Cleanroom-based production and assembly environment

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Beam shaping for continuous industrial operation

Fixed and variable magnification up to 85 kW

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The laser cutting market is shifting toward higher laser power to increase productivity and extend thickness capability, while raising requirements for process stability and robustness. This article analyzes how cutting head design, focusing on fixed and variable optical magnification, enables effective high-power cutting. Cutting results for laser fusion and oxy-fuel cutting show that optical configuration has a significant impact on the process window and cut quality across application segments.

Laser cutting technology is currently shaped by two converging developments: a rapid increase in available laser power and a parallel shift toward higher process automatization [1]. Over the past decade, fiber laser output has risen from single-digit kilowatt levels to industrial systems exceeding 50 kW, with demonstrations reaching well beyond 100 mm of steel thickness (**Figs. 1, 2**). This escalation, driven by declining cost per kilowatt and advances in fiber sources, has enabled laser cutting to enter application domains historically dominated by plasma cutting [1–3]. For example, air-assisted laser cutting can cleanly cut 20 – 40 mm carbon steel at speeds far beyond what oxygen cutting can achieve, significantly improving throughput for thick steel parts [2]. For laser cutting to replace plasma cutting, cutting heads must reliably withstand extreme laser powers and harsh process conditions, enabling continuous 24/7 cutting of thick materials. At the same time, the demand for flexibility and intelligence in laser cutting heads has increased, as many fabricators process a broad range of materials and thicknesses – from thin sheet to medium plate – as well as complex geometries. Machine dynamics and part handling often become the limiting factors beyond ~10 kW, meaning that process stability, clean piercing, and smart automation contribute more to overall productivity and quality than additional laser power [1]. With rising power levels, thermal loading, optical contamination, focus shift, and process disturbances become dominant effects that can rapidly degrade process stability. Consequently, modern cutting heads must combine optical performance, sensor technology, active control, and maintainability into a tightly integrated system. As a result, the cutting head increasingly governs how efficiently available laser power is translated into stable and productive cutting.

Fixed magnification – high-power robustness and productivity

The ProCutter 2.0 Plus is a scalable cutting head platform designed for continuous industrial operation at laser powers of up to 85 kW. It can reliably handle this level of laser power, enabling heavy-plate fabrica-

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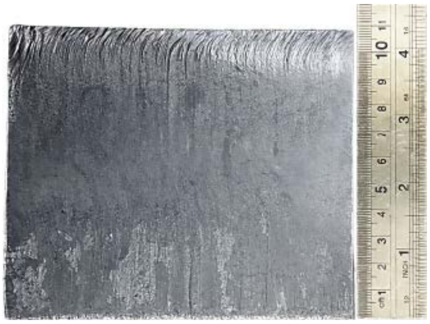

Fig. 1 Mild steel cut-edge produced with the Precitec ProCutter 2.0 Plus: material thickness 110 mm, laser power 60 kW, cutting speed 0.6 m/min, assist gas O_2

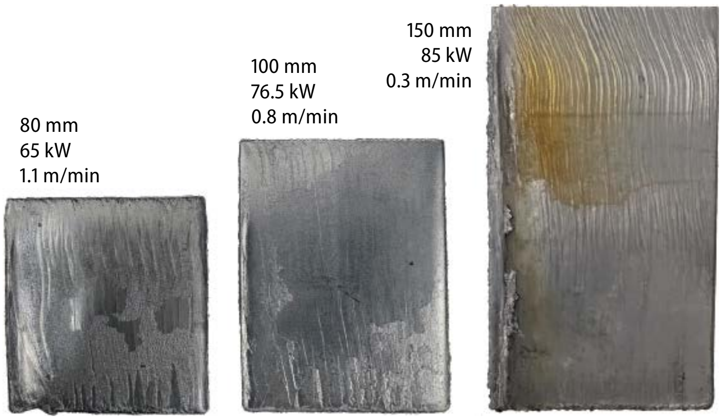

Fig. 2 Representative mild steel cutting results obtained with the ProCutter 2.0 Plus

tion, very thick material processing, and other maximum-throughput applications. In this context, laser cutting is increasingly replacing plasma cutting in applications that were traditionally plasma-dominated. **Figs. 1** and **2** show mild steel samples produced with the Precitec ProCutter 2.0 Plus (**Fig. 3**) at laser powers of up to 85 kW using a 150 µm fiber and oxygen as process gas, illustrating the achievable mild steel thickness range in high-power laser cutting.

