Laser Combined with Water Jet for Manufacturing of Medical Devices

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Abstract
The medical device industry increasingly uses precision cutting tools for many operations. The requirements are usually very high. A new technology able to meet these requirements is now available: the water-jet-guided laser technology. Coupling a laser beam into a thin water jet prevents contamination, which is unavoidable with dry lasers, and also prevents a heat-affected zone from forming. Currently, it is used to cut stents, blades and needles. It is also used for cutting of piezo-ceramic substrates for ultrasound devices.

Introduction

Micro machining tools are today widely used in all state-of-the-art industries, including the medical device sector. Medical devices have particularly high manufacturing requirements: clean surfaces, smooth edges, no thermal or mechanical damage and high cutting accuracy. Various processes are commonly used, such as lasers and etching. Today, a new technology based on laser and water is available when a damage-free process is required: the water-jet-guided laser technology.

1. Water-Jet-Guided Laser

Also called Laser MicroJet, this unique technology is based on focusing a laser beam into a nozzle while passing through a pressurized water chamber. The water jet emitted from the nozzle guides the laser beam by means of total internal reflection that takes place at the water-air interface, in a manner similar to conventional glass fibers. The water jet can thus be referred to as a fluid optical wave-guide of variable length (see Figure 1).

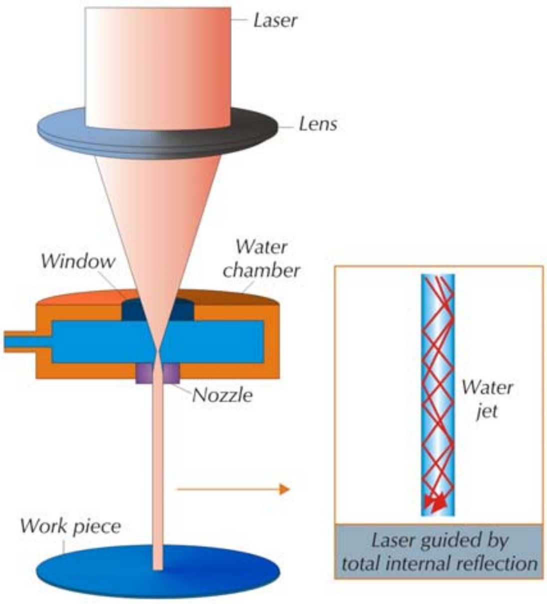

***Figure 1** – Principle of the coupling unit: coupling the laser beam into the water jet*

The lasers used are either flash-lamp-pumped IR lasers or multimode diode-pumped Q-switched lasers, operating at 1064 nm (infrared), 532 nm (green), or 355 nm (UV); the laser wavelength can be chosen freely as long as it fits the water transmission spectrum. Pulsed laser power are used, as during the pause between the pulses, the water jet efficiently cools the work piece in the surroundings of the laser-processed area (pulse durations of less than 100 µs). Regarding the water jet, pure de-ionized and filtered water is used to make sure that the jet does not contain anything that could either absorb or scatter the laser light. It is pressurized between 100 and 500 bars, depending on the nozzle diameter. As the jet is only hair thin, and because of the low pressure, the water consumption is very low – about 1 liter per hour at 300 bar water pressure. The nozzle is usually a diamond or a sapphire with a precision-drilled and polished circular hole for the water to exit through. Such nozzles generate a long, stable water jet, and their diameter ranges from 25 to 100 µm. At present, the minimum beam diameter that can be reached is 22 µm.

The water jet applies a mechanical force low enough to leave the material unscathed when exposed to the bare jet (less than 0.1 N, 10 times lower than the one applied by the gas jet in conventional laser cutting, which ranges typically from 1 to 5 N, that can be considered as negligible). Abrasive sawing also generates much more mechanical damage than the water-jet-guided laser.

