High Speed Thin Metal Cutting Using Fiber Laser Technology

Using laser systems on challenging geometries

Manufacturers are continually looking for more reliable, faster and more cost effective manufacturing solutions to stay competitive in the global marketplace. One area where this need is especially prevalent is precision cutting of thin metals for medical, electronics and industrial applications.

There are several methods available for precision cutting of thin metals less than 0.06-inch thick used for these applications, which include materials such as stainless steel, titanium, nickel, and aluminum. The major options, lasers, electric discharge machining (EDM), water-jet, and chemical machining each have a role to play. However, precision fiber laser cutting technology is now emerging as the preferred choice for many thin metal cutting applications, particularly when superior edge quality, tight dimensional tolerances and/or high volume production is required.

In addition, more capable fiber lasers integrated into turnkey systems with multi-axis motion maximize precision, throughput and cut flexibility. This technology offers both a cost effective high accuracy cutting solution and provides component designers more freedom to create challenging geometries unconstrained by cutting technology limitations.

SOLID STATE LASER CHOICES

Laser cutting is ideally suited for making complex shapes because it is not limited by part geometry. Because the laser cutting tool does not rely on touching the part, it can be oriented to make any shape or form. Table 1 lists the general benefits of laser cutting.

Non-contact process
Minimal thermal input or HAZ
Sub 0.001" diameter beam width
High precision with single pass
Superior “as cut” edge quality
High level of process control

Table 1 – Benefits of laser cutting

Fiber lasers and pulsed Nd:YAG (neodymium-doped yttrium aluminum garnet) lasers are the two solid state laser options used most for fine cutting of the type of thin material (<0.060-inch or 1.5millimeter (mm). The fiber laser offers some key advantages over the pulsed Nd:YAG technology, including finer focused spot sizes enabling high resolution, higher repetition rates for faster cutting speeds, and a lower cost of ownership. For these reasons, it has become the laser technology of choice for thin metal precision cutting.

FIBER LASER

Fiber laser cutting technology offers exceptional control over pulse width, power, and focus spot size. Fiber lasers around 100-500W are ideal for working on materials from 0.002 to 0.06-inch thickness and above that must be cut to high dimensional accuracy. Because the laser beam does not have any physical presence, it makes no contact with the material. It does not push, drag, or impart force that might bend a part or cause flex that would have a negative impact on process control.

Fiber lasers also offers minimal thermal input, with fine control over how hot the work area gets. This is important because small parts heat up quickly and might otherwise overheat or deform. Fiber lasers are highly focusable to about 15 microns, which is about 1/6th of the width of a strand of human hair. This makes it feasible to remove the minimum amount of material to make the cut, resulting in extremely high precision and accuracy.

Figure 1 shows a typical 200W fiber laser. Table 2 lists the benefits of the fiber laser for precision thin metal cutting.

Figure 1 – Typical fiber laser

Relatively low cost
Exceptional beam quality for excellent cut quality
Small narrow kerf width (0.002") provides high cut resolution
High focused power density maximizes cutting speeds
50,00 to 100,000 hours of maintenance free operation
Electrical power to laser conversion efficiency-30%
Small footprint-ease of integration

Table 2 – Fiber laser benefits

Within the category of fiber laser cutting technology, fiber laser cutting with "gas assist," also known as fusion cutting, is frequently used to manufacture a wide variety of precision metal components including laminates, bone saws and electronic sub assemblies. The term "gas assist" refers to the fact that the laser energy delivered to the cutting zone is assisted with a coaxial gas flow, typically oxygen and nitrogen. Argon and air can also be used. Oxygen provides an exothermic reaction that can increase cutting speeds by up to 50 percent and provides a fine molten material ejection. In contrast, nitrogen cools the cut, requiring more laser power but offering increased cut quality and oxide-free edges, specifically for stainless steels with increasing thickness.

Figure 2 shows examples of products cut using this technology.