Despite its increased power capability, the ProCutter 2.0 Plus retains a compact, lightweight design thanks to improved optical components and thermal management. Optimized substrates and coatings minimize absorption losses and mitigate thermally induced lensing effects [4]. The optical design supports fixed magnifications of up to $M = 3.0$, enabling adaptation to different material thicknesses and application requirements. A dual protective-window cassette increases service life and process reliability by separating contamination-prone regions from critical optical elements. The extended focus adjustment range allows thicker plates to be cut without compromising process stability.

At laser powers of up to 85 kW, the high thermal load on the cutting head – particularly at the nozzle – becomes a critical factor for maintaining stable cutting conditions, especially in thick materials. The ProCutter 2.0 Plus incorporates an improved nozzle cooling gas design, including enlarged cooling channels and optimized nozzle precooling, to ensure stable temperature conditions at the nozzle. This robustness supports stable cutting processes using oxygen, nitrogen, and compressed air, enabling reliable processing of thick materials with reduced dross formation and improved edge quality.

Fig. 3 ProCutter 2.0 Plus

To ensure continuous industrial operation, the ProCutter 2.0 Plus integrates extensive process and condition monitoring. Built-in sensors for pierce-through detection and cut-loss detection enable real-time identification of process disturbances and prevent unproductive machine time. Additional sensors monitor optical contamination, pressure, temperature, and focus drive status. All sensor data are accessible via a graphical interface and standard industrial fieldbuses, facilitating integration into automated production environments and higher-level process control systems.

The ProCutter 2.0 Plus addresses the key technological challenges of laser cutting at power levels up to 85 kW through a combination of robust optical design, optimized thermal management at the nozzle, and comprehensive sensor integration. By enabling stable, automated, and maintainable operation under demanding industrial process conditions, it provides a reliable cutting head solution for next-generation high-power laser cutting systems.

Variable magnification – beam shaping and adaptability

While fixed-magnification cutting heads optimized for thick-plate and heavy-section processing address applications focused on maximum throughput and extreme material thicknesses, many industrial users operating in the 15 – 30 kW

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range process a broad spectrum of parts – from thin sheet to medium and thick plate – often within the same flatbed system. In this context, the ProCutter Prime is Precitec's flagship 2D flatbed cutting head for laser powers of up to 30 kW. It combines a premium optical design with variable magnification to deliver high precision and adaptability across a wide thickness range. The cutting head supports stable, high-quality cutting of both thin and thick sheet metal within a single system, enabling flexible operation across diverse applications. In this way, it bridges the gap between flexible zoom-based cutting and robust industrial high-power operation.

The ProCutter Prime's core feature is its zoom optic, which offers continuously adjustable magnification from $M = 1.2$ to $M = 4.0$ in fine increments. This allows the laser spot diameter to be dynamically adapted to the material thickness and process phase while the laser remains active, enabling seamless transitions between piercing, lead-in, and contour cutting. Low magnification settings provide high power density for fast and reliable piercing, while increased magnification during lead-in and contour cutting stabilizes the melt flow and enlarges the process window.

The results presented in **Figs. 4** and **5** show the relationship between material thickness and laser spot diameter, as well as the achievable process windows for cutting mild steel using laser fusion (N_2) and laser oxy-fuel (O_2) with the ProCutter Prime. Data points represent measured cutting results obtained at constant cutting speed for a given material thickness, while the solid lines indicate curve fits to guide the eye. This approach allows the isolated assessment of the influence of optical magnification on process stability and cut quality, independent of cutting velocity. In both cases, a distinct range of spot diameters enables stable, high-quality cutting within defined lower and upper limits.

