# Pushing the envelope of liquid-jet guided laser machining applying modern IR fiber lasers

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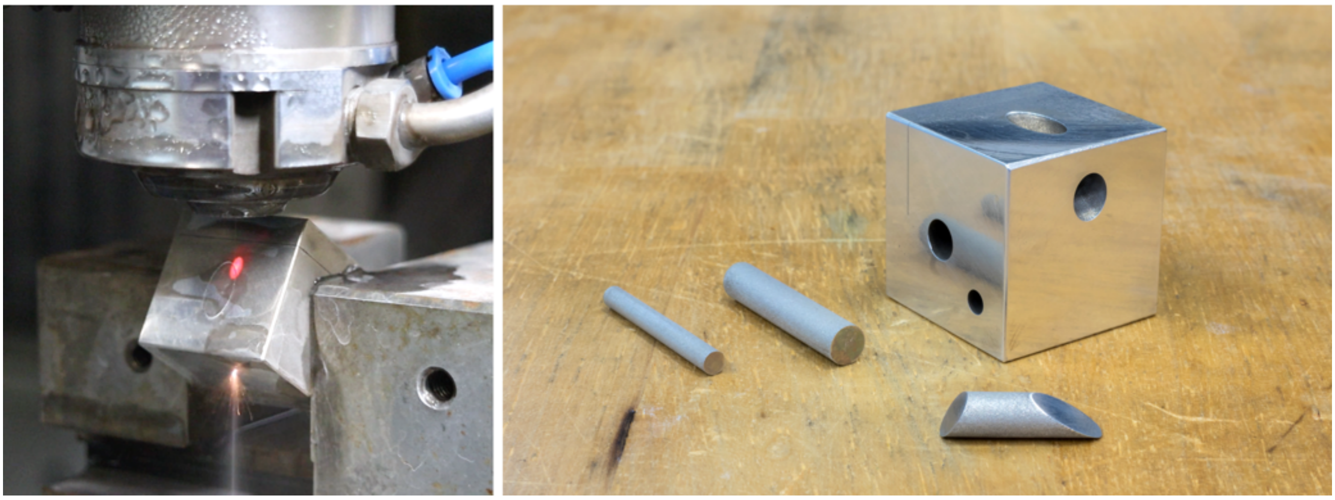

***Fig. 1**: An Avonisys waterjet guided laser system seen in action while machining a 24mm aluminum cube. Cutting through the complete 24mm depth can be achieved while applying modern IR fiber laser technology.*

Liquid-jet aka waterjet guided laser technology is meanwhile more than 30 years old, yet still appears to be an odd duck among other more widely applied laser technologies. Recently new technological developments were made in an effort to expand the scope of the liquid-jet guided laser into industrial applications that require 24/7 production processes. A laser head and laser coupling method have been successfully developed to enable the use of modern high-performance fiber laser sources and efficiently unleash multi kilowatts of power into tiny waterjets. Additionally, the operation and the maintenance procedures for the technology have been simplified significantly, providing a user-friendly experience.

## History of the waterjet guided laser

It's not so commonly known, but back in the year 1986, Aesculap-Werke AG, based out of Tuttlingen, Germany, invented the first system that guides a laser beam to a work piece by applying the principle of total internal reflection inside a liquid column [1]. For this purpose, a small liquid column was flown around the aperture of an optical fiber. In 1991 LASAG AG refined this principle by generating the liquid column using a waterjet nozzle and focusing the laser beam into the nozzle inlet [2]. Building on the same laser coupling principle as LASAG, yet another refinement step was made by B. Richerzhagen in the year 1994 [3], which was then commercialized by Synova SA from 1997 in the way that most people know of this technology today.

## Technological challenges to overcome

In the summer of 2013, the founding engineers of Avonisys AG were confronted with the challenge of machining deep micro-slots with a cumulated length of several meters into the concave inner surface of molds. A complex 5-axis full sync CNC-machining job during which an individual work piece had to be laser machined for up to 24h uninterrupted. In theory this task would have lend itself well to the characteristics of the liquid-jet guided laser as it was already available on the market for many years.

*[ …existing theories had to be questioned and a completely new waterjet guided laser system was developed. ]*

Thus, before deciding whether to proceed and commit to such task, a series of machining tests were conducted on available 3rd party liquid-jet guided laser systems installed at job shop companies. It was rapidly found out that the task at hand was far from trivial and that important challenges had to be overcome in order to manage such complex machining task successfully. This led to the formation of Avonisys and was the starting point of an extensive development period in which many fundamental experiments were performed, existing theories had to be questioned and resulted in the development of a completely new liquid-jet guided laser system.

## Avonisys developments

One of the first and most important hurdles to tackle was finding a solution to keep concave work piece surfaces and deep pockets inside a workpiece free from process water accumulation during the actual machining process. This seems paradox as water forms the fundament of a waterjet guided laser. However, for a technology that heavily relies on guiding substantial amounts of laser energy inside a liquid-jet by total internal reflection, it is easy to understand that a proper water-to-air interface is paramount, especially until the waterjet reaches the work piece surface. Having said that, machining inside a pocket is not principally impossible, but as soon as the level of water accumulation passes a certain critical height, it will collapse onto the waterjet and in consequence laser light scatters out of the jet in an uncontrolled manner, hence the process "drowns".

