Efficient Industrial Application of Near-Infrared Laser Sources

Fiber lasers, Nd:YAG or Nd:YVO lasers may be combined with either flat-bed or galvanometer systems as well as with fixed-beam systems for marking, engraving and cutting applications. Specific application and economic constraints, e.g. maximum investment amount, usually define the optimal combination clearly. Observed advantages and disadvantages of fiber lasers are addressed from technical application and economic perspectives, specifically in comparison to established near-infrared laser systems Nd:YAG and Nd:YVO

The requirements of the industry - especially for marking systems - are known and self-evident. Economically speaking, it must be possible to amortize the system in a short time, typically over a time period of up to 2 years. The following requirements and properties are derived from this constraint, and they apply also to non-laser based marking systems:

- High processing speed (or short cycle time)
- Greatest possible machine availability
- Short setup time and easy handling
- If applicable, easy to integrate into existing production lines
- Low operating costs for raw materials, wear parts, power consumption and environmental impact

These properties guarantee low marking costs per piece with high throughput. In general, when an integrated galvanometer system is used, marking costs are estimated to lie between 0.5 % and 3 % of the total cost to produce a product. That is, fully-automated galvanometer systems in production lines deliver low marking unit costs at high throughput. Flat-bed systems produce significantly higher quality - in comparison to galvos - over working areas that are several times larger but at lower throughput. Furthermore, laser plotters, as well as systems with fixed beams, offer the fundamental advantage of producing a laser beam that is usually better focused with an incident angle that is always perpendicular to the work-piece. A laser-based marking system - especially in a production line - must have the following qualities if it wants to attain the properties listed above:

- Robustness and high MTBF, to guarantee availability, even in harsh industrial environments
- Maintenance-free, thereby eliminating maintenance costs and downtimes
- High efficiency, above the entire laser source, to minimise energy costs
- Compactness for simple integration: This is especially crucial if the laser system must be integrated into existing lines that do not provide any dedicated space for them
- Long life, so that they operate profitably for as long as possible after amortization
- High beam quality to achieve the same results, at lower laser power, as more powerful lasers do with lower beam quality, and to attain high resolution

On the application side, it must be guaranteed that the applied markings are of high quality, durable and tamper-proof. The quality of the marking can mean the following: Good legibility of plain text, easy to decode bar code and data matrix code, high resolution of "sub-millimeter markings" (e.g. for hidden markings), and thermal, mechanical and chemical resistance of markings for work-pieces subjected to high temperatures, mechanical stress, mechanical wear or aggressive substances in later use.

State of commercially available technology

Described below are commercially available lasers whose average powers lie between 5 W and 20 W. This article intentionally avoids addressing lasers that have been available for just a short time, or lasers for which only "marketing optimised" announcements exist. Before a laser source is integrated in devices, whose availability is crucial in determining the content or discontent of the customer, it must pass extensive tests. In the process, it has been found that close cooperation (in beta testing, definition of a clear requirement profile) between the machine builder and laser source producer further improves the quality and economy of the laser sources.

Brief description of Nd:YAG lasers

Diode-pumped Nd:YAG lasers and Nd:YVO lasers ('Vanadate' lasers) are established near-infrared lasers, which are usually used to mark metals, plastics and sometimes ceramic materials. These lasers were established in the early 1990s, since that is when pump-diodes suitable for industrial applications at low laser power became available.

Both lasers have a crystal as their laser-active medium - and the rest of their layout is also largely identical. In comparison to lamp-pumped YAG lasers used previously, diode-pumped lasers represented a gigantic leap forward, offering better beam quality, significantly improved optic-optic efficiency (just a few percent for lamp-pumped systems vs. 30 - 50 % for diode-pumped systems), the resulting lack of need for water cooling (an air or Peltier cooling system is sufficient for marking systems), more compact construction, substantially increased service intervals (max. 1,000 h for lamps vs. 5,000 - 10,000 h for diodes).

