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Integrated Hole and Countersink Inspection of Aircraft Components

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ABSTRACT

Precision hole inspection is often required for automated aircraft assembly. Direct contact measurement has been proven reliable and accurate for over 20 years in production applications. At the core of the hole measurement process tool are high precision optical encoders for measurement of diameter and countersink depth. Mechanical contact within the hole is via standard 2-point split ball tips, and diametric data is collected rapidly and continuously enabling the system to profile the inner surface at 0 and 90 degrees. Hole profile, countersink depth, and grip length data are collected in 6 seconds. Parallel to the active process, auto-calibration is performed to minimize environmental factors such as thermal expansion. Tip assemblies are selected and changed automatically. Optional features include concave countersink and panel position measurement.

INTRODUCTION

Hole inspection is an important part of any drilling process, and integration of the inspection into an automated system is critical to maintain high production rates, accurate quality control, and real-time traceability. Electroimpact has incorporated hole diameter and countersink depth measurements into its automated systems for holes ranging from 3.3 mm to 25.4 mm. Generally, diameter accuracies of ±0.009mm and countersink diameter accuracies of ±0.012mm can be achieved.

SYSTEM OVERVIEW

The hole probe discussed here is the evolution of a design that has proven accurate for over 20 years. The core of this system is a two-point direct contact bore gauge. The bore gauge is mounted in a quick-change assembly that is also used for countersink measurement. Typically, a separate quick change assembly is supplied for each nominal hole size, and can either be swapped manually by the operator or automatically in an tool changer along with the cutters. The diameter range that can be measured by a single bore gauge ranges from 0.1mm to 0.8mm, depending on nominal diameter and diameter tolerance. The measurement itself is performed using an optical encoder mechanically coupled to the probe tip. This method has been proven to be very reliable as well as very accurate.

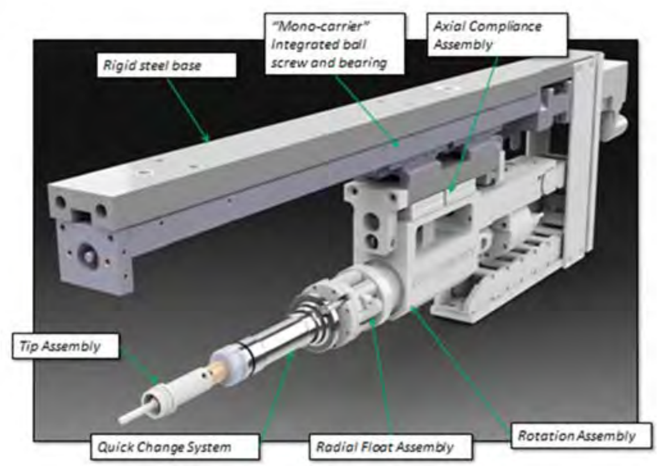

Figure 1. Hole probe main assembly.

The bore gauge, quick change mechanism, and encoder are all mounted on a radial floating assembly which ensures that small misalignments between the probe and the drilled hole do not adversely affect measurement.

The measuring apparatus is mounted to a mono-carrier which integrates a ball screw, linear guides, and support bearings into a single compact unit. A servo motor mounted on the back of the tool assembly moves the system forward through the nosepiece. Furthermore, the mono-carrier is mounted to the probe assembly via a spring loaded "crash base". By doing so, the probe is inherently low impact and can survive many different fault scenarios such as incorrect diameter holes, severe misalignment, or incorrectly installed measurement tips.

Electrically, the optical encoder is wired to a high speed 32-bit counter module. The module is configured as part of a high speed synchronous node, allowing measurements to occur at the same cycle as the NC further reducing delay, increasing processing speed, and minimizing jitter.

Figure 2. Typical quick-change assembly with bore gauge and countersink measurement.

During the course of a cycle the probe there are four main steps performed by the NC. First is the calibration, second are the layer measurements during while entering the hole, third is the countersink measurement, and last are the layer measurements at 90 degrees while exiting the hole.

Calibration

As stated before, the hole probe is calibrated in parallel to the drill preparation and drill cycle of the robot. This prevents a decrease in cycle time while increasing the accuracy of the measurement by continually adjusting for various internal and external changes to the measurement system. To achieve parallel operation, Electroimpact designs its process heads so that the probe calibration rings are set in line with the probe, while the machine is in drill position. The calibration ring selector is then actuated such that the corresponding proving ring is coaxial with the hole probe, and thus able to be calibrated during the drill process.