Known methods in which an assist gas stream is directly enveloped around the waterjet and leaving through the same exit aperture as the waterjet turned out not suitable to solve this problem. The pressure that is required to achieve adequate water removal from pockets adversely impacts or even vaporizes the waterjet, thus making proper laser light transmission impossible. Fig. 2 illustrates how the laser process "drowns" when a proper water-to-air interface of the waterjet is missing.

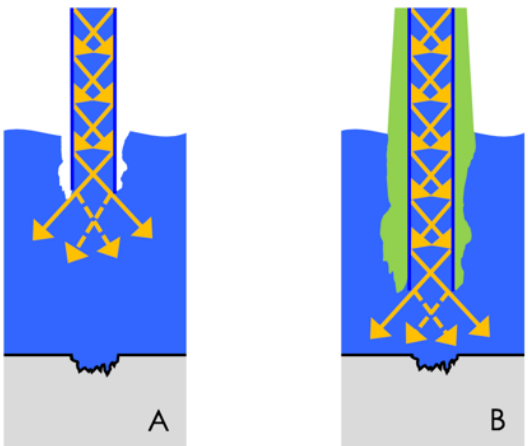


***Fig. 2**: A) Kinetic energy of waterjet alone is insufficient to maintain water-to-air boundary. B) Direct-enveloping assist gas stream is insufficient to maintain water-to-gas boundary.*

To overcome this problem, the Air-Jet system [4] was developed, and it turned out to be a game changer. Air-Jet essentially is a co-axial stream of compressed air around the waterjet but without interference of the Air-Jet with the waterjet until reaching the surface of the work piece. For this purpose, the waterjet and the Air-Jet leave the laser head through two separate openings that are spaced apart. Fig. 3 illustrates the working principle of Air-Jet when machining a slot into a cavity.

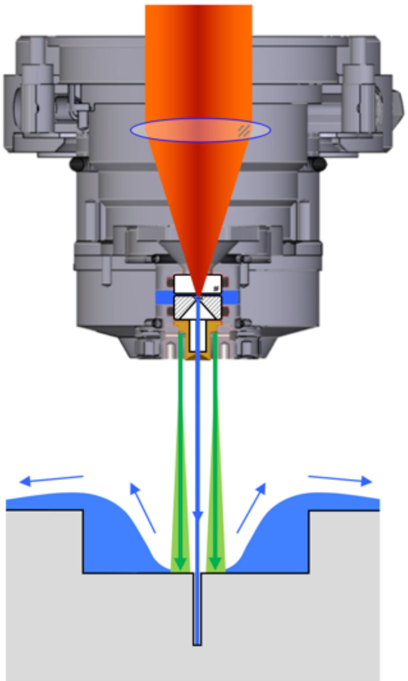

***Fig. 3**: Working principle of the Avonisys Air-Jet. Effective removal of water accumulation from 3-dimensional work piece surfaces.*

The Air-Jet pressure and flow volume can be adjusted to efficiently clear work piece topography from water accumulation. Fig. 4 illustrates that even inside deep pockets the working area of the laser is kept dry without harming the waterjet's energy transmission and thus allowing the material evaporation process to fully unfold.

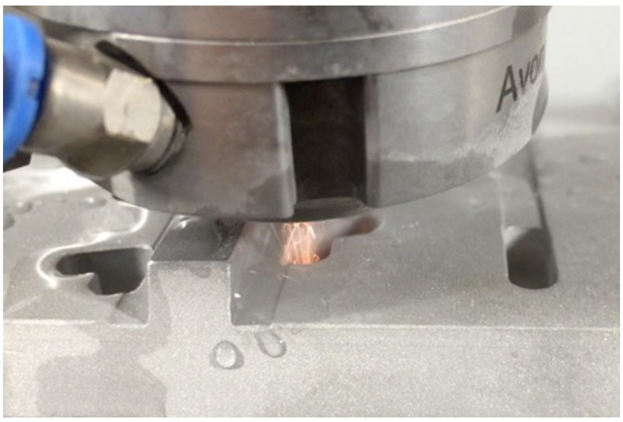

***Fig. 4**: Air-Jet technology keeps the laser processing area dry, even inside blind pockets.*

A positive side-effect of the Air-Jet, as shown in Fig. 5, is the mitigation of back-splashes and other waterjet disturbances that can otherwise disrupt the waterjet and cause damages to the work piece. Air-Jet forms a distant cylindrical protection shield for the waterjet.