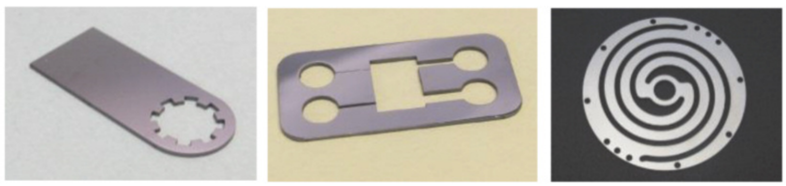


Figure 2 – Examples of precision cutting using gas assist

The fusion gas assist cutting method can be used for both on-axis (90º to surface) and off-axis (angled to surface) cutting. The process is simple and easy to implement, using a co-axial gas nozzle integrated into the focusing optics. Based on the thickness of the part, the fiber laser beam is focused to a spot diameter of between 15-70 microns. While the material is still molten, a 0.02 to 0.04-inch diameter gas jet nozzle that is coaxial with the laser blows away the molten material. The desired features are produced using this continual cycle of melt, then melt ejection. The distance between the laser and the material must be maintained precisely.

Fusion/gas assist fiber laser cutting technology is well suited for precision cutting of stainless steels 300 and 400 series, nickel and aluminum alloys. **Figure 3** shows a close up image of the laser cutter focusing optics with the co-axial gas assist nozzle.

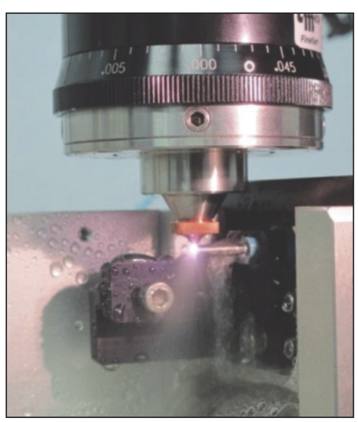


Figure 3 – "Wet" cutting of a medical tube
Small flow of water in the tube ID aids the cutting process

Laser cutting produces superior cut quality and high resolution cut paths, a key requirement for manufacturers of precision components. This can significantly reduce the amount of post-processing needed. The recast layer (a small amount of material that doesn't get blown away during the process) is usually less than 0.0005-inch thick and burring in many cases is under 0.0005-inch. Cut width (or kerf width), can be extremely small, typically less than 0.002-inch.

The dimensional accuracy of fiber laser cut parts is extremely precise, routinely around +- 0.001-inch. This accuracy is very useful for producing the saw tooth geometries for medical cutting blades, metal laminates, fine electronic sub-assemblies, as well as mechanical sub-components.

Fusion gas assist cutting requires an intense laser source to quickly heat up the metal to the melting point as the gas is applied to remove the molten metal from the cut kerf at the same time. Careful process optimization is required to control the cut quality, minimize the heat affected zone and maximize cut speed. Single mode fiber lasers with average power of 100-500 watts are ideally suited for this application in stainless steel, nickel, titanium, aluminum, and other grey metals.

Figure 4 illustrates the "as cut" edge quality and smooth surface that laser cutting with fusion/gas assist can produce – better than 12 micro-inches (0.3048 μ). **Table 3** lists the benefits of the technology.