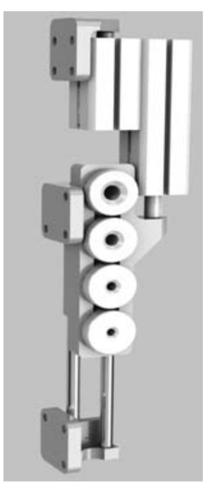

Figure 3. Proving ring selector allows calibration of hole probe concurrently with drilling.

Measurement Cycle

During the measurement cycle, many operations are happening simultaneously. The measurements that can be taken during a single probe routine are multi-depth diameter measurement, stack measurement, hole profile, and countersink depth or diameter measurement.

For diameter measurement, a depth offset is specified for where the diameter value should be recorded. The hole profile is not typically used because there can be various anomalies due to contamination at the hole entrance, exits, and interfaces. These offsets can be specified per stack layer and can also be set via the part program. This enables processes to be monitored in typically difficult situations such as multiple material stack-ups which can have drastically different values depending on material.

Stack or grip measurement is achieved by capturing the depth at which the diameter gauge enters and exits the hole and finding the difference. The probe is fed at a constant speed during this cycle to minimize the effect of any lag that may be present in the system. This method is very accurate and is often used to verify that the correct fastener has been chosen for installation.

While measuring, a trace can be obtained along the entire depth of the hole. The NC records the measured bore diameter during insertion, rotates the probe 90 degrees, and then records diameter as the axis is retracted from the hole. Using this method, holes that are ovalized, conical, have large gaps, or otherwise mis-formed can be detected by the machine or operator.

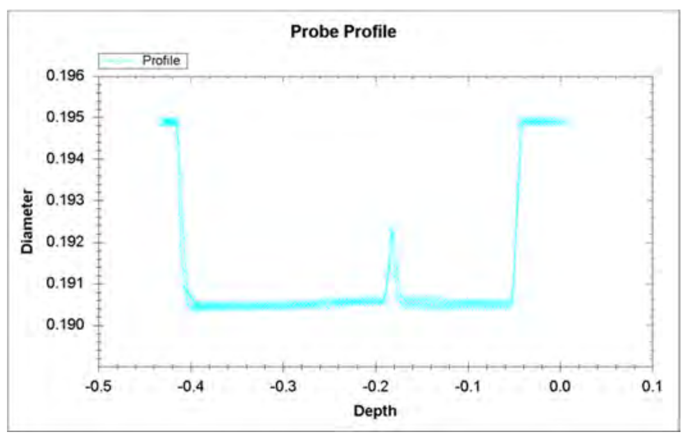

Figure 4. Example hole profile of 0.4” stack-up of 2 plates with a 0.020” gap.

Currently there are two types of systems in use for measuring countersinks. Although they vary slightly in design, the principle of how they measure countersink depth are quite similar. The first uses a “lander” that contacts the work piece around the drilled hole and is pushed back as the probe is bottomed against the inside of the countersink. The lander style system is less expensive than the other style, especially in cases with fewer different hole sizes (which means fewer quick change assemblies).

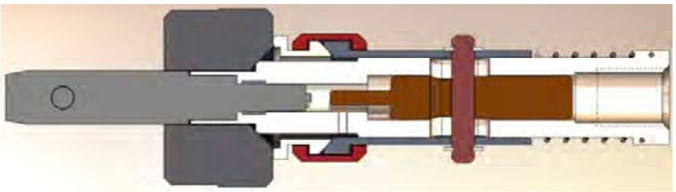

Figure 5. "Lander" style countersink measurement.

The second system uses a second optical encoder which directly measures the deflection of the crash base for a given actuation of the mono-carrier. This allows for the use of the probe on concave surfaces which the lander type system is unable to do. Additional benefits of the two encoder system include using the probe to detect panel position or for rivet tail measurement.

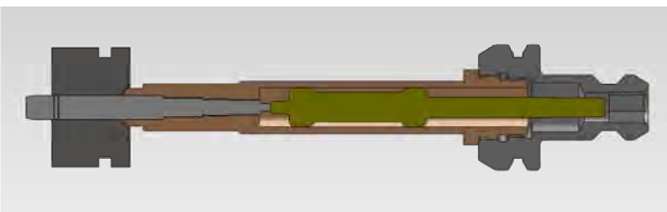

Figure 6. Countersink measurement using second encoder.

ACCURACY AND REPEATABILTY

Repeatability

This experiment is designed to test the accuracy and repeatability of the hole probe assembly measurements.