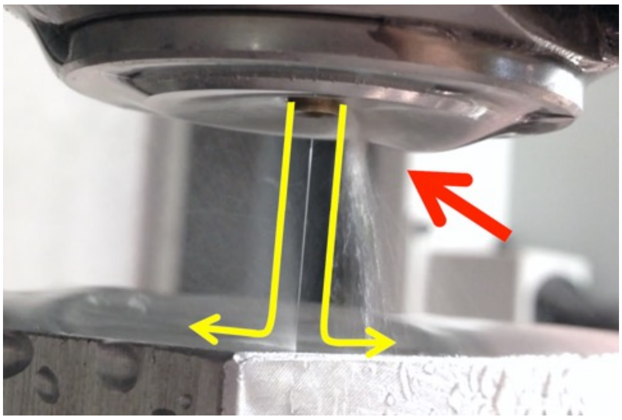

***Fig. 5***: *Droplets (red arrow) are blown away before they can touch the waterjet. Air-Jet creates a protection zone (yellow arrows) around the waterjet to avoid disturbances.*

A second important aspect for robust waterjet laser machining, is consistent high transmission of laser energy without damaging the waterjet nozzle orifice. Typically, materials such as sapphire or synthetic diamond are applied to manufacture the waterjet nozzle orifice, which can have a diameter ranging from only 30 – 80µm for typical waterjet guided laser applications. Needless to say, special measures are required to protect the nozzle orifice against the high amounts of laser energy that need to be transmitted through it for work piece treatment. Typical waterjet guided laser systems apply high-NA focus optics and place the laser focus in the nozzle inlet plane, regardless of the nozzle diameter and regardless of the laser properties. From an optics point of view this did not seem to be the best approach and in a quest for increasing laser energy throughput and increasing the nozzle life time, Avonisys started a series of fundamental experiments. Many dozens of sapphire and diamond nozzles have been sacrificed in an empirical process to derive the perfect coupling point for different nozzle diameters, different focus optic geometries and different laser beam properties ($M^2$ / BPP). This ultimately resulted in a coupling method [5] based on geometrical relation that is applied to achieve accurate and repeatable coupling of high-power laser beams:

$$CP = \frac{0{,}5 \times CF \times D_N}{\tan(\theta/2)}$$

Where *CP* is the coupling point of the laser focus spot as offset value below the nozzle inlet plane, *CF* is a coupling factor representing an energized beam diameter ($1/e^2$, 98%, 100%, etc.), $D_N$ is the nozzle diameter and $\theta$ is the focus cone angle of the laser beam based on the laser BPP in combination with the collimation and focusing optics. The effect of high-power focus shifting in some cases needs to be considered too, but as Fig. 6 illustrates essentially this formula describes how deep the laser focus cone can be placed into the nozzle orifice cavity without introducing laser energy that exceeds the damage threshold of the nozzle material.

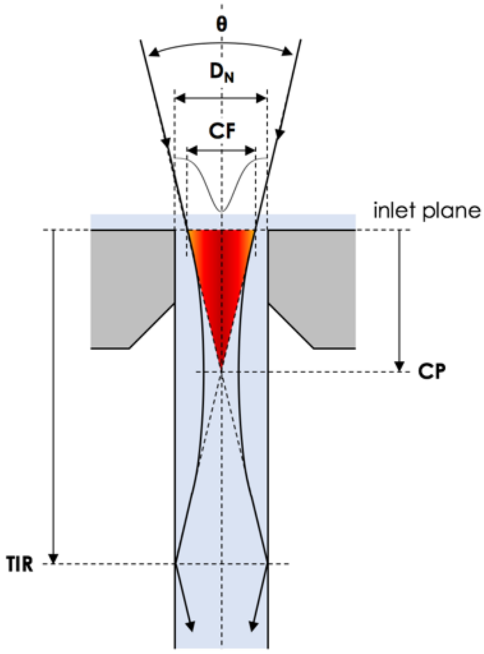


***Fig. 6***: *Laser coupling scheme based on reduction of the energetic impact of laser to the waterjet nozzle orifice.*

Target is that internal reflection of the laser beam inside the waterjet only starts below the nozzle orifice where the waterjet has reached its stable laminar diameter. Coupling as deep as possible additionally has the purpose to increase the spot diameter of the laser beam on the lower side of the laser window that faces the water chamber inside the laser coupling module. A bigger laser spot equals a lower energy density and thus longer lifetime of the laser window. As Fig. 7 illustrates, a coupling factor of 0,67 allows 98% of the laser energy to pass through the nozzle orifice. In consequence only 2% of laser energy is allowed to incident the top surface of the nozzle. A coupling factor of 0,5 on the other hand ensures 100% power transmission through the orifice.

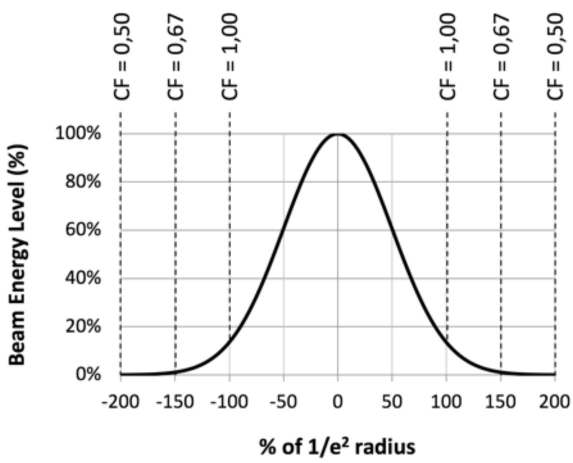


***Fig. 7***: *Relation of coupling factor and power transmission through the nozzle orifice.*

On top of that, also hydraulic effects were taken into consideration to derive the best laser focus coupling point and the best point of first internal reflection of laser rays inside the waterjet. In particular the presence, the effect and the relevance of hydraulic flip was analyzed. Hydraulic flip essentially describes the phenomenon that the waterjet contracts after passing the nozzle inlet and remains of a smaller diameter than the orifice, also when exiting the nozzle. This effect is only reported for very particular nozzle designs. R. Cadavid for example provides detailed insight in the various aspects of cutting with and conditioning of fluidjets of small diameters [6].