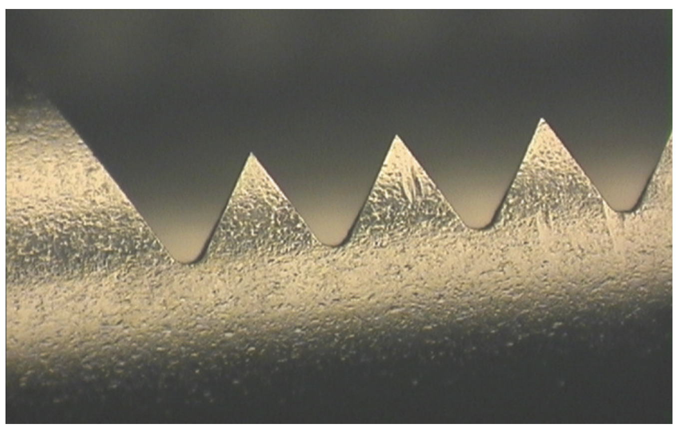


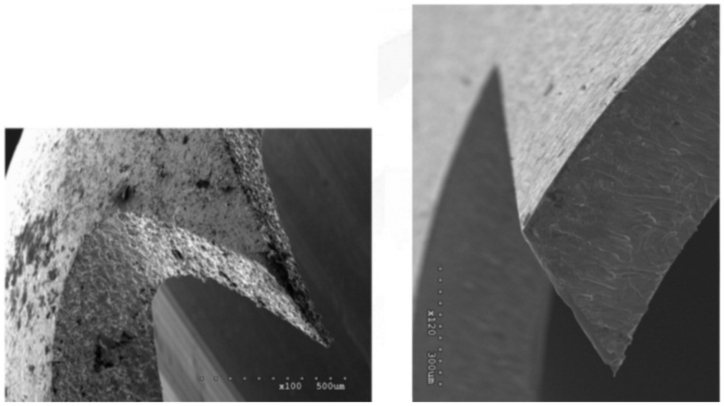
Figure 4 – Laser with gas assist as cut edge quality

Highest cut quality
Dimensional accuracy (±0.001)
Little or no dross/burr on exit side
Cut kerf width <0.002"
Highest resolution cut paths
3 dimensional geometries
Minimal heat affected zone (HAZ)
Off-axis cutting
Exceptional "as cut" roughness <12 micro-inches (0.3048 microns)

Table 3 – Fusion gas assist laser cutting features and benefits
Competing non-laser processes

WIRE EDM

Wire EDM is the most widely used traditional precision cutting technology for cutting thin metals. The cost of wire EDM equipment is significantly less than that of laser equipment. However, laser processing offers faster cutting speed, superior edge quality and greater precision compared with that of EDM. **Figure 5** shows a comparison of cut quality between a single pass EDM and a laser.



Wire EDM ***Laser***

Figure 5 – Cut quality comparison of single pass EDM and laser

For some high volume EDM applications, several parts may be secured in a special tooling fixture and machined in a single pass. This multi-up EDM process offers a unique advantage over laser gas assist cutting, which can only cut one part at a time.

However, the wire EDM process has several limitations. The wire EDM cutting cycle can only proceed in a two dimensional geometry. Bevels or other three dimensional geometry requires a separate set up, program and cutting process, which adds to the total process time. By comparison, laser equipment can cut three dimensional geometries in a single pass, using a 5 axis motion package. Also, wire EDM has a minimum cut width of about 0.004 to 0.006-inch, which makes it unsuitable for sharp inside corners. Lasers can make sharper inside cuts. In addition, wire EDM is unable to cut single sided features; therefore, cutting a single-sided slot is not possible.

For lean manufacturing, another issue is floor space. A typical wire EDM machine can be as large as 10 to 12 feet square, while a laser cutting system is 5 to 6 feet square or less. Finally, in order to obtain the same high quality cut as a laser cutting machine, wire EDM may require up to four separate passes, which adds considerable process time to the operation.

On balance, when edge quality is a major issue, the laser fusion cutting process produces the best results.

WATER JET CUTTING AND ELECTRO-CHEMICAL GRINDING (ECM)

A variety of other cutting applications may be used, including water jet cutting and electro-chemical (ECM) grinding, but in general these methods are less effective than either laser or EDM. Water jet cutting is slow and has geometric limitations. ECM achieves quality similar to EDM, but ECM requires the disposal of the electrolyte used in accordance with hazardous waste regulations, and some electrolytes produce hexavalent chrome when cutting steels. Finally, ECM's use of hard tooling makes it much less flexible than laser cutting.

LASER SYSTEM SOLUTIONS – THE KEY TO SUCCESS

Using lasers for precision cutting has many benefits, but actually achieving them depends on successful system integration. Designers need to develop an entire system where the motion, laser, beam delivery and optics, software, and tooling all work properly and are integrated into a whole that supports the process and desired work flow.

In addition to using the most optimum laser for the application, each system requires a sturdy workstation, ruggedized beam delivery and optics, a motion package with programmable motion, HMI, and full-featured control software with post processor capability. The motion, laser, software, and tooling must all work together to get the desired end product and long term performance.