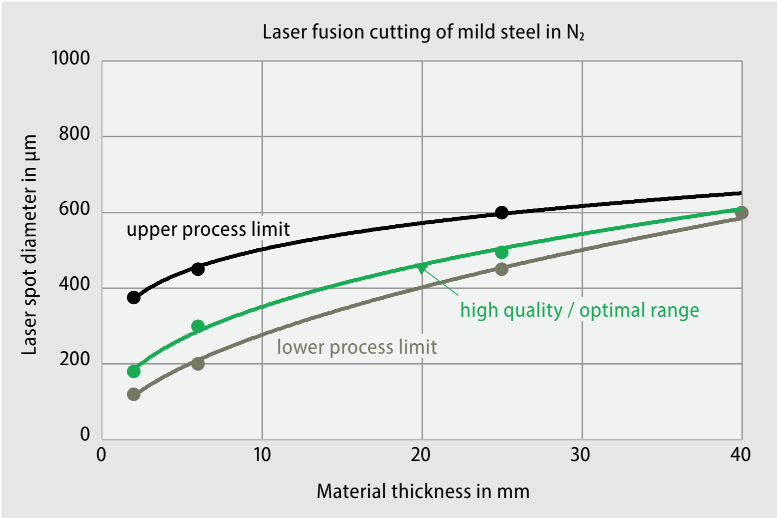

Fig. 4 Cutting results showing the influence of magnification in laser fusion cutting of mild steel using nitrogen. Details of the experimental conditions are described in the text.

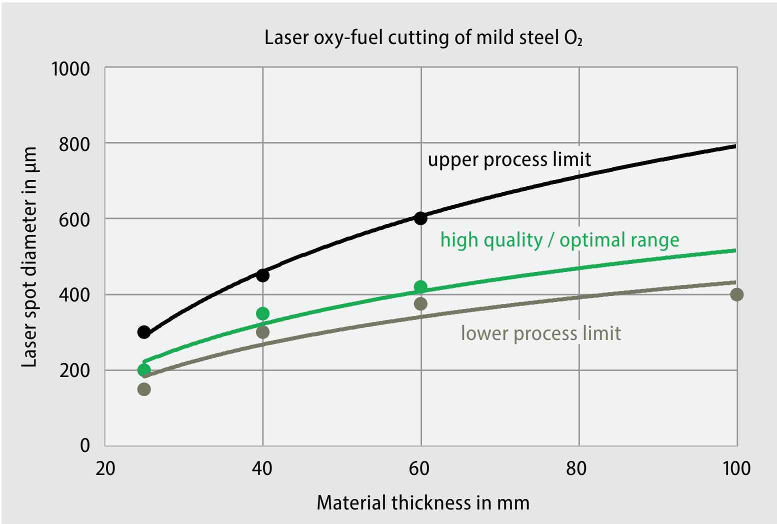

Fig. 5 Cutting results showing the influence of magnification in laser oxy-fuel cutting of mild steel using oxygen. Details of the experimental conditions are described in the text.

In laser fusion cutting with nitrogen, material removal relies exclusively on laser-induced melting and subsequent melt ejection. Consequently, increasing the material thickness requires the laser spot diameter to be gradually enlarged to maintain a stable kerf. The resulting process window narrows with increasing thickness. In contrast, the process window widens with increasing thickness in laser oxy-fuel cutting due to the additional energy contribution of the oxidation reaction. It should be noted that fewer data points are available at higher material thicknesses in both diagrams.

Overall, the results demonstrate that the laser spot diameter has a significant influence on process stability and achievable cut quality in high-power laser cutting. By providing variable optical mag-

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nification, the ProCutter Prime introduces an additional degree of freedom for process optimization, complementing established control parameters such as cutting speed and focus position. This flexibility allows users to balance productivity and process stability according to application requirements. By adapting the beam profile to the specific process conditions, the ProCutter Prime supports robust and high-quality cutting across a wide range of materials and thicknesses.