For different reasons Avonisys did not want to rely on the presence of hydraulic flip for the development of its coupling method. On one hand this would strongly limit the variety of nozzle geometries that would be usable. But far more important, the waterjet was considered not to be a 100% perfect light guide, even in case of hydraulic flip and it was expected that significant amounts of laser energy, especially when using high-NA optics would be coupled out of the waterjet into the side walls of the nozzle orifice. Practical experiments with sharp-edged low-aspect waterjet nozzles, capable of producing hydraulic flip, confirmed this point and it was shown that when using high-NA optics to focus a laser beam into the nozzle inlet plane, such nozzles were subject to damage of the rear side of the nozzle orifice within just a few working hours. On the other hand, when the laser focus spot was placed below the nozzle inlet plane with a lower NA focus lens and as calculated with the coupling formula, no nozzle damage occurred. A comparison of the traditional laser coupling method (A) and the Avonisys method (B) is shown in Fig. 8.

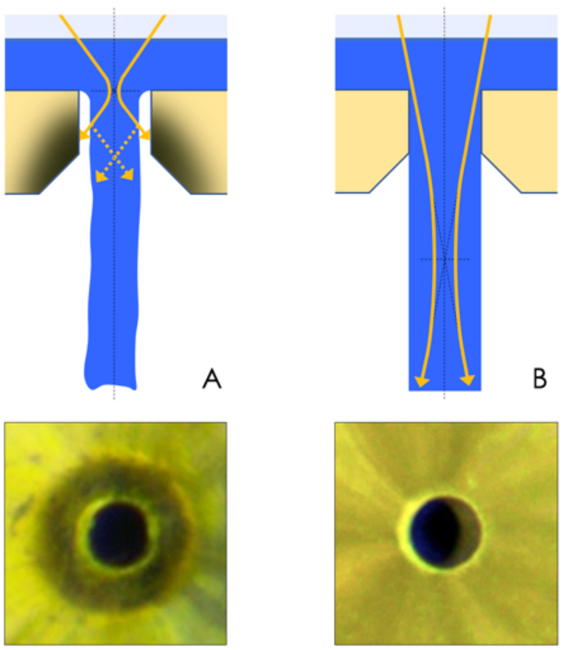


***Fig. 8***: *A) Typical system: high-NA optics cause internal reflection to start within nozzle orifice. Out-coupled laser energy damages the orifice. B) Avonisys: internal reflection starts far below the nozzle orifice. The nozzle orifice remains intact, also at higher laser power.*

Table 1 shows the focus shift corrected coupling point values for a 1075nm fiber laser with a BPP of 2.1 and a 37° 1/e$^2$ cone angle (in air and corrected for water).

| **Nozzle orifice Φ** | 30µm | 40µm | 50µm | 60µm | 70µm |
|---|---|---|---|---|---|
| **Coupling Point** | -141µm | -171µm | -201µm | -231µm | -261µm |

***Tab. 1***: *Laser coupling point for various orifice diameters*

A dedicated focus Z-drive (Fig. 9) was developed to allow setting the precise coupling point of the laser focal plane in a reliable and repeatable manner.

***Fig. 9***: *Avonisys Focus Z-drive with 6mm Z-travel and 10µm increment scale.*

Setting the best coupling point is now fast and accurate: In a first step a laser focus spot of low energy is projected onto the nozzle orifice. The Z-drive is then adjusted to deliver a sharp image of both the nozzle inlet plane and the laser focus spot. The nozzle orifice is then centered mechanically to the laser spot. Lastly, the focus lens is moved down with the Z-drive to the required coupling point, for example to a -200µm coupling point, which is achieved by rotating the focus Z-drive by an amount of 20 scale units in clockwise direction. The system is now properly setup to transmit a high-power laser beam through the waterjet nozzle without damaging it. As can be seen in Fig. 10, the focus Z-drive and the laser coupling assembly mounted below it take up approx. half the space of the whole laser head and underline how important both these modules actually are for a stable high-power laser process.


***Fig. 10***: *Avonisys LJFK45 series laser head.*

## The Infrared paradigm

Nowadays waterjet guided laser systems more or less exclusively apply green (532nm) nanosecond YAG lasers. Partly because of the work piece material behavior, but mainly because of the consideration of lower absorption of the water for this wavelength. Although Near-Infrared light is indeed absorbed by water to a much larger extent then visible light and in particular the spectrum around the color green, this turned out not to be the main driver for effective laser power transmission to a work piece. During the development of the coupling method, Avonisys engineers found out that flat (low-NA) coupling angles are particularly favorable to transport very high amounts of laser energy to a work piece. In other words, keeping the perimeter rays of the laser focus cone well below the critical out-coupling angle of the water-to-air interface strongly reduced unwanted out-coupling and scattering of laser energy.