ENCLOSURE AND CNC MOTION OPTIONS

Laser cutting applications are normally conducted inside a Class I, eye safe enclosure. These enclosures must meet FDA's CDRH (Center for Devices and Radiological Health) and ANSI (American National Standards Institute) Z136.5 Class I safety standards for high power laser systems. Class I enclosures must include redundant safety interlocks on the access doors and removable panels. All viewing windows must have the appropriate power density value to absorb the laser output. Enclosures must also have proper warning labels, emergency stop and indicator lights. A variety of other features are required, including a highly stable platform suitable for system components, and a heavy steel or granite base plate and vibration isolation footings to handle vibration and shock.

TWO DIMENSIONAL XY AND TUBE CUTTING

The cutting of planar XY parts is completed using a motion set-up known as flying optics. Linear stages are used to provide high acceleration over short distances as well as accuracy to ± 5 microns. The loaded parts remain stationary while the cutting path is traced by a gantry system fixed to the focus head, as shown in **Figure 6**. Laser beam delivery using a fiber cable is much more convenient than CO_2 cutting systems that use mirrors. XYZ systems typically utilize a focus control system that ensures that the working distance of the nozzle to the part remains consistent.

This guarantees that quality is maintained throughout the path, irrespective of any part variation in the Z plane. For XY cutting of stainless steels, it is common to use high pressure nitrogen assist that requires up to 250 psi pressure, because this provides a superior edge quality over oxygen gas assist.

A tube cutter can be 2 axes up to 4 axes, depending upon the cut geometry and level of machine flexibility needed. At the heart of the system is the high speed high precision direct drive rotary and X stage that form the "lathe" part of the system. The rotary stage concentricity "total in round" is typically less than 10 microns, as is the X axes accuracy. The focus head may remain stationary or be mounted to a Y and Z stage to enable off-axis tube cutting.

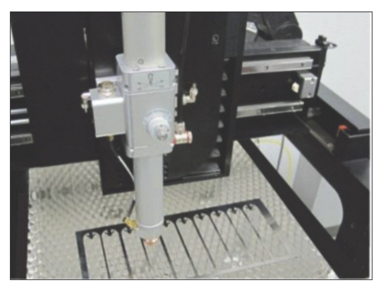


Figure 6 – XYZ gantry system for planar part cutting

These machines offer the option for both “wet” and “dry” cutting. Wet cutting runs water through the inner dimension (ID) of the tube to be cut, which prevents any thermal damage to the tube diameter and is typically used if the ID less than 0.06-inch. A length of tube can be loaded into the system and is automatically advanced by means of the x stage of the lathe and a pneumatic collet on the rotary stage. In contrast to the XY systems that use nitrogen, oxygen is preferred for cutting stainless steel because the molten material is ejected in a much finer size particle that either does not adhere to the ID of the tube or is readily removed with an electro-polish process. **Figure 7** illustrates this setup.

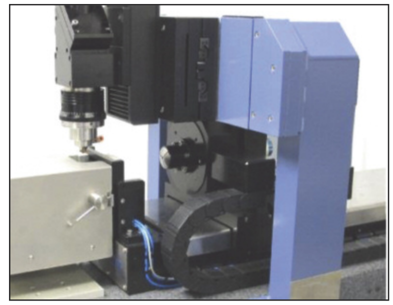


Figure 7 – X and rotary plus YZ motion tube cutter

THREE DIMENSIONAL CUTTING

A 5-axis CNC motion package is required for laser machining three dimensional features. The axes configuration can be executed in a number of ways. One unique approach uses a rotary mounted to a rotary on an XY stage, along with a focus head on the Z axes, as shown in **Figure 8**. This offers a compact, motion-efficient solution, most commonly used in the medical industry for an array of arthroscopic tools, laparoscopic instruments, and flexible tubes. One unique feature capability of the laser in 3 dimensional cutting is the ability to cut compound angles that may be a negative taper on a corner or sharpening of an edge without having to remove the part from the machine.