Brief description of fiber lasers

For just a few years now, CW fiber lasers as well as pulsed fiber lasers have been available in industrial quality. Both variants are especially well-suited to marking tasks. The idea of this laser type was proposed as early as 1964. It was possible to achieve an economic breakthrough after quite a few existing technologies - most of them from the telecommunications industry - were transferred cost-effectively to the fiber laser: Growing highly pure fibers, and doping the same fibers, splicing (low-loss coupling of two glass fibers), availability of powerful and well-modulated diode lasers, "laser-on-a-chip".

CW fiber lasers can be modulated up to about 25 kHz via pump diodes, but without any power overshoot. This operating mode is also referred to as "free running mode". Pulsed fiber lasers are usually designed according to the "Master Oscillator Power Amplifier Scheme" (MOPA). Systems of this construction type that are commercially available and have proven themselves in industrial applications with an averaged power of up to 20 W have the following specifications: Repetition rate up to maximum 100 kHz, pulse duration 80 - 120 ns, pulse peak powers up to about 12 kW, pulse energies up to max. 1 mJ.

The pulsed fiber lasers consist of a 'master oscillator' (also called 'seed laser') and a fiber-coupled "power amplifier". The former is either a diode laser or a "laser-on-a-chip" with an averaged power ranging from several milliwatts to max. 150 mW. This laser emits pulses with a defined pulse form. In the case of "laser-on-a-chip" a laser is integrated on a single chip: The laser-active medium mirrors and other optical components are all integrated here. The amplifier consists of an Ytterbium-doped glass fiber that is supplied with energy via fiber-coupled pump diodes. When a laser pulse is to be generated, first the pump diodes provide a charge (a population inversion) to the amplifier fiber. Before it discharges by spontaneous emission, the seed laser emits a pulse that is amplified several hundred fold up to a maximum of a thousand fold when it passes through the fiber. The amplification occurs in a single pass (single-pass amplifier).

State-of-the-art technology for today's customer needs

Near-infrared lasers are normally the most economical laser source for colour-change markings on plastics and for marking and engraving on metal. Far-infrared lasers (e.g. CO2 lasers) with low power are generally not suitable for metal processing, since the wavelength of 10.6 μm is normally absorbed insufficiently by metals. Lasers in the visible light spectrum or in the ultraviolet spectrum are usually too expensive compared to near-infrared lasers.

Therefore, in selecting a suitable laser source it is necessary to consider the application and machine type. Nd:YAG, Nd:YVO and fiber lasers are available in large production volumes and from an adequate number of suppliers. It should be mentioned in passing that the Vanadium laser is the better YAG laser for marking applications and medium power levels up to 20 W. Both lasers can be pulsed by quality switches (Q-switches) and emit laser light with comparable parameters: 1064 nm wavelength, pulse duration between 6 ns and 50 ns, pulse peak power in the tens of kW range, pulse energies up to 0.6 mJ. However, especially where marking applications are involved, the YVO has the following advantages compared to the YAG:

• Higher repetition rates are possible: Up to 200 kHz for YVO vs. 100 kHz for YAG (one reason is the significantly greater amplification of the YVO),

• Lower thermal drift in output power, since the absorption bands for the pump light is broader for Vanadium than it is with the YAG.

Advantages and disadvantages: FL vs. YAG

Some of the advantages that have already been enumerated in comparison of lamp-pumped vs. diode-pumped methods also apply to a comparison of fiber lasers vs. YAG / YVO, although the improvements are of course not so severely pronounced:

• Higher wall-plug efficiency: Up to 3% for pulsed Nd:YVO vs. 6-10% for pulsed fiber lasers,

• More compact construction,

• No replacement of pump diodes necessary for FL (expected life >50,000 hours), life of the pump module is max. 10,000 hours for YVO lasers,

• The "all-in-fiber design" of the fiber laser means that laser- and pump light within the laser is always routed in glass fibers. This makes the system insensitive to dirt and vibration;

• No first pulse problems, or no severely pronounced problems.

