A Coherent White Paper

Heavy Metal Pipe Cutting for Oil Wells

Slotted steel pipes (slotted liners), as widely used for oil exploration and production, represent a significant heavy metal cutting application that is currently serviced by CO_2 lasers but may soon switch to kilowatt fiber lasers.

Abstract

Slotted liners are heavy gauge (10 mm wall thickness) steel pipes fabricated in sections up to 12 meters in length. Up to 10,000 slots – often with a precise keystone profile – must be cut through the wall of each section so that the pipe acts as a sieve in the well to block sand sediments and other debris from the extracted oil. Slab discharge CO_2 lasers such as the Coherent DC 030 have been the tools of choice for cutting the slots, particularly those requiring a precise keystone profile that could not be readily cut mechanically. In this whitepaper, we examine this heavy metal cutting application and see why kilowatt class fiber lasers such as the Coherent HighLight® FL series are starting to penetrate this market.

Laser Metal Cutting Advantages

Heavy metals, in this context, refer to substrates at least several millimeters in thickness where a multi-kilowatt class laser competes against conventional sawing and milling, thermal torch cutting, and even abrasive water jets (AWJ). The laser is the cutting tool of choice in many heavy metal applications because of its unique combination of advantages derived from its small spot and high power density. These include a small heat affected zone, virtually no part distortion, high quality on both cut edges, small kerf width, high dimensional accuracy including the beginning and end of each cut, the ability to cut sharp corners, and fast piercing. Also, there is no tool wear with laser processing so these advantages are consistent over time.

Laser cutting is also a very flexible process for cutting difficult 3D geometries and shapes that lends itself to automation under digital control. In addition, for cutting closed features (e.g., slots and cutouts) that require piercing, the same laser can perform both the piercing and the cutting, maintaining the same kerf width throughout.

In contrast, the thermal torch is a tool with lower edge quality and dimensional accuracy. The saw (and milling tool) is slow, and struggles with complex shapes and side profiles, and the performance deteriorates over time. The AWJ is a slow tool that is an environmental challenge, producing incredible noise and consuming tens of kilograms of garnet dust per hour. Plus the AWJ lacks the depth control afforded by a focused laser beam; for instance, it cannot cut a hole in a tube wall without damage to the opposite wall.

Slotted Pipes for Oil Exploration and Production

Slotted steel pipes, often called slotted liners, are used for oil exploration and production. While high quality crude oils have low viscosity, many oil fields around the world (e.g., Venezuela, Russia, United States) yield heavy oil. This is relatively viscous, and typically contains a significant amount of sand, and even gravel. The oil industry developed slotted liners to deal with this challenge. A slotted liner is a steel tube containing many through slots in its sidewall, which is used to line parts of a drilled well (Figure 1). Specifically, they are used throughout the production zone where oil flows through the slots into the pipe and up to the wellhead. In normal well operation, these slots act as a sieve to exclude about 95% of the particulates.

The slotted liners are expected to last the lifetime of the well, which can be many years. In order to withstand pressure and abrasion over this period, they are typically fabricated from steel tubing with a 10 mm wall thickness. Tube diameter ranges from 20 to 30 cm, and the lengths range from 5 to 12 meters. Fortunately, rusting is not a significant issue in the anoxic environment in an oil well, allowing the use of mild steel.

Figure 1. Slotted liners used for heavy oil production incorporate thousands of slots that must be cut to specification.

Long term successful well production critically depends on having the correct slot dimensions, the optimum number and pattern of slots, and often on the profile of the slots. The slot dimensions are chosen to match the expected particulate sizes; for heavy oils, the widths range from 0.25 mm to > 6 mm, with a typical slot length of 100 mm. For each pipe, the sheer number of slots per unit length is quite daunting; the industry standard for heavy oil wells is 3% of total surface area throughout the production zone. For a 12 meter pipe section, that can translate into up to 10,000 separate slots. The oil industry also requires several different patterns of slots depending on the well specifics, including symmetric, staggered and offset arrangements.

Slotted liners are also used to obtain extra heavy oil (bitumen) from horizontal wells using active extraction techniques such as cyclic steam stimulation (CSS) and steam assisted gravity drainage (SAGD). In addition, they are used for extracting coal bed methane (CBM) from horizontal wells. And the uses for slotted liners go beyond just oil production. Similar tubes are also used in some water wells, in geothermal power plants, and in test wells. Thus, slotted pipes represent a high volume market.