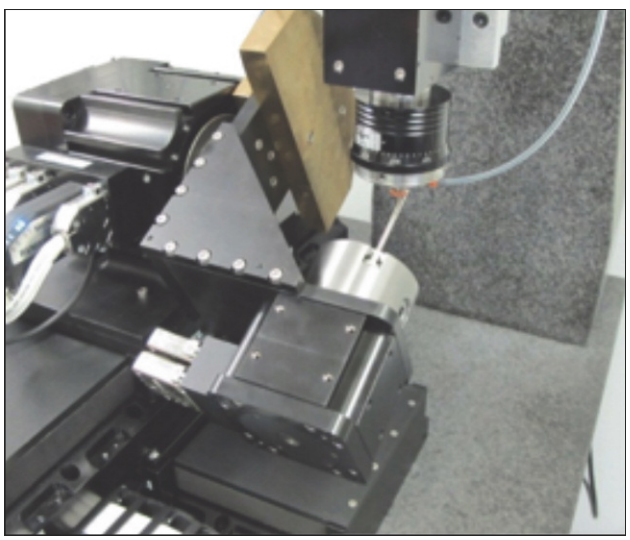


Figure 8 – Interior of 5 axes multi-axis laser fusion cutting system

The multi-axis system design permits designers greater flexibility to choose the best configuration and cut geometry for their particular product.

CAD DESIGN AND POST PROCESSING SOFTWARE

Complex laser cutting operations require full-featured programming software for controlling the laser parameters and precision motion functions. This is achieved by transferring a digital 3-dimensional CAD model to a computer with post processing software that generates the tool path instructions and functions for the laser and motion system to complete the actual part. The graphic user interface flat panel display provides the operator/programmer with a full suite of controls for laser process settings and CNC motion programming. Nesting software, specifically for XY cutting, for tool path and thermal optimization as well as maximizing material usage is another part of programming.

The programming software can also provide tools for gathering and storing process data for verification and validation for external and in-house documentation requirements. Programming and external communication is provided via a dedicated PC and Ethernet connectivity. Remote programming and system diagnostics may also be possible with the Ethernet features.

FINAL THOUGHTS

With an established benchmark of cutting speed and precision, many manufacturers have already implemented or are looking at fiber laser cutting as a means of increasing throughput and accuracy. Such a system offers both process cost savings, downstream manufacturing benefits, and better products. These numerous cutting opportunities cover a broad range of materials, including steels and aluminum, with material thicknesses from 0.002-0.06-inches, and with the suitable system, an array of geometries.

AMADA MIYACHI AMERICA, INC.

1820 S. Myrtle Ave. • Monrovia, CA 91016 US
T: (626) 303-5676 • F: (626) 358-8048
info@amadamiyachi.com • www.amadamiyachi.com
ISO 9001 Certified Company • 24/7 Repair Service: 1-866-751-7378

MIYACHI UNITEK | MIYACHI PECO | MIYACHI EAPRO

AMERICAS

Amada Miyachi America Midwest
Wixom, MI 48393
T: (248) 313-3078
midwestsales@amadamiyachi.com

Amada Miyachi America Mexico
El Paso, TX 79925
T: (915) 881-8765
mxsales@amadamiyachi.com

Amada Miyachi do Brasil Ltda.
Sao Paulo, Brasil
T: +55-11-4193-3607
antonio.ruiz@amadamiyachi.com

EUROPE

Amada Miyachi Europe GmbH
Puchheim, Germany
T: +49 (0) 89 83 94 030
infode@amadamiyachi.eu

ASIA

Amada Miyachi Co., Ltd.
Noda, 278-0016 Japan
T: +81-4-7125-6177
sales@miyachi.com

Amada Miyachi Shanghai, Co., Ltd.
Shanghai, China
T: +86-21-6448-6000
zqzhang@msc.miyachi.com

Amada Miyachi Korea Co., Ltd.
Gyeonggi-do, Korea
T: +82-31-8015-6810
dykim@mkc.miyachi.com

Amada Miyachi Taiwan Co., Ltd.
Taipei, Taiwan R.O.C.
T: 886-2-2397-4778
keigaku@miyachi.com

Amada Miyachi (Thailand) Co., Ltd.
Samutprakarn, Thailand
T: +66-2751-9337-8
info@mtl.miyachi.com

Amada Miyachi Vietnam Co., Ltd.
Ho Chi Minh City, Vietnam
T: +84-8-3771-7972

Amada Miyachi India Pvt., Ltd.
Bangalore, Karnataka
T: 080-4092-1749 & 3549
info@miyachiindia.com

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