Integration of machining and inspection as adaptive machining

The main challenge for manufacturers today is developing the ability to produce high-quality products on a consistent and rapid basis. Global competition is enabling customers to demand and receive machined components with better appearance, higher accuracy and with shorter lead times than ever before. Rising material prices and greater complexity in advanced components are making the cost of parts and the risk of scrap higher than ever making it even more important to minimise the risk of concessions. Proper inspection and quality control methods are no longer a luxury. Furthermore, inspection can no longer be something used only after the part is complete as a final check before shipment. Inspection must play an integral role in any manufacturing business that wants to grow and compete effectively on today's global stage. Simply dropping some new quality control procedures into the mix is not enough. Inspection must be fully-integrated into the manufacturing process for the investment to transform the manufacturing process and result in significant efficiency gains.

The traditional relationship between manufacturing and inspection is that machining is first completed on the company's machine tools and the components are then transferred to dedicated inspection equipment to be approved or rejected. However, as machining techniques have become more sophisticated, and as components have become larger and more complex, there are a growing number of cases where closer integration is required to give the highest productivity and the best possible reduction in concessions. Instead of a simple linear progression from CAD to CAM to machining to inspection, a more complicated series of checks and adjustments is needed, with extra data needed to fill any gaps in the information available at the various stages. These new processes can be grouped under the heading of "adaptive machining".

The programming of most machining operations is based around knowing three things: the position of the workpiece on the machine, the starting shape of the material to be machined, and the final shape that needs to be achieved at the end of the operation. Adaptive machining techniques allow successful machining when at least one of those elements is unknown, by using in-process measurement to close the information gaps in the process chain. It allows much more accurate machining, often eliminates costly and tedious hand work operations, and it allows any errors to be spotted earlier in the manufacturing process and resolved more quickly and at lower cost.

Software fixturing

The most common cases when adaptive machining is required are those where the exact position of the workpiece on the machine is unknown. With large or heavy components, such as landing gear components, moulds for bigger parts like composite body structures, or forming tools for wing and fuselage panels, achieving the correct position and orientation of the stock on the machine is a major challenge, taking many hours of checking and adjustment. It is often easier to adjust the datum for the toolpaths to match the position of the workpiece, than it is to align the stock in exactly the desired position. This approach has been used in the machining of geometric features for some time.

An equivalent solution for the manufacture of complex shapes and surfaces is now available that gives the same benefits of shorter set-up times and improved accuracy.

The first stage in this approach is to create an inspection sequence using off-line programming so there is no interruption to the machine tool's cutting time. This sequence is run using the machine tools spindle probe just like a CMM and collects a series of points from the work piece. These points are then used by the software to generate a best-fit alignment between the CNC Code and the part. Any mismatch that is found is then used to define a datum shift between the nominal position of the CNC code to be used to machine the part and the actual position of the work piece on the machine-tool. The software can then transfer this data to the machine tool control to compensate for the alignment differences eliminating the mismatch.

On-Machine Verification

On-Machine Verification is another technique which uses probing equipment on the machine tool. It allows initial checking of machined parts to be carried out in situ on the machine rather than having to transfer them to coordinate measuring machines for inspection. The main advantage of this On-Machine Verification is that any mistakes are discovered where they can be corrected – on the machine tool. Repeated cycles of machining and inspection, interspersed with long set-up times on the respective pieces of equipment, are avoided, meaning that overall manufacturing times can be reduced.

The most obvious benefit of On-Machine Verification is for those manufacturers that do not have existing inspection capabilities, for example those companies making parts so large that dedicated measuring equipment would be prohibitively expensive. However, companies that do have specialist equipment for their final inspections can also benefit. On-Machine Verification can give huge time savings by enabling the quality of the component being machined to be monitored at critical stages in the manufacturing process. This allows any errors to be detected earlier, and so corrected more quickly and at lower cost. For example, it will be possible to check that the correct amount of stock has been left on the component after a roughing operation, rather than having to wait until all machining operations have been completed before discovering that an error has been made. Similarly, the extent of any damage caused, for example, by a tool breakage, can be assessed and a decision made immediately to determine whether the part can still be completed within tolerance.

Of course, there are already a variety of manual methods for undertaking such checks between machining operations. However, like all manual operations, these are time-consuming and prone to human errors and inconsistencies. Furthermore, they are based on inspection against drawings, when most design data is now issued as electronic CAD files. On-Machine Verification is a more automated and more consistent process than manual measurement, and is based on checking against CAD data.

On-Machine Verification will also benefit companies with customers that insist on independent inspection of their work. By carrying out an initial verification on the machine, errors can be detected, and corrected, that might otherwise not be found until after the component had been shipped to the inspector.