Due to the excellent laser beam quality as well as low maintenance characteristics of modern fiber lasers, Avonisys was keen on "forcing" as many applications and materials to fit this type of laser. Mainly to keep the system setup as simple and as robust as possible for industrial 24/7 usage scenarios. This did not work immediately, but step by step the bar could be raised and cutting depths as well as cutting quality were increased to astonishing levels. Not all fiber lasers are created equal and different fiber laser types that on paper should be able to deliver similar results, turned out to differ quite a bit in praxis. The redPOWER QUBE fiber laser series [7] by SPI Lasers (Fig. 11) pairs particularly well with the Avonisys waterjet guided laser process. When it comes to deep micro-cutting and deep micro hole drilling with excellent surface quality, the beam quality and pulse characteristics of SPI's redPOWER CW-M lasers are game changing.


***Fig. 11**: SPI Lasers redPOWER QUBE fiber laser as used by Avonisys AG in its waterjet guided laser systems (Source: SPI Lasers UK Ltd).*

"SPI has helped to carefully analyze typical laser parameters for our application portfolio, based on which we together selected a first laser source to put to the test." says Jens Gaebelein, co-founder and CTO of Avonisys. "Using a CW-M fiber laser compared to a similar spec QCW fiber laser has brought us specific advantages for our waterjet guided laser process. It is now possible to drill significantly deeper micro holes in hard materials such as Inconel and Tungsten Carbide reliably (Fig. 12). For this purpose, the consistent and good beam quality as well as convenient laser pulse shaping options that come with SPI fiber lasers have opened up completely new drilling and cutting strategies." adds Gaebelein.

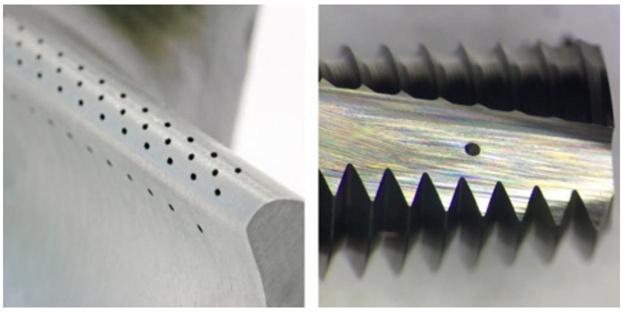

***Fig. 12**: Left: inclined 0.3mm holes up to 6mm deep in Inconel airfoil. Right: inclined 0.3mm hole 2mm deep in tungsten carbide threading tool.*

"The installation of the laser source with the Avonisys waterjet guided laser process was surprisingly easy." says Mark Southwell, Field Service Manager at SPI Lasers. "After connecting the optical fiber to the QBH connector of the Avonisys laser head, the waterjet nozzle could be easily aligned to the laser focus spot. Literally minutes after connecting the laser for the first time we were already cutting material. This was a very positive surprise to me and not what I expected." adds Southwell.

Next to micro hole drilling, Avonisys has tested how far it could take the SPI laser for straight and shaped cut-throughs. As benchmark material (for vulcanization molds) aluminum was used. Based on experience with QCW fiber lasers it was expected that the laser process with SPI would be able to cut approx. 10-12mm deep and then reach its limit. This depth in itself would already have been fantastic. Surprisingly it was possible to cut through the complete thickness of a 24mm aluminum "reference" cube, which is a significant performance increase. Further tests in silicon as well as black ceramic material were performed as shown in Fig. 13.

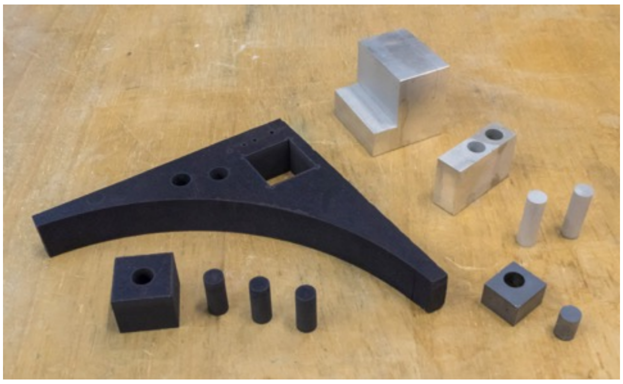

***Fig. 13**: Results of waterjet laser micro-cutting with SPI redPOWER QUBE 2kW version. Aluminum 24mm depth, Black ceramic 12mm depth, Silicon 7mm depth.*

The Air-Jet system as well as coupling method played an important role for pushing the boundaries of the IR waterjet guided laser too. Air-Jet for example also keeps deeper cutting slots free from water to a large extent, which helps to maintain a better evaporation process (less energy losses in longitudinal direction of the cutting kerf). The coupling method on the other hand ensures that as much power from the laser as possible is actually delivered to the work piece. Thus, in sum it is safe to say that Avonisys has successfully implemented modern IR fiber laser sources from SPI into its systems to achieve cutting performance that no one would have considered possible with an Infrared waterjet guided laser. Meanwhile Avonisys and its customers have installed various 1.5kW, 2kW as well as the newer 3kW redPOWER QUBE fiber lasers at various customers sites in Europe and Asia (with max. power selected based on customer application).

