External power control and regulation of sealed CO_2 lasers

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External power control and regulation of sealed CO_2 lasers opens up new applications in the packaging, electronics, glass and automotive industries, in which CO_2 lasers with their particular characteristics could not previously be reliably used.

Sealed CO_2 lasers with a power of up to 700 W have been effectively used for many years in conjunction with galvanometer scanners for beam deflection in various industrial applications. As well as typical uses such as cutting, perforation and marking of different materials, this technology has also established itself in alternative materials processing applications, for example bleaching jeans or decoration of ceramics.

However, other potential applications such as cutting labels or spacers and non-destructive glass marking face such high requirements in terms of the results, that they have previously been very difficult or impossible to realise using CO_2 laser systems. For these applications, the well-known method of laser power control using pulse frequency and pulse width alone is often inadequate, as the required processing quality cannot be achieved. CO_2 laser systems have clear advantages over mechanical methods. These include high flexibility, short down-times, the possibility of creating clear cuts using burn-up, and a highly developed capability to process compound materials or create ultra fine structures.

This dilemma can be resolved by external power control and regulation, which reduces fluctuations in CO_2 laser power to a minimum. This opens up numerous new applications for CO_2 lasers. It is important to differentiate between the concept of control, which involves specifying a target value, and regulation, which also includes comparison of the actual value with the target value.

The following sections first explain the problems of using CO_2 lasers and then outline available solutions.

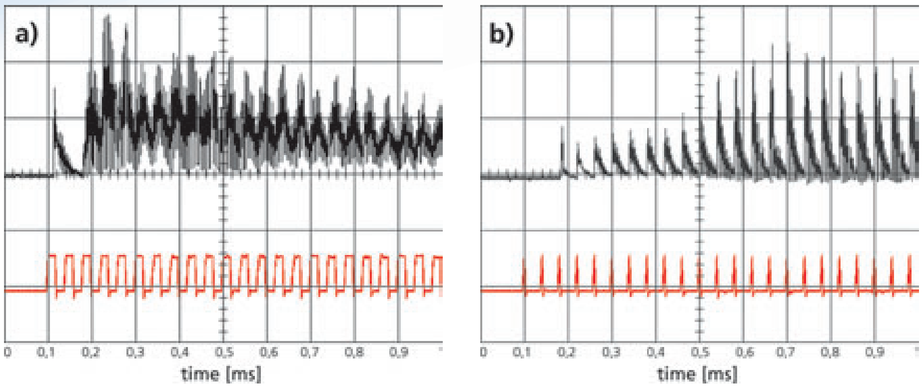

***Figure 1**: Input signal (red) and measured laser power at 25 kHz, a) with 50% duty cycle: fast build-up of laser power, excess power at beginning, b) with 10% duty cycle: slow build-up of laser power, insufficient power at beginning*

1 Power fluctuations of CO_2 lasers

When using CO_2 lasers, there are several obstacles to be overcome which result directly from the principle of the gas laser. Light stimulation is performed by a plasma, comparable with the gas discharge in fluorescent tubes. These physical processes cannot be perfectly described – they are influenced by a variety of factors such as gas pressure, gas composition, stimulation frequency and impurities in the gas. The interaction of these factors can cause the power output of sealed CO_2 lasers[1] to fluctuate by up to 10% of the target power.

1.1 Switch-on characteristics

When a CO_2 laser is switched on and the pulse frequency or pulse width is changed to a new value, it can take up to several 100 µs before the new laser power is established and stable. The switch-on behaviour and the time delay between setting a new laser power and its stable establishment can differ greatly depending on the frequency and the duty cycle (**figure 1**).

It is not even certain that the time delay or the transient response will be constant with the same frequency and duty cycle. This means that switching the laser power on and off or setting a new operating point can result in excessively weak or heavy processing of different sections of the material.

1.2 Dynamic effects

If an XY scanning head is to be used to create a corner in the processing contour, for example, one of the galvanometer scanners needs to be decelerated and the second needs to be accelerated. Assuming a constant laser power, this leads to a temporary increase in the quotient of the laser power for each unit of travel during the deceleration and acceleration process. The material is therefore too heavily processed, which causes swelling of the contour or penetration in the corner (**figure 2**).

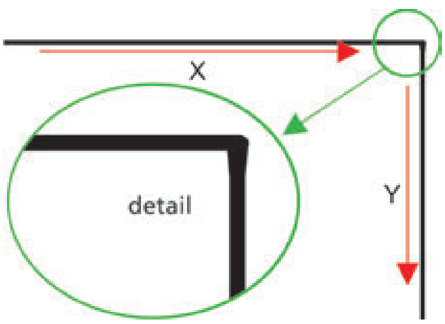

***Figure 2**: Excessively heavy processing of material at a corner*

[1] Only sealed CO_2 lasers have been investigated.

