process
- A machining platform that includes milling, grinding and EDM, along with 5-axis capability
- A turnkey process with the reliability and stability to reproduce the same kind of parts day in and day out with minimal adjustments
- A supplier that automatically conducts testing, 3-D modeling, and time studies prior to setting up the machine and running parts
- A provider that has capabilities for automation
- The ability to monitor key machining processes to help maintain the closed-loop process

By having the proper resources in place to execute this type of solution, manufacturers can ensure a smooth and accurate process.

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