On the other hand, an YVO laser can typically be operated between 10 kHz and 200 kHz. The high repetition rates are indispensable on flat-bed systems with high resolution. Another advantage of an YVO laser lies in its better pulsability or shorter rise and decay times. That is why a fast raster engraving tool with a flat-bed laser at high resolution cannot employ a fiber laser. Moreover, the pulse peak power of YVO lasers is substantially greater than that of fiber lasers. This can be advantageous in colour-change markings on polymers. Experimental experience shows that this advantage is decisive in about 10 to 15 % of plastic applications.

Finally, when using fiber lasers, it should be considered that back reflections must be avoided, since in the worst case the back reflection can act like a seed pulse.

Typical for fiber lasers - in contrast to YAG/YVO lasers - is that the averaged output power is not a function of the repetition rate (frequency). In YAG/YVO lasers, at a repetition rate of 10 kHz only about 50% of the maximum average power is output. With increasing repetition rate, the output power rises: Starting at about 40 kHz greater than 90% is the maximum power is output.

This means that the fiber laser supplies significantly higher pulse energies between 20 kHz and 40 kHz. This is generally advantageous in ablation processes. Experimentally it can be clearly stated that despite the longer pulse duration of the fiber laser (typical 80 - 120 ns vs. 10 - 30 ns for Q-switched YAG/YVO lasers) and its significantly lower pulse peak power (typically 5 - 12 kW vs. 20 - 60 kW for Q-switched YAG/YVO lasers) it is not possible to produce a metal engraving in the same amount of time and at the same quality using a YAG/YVO laser at 20 kHz compared to a fiber laser system. Fiber lasers are usually the first choice for galvanometer-based laser systems, because pulse repetition rates above 100 kHz are not necessary, and it is easy to compensate for the slower power rise and fall times at beginning or end vectors.

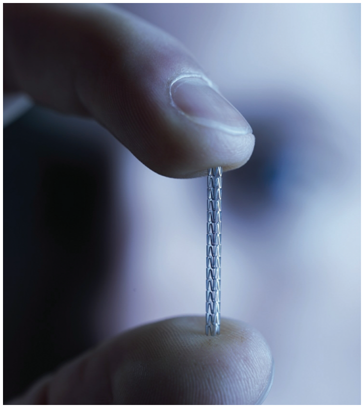
On fast flat-bed systems with higher resolution, high pulse repetition rates are absolutely necessary (resolution x travel speed = minimum repetition rate). Moreover, the high dynamics in power rise and fall, guarantees that individual pixels are really circular in shape and not elliptically distorted, for example.

Sensible application -which source and when

Fast flat-bed systems (laser plotters) with high resolution usually have a short focal distance lens (e.g. 3.2 inch = 81.3 mm) and a focal diameter of approx. 25 µm. This enables a resolution of 1,000 dpi (dots per inch): 1,000 consecutive foci that contact one another (no overlap, no gap) yield 1 inch (= 1 inch = 25.4 mm). If a flying lens now travels at 100 inches/s (= 2.54 m/s), a repetition rate of at least 100 kHz is necessary to create a continuous line. This travel speed is the theoretical upper limit for a laser source that is pulsable at max. 100 kHz and has a focal diameter of 25 µm. In reality, however, the laser rise and fall times are already exhausted at speeds of less than 0.5 m/s. These types of systems must therefore be combined with an YVO laser. High feed rates (rates up to 3.5 m/s have already been achieved) can be used primarily on plastics due to the high intensity of focus (small focal spot due to short focal distance and high pulse peak power).

Slower flat-bed systems (or flat-bed systems with lower resolution), which should result in low investment costs, are inevitable for CW fiber lasers. These are relatively cost-effective, can be modulated up to about 25 kHz and in any event are well-suited for vector marking. This assumes, of course, that the laser plotter also permits this operating mode (and not just raster markings). This method enables anneal markings on metals and - despite the lack of pulse overshoot - markings on some plastics. Galvanometer systems with standard optics (focal length 160 mm) have a laser focal spot of about 40 µm. At a repetition rate of 100 kHz, feed rates of up to 4m/s are therefore possible (40 µm x 100 kHz = 4 m/s). At this speed, the averaged laser power is the limiting factor in well over 90% of applications, and not the upper limit of the laser's repetition rate. Since galvanometer systems are often integrated in production lines, the attributes of the fiber laser are decisive arguments here: Maintenance-free, highly efficient (resulting in lower energy costs), intrinsic protection against dirt and insensitivity to vibration.

