Improved Control in Laser Drilling

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Turbine engine manufacturers are continuously working to increase the quality and reduce the cost of their machining operations. In many cases, increasing quality is the fastest route to cutting costs since inspection and rework costs can be significant. For this reason, recent efforts in laser process development have focused on increasing the quality of laser drilled holes while maintaining the same or even increasing throughput.

Precision laser drilling of 3D components requires precise control of the laser beam relative to the actual workpiece surface. It also requires a means for maintaining the hole size and shape over a range of hole diameters. This paper summarises results from efforts to develop tools and techniques for improving the consistency of laser drilled holes in turbine engine components.

Several approaches to improving the consistency of laser drilled holes have been explored, as listed below:

Objective	Approach
Control focused beam diameter	Drill at the centre of the focus range ('At Focus' drilling)
Compensate for material thickness variations	Breakthrough detection
Compensate for material shape variations	Focus control at the drilling location

'At Focus' Drilling

Many turbine engine component designs use a range of hole sizes to achieve the desired cooling performance. Furthermore, within a given process, capability to make small ~~(0.025 mm)~~ changes in hole size is desirable in order to fine-tune airflow for a component or region within a component.

The most common approach for making small and even moderately large (a few tenths of millimetre) changes in hole size has been by defocusing. Defocusing affects hole size by adjusting the location at which the beam intersects the workpiece surface. Defocusing may also create a need to change laser parameters in order to achieve the optimum power density and minimum taper, a factor affecting airflow.

Defocusing inherently gives rise to significant variations in hole size since, as shown in figure 1, even small errors in the amount of defocus can change hole size. For the case shown in figure 1, defocusing by 4.5 mm is required to achieve a 0.46 mm diameter hole with a 14.5 mm diameter beam. For this situation, a variation of ±1.5 mm from the correct defocus position will produce a holes size variation of just under 0.1 mm, large enough to produce a significant change in airflow.

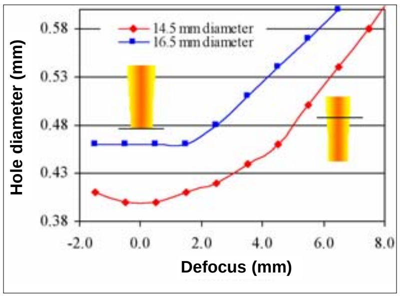


Fig. 1: Laser drilled hole diameter vs. amount of defocus for two beam diameters and a 200 mm focal length focusing lens

'At focus' drilling offers significant advantage. From Figure 1, one can see that for either diameter beam, drilling in focus ('0 defocus') provides a margin in beam to workpiece position of ±1.5 mm for a 200 mm focal length lens. Over this range, the change in hole diameter is negligible.

We have shown that airflow consistency is improved by drilling in focus and, instead of defocusing, changing hole size by changing the beam diameter at the focusing lens according the relationship:

$$d = \frac{4\lambda F}{\pi D} M^2 \qquad (1)$$

Where:
- d = focused beam diameter
- λ = laser wavelength
- F = focal length of the focusing lens
- D = beam diameter at the final focusing lens
- M^2 = beam propagation ratio (beam quality)

'At Focus' drilling is becoming more widely adopted as the means become available for systematically and predictably changing hole size from within a production process. This is being made possible through use of an automated, CNC programmed and controlled beam expanding telescope within the beam path to magnify the laser beam while maintaining the collimation and quality of the laser beam.

Breakthrough Detection

Variations in material thickness and the efficiency of removing material from the hole are among of the reasons why percussion drilled holes often require a varying number of pulses to produce a hole of the desired dimension and air flow. Breakthrough detection has been demonstrated to improve hole consistency by detecting the actual number of pulses required to produce the hole. With the method employed here, the user can, from within the drilling program, define the appropriate action. This action can involve immediately stopping drilling or delivering a pre-defined number of additional 'clean-up' pulses.

Figure 2 shows the distribution of exit hole diameter produced both with breakthrough detection and using a fixed number of pulses (without breakthrough detection). This data shows that while the mean hole size is the same within 2%, the distribution of hole size is significantly narrower when using breakthrough detection.

