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Automated cutting by water jet-guided laser using a break-through sensor.

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Abstract

The Laser Micro-Jet® is now a well-established technology among others for micro-machining and high-quality machining of hard and composite materials, with the advantages of narrow parallel cut walls without focus adaptation, minimizing the heat-affected zone and the avoidance of burrs.
This contribution describes the development of a break-through sensor measuring light from the machining point through the light-guiding water jet. By detecting a completed cut, additional safety cutting passes can be reduced and the cutting is stopped just in time, thus minimizing processing time and maximizing feature completion rate.
The sensor enables an optimized, automated cutting as well as remote monitoring which represents a significant step towards industry 4.0. The technology is now employed on an industrial scale by several customers, showing the high potential of the technology: The processing time is reduced by 5-20 %, the success rate reaches at least 99.3 %.

Keywords: sensor; water jet guided; laser; WJGL; automation;

1. Introduction

The Laser MicroJet® (LMJ®) technology is used for subtractive manufacturing by a water jet-guided laser (WJGL). The laser is guided by total internal reflection to the workpiece, thus maintaining a small laser spot over several centimeters in working distance (as it is illustrated in Fig. 1). This way, WJGL machining combines the accuracy of a hair-thin (25 to 100 microns) cylindrical pure water jet with the high throughput of Nd-YAG lasers, as shown in Fig.1.

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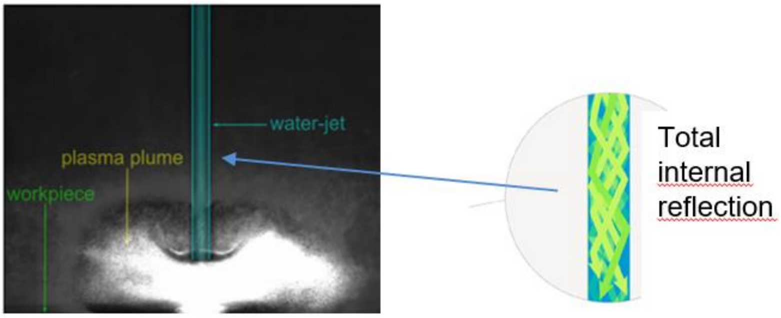


Fig. 1. High-speed camera image and schematic view of machining by Water Jet Guided Laser machining, based on total internal reflection in the water jet.

LMJ is well suited for a great variety of applications in domains such as diamond cutting, watch movement components, precision slot cutting and hole drilling as well as ceramic and silicon wafer dicing. Over the recent years it has proven to be effective for a large variety of diamond applications, especially for brilliant cutting of rough natural diamonds and for slicing of PCD-diamonds. It also receives considerable interest from the aerospace and energy sectors for cutting and drilling tough-to-machine materials such as ceramic coated nickel-based superalloys and ceramic matrix composites (CMC) such as SiC/SiC and Ox/Ox.

The cooling by the water jet guarantees machining with a minimum heat affected zone (HAZ), such that the material properties are only modified on the very surface of the cuts. At the same time, the water flow limits the re-deposition of ablated material and therefore prevents the formation of burrs at the edge of the cut.

According to the state of the art, the Synova LMJ system relies on green lasers (532 nm) having negligible water absorption, in contrast to IR lasers which typically lose 30-60% of the laser power in the water jet between nozzle and workpiece. At the same time pulse lengths of 100-200 ns guarantee a high surface quality as well as an efficient ablation due to a high peak intensity at moderately high average powers of 10-400 W.

2. Break-through detection for automatic, faster cutting

In water jet guided laser machining, cutting and drilling is typically performed in a multi-pass manner, following a toolpath several times with material removal of the order of typically 150 µm per pass.

Laser cutting and drilling of features generally uses a fix set of machining parameters and a predetermined number of machining passes. However, the actual number of passes until the part is completely cut-through can vary from cut to cut (or hole to hole) due to variations in the workpiece material or in the machining process.

In a first step, the process-related variations in material removal rate have been reduced to a minimum through process development and hardware improvements. Nonetheless, additional machining passes still need to be added as a safety margin in order to guarantee a completed cut-through of each individual feature. The development and addition of a Break Through (BT) sensor disrupts this methodology by guaranteeing a full cut and finishing a feature just-in-time.

Using the BT-sensor, the machine is able to decide automatically when to move on towards the next cut without operator intervention. This is especially useful for workpieces on which cuts of multiple features have to be performed in sequence and where rework is not practical The automatic detection also guarantees that the machine self-compensates for local or global process variations.