2. Differences with Conventional Laser Cutting

2.1 Parallel Laser Beam

In conventional laser cutting, the laser is focused on the piece that has to be cut. The beam has a conical shape before and after the focal point. Therefore, the working distance is rather short and a precise focus-control system is required. On the contrary, when using a water jet to guide the laser beam, the working distance corresponds to the part where the water jet is stable. This part is usually several centimeters long, depending on the size of the nozzle – about 100 times longer than with a standard-focused laser. After the nozzle, the microjet is perfectly cylindrical and constant, resulting in an excellent kerf parallelism after processing and the possibility to reach an increased cutting depth.

2.2 Cooling

Over-heating is one of the main problems of laser-based cutting technologies, since the cut is achieved by heating the material (ablation). A major advantage of the use of water is the prevention of thermal damage within the material by cooling the laser-processed area and its surroundings between the laser pulses. The heat-affected zone is so greatly reduced, that the usual negative effects (such as micro-cracks, oxidation or low fracture strength) are practically eliminated.

2.3 Material Removal

The second important problem of laser technologies is the removing of the molten material generated by laser ablation. In conventional laser cutting, an assist-gas stream is used for this task; however, this technique is not efficient enough, because of the low density and compressibility of the gas. Using a water jet improves the material removal, as the kinetic energy of the water passing through the kerf is high. The remaining particles are instantly cooled by the water jet.

2.4 Cleanness

Adding a protective coating to the material is the common solution in conventional laser cutting to avoid particle deposition on the surface of the work piece. This increases the process running costs as two additional steps are required. Such operations are not necessary with the Laser MicroJet because the system generates a water film on the surface of the piece, where the particles, already cooled by the water jet, remain in suspension.

3. Application: Medical Devices

Because it only generates negligible thermal damage and contamination compared to conventional dry lasers, the water-jet-guided laser offers interesting advantages to medical device manufacturers. The process has been adapted to the manufacturing of stents, blades and needles. It is also used for cutting piezo-ceramic substrates for ultrasound devices.

3.1 Stents

Stents are mesh tubes that improve the blood flow in vessels affected by insufficient width due to vascular afflictions. The intricate stent structure has to be cut out from planar sheets or tubes. Because it will be placed inside the human body, the stent quality is paramount resulting in high requirements during the fabrication: no cracks and clean surfaces with neither attached dross nor burrs. As the materials are very heat sensitive, low thermal loading is essential. Mechanical and chemical methods such as sand blasting and electro polishing can be used to remove dross and moderate heat-affected zones after cutting. Such methods are necessary when using conventional dry lasers (typically pulsed Nd:YAG lasers), with a gas jet to remove the molten material from the cut. Reducing these post-processing steps by using a technology which improves the cut quality would represent an significant improvement.

Figure 2 shows a detail of a Nitinol stent. It is the typical quality obtained after Laser MicroJet cutting, as no chemical post treatment was applied. Only a soft rinsing in de-ionized water has been applied. There is no visible heat-affected zone, no oxidation, no thermal deformation, no change in elastic properties and no cracks.

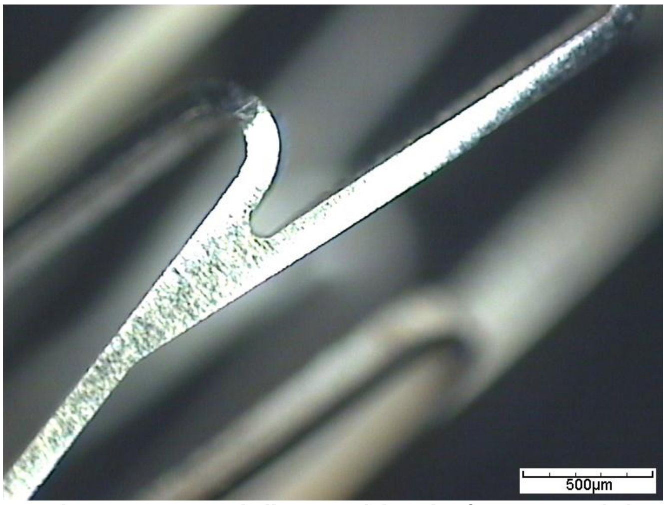

Figure 2 *– Detail of a stent in shape-memory metal alloy Nitinol directly after cutting with the Laser MicroJet (thickness: 200 μm)*

For this stent, a pulsed infrared laser (wavelength: 1064 nm, average power: 23 W) and a 30-µm nozzle were chosen as the most suitable configuration. The stent is fixed on a rotary axis with a tubular plastic fixation during cutting and water is sent inside the stent to prevent damaging the inner wall.