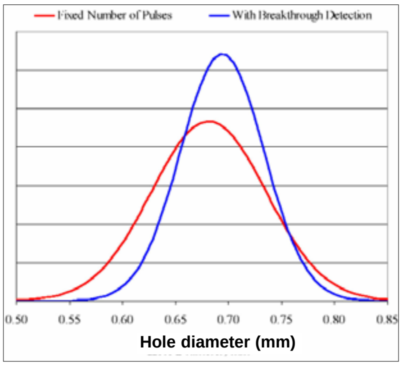
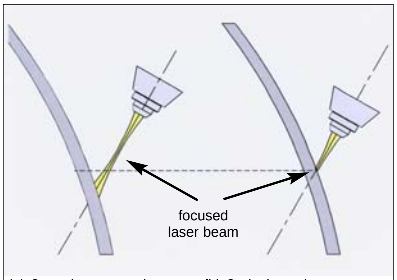


Fig. 2: distribution of exit hole diameter.
Breakthrough detection produces more consistent holes and airflow by compensating for process and material variations. Results are for holes drilled at 30° angle to the surface in 1.5 mm thick Inconel 718 sheet.

Focus Control at the Drilling Location

Controlling the location of the focused laser beam relative to the workpiece surface is one of the key methods for producing consistent holes. The traditional method for focus control is based on closed loop control of the capacitance between the workpiece and the gas assist nozzle. To be effective in maintaining focus, this device relies on a fixed relationship between the laser beam focus and the gas assist nozzle.



(a) Capacitance sensing
hole size and location are influenced by sensing material at the side of the assist gas nozzle/sensor.

(b) Optical sensing
hole size and location are not affected by material adjacent to the assist gas nozzle.

Fig. 3: A comparison of optical and capacitive sensing. More accurate and consistent hole size and location are realized using optical focus control since it senses only at the location to be drilled and does not, like capacitance sensing, detect material at the side of the assist gas nozzle/sensor.

Capacitance sensing has been used for many years despite some limitations for laser drilling:

1. The sensing area is relatively broad, detecting material around the nozzle, including at the side. For shallow angle drilling, the hole can be located several millimetres from the area on the workpiece that is detected by the capacitance sensor, typically at the side of the assist gas nozzle. Sensing at such distance from the location of the hole can result in variations in both position and hole size (Figure 3).
2. Capacitance sensing requires a conductive surface and, for this reason, cannot be used reliably with surfaces having relatively thick thermal barrier (ceramic) coatings.

An optical means of workpiece detection, Optical Focus Control (OFC) has been developed and demonstrated through work with Snecma Moteurs [1]. The technique is based on conoscopic holography, a method having its roots in metrology and reverse engineering. With OFC, the output from a laser diode is focused using the same focusing lens as the Nd:YAG drilling laser. The focused laser diode radiation strikes the workpiece and a portion of the radiation is reflected back through the optical path. This returning energy is processed by the sensor to give the location of the reflecting surface relative to the focusing lens.

This method addresses the need for detecting the workpiece surface at the hole location even for shallow angles. Also, since it is a direct measurement device, it is faster than capacitance sensing - it is not necessary to 'find' the surface and maintain a calibrated offset as is the case with capacitance sensing.

Conclusions

Several methods for increasing the consistency of laser drilled hole have been investigated. Work to further characterise the benefits of these methods as well as explore new methods is on-going.

However, we have shown the following:

1. 'At focus' drilling provides a more robust process by allowing greater error in actual workpiece position relative to the beam while maintaining a constant hole size. The technique has been made practical through an automated means of adjusting hole size by changing the diameter of the beam entering the focusing lens . More controlled hole taper contributes to greater air flow consistency for cooling holes.
2. Breakthrough detection contributes to more consistent quality, primarily by maintaining greater consistency of exit hole diameter in components having varying thickness.
3. Optical focus control improves quality by measuring the actual position of the workpiece surface at the hole location. It is also faster than more traditional methods for focus control.

Fig. 4: A laser drilling head fitted with Optical Focus Control. OFC uses a diode laser coaxial with the drilling laser to detect the surface at the drilling location. This approach works with both coated and uncoated surfaces.

References

[1] VanderWert, T.L., Widmer, F., (2004) “Precision Drilling with OFC”, Industrial Laser Solutions, May 2004.

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