Companies already having suitable inspection equipment might think that On-Machine Verification is an unnecessary operation that can cost valuable machining time. However, if the whole process is considered, there is considerable potential to reduce delivery times. If a part has to be transferred to a dedicated CMM and the inspection shows any errors, the component must be returned to the machine tool and re-clamped in position before being machined again. This is time-consuming for any component but can take many hours for any large, heavy item, such as a press tool for an automotive body panel. In addition, any mistakes during the set-up back onto the machine tool could result in a new series of errors in the component, and so lead to a further cycle of inspection and re-machining.

With On-Machine Verification, the part can be checked at each stage. The inspection on specialist measuring equipment only needs to be undertaken once at the end of the manufacturing process. This more regular verification ensures that there will be greater accuracy throughout the process, that the component will be produced within specification, and that costly concessions will be much less likely.

There are concerns about the reliability of using a machine tool to check its own work. Traditionally, measurements made with a machine tool on the shop floor could not duplicate the accuracy possible on a dedicated CMM in a climate-controlled environment. Times have changed and many machine tools are capable of accuracies comparable to CMM's and the higher accuracy required by today's manufacturing operations have required many machine shops to implement climate controls on the shop floor in order to maintain process stability. In order to facilitate this, the machine tool must be put through a routine accuracy check just as CMM's typically are. The quality of the results from machine tools can be checked against known artefacts in exactly the same way that the inspection accuracy of a CMM can be confirmed. Trials undertaken by Renishaw have shown the results from machine tool measurements to be both more accurate and more consistent than was expected.

The move of the checking process from the CMM room to the factory floor means that the results need to be both quick and easy to produce and understand. Since there may no longer be specialist metrologists to interpret the data produced, making the best use of On-Machine Verification requires a software interface that is not only simple enough for machine-tool operators to use but that also gives both quick and easy comparison of tooling and sample components against CAD data. The output must be clear and comprehensive reports that can be understood by everyone involved in the product development process, not just inspection specialists.

Machining of near-net shapes

Most examples where the exact starting shape is unknown result from near-net-shape manufacturing processes like castings and forgings, or from imprecise repair techniques, such as welding. The main requirement in these cases is to allow an even distribution of material to be removed around the component to avoid over-machining in some areas and under-machining in others. Other benefits include the ability to give a smooth transition between machined and un-machined areas and a reduction in air cutting.

Depending on the degree of uncertainty of the shape, a probing solution or a reverse engineering solution can be used. Typically, machining of near net shape preforms uses a probing path to determine the form of the starting stock. This is generated and executed in the same way as the probing paths used to determine the part position in the electronic fixturing process described above. The final shape to be achieved can then be orientated within the envelope representing the starting shape to give an even thickness of material on the surfaces to be machined and ensuring that a good part can be machined from the blank.

When there is greater uncertainty over the starting shape, which can result from component or tooling repair, reverse engineering software can be used to create a complete model of the areas to be machined. This can then be used within the CAM system to create toolpaths specific to that component. Many CAM systems can now produce toolpaths from the triangle models generated by reverse engineering programs, so eliminating the need to create a fully-surfaced CAD model.

Machining unknown shapes

The most challenging adaptive machining operations are those where the final shape of the component is unknown. This usually is needed when undertaking repairs to components that have been changed from their nominal CAD shape during service, for example, turbine blades that have been distorted by the high temperatures in aircraft engines. A similar problem can arise when repairing tools that have been modified after their initial manufacture, such as press tools that may have been adjusted to compensate for spring back, so that the original CAD data no longer matches the actual component.

The initial stage in these cases is to probe the component to determine the extent of its deviation from the nominal CAD data. Then, the CAD model can be adjusted to bring it into line with the actual geometry. Finally, toolpaths can be generated for the required areas with a CAM system.

Another application area is the trimming and drilling of large composite components, such as wing and fuselage structures for aerospace panels. These parts are relatively flexible and their manufacturing methods do not have the consistency of metal panels. These factors mean that automated finishing methods are difficult to apply. Manual methods are too slow and struggle to meet the increased demands for quality and consistency in both the aerospace and marine industries. In these cases the machining process and the inspection process are engaged in continuous feedback. The part is initially inspected and areas and the toolpaths are aligned just as is done with software fixturing. Once machining begins, there is a continuous process of machining – inspection – alignment that is carried out as further machining operation are done and the part flexes and stress relieves during the removal of material. This process can often completely eliminate the hand working processes often required and dramatically improve both accuracy and working times.

Summary

Companies wanting to use adaptive machining processes must understand that they tend to be more complex and process-specific than conventional CAM programming. Most adaptive machining projects will require some specific consultancy and customisation work by a highly skilled engineering staff as part of the implementation. Despite this cost, however, these projects often have some of the quickest payback periods of any improvement project undertaken.

Despite this added complexity, with productivity now a key issue for all manufacturing companies, anything that can reduce waste or improve efficiency must be worthy of further investigation. Adaptive machining processes have the potential to achieve both these goals, making them something that progressive manufacturers cannot afford to ignore.