### Consistent high power transmission

To serve specific applications, it can for example be required to change from a 70µm waterjet nozzle used in one job to a smaller 30µm waterjet nozzle used in another. After such nozzle exchange, the nozzle orifice in most cases will not be exactly centered to the laser beam anymore. This is for example related to manufacturing tolerances of waterjet nozzles. The orifice position in the XY plane can differ up to some orifice diameters. In the Avonisys system this does not matter at all because of the way how the waterjet nozzle is aligned to the laser beam. The method is very straightforward but really effective. Unlike typically applied, Avonisys does not employ any tilting mirrors to adjust the XY-position of the laser focus spot relative to the nozzle orifice.

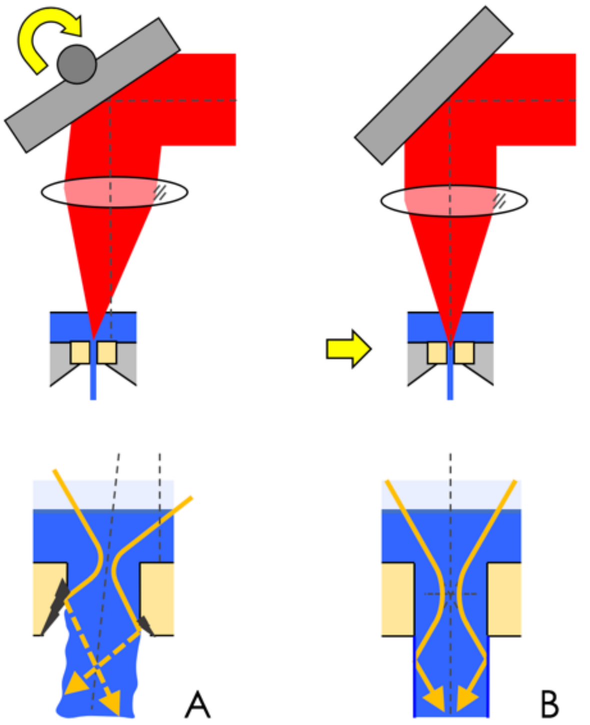


***Fig. 14**: A) Typical system: laser-to-nozzle alignment by tilting mirror to move the laser spot. B) Avonisys: nozzle-to-laser alignment by moving the nozzle underneath the laser spot.*

To ensure consistent and high power transmission, Avonisys prefers to avoid off-axis laser radiation to the nozzle orifice. As illustrated in Fig. 14, the nozzle orifice is centered to a perfectly aligned laser beam (right), rather than dis-aligning the laser beam (left) to compensate for nozzle tolerances. This method of nozzle-to-laser alignment for a waterjet guided laser system is not new and was first applied around the early 2000's by Prejet Präzisionstechnik AG, based out of Steffisburg, Switzerland [8]. Avonisys has refined the method with a durable and moisture-sealed push-pull mechanism that allows the entire coupling module to be adjusted in the XY-plane, relative to the focus lens, with micrometer precision.

Next to consistent power transmission, the nozzle-to-laser coupling method has further strong benefits. Avoiding asymmetric energy distribution inside the jet yields more consistent cutting results and avoids increased nozzle wear. In addition, it keeps the laser head robust as it eliminates the need for electro-mechanics that would tilt one or more mirrors.

### Jet coherence versus jet stability

It is obvious that a coherent waterjet is a prerequisite for the waterjet guided laser to work in the first place. Increasing the coherent length of waterjets has been subject of studies for a long time. In depth research that focuses on increasing the coherent length of particularly small waterjets (30-80µm) was performed by R. Cadavid and D. Wüstenberg in the early 2000's. They showed that reducing the ambient pressure around the waterjet or surrounding the waterjet with a light gas such as Helium increases its coherent length [9]. As practical solution that could fit on any waterjet cutting head, Cadavid and Wüstenberg suggest the so-called co-flowing helium technique in which a stream of Helium is blown parallel around the waterjet using a gas collimator [10] (Fig. 15).

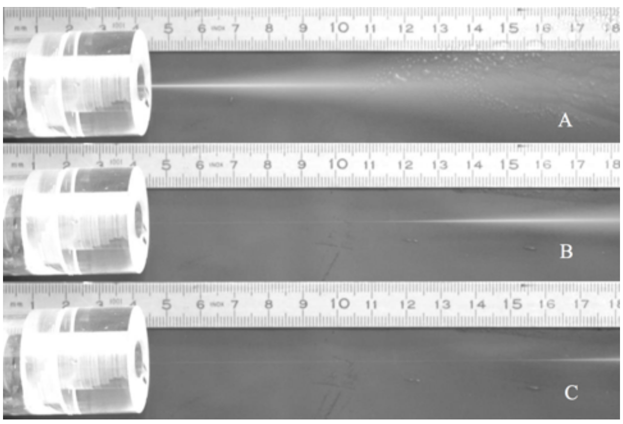


***Fig. 15**: Nozzle diameter 36µm, system pressure 140 MPa, helium flow A: 0 cm3/s, B 28 cm3/s, C: 69 cm3/s; the zero of the ruler is set to where the waterjet orifice is located. (Source: Cadavid [6] Fig. 93 on page 128 and Cadavid and Wüstenberg [10] Fig. 5 on page 284).*

To achieve the best balance between coherent length and consumption of Helium gas, Cadavid analyses various gas nozzle designs [6]. Very good results are achieved when the waterjet is guided through a gas outlet nozzle (gas collimator) which is arranged at a distance from the waterjet nozzle and forms a stream of Helium around the waterjet using a funnel-shaped downwardly converging wall (Fig. 16).