Slot Cutting with CO_2 Slab Lasers

Laser cutting of these slots was first adopted a number of years ago as an alternative to sawing and milling. However, the thickness of the steel and the number of slots dictates the use of several kilowatts of CW laser power in order to achieve an economically competitive process throughput. And for many years there was no simple way to integrate a CW laser that could cost-effectively deliver this performance along with the necessary beam quality, 24/7 capability, and minimal maintenance requirements.

Figure 2. This application requires a multi-kilowatt laser to achieve target throughput rates.

The slab discharge CO_2 laser completely changed this situation, providing high beam quality, kilowatts of power in a compact platform, low cost of ownership, and 24/7 reliability. Here the low pressure laser gas is confined between two narrowly-spaced large area copper electrodes as indicated schematically in Figure 3. A stable plasma is then maintained by RF excitation through these electrodes. The water cooled electrodes control the temperature of the laser gas, maximizing laser efficiency. Within the resonator cavity, the laser light is reflected by parabolic mirrors, before a portion of this radiation is allowed to exit the resonator area through a diamond window. Together with a spatial filter, this arrangement produces a high quality TEM_{00} beam with a circular Gaussian profile and a M^2 value of 1.2, which is ideal for tight focusing and precision metal cutting. Moreover, this architecture also eliminates the need for a conventional output coupler, which is one of several factors ensuring inherent long term alignment stability.

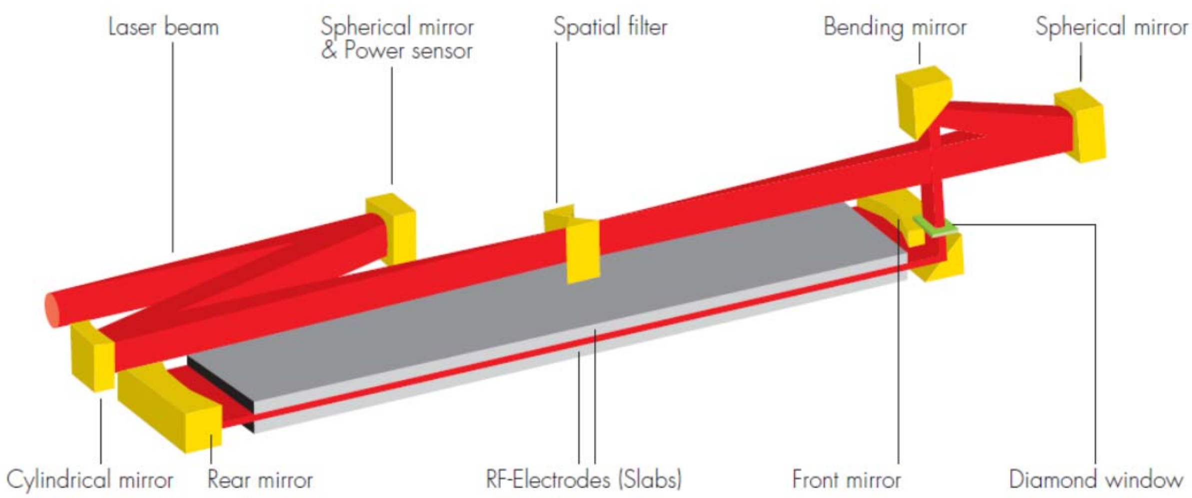

Figure 3. In a slab discharge laser such as the Coherent DC 030, the laser gas is RF excited by two closely spaced flat electrodes. The laser power scales with the area of these electrodes.

The slab discharge CO_2 laser also provides low cost of ownership, which is vital when competing against low cost mechanical or thermal methods. This low cost has several contributing factors. First, the laser has modest maintenance requirements. For example, the resonator maintains long-term alignment without operator intervention. Second, the laser gas is diffusion-cooled via the copper electrodes, so there is no need for pumps or blowers and other associated moving parts, as used in legacy kilowatt gas lasers. In addition, the slab discharge laser produces power on demand, with minimal energy consumption while in standby mode. The effective cost of integration is also low because the slab discharge geometry enables a relatively compact laser head in contrast to traditional gas lasers with long plasma tube discharges. Moreover, in lasers like the Coherent DC 030, the RF power supply is located within the compact laser head, eliminating the cost and potential reliability challenges of a high power RF umbilical.