Examples of applications, where a break-through detection can be employed are shown in Fig. 2. In faceting of rough natural diamonds (Synova daVinci (2019)), a break-through sensor is especially valuable, since material properties can vary strongly from stone to stone, as well as inside a stone. Therefore, variations in cutting times of up to 50% are observed, and it is difficult to cut with a predetermined number of passes. Another example where a break-through detection is employed is slot-cutting in thick Silicon wafers, where typically >100 passes are used for completing a cut.

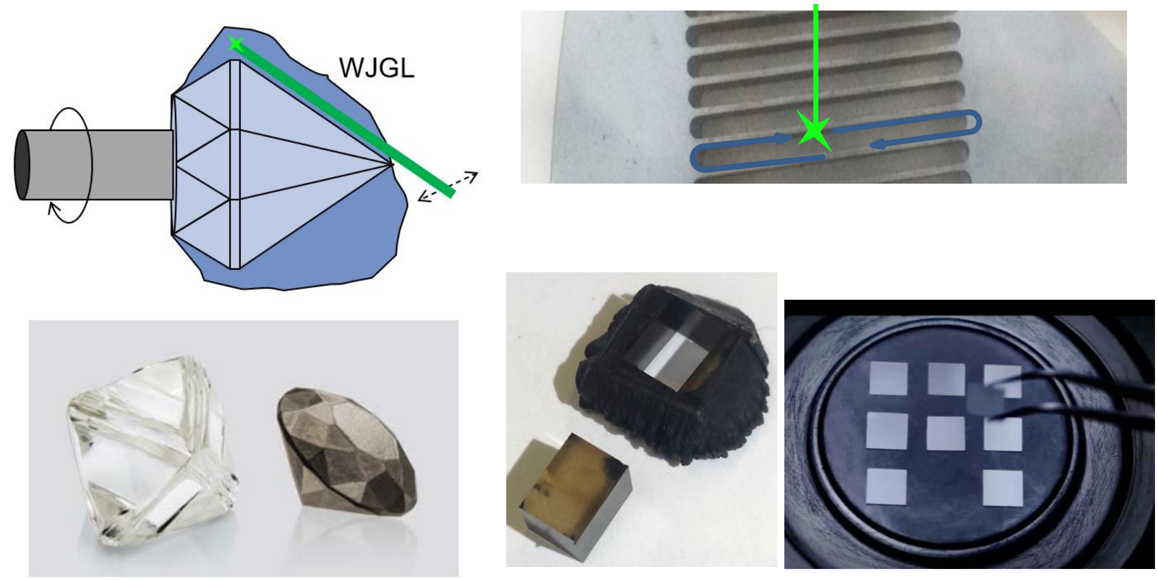


Fig. 2: Multi-pass cutting with Water Jet-Guided Laser. Left: Faceting of rough natural diamonds in the Synova DaVinci Diamond Factory®, from rough diamond to brilliant. Right top: Slot-cutting in 8mm thick Silicon wafer. Right bottom: Diamond slicing of CVD (Chemical Vapor Deposition) grown diamonds. In a first coring step, the carbonized layer is cut off, then the remaining block is cut in fine slices.

Similarl to a break-through sensor, nowadays pierce sensors are employed in conventional laser machining (Harrison et al., Richmond (2017), Precitec (2016)), which are mostly used for reducing the dwell time and for consistent hole quality, when piercing metal sheets as a first step of cutting. These sensors mostly work with the detection of back-reflected laser light and detecting its absence when the piercing is completed.

Alternatively, camera-based systems have been developed for break-through detection in drilling or cutting (Ho et al., Zhao et al.).

The novelty of this contribution is that the break-through sensor is applied to a water jet guided laser system. Because the light path includes passing through the water jet, it cannot be taken for granted, that the light back from the machining point will follow the same optical path back through the optical head. Due to a misty environment around the machining point, camera-based systems proved to be functional (GE patent mentioned?) but less robust and necessitate adjustments of the camera depending on the application.

3. Break-Through Sensor Setup

The patented concept of the Synova break-through sensor is shown in Fig. 3. It does rely on a detection of light that is coupled back from the machining point through the water jet and through optics of the machining head towards a detector.