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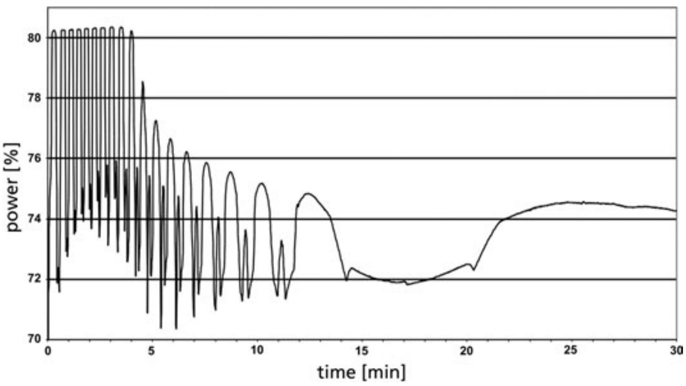

***Figure 3**: Typical power fluctuations of a CO_2 laser (here: Synrad 48-2, rated power 25 W) after initial switching on*

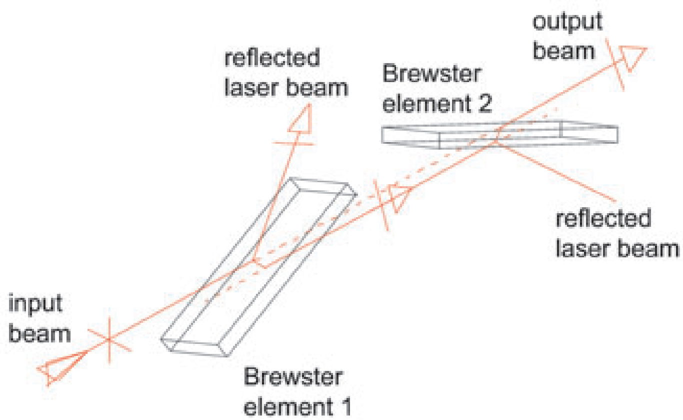

***Figure 4**: Brewster elements for controlling the power of a CO_2 laser*

1.3 Thermal and other influencing factors

Power changes in CO_2 lasers can have various other causes:

- Heating processes in the laser resonator cause significant power fluctuations, which can mainly be observed in the first few minutes after switching on the laser (**figure 3**).
- Fluctuations in the cooling water temperature and the ambient temperature of the laser can have a similar effect.
- Dirt on the laser's optical system, gas losses and similar damage result in a slow reduction in the maximum available laser power.

In addition to the power fluctuations of CO_2 lasers described above, instability can occur when setting a duty cycle of below 10%, because the plasma then becomes extremely unstable or can go out altogether. At the same time, changes in the linear polarisation of the laser and fluctuation in the wavelength can be observed, caused by variation of the pulse actuation frequency.

As a result, process issues caused by varying speed of the laser beam focus over the work area, can not alone be solved through changes in repetition rate and duty cycle.

2 External power control and regulation of linear polarised CO_2 laser radiation

Raylase's patented PCD (Power Control Device) technology allows both high-speed power control depending on the processing speed using an I-PCD module, and regulated compensation for power fluctuations of CO_2 lasers using a PowStab module. These two processes are carried out externally, can be combined with one another and are independent of the laser manufacturer. The only requirement is a linear polarised CO_2 laser beam typically up to 1 kW in quasi-cw or pulsed mode with a constant frequency and a fixed duty cycle.

2.1 Speed dependent power control

Power control depending on the processing speed is synchronised, e.g. with 2 or 3-axis galvanometer deflection units, by synchronously rotating two anti-reflection coated Brewster elements in opposite directions in the laser beam. When the normal to the surface of a Brewster element is located in the polarisation plane of a linear polarised laser beam, 100% transmission is achieved, while conversely the figure falls to 0% as soon as the normal to the surface of the element is vertical to the polarisation plane (**figure 4**). Appropriate rotation of a Brewster element can thus control the transmitted laser power as required and the non-transmitted laser power is collected in a radiation trap. With two Brewster elements rotating synchronously in opposite directions, faster switching times are achieved with half of the angle of rotation. The use of galvanometer scanners to rotate the Brewster elements enables fast switching times (0-100% transmission) of 1 ms to be attained. If the physical offset introduced by this technique between the output and input laser beam has to be compensated, two Brewster pairs are used instead of the two Brewster elements rotating in opposite directions. These pairs rotate in opposite directions but the elements within each pair rotate in the same direction.

As the polarisation of the transmitted beam follows the rotation of the Brewster elements, controlling the power causes a rotation in the polarisation direction. If this is not wanted, the original polarisation direction can be restored at the output using a so-called Brewster cleaner. This is a fixed Brewster element with the normal to the surface of the element in the polarisation plane of the original laser beam.

As power control is external, beam splitters allow several parallel modules to be connected to a single laser to control the power of partial beams.