Methods

The experiment was performed using an existing robotic drilling system at Electroimpact. The system was composed of an Electroimpact Accurate Robot platform, with a process head consisting of a Spindle, Probe, and Camera. A part program was written to drill 10 holes in a 0.420" titanium coupon stack and measure each hole 10 times. Each measurement included hole diameter, countersink diameter, and full hole profiling. After measurement with the robotic system, each hole was manually measured for diameter using a bore gauge and countersink depth was measured using a TruLok countersink diameter gauge.

Results

Probing Cycle Time	
Calibration Cycle Time (Parallel to Drill)	4 sec. seconds
Average Probe Cycle Time	6 sec.
Hole Diameter Measurements	
Manual Bore Gauge Average	0.19059"
Robot Probe Average	0.19067"
Robot Average Deviation	0.00012"
Robot 3-Sigma Error	0.00035"
Countersink Diameter Measurements	
Manual TruLok Average	0.37950"
Robot Probe CSK Average (100deg)	0.37878"
Robot Average CSK Deviation	0.00016"
Robot CSK 3-Sigma Error	0.00048"

Table 1. Probe Accuracy and Repeatability Results

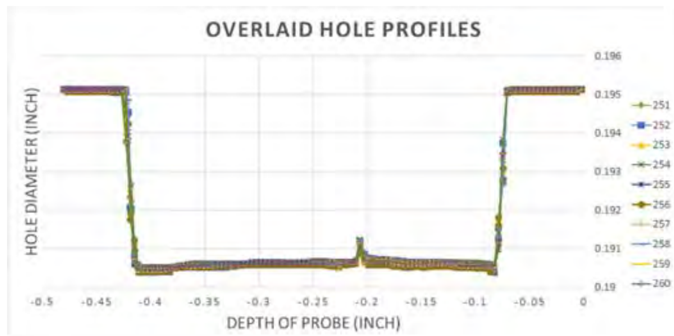

Figure 7. Series of 10 consecutive overlaid hole probe measurements

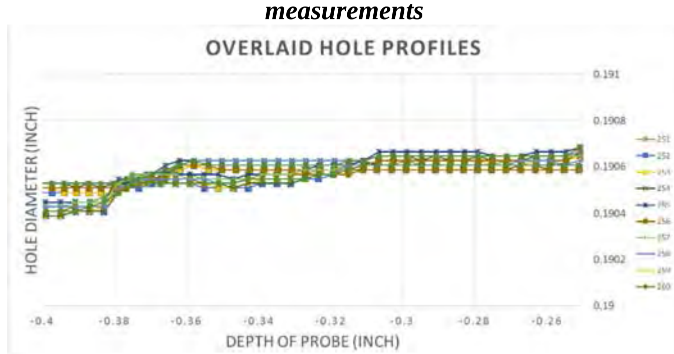

Figure 8. Series of 10 consecutive hole probe measurements zoomed in for clarity

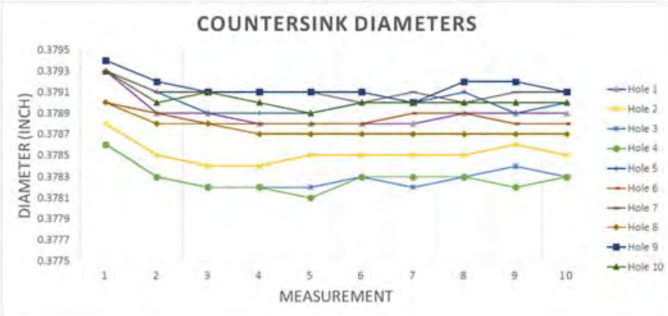

Figure 9. Series of 10 consecutive Countersink Diameter Measurements

Discussion

The above datasets shows that the hole probe is capable of making very accurate hole diameter and countersink measurements in a consistent and repeatable fashion. With very small deviations between each measurement cycle the conclusion can be made that the repeatability is very high. Additionally, the strong correlation between the robot probe measurements and manual gauge measurements shows that measurement is also very accurate.

SUMMARY/CONCLUSIONS

In order to ensure that drilled holes meet specification, and that this can be done efficiently during the drilling process, automated hole and countersink measurement is an important part of an automated drilling system. There are several distinct advantages to direct contact measurement of holes, including enhanced accuracy, full profile data, and easy stack thickness measurement. With a long track record of operation and easily accessible data, clear conclusions about hole quality can be made to create robust processes for production.

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