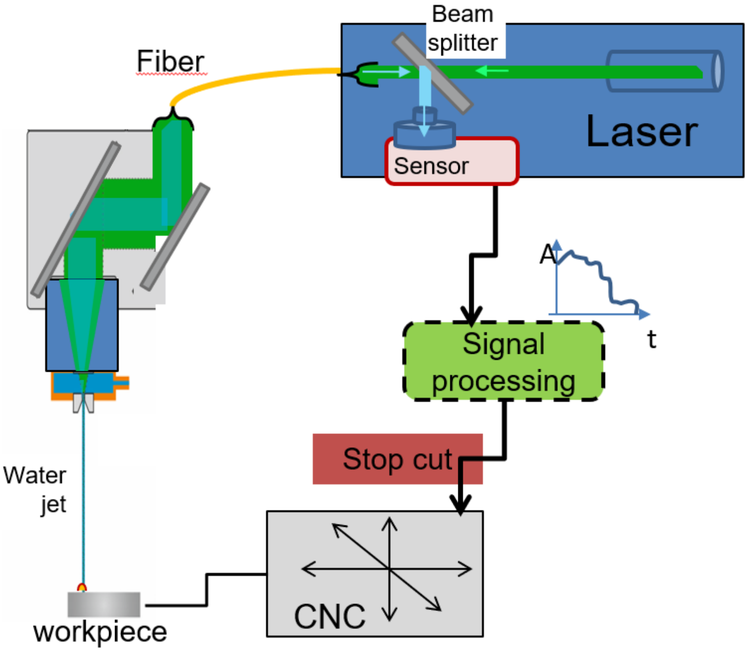


Fig. 3: Schematics of a cut control by a break-through sensor integrated into the laser.

Two versions of a breakthrough sensor have been developed at Synova, one being integrated into the machining head, the second being integrated at the laser. A first version of a break-through detector for the WJGL-technology was initially developed in collaboration with Fraunhofer IPT (Institute for Production Technology), with a sensor module added onto the machining head. The heart of this sensor is the module on the machining head shown in Fig. 4 (left), including a beam splitting element, which splits the measuring light from light of the machining laser. Both back-reflected laser light and other wavelengths can be employed for the detection. From the sensor module, the measuring light is coupled into an optical fiber towards a highly sensitive detector unit, measuring the light intensity. The signal amplitude is then analyzed in the machine control software (see Fig. 5), in order to differentiate between a cutting process and a pierced workpiece by a drop in signal amplitude.

As soon as the signal processing detects a completed cut, the CNC-machine control moves on to the next cut on the workpiece or signals to the machine operator that the workpiece is completed.

A second version of a break-through sensor was then developed for an integration at the laser (Fig. 4, right). The advantages of this version are a reduced size and weight of the machining head, as well as a higher signal-to-noise ratio.

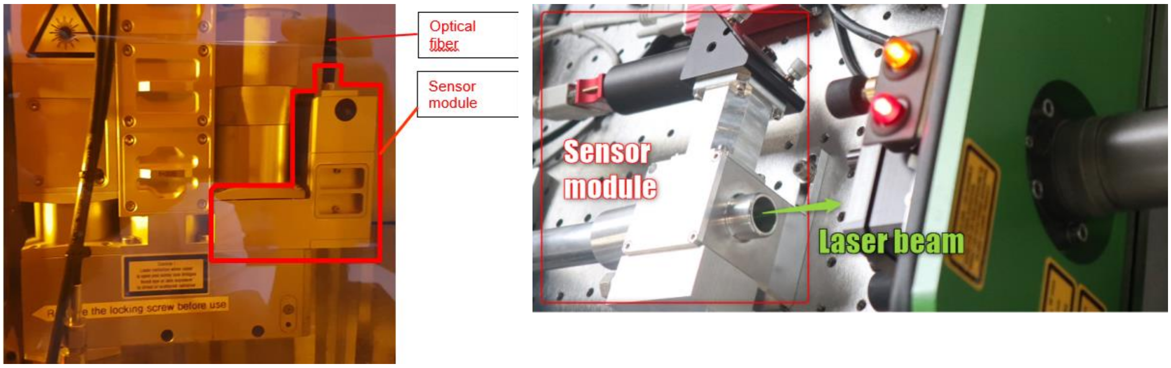
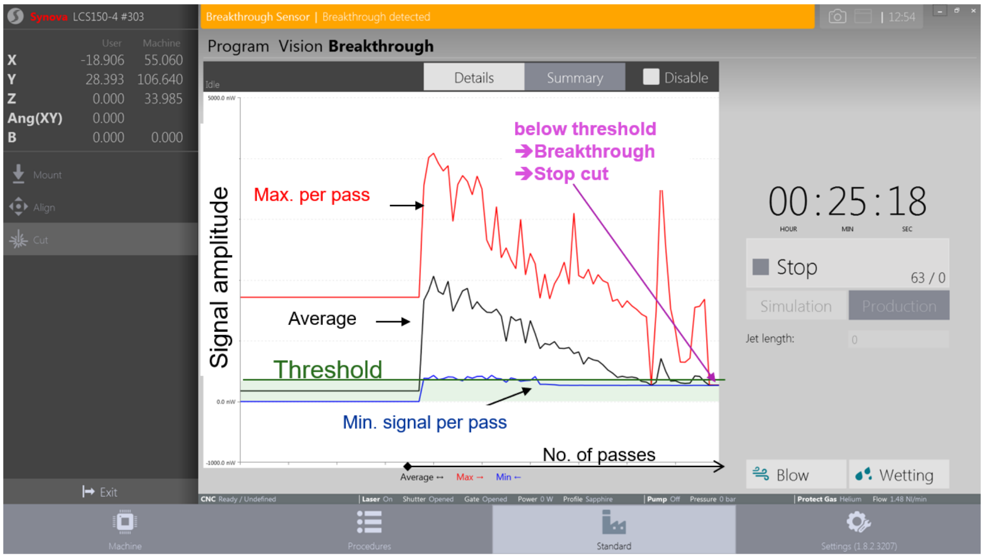