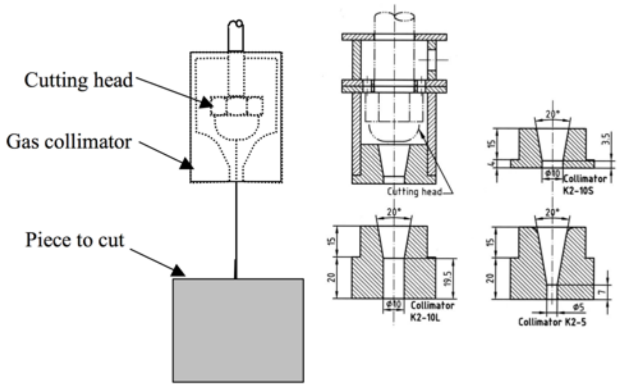


***Fig. 16**: Various gas outlet nozzles (gas collimators) as presented by Cadavid (Source: Cadavid [6] Fig. 99 on page 136 and Fig.115 on page 148).*

As part of his research, Cadavid also considered the co-flowing Helium technique to be applicable for waterjet guided lasers and referenced [6] to Laser MicroJet® technology [3]. Cadavid's consideration appears to be correct as after publication of his body of work the co-flowing helium technique seems to have found its adoption to the Laser MicroJet® [11] in a nearly identical manner as previously described by Cadavid.

Also, Avonisys waterjet guided laser technology relies on the presence of a coherent waterjet. However, for its applications Avonisys is targeting the most stable waterjet and not the longest coherent waterjet. The reason for this becomes apparent when considering the waterjet guided laser process a dynamic process. In other words: typically, the laser head is moved in XYZ direction with a certain feed speed and can accelerate and decelerate rapidly to create specific cutting geometries. During such movements the waterjet is forced through static air and exposed to increased friction, which can lead to reduction of coherent length or even bending of the waterjet of up to 0.1mm. Enveloping the waterjet with a light gas such as Helium does not mitigate this problem as the density of such gas is too low to protect the waterjet from movement-induced friction and drag.

Avonisys therefore has chosen a different approach with its Air-Jet technology. As previously mentioned, Air-Jet forms a cylindrical air protection barrier around the waterjet by guiding a higher pressure stream of compressed air through a separate opening that is spaced apart from the waterjet outlet. The pressure of the Air-Jet can be increased to a pressure level that can keep the laser machining point on the work piece free from water accumulation and at the same time create a protected working zone (Fig. 17) for the liquid-jet guided laser. The protected working zone mitigates friction disturbance of the waterjet caused by the static (vapor enriched / aerosol) ambient air during movement of the laser head. In addition, it avoids jet disturbances, such as back splashes that are caused by reflected water and debris while machining a work piece.

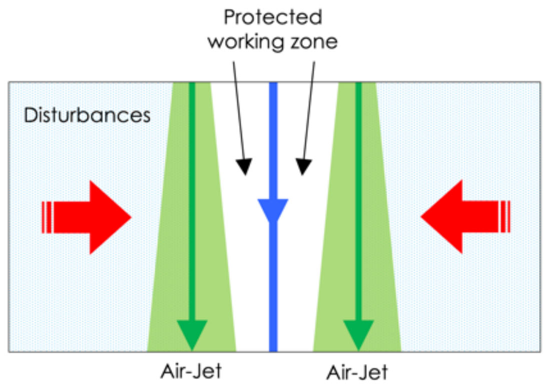


***Fig. 17**: Protected working zone for the liquid-jet guided laser.*

One consequence of applying Air-Jet is that the coherent length of the waterjet is reduced yet becomes highly stable within the remaining working length. Air-Jet creates a defined atomization point of the waterjet where the diverge flow portions of the Air-Jet barrier intersect with each other (Fig. 18). To precisely steer the atomization point different Air-Jet inserts can be applied.