3.2 Blades

The Laser MicroJet technology is also applied to other medical devices such as blades and needles. An example of such applications is the cutting of silicon ophthalmic blades. In this case, the Laser MicroJet is used to create the blade contour and fixation holes, while the cutting edge is produced by etching. Using a Nd:YAG green laser (wavelength: 532 nm, average power: 30 W), high cutting rates were reached, while improving the cut quality. With such parameters, the obtained quality should lead to better results in terms of fracture strength. The resulting speed was 15 mm/s for 350-µm thick silicon. The edge quality of the contour is shown in Figure 3.

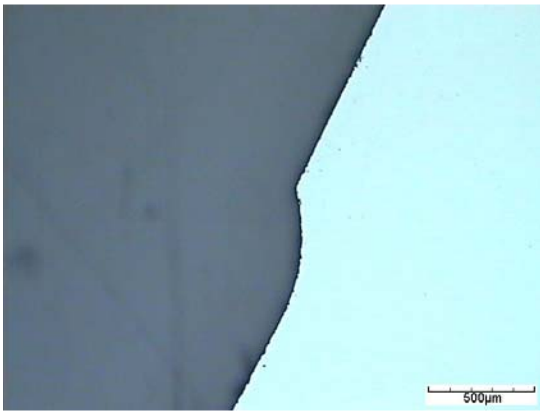

Figure 3 *– Edge of a silicon blade for ophthalmic surgery (contour), directly after cutting with the Laser MicroJet*

3.3 Piezoelectric Materials

The water-jet-guided laser technology has already proven its capabilities with different sorts of ceramic materials for the electronic industry. In the medical field, piezoelectric (PZT) materials, which are also ceramics, are used for ultra sound devices. Because it is a gentle process, the brittle PZT does not suffer from thermal or mechanical damage while processed by Laser MicroJet. Any shape can be produced, and contamination is negligible. Figure 4 shows 600-µm deep circular grooves in PZT. Cut edges are clean; the material structure in the area surrounding the grooves is unaffected.

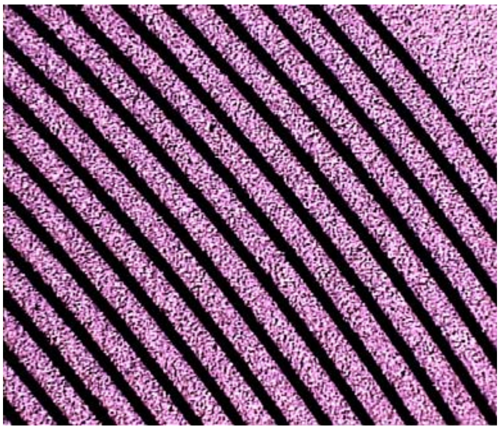

Figure 4 *– 600-µm deep circular grooves in PZT*

4. Conclusions

The water-jet-guided laser is a unique technology fundamentally different from conventional lasers. It offers several advantages to the medical device industry, such as efficient molten material removing, reduced particle contamination, minimal heat-affected zones, high speed in small dimensions and negligible mechanical constraints on the work piece. It is therefore well adapted for processing metals such as stainless steel, and shape-memory alloys; almost any shape can be produced in very small dimensions, thanks to the thin jet of 22 microns. It has already proven advantageous for PZT and silicon blade cutting, and is currently being optimized for other medical devices such as stents. Some of the current research targets are smaller water jet diameters (down to 10 µm), new laser types and new wavelengths.