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MEDICAL ADDITIVE MANUFACTURING

INSIDE LOOK:

How the Mayo Clinic is Using 3D Printing

3D printing presents challenges in workholding for finish machining

Workholding for High Accuracy Medical Device Machining

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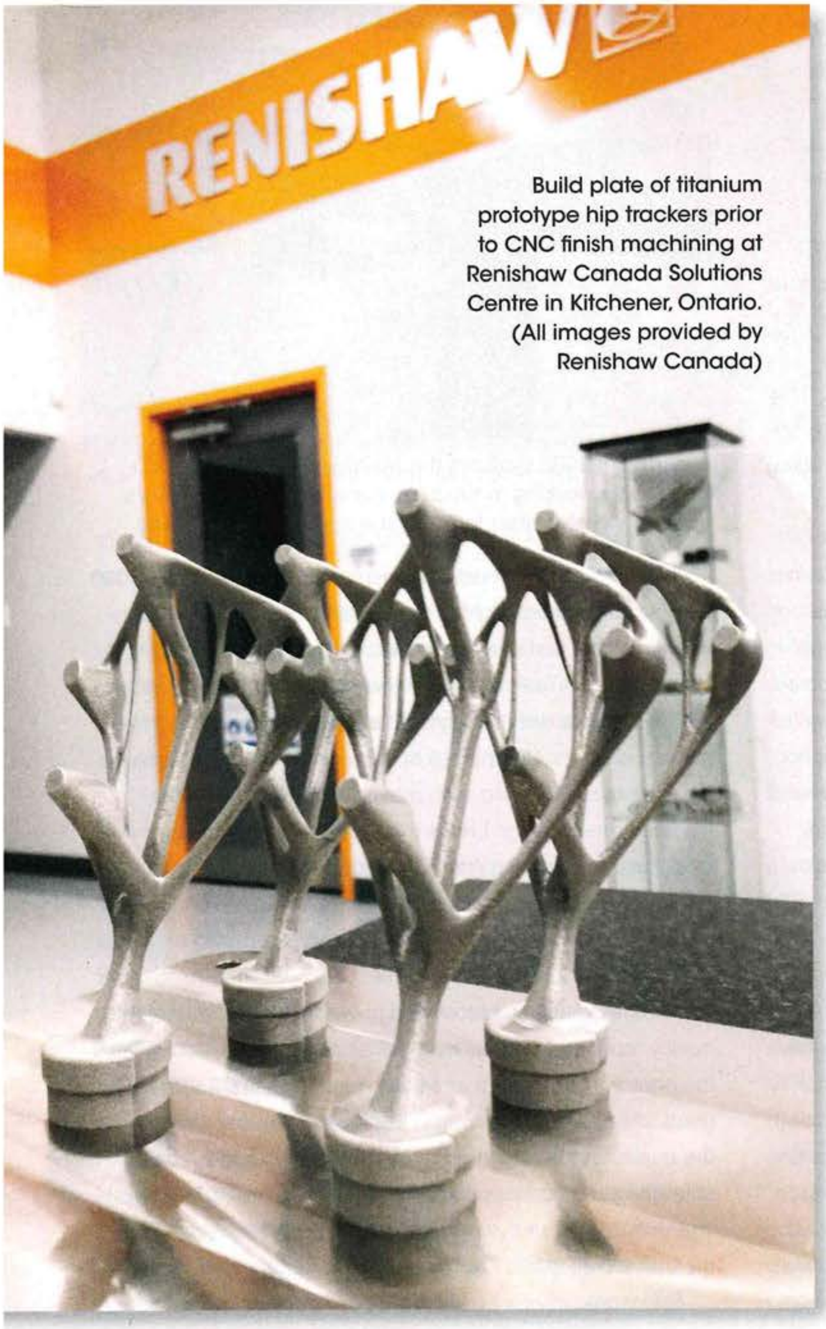


Build plate of titanium prototype hip trackers prior to CNC finish machining at Renishaw Canada Solutions Centre in Kitchener, Ontario. (All images provided by Renishaw Canada)

Metal 3D printing can enable rapid, low cost iterations of new medical devices, since no tooling costs are involved.

All devices need testing to uncover problems and develop solutions—allowing the product shape to change "for free" is a powerful advantage with Additive Manufacturing (AM). Other benefits flowing from AM besides enabling more complex geometry are improved accuracy with no component tolerance stack up, and a simplified supply chain with reduced part count.

Printing is usually not the end of the process. Almost always, after printing and any heat treatment, metal parts require some machining in a few areas. Sometimes to improve surface finish, more often to allow fasteners to lock the component in place. For example, spinal clamps can expand with living hinges, or a captive ball and socket can be printed as one and locked with a set screw. In both cases the threads will be machined rather than printed. If machining is only required in one direction, then parts can sometimes be machined on the build plate. Usually machining is required from multiple directions and it is impossible to access these areas with multiple parts printed on the plate.

The workholding challenge is then how to best hold the component for machining after it is removed from the build plate.