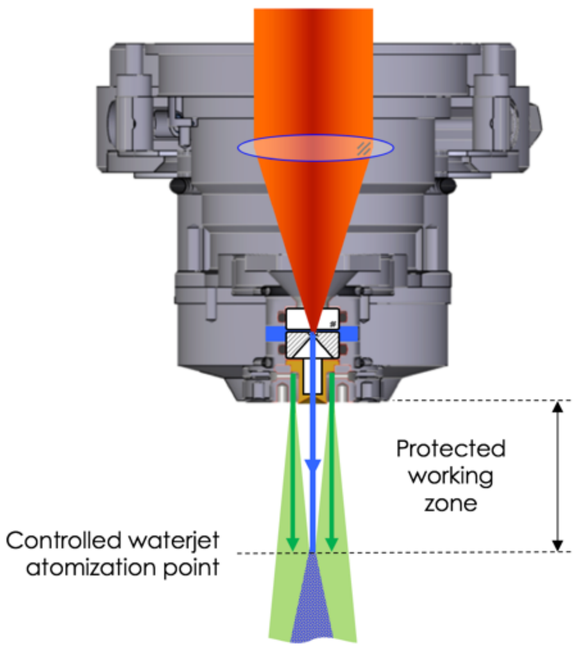


***Fig. 18**: Air-Jet creates a protected working zone above the controlled waterjet atomization point.*

The protected working zone for a standard Air-Jet insert is approx. 25mm. A typical working distance to a work piece within this zone is set to 16-18mm. Longer stand-off distances can be achieved by increasing the length of the Air-Jet insert. The waterjet then exits the laser cutting head at a further distance and is protected against ambient influences while traveling inside the Air-Jet insert.

## System build & maintenance optimization

The Avonisys waterjet guided laser system consists of 2 main units. A high-pressure water-pump and a laser cutting head.

*[ …we have approached it through the eyes of an end user and have designed many features of the system accordingly... ]*

The high-pressure water pump (Fig. 19) is connected to city water that is purified and filtered in several steps (city water → de-ionization → 2-step filtration → pressure amplification & damping → fine filtration). The pump system is designed to deliver a pulsation free stream of water to the coupling assembly of the laser head that depending on pump configuration can have an output pressure of up to 600 bar. With its very compact size of only 65cm x 42cm x 50cm it can be flexibly fitted into a CNC machine cabinet. The only maintenance consists of exchanging / regenerating a DI-cartridge as well as replacing fine-filters periodically. Depending on capacity and system usage this is typically done twice per year.

The Avonisys laser head (Fig. 10) consists of beam delivery optics, a high-resolution camera system for nozzle alignment, a focus Z-drive and a coupling assembly mounted to a lateral XY-alignment system. Periodic maintenance is only required for the laser coupling assembly that contains a laser window and a waterjet nozzle.

***Fig. 19****: Compact Avonisys HD-water pump.*

Inherent to the applied technology principle, the laser window is exposed to substantial amounts of laser energy and thus prone to some degree of wear. To facilitate quick and uncomplicate maintenance of the coupling assembly, it has been constructed accordingly [12]. The coupling assembly is mounted to the laser head with a quick-release bayonet (similar to the principle of a digital system camera). After releasing the coupling assembly, the window holder can be independently removed as shown in Fig. 20. The entire process of removing the coupling assembly, replacing the laser window, reinstalling the coupling assembly and fine-aligning the nozzle is performed in under 5 minutes.


***Fig. 20****: Left: Coupling assembly easily removed using a quick-release bayonet. Right: Window holder independently removable.*

The waterjet nozzle itself is considered a tool that is exchanged to meet a certain machining job requirement. Having said that, also the waterjet nozzle orifice is prone to some degree of wear, similar to that of a regular waterjet cutter. The waterjet nozzle can be conveniently replaced and aligned while the coupling assembly remains attached to the laser head. This also takes just some minutes to do. About the design of the system Jens Gaebelein comments: "After identifying all critical items, it was a challenge to design the right hardware that was able to do the job while at the same time keeping the system as simple as possible. Although we have a background in physics and engineering, we were not and are not laser scientist. Strange as that sounds it has helped us to approach certain problems with an unbiased mind finding innovative ways to overcome hurdles". "One can say that we have approached it through the eyes of an end user and have designed many features of the system accordingly." adds Jeroen Hribar, co-founder and CSO of Avonisys.

## Summary and outlook

A new waterjet guided laser system has been developed and commercialized by Avonisys that suits 24/7 complex 5-axis full sync CNC laser-machining jobs. For this purpose, a coupling method that allows efficient and high laser power transmission through small waterjets has been developed. Additionally, an Air-Jet system that avoids water accumulation on work piece surfaces and inside pockets has been implemented. The Avonisys technology pairs particularly well with modern high-performance CW-M IR fiber lasers. This makes the overall process very robust and reduces maintenance. Small waterjet nozzles of down to 30µm can be applied in an industrially robust manner.

Recently also very tiny waterjet nozzles of only 25µm have been applied in the Avonisys system. During first coupling and cutting tests with a 3kW CW-M laser more than 2kW of peak power using shorter pulse lengths could be applied to cut tiny details in precision metal sheets. Further development in the robust use of tiny waterjet nozzles is under way. Furthermore, the adaptation of additional SPI fiber lasers, such as ns-IR lasers is planned.

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## About Avonisys

Avonisys is an engineering and technology company based out of Zug, Switzerland. It is specialized in laser micro-machining processes applying waterjet guided laser. It develops, builds and sells waterjet guided laser packages also branded as "Laser Micro Milling" technology and offers fully integrated Laser CNC machines together with established machine building partners. Around its core waterjet guided laser technology, Avonisys holds over 22 patents and patents pending.

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