Stent cutting lasers represent a special case. Stents are expandable cylindrical stainless steel screens used to expand blood vessels. It is most economical to cut the stents from small metal tubes using CW fiber lasers (powers of about 100 W - 200 W). A medium power level is crucial in cutting processes of this type.



Stent cutting with a revolutionary double-head laser from Trotec is a special solution.

An equally powerful YAG or YVO CW laser would be significantly more expensive, both in terms of initial investment and operating costs, due in particular to the necessity of replacing the pump module. Moreover, in this power class the beam quality is better on fiber lasers than it is on comparable YAG / YVO lasers. This guarantees higher cutting quality.

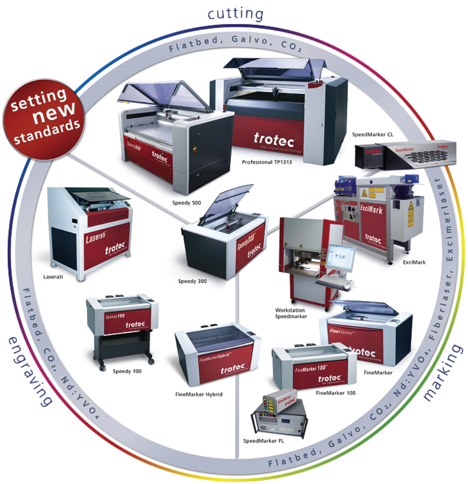
Prospects

Since about mid-2006, near-infrared laser sources have been available (at least as beta version devices) and are undergoing further in-depth testing based on their specification data. YAG lasers integrated on a silicon chip are pushing into power ranges that are well-suited for marking applications. The compactness and robustness of these systems signify a distinct improvement compared to existing YAG laser sources. In the area of fiber lasers, quite recently systems have become available that can be pulsed up to 500 kHz. Pulse peak powers and pulse times of these systems are higher or shorter than those described in this article. But, as already mentioned, these new systems must be able to deliver this performance over their entire life, before they will be integrated into machines. Moreover, total life cycle costs must be evaluated compared to existing systems.

Summary

To continuously succeed in offering economic solutions, each technological innovation must be examined for its suitability in specific machines. In its fiber laser systems, Trotec is utilising a new, alternative laser source option that has been available in industrial quality for a relatively short time. This source has its strengths, and it will partially replace 'classic' YAG/YVO lasers. However, as is often the case with innovations, what is new is generally not a cure-all. Well-known technologies that have proven themselves over time, such as Vanadium lasers, will continue to be irreplaceable for fast, high-resolution laser plotters. However, in the case of cost-effective, slower plotters, the CW fiber laser may replace some "classic" YAG/YVO galvo workstations.

In galvanometer systems operated on production lines in harsh industrial environments, a fiber laser is significantly more economical than a YAG/YVO laser.



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Throughout its history the Trotec company, founded in 1997, has succeeded in setting new standards with its innovations. Today, Trotec offers solutions for numerous requirements in marking, engraving and cutting (of non-metals) using laser technology. Trotec has evolved into a true "global player" with many thousands of installed systems in over 90 countries.

Trotec has an extensive product line-up covering CO2, Vanadat and fiber lasers on flatbed and galvanometer systems as well as excimer laser galvos and stent cutting machines (based on CW fiber lasers). This broad range of products makes it possible to select the right system based on customer requirements. The advantage here is that a "complete tool box" is available. If just a single laser machine type were available, this would be analogous to having a tool box that only contains a hammer. Every problem would then have to somehow be made to take on the "form of a nail".