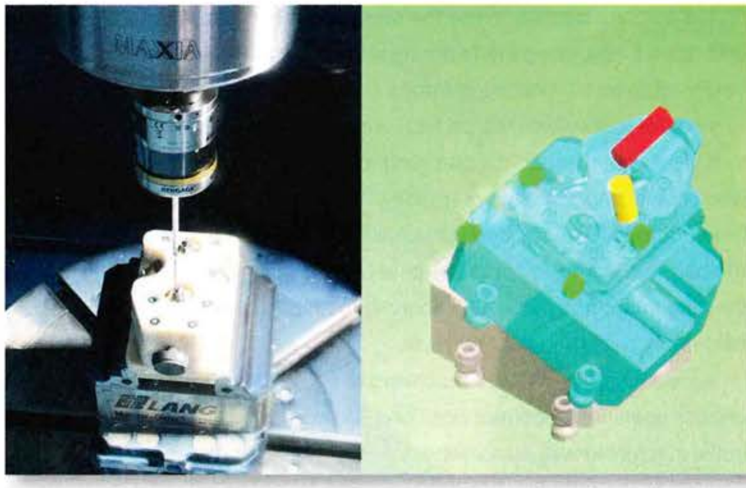
3D Printed Workholding

Plastic printed jaws are often a good first option, as they are cheap to manufacture—typically in just a few hours on a desktop printer, and can conform to complex geometries (although the design of the jaws can be more time consuming than a simple

Boolean subtraction of the component from the plastic). When the design changes after product testing it is easy to print a new set of jaws.

The main disadvantage of plastic jaws is that they will often distort the component as they are tightened. Although the jaws hold the part rigidly for machining, when the component is released from the fixture any machined bores may no longer be perfectly round, and true positions of features will have moved slightly as the component relaxes back into its unloaded shape.

A recent collaborative project involving Renishaw, University of Waterloo and Intellijoint Surgical investigated a printed alternative design for an optical tracker used in total hip arthroplasty. The tracker provides surgeons with intraoperative measurements, enabling proper establishment of cup position, equalization of leg length and restoration or maintenance of offset and joint center of rotation.



Plastic conformal jaws and best fitting coordinate transformation performed by NC-PerfectPart software after CNC probing.

The tracker body was monolithically printed in titanium alloy Ti6-4, stress relieved and then cut from the build plate ready for finish machining of the kinematic mount and the four posts that hold the optical reflector globes.

A plastic set of jaws was designed to clamp the part while leaving the machining areas exposed. Although the plastic jaws clamp the part rigidly, they never clamp the part repeatably, so the exact position of the part must be found using a machine probe and best fitting software such as NC-PerfectPart, from Metrology Software Products Ltd. (MSP). Originally developed for machining of high value aerospace and Formula 1 composite structures, this software is perfectly suited to the challenge of precisely locating an organic-shaped AM part with no obvious datum features.

Hip tracker being adhesively bonded to Blue Photon grippers using UV light. This solution holds the part rigidly but without the distortion caused by clamping forces from plastic jaws.

Points are selected on the component in the CAD environment and the deviations from nominal positions are measured by the probe on the CNC machine. The NC-PerfectPart software then creates a best fit alignment that is a 6-axis coordinate transformation—both translation and rotation. This coordinate shift is automatically recalled into the machine controller before CNC programs are executed.

The machine probe is also used to automatically achieve very high tolerances by employing a "cut/measure/cut" strategy. Features are semi-finished, measured and compensation automatically applied to achieve tight drawing specifications on final machining passes. This approach allows for variables such as cutter/part deflection under load, and tool variation from programmed size.

Problems and Solutions

Unfortunately, the hip tracker component flexed imperceptibly when the plastic jaws were clamped, resulting in true position errors greater than 0.3mm on the machined posts. While the component had been optimized for handling loads during surgery, it had not been designed to resist machining forces.

In order to machine the part accurately it was essential not to bend it with mechanical clamping, but at the same time it was equally important to add rigidity. The solution was to use Blue Photon's UV activated adhesive and grippers. By gluing the part onto four gripper posts (that transmit UV light to cure the glue in approximately 90 seconds) the hip tracker was held firmly but still in the free state.

An aluminum block was machined to hold the four gripper posts in the correct positions for the tracker body. Initial machining was successful on the three posts directly bonded to the grippers, but one post was cantilevered above the gripper and vibrated during machining. A plastic support block was printed to hold this post and eliminated this problem. By cradling the part, the support block also allowed for more accurate positioning of the tracker prior to the glue being cured. The glue thickness is optimally around 1 mm, and after machining the part and fixture can be separated by simply immersing the assembly in near boiling water for a few minutes, and then peeling apart.

The only disadvantage of using the glue grippers appeared to be the extra work to design and machine the gripper fixture. However, on a subsequent project for an industrial impeller Renishaw used plastic printing to produce the gripper fixture instead of machining. This proved that the manufacture of a robust, custom workholding solution can be reduced to an overnight desktop print.

Refining the Procedure: Generative Design

An improved workflow for producing glue gripper fixtures is to use generative design software, such as Autodesk's Fusion 360. It would automatically create the connections required between the grippers and for example a chuck that will hold the fixture on the CNC machine.

The procedure for a patient specific medical device like a cranial plate would be as follows. The number and placement of the grippers would be determined by the manufacturing engineer. "Preserve" regions would then be defined around each gripper as a cylindrical "bushing" with obstacle clearance regions extruded axially above and below each gripper to allow for insertion and captive nut placement. The cranial plate is also defined as an obstacle that must be avoided. A preserve ring would be defined, and constrained, to enable the completed fixture to be held in a chuck. Loads are added to the gripper bushing preserve regions to represent machining forces that must be resisted. The software can then solve the structural connection of all the parts for maximum stiffness.

One of the barriers to adoption of patient specific solutions is the high design cost typically involved. Using generative design coupled with plastic printing is an innovative solution that largely automates the workholding process with Blue Photon's adhesive grippers.

Workflow for automatic design of a Blue Photon fixture for a cranial plate. Generative design workspace (Autodesk Fusion 360) shows green preserve and red obstacle geometry. This process requires no expert CAD design time and will automatically be optimized to maximize stiffness under the applied machining loads.