Fig. 4: Break-through sensor modules integrated at the optical head (left) and at the laser (right).

4. Cutting with break-through sensor

A typical signal, as well as the logic for deciding whether a break-through is completed is shown in Fig. 5, as displayed by the Synova HMI software Synapse. The signals here represent the max., min. and average of the sensor signal over each pass. Only when the max. signal over one cutting pass has decreased below a certain threshold, a signal for a breakthrough and a completed cut is given to the machine controller, which will move on to the next cut.



	User	Machine
X	-18.906	55.060
Y	28.393	106.640
Z	0.000	33.985
Ang(XY)	0.000	
B	0.000	0.000

Fig. 5: View of the signal evolution over the full cut of one feature, as displayed by the HMI software. A break-through signal is given when the max. per pass is below a pre-determined threshold.

With the help of this break-through sensor, generally improvements in machining time between 5% up to 20% is achieved (depending on the application), because additional safety margin passes are eliminated. The greatest improvements are achieved for faceting natural diamonds and other gemstones where it is difficult to predict the number of passes for completing a cut.

The break-through sensor in both versions (on optical head or laser) has now been fully industrialized and is employed in industrial production sites for automatized cutting.

In addition to the conventional break-through sensor described here, tests have been performed to use the sensor setup for a LIBS-measurement (Laser-Induced Induced Breakdown Spectroscopy). The spectrally resolved measurement shall be used to distinguish which material is being machined. This way, the machine is able to stop the ablation process as soon a certain type of material is attained in a multi-layered workpiece. The tests showed that a spectrally resolved detection of the machining plasma is possible, but that further development is required for material-specific ablation.

5. Conclusion and Outlook

The concept of break-through detection has been applied to water-jet guided laser machining in order to optimize the machining time. In the multi-pass cutting by Water-Jet Guided Laser (WJGL), this is achieved by strongly reducing extra safety cutting passes that are otherwise added in order to guarantee a completion of each cut under slightly varying machining times. At the same time, the intervention of machine operators in the cutting process is minimized, which reduces both workload and human errors. The cuts are guaranteed by the BT-sensor therefore achieving a success rate of 99.3 % and higher. This way re-machining for correcting non-cut features can be reduced, which otherwise consume a lot of both operator and machine time.

Synova has developed two types of break-through sensors, integrated onto the cutting head in one version and inside the laser in a second version. Both sensor versions rely on a detection of light coupled back from the machining point through the water jet and some optics. An uncomplicated, robust signal processing then uses the live signal in order to decide whether a cut has been completed, in which case the machine control moves on to the next cut.

In industrial applications, reductions of machining times by 5-20% have been observed, which greatly justifies the development effort put into the sensor and control system.

In the future, the break-through sensor shall be employed on a larger scale and employed for further applications. Furthermore, additional features are in development, such as a live detection of the type of machined material and automated localized rework.

The developed automatic cutting system is sold both as an option for any LMJ machine, or as a retrofit to existing systems. Improve your production with a break-through sensor!

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