With 3 kilowatts of output power, the DC 030 laser has proved particularly advantageous in this application where "keystone" slots are required. With conventional slot profiles, particles can get stuck. Eventually, as the blockages multiply, the oil flow will diminish. To eliminate this issue, many wells use slotted liners incorporating keystone slots that maximize filtering while minimizing clogging. The width of these slots is tapered where the outer width is narrower than the width at the inner tube wall (Figure 4). While mechanical tooling can often cut straight slots competitively with lasers, the keystone slots are another matter. Milling tools can only achieve a limited range of tapers, and only for the wider slots. Laser cutting has no such problems. Furthermore, the slow-flow slab discharge laser can be pulsed at up to 5 kHz with power on demand; pulsed operation is optimum for initial piercing of each slot, which is then cut using CW output. This means the end of each slot is completely regular with no piercing anomalies. Plus the focusability of the high quality beam from a slab discharge laser delivers a high edge quality and minimum HAZ, making it ideal for even the narrowest slots and avoiding the need for post-processing.

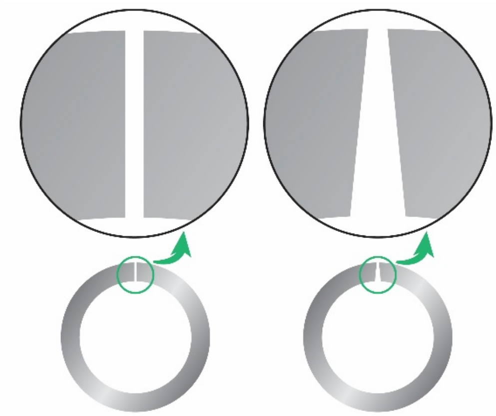

Figure 4. Slots with a keystone cross section are designed to eliminate blocking with trapped particulates. These slots are particularly difficult to create with non-laser methods.

Fiber Lasers Poised to Take Over

In recent years, the performance of fiber lasers has been steadily increased, particularly in the area of higher output power. For instance, Coherent now offers fiber lasers with up to 10 kilowatts of output – enough power to cut mild steel with thicknesses up to 30 mm. Production of slotted liners is just one of several heavy metal applications that are at various stages of adopting or evaluating fiber lasers as an alternative to CO_2 and other lasers. As an experienced vendor of both high-power CO_2 and high-power fiber lasers, we are seeing a strong demand for comparative evaluations of these two laser types in our applications development laboratory.

In the past year we have worked with tool builders in the slotted pipe market to successfully qualify a 2.5 kW fiber laser that delivers similar speed to the 3 kW slab discharge CO_2 laser.

Tool builders are looking at high power fiber lasers because of several factors. The output wavelength is obviously a major difference between the two laser types. The CO_2 laser produces mid-infrared output at a wavelength of 10.6 μm. This is delivered to the cutting head using free space optics enclosed in articulated arms. These tubular arms have to be continuously purged to avoid any damage to the mirrors. The fiber laser wavelength of 1 μm can be efficiently transmitted through flexible glass fibers enclosed in a well-protected cable. The use of flexible cable greatly simplifies integration and eliminates any spatial constraints due to articulated beam delivery arms. In addition, the all solid-state fiber laser offers even lower maintenance than a CO_2 laser, as well as much higher electrical efficiency, lowering service costs and electrical costs. The end result is lower cost of ownership and projected lower cost per part. As a result of these advantages, we expect to see increasing adoption of fiber lasers in this application.

Summary

For many years, CO_2 lasers dominated the market for metal cutting applications, particularly for thicker metals. But the inherent advantages of fiber laser technology and specific advances in kilowatt class fiber lasers have caused numerous applications to convert to fiber lasers. Cutting slots in the liner pipes used in the oil industry appear to represent another application now poised to transition to fiber laser technology. So for foreseeable future, Coherent is committed to supporting both laser technologies, allowing the system builders and end users to select the optimum laser source for their specific application.