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Visible Lasers

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DRILLING WITH FIBER-TRANSMITTED, VISIBLE LASERS

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Abstract

High power and radiance copper-vapor laser technology developed at Lawrence Livermore National Laboratory shows great promise for many materials processing tasks. We recently transmitted the visible light produced by these lasers through fiber optics to perform hole drilling experiments. We found the tolerances on the hole circularity and cylindricity to be excellent when compared to that produced by conventional optics. This technique lends itself to many applications that are difficult to perform when using conventional optics, including robotic manipulation and hole drilling in non-symmetric parts.

Introduction

During the past several years, Lawrence Livermore National Laboratory (LLNL) has developed cutting and drilling capabilities using high power, high radiance, visible lasers. These lasers, copper-vapor and copper-vapor laser pumped dye, were originally developed for laser isotope separation. Previous copper-vapor laser drilling studies^{1,2} have focused on percussion drilled holes with sizes ranging from 5 to 100 micron diameters. Presently, we have used these lasers with fiber optic beam delivery to determine the quality and efficiency of hole drilling using a much lower radiance beam quality.

Description of Equipment

Laser System

A Laserdyne 520, 3-axis CNC machine workstation was used to move the workpiece in relation to the laser beam. Workpieces were aligned perpendicular to the travel path of the beam. We used the LLNL developed copper-vapor laser technology to produce the light used for these experiments.

Fiber-Optic Delivery

The fiber attachment was made to the beamline at the last turning mirror before entering the Laserdyne workstation. The total length of fiber traversed by the laser beam was approximately 5 meters. We used a 0.6 mm diameter fiber, which easily transmitted the 200 W of green light that was the maximum used for these experiments. The literature shows examples of troubles in coupling to fibers with visible lasers³, but we had few problems with fiber failure due to hot spots or heat buildup at the fiber ends. Figure 1 shows several fiber-transported beamlines used in an isotope separation application.

The end effector used on the fiber consisted of three lenses. These lenses reduced the beam spot size from the 0.6 mm fiber diameter to an approximately 0.2 mm diameter focused spot. Different combinations of lenses allow the focused spot size to change. However, for these studies, we were interested in the using smallest spot possible after beam transmission through an optical fiber.

Beam Measurement Diagnostic

Figure 2 shows a schematic of the beam measurement system used in these experiments. Beam spot size measurements are important to determine the focus spot placement during drilling and aid in approximating the hole size to be expected after drilling. Through use of z-axis movements, this diagnostic also allows measurement of depth of focus, beam divergence and beam convergence.

Experimental Results

We drilled several sets of holes in AISI 304 stainless steel using the fiber optically delivered, copper-vapor laser. We compared these results to those from previous studies^{1,2} that used conventional optics. The minimum hole size obtained by a fiber optically delivered laser is controlled by the optical configuration in the end effector. For these studies, we obtained 0.2 mm hole sizes and found them to be very repeatable, as shown in Figure 3. We found the hole circularity to be very good - especially when compared to that obtained using percussion drilling with conventional optics. Diametral circularity tolerances secured by this method were roughly ± 0.01 mm. Figure 4 shows a metallographic cross section of one hole from Figure 3. This shows the sidewalls to have very good cylindricity. The section also shows the lack of a heat-affected zone along the hole sidewall.

For comparison, we used holes drilled in the same material using conventional optics. As shown in Figure 5, these holes are approximately 0.05 mm diameter. The diametral circularity, approximately ± 0.01 to 0.02 mm, is poor when compared to the above samples, although still adequate for most applications requiring small diameter holes. Cylindricity, however, is not as good in the holes drilled with conventional optics. The heat-affected zone, similar in nature to the fiber optically drilled holes, is not present in the holes drilled using conventional optics. These holes are made at much higher rates, as expected due to the higher intensity beam developed by conventional optics.

Summary

Fiber-optic light transmission in the visible wavelengths offers great flexibility to this area of laser materials processing. The hole quality produced by these methods is extremely good, with tolerances similar to holes made by conventional machining processes, but without the need for part contact or machining lubricants. Trade-offs in ability to change hole sizes quickly and in lengthened drilling times must be considered for applications not requiring extreme tolerances.

Acknowledgments

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Figure 1. Fiber transported copper-vapor lasers used for isotope separation.

Figure 2. Beam measurement diagnostic.

Figure 3. Repeatable, high quality holes drilled by fiber-optically, transported copper-vapor lasers. Nominal hole size is 0.2 mm diameter in this 0.38 mm thick stainless steel specimen.

Figure 4. Metallographic cross-section from a hole shown in Figure 3. Note the high degree of cylindricity and lack of heat-affected zone.

Figure 5. Holes drilled using conventional optics on a copper-vapor laser. Hole sizes are approximately 0.05 mm in this 0.38 mm thick stainless steel specimen.

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