Despite its optical flexibility, the ProCutter Prime is designed for continuous industrial operation at laser powers of up to 30 kW. High-quality optics with optimized substrates and coatings minimize absorption losses and mitigate thermally induced distortions [4]. The optical layout is engineered to maintain stable performance during long cutting cycles and under demanding industrial conditions. An optimized cutting gas flow with enlarged channels reduces turbulence and supports efficient melt ejection, particularly for stainless steel and mild steel within the medium thickness range.

Comprehensive sensor integration enables real-time monitoring of optical conditions, temperature, pressure and system status. All relevant data is accessible via a graphical user interface and standard industrial communication interfaces, facilitating integration into automated production environments and condition-based maintenance concepts. The ProCutter Prime's smart maintenance concept is designed for advanced, service-oriented industrial operations (**Fig. 6**). Front-side access to the optical components is provided, simplifying maintenance procedures directly at the machine. The fully cartridge-based design enables tool-free replacement of optics and protective windows within minutes, significantly reducing service effort and easing maintenance workflows.

Fig. 6 ProCutter Prime maintenance concept

Designed for laser powers of up to 30 kW, the ProCutter Prime supports high-power laser cutting applications requiring flexibility, robustness, and consistent cut quality across a wide range of materials and thicknesses. Its optical design enables both thin-sheet and thick-plate processing within a single platform, making it well suited for job shops and contract manufacturing environments.

Smart and robust process stabilization for continuous operation

In addition to the optimized optical design, both the ProCutter Prime and ProCutter 2.0 Plus integrate BeamTec technology for active compensation of thermally induced focus shift. At high laser powers, absorption in optical components leads to gradual thermal lensing, which can shift the focal position out of the stable process window during long cutting cycles. BeamTec continuously compensates for this effect by dynamically adjusting the focus position during operation [4]. Working in combination with the optimized optics and advanced thermal management, BeamTec stabilizes the effective focus position at the workpiece, enabling a robust and reproducible cutting process and minimizing the impact of thermal lensing even at elevated laser power levels [4].

Both the ProCutter Prime and ProCutter 2.0 Plus are designed for integration into condition-monitoring and data-driven production environments. The CutBox Pro control platform provides real-time access to process and system parameters as well as standardized Industry 4.0 connectivity via OPC UA and industrial fieldbus interfaces, enabling seamless integration into higher-level machine and factory control systems. Comprehensive sensor

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coverage, combined with robust optical protection and contamination management, supports reliable 24/7 industrial operation while enabling continuous condition monitoring and system diagnostics. This architecture enables predictive maintenance strategies by allowing early detection of optical degradation, thermal load, or process deviations, reducing unplanned downtime and stabilizing long-term performance [5]. These capabilities are complemented by global service availability, spare-parts logistics, training, and lifecycle support across the entire ProCutter family.

For high-power laser cutting heads, reliable operation is determined not only by optical design and control concepts but also by the cleanliness of the manufacturing environment. Particulate contamination on optical components can cause localized absorption and thermal instability under high optical intensities, making cleanroom conditions a prerequisite for assembly. This requirement is fulfilled through controlled cleanroom-based production and assembly processes (image **p. 41**).

Both cutting head concepts incorporate active focus stabilization, comprehensive sensor monitoring, and cleanroom-based manufacturing. These features ensure robust, data-driven process stability and consistent cut quality during continuous high-power operation.

Conclusion

The ongoing market shift toward higher laser power is broadening the scope of laser cutting, extending it to application areas previously dominated by plasma cutting. This development is accompanied by increasing technical demands regarding process stability and robustness. As laser power increases, the cutting head becomes a key system element enabling the effective use of available power in industrial cutting of different materials and thicknesses. The Precitec ProCutter 2.0 Plus and ProCutter Prime address these requirements in their respective market segments. Both feature optimized optics, effective thermal management, active focus-shift compensation, and comprehensive condition monitoring, supporting stable cutting performance during long production cycles.

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