2.2 Fluctuation compensated power regulation

To regulate the CO_2 laser power to deviations of $< \pm 1\%$ of a target value, the power is first continuously measured. This allows power stabilisation to be performed from a PC using a PID control algorithm. The module (**figure 5**) essentially consists of:

- An anti-reflection coated Brewster element, which is rotated in the beam by a galvanometer scanner
- A water-cooled radiation trap
- A partial reflector
- A high-speed power meter with AD converter

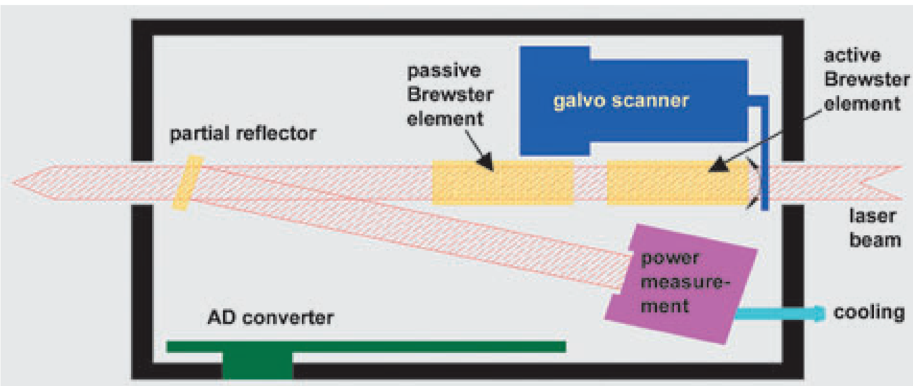

***Figure 5**: Basic schematic illustrating the concept of external power control for a CO_2 laser*

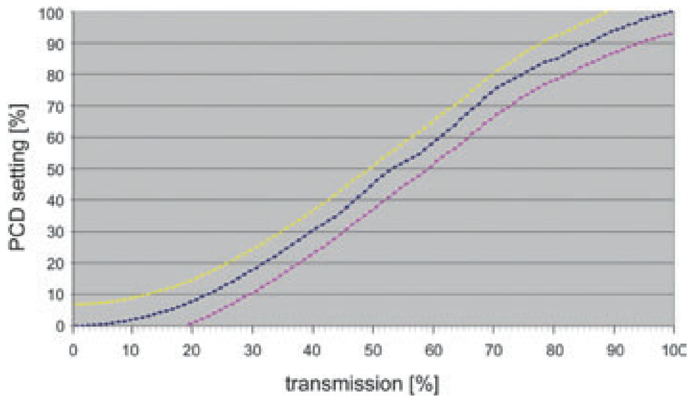

***Figure 6**: Characteristics of the external power control, transmitting a CO_2 laser beam*

***Figure 7**: Corner processing with external power control*

The speed of the power regulation is not so much limited by the galvanometer scanner for rotating the Brewster elements as it is by the integrative (noise eliminating) measurement on which the regulation is based. Nevertheless, fast regulation times in the range of less than 200 ms can be achieved.
To compensate for position instabilities in the laser beam, which have a negative impact on the measured laser power, a focusing element is installed between the partial reflector and the cooled detector to ensure that the focal spot of the measuring beam is much smaller than the measuring area.
To protect the detector against overload, it can be useful to fit a reducer. Photocells have proven to be effective detectors, as pyrometric power measurement despite cooling is too susceptible to changes in the ambient temperature and also has an excessively long response time.
If variable pulse operation is required for a power stabilised application, this can be achieved using a downstream acousto-optical modulator.

3 Results

The power of CO_2 lasers can be kept within narrow tolerance limits using external power control (**figure 6**).
Transient instabilities in the laser power in pulse mode and the resulting losses of processing quality are prevented as the CO_2 laser is operated at a constant frequency and constant duty cycle. Controlling the CO_2 laser power as a function of the speed of a 2 or 3-axis deflection unit allows excessively heavy processing of the material in corners to be prevented (**figure 7**).
External power control significantly improves the stability of the laser power. Tests with different types of sealed CO_2 lasers revealed a power stability in the range 0.1 to 2% (see **figure 8** and **figure 9**). Manufacturers normally specify a power stability of approx. ±7%.

4 Example applications

The external power control and regulation methods outlined allow an exceptionally high processing quality to be achieved with CO_2 lasers for materials such as paper, cardboard, plastics (e.g. ABS, polyester, PP, PE etc.), compound materials or special doped flat glass.
Possible applications also include the packaging industry, e.g. for cutting labels, or in the electronics industry for cutting spacers (**figure 10**). Non-destructive marking of special doped flat glass (**figure 11**) is required for decorative applications, in biotechnology and in the automotive industry.
Because of the modular nature of the PCD technology, a CO_2 laser can be combined with various elements in industrial applications, as shown in **figure 12**:

- Power regulation module
- Several parallel power control modules
- Several 2 or 3-axis beam deflection units

5 Summary

The fluctuations and instabilities that occur in sealed CO_2 lasers are typical of gas lasers but can be significantly reduced using external power control and regulation. This opens up new applications that were previously unfeasible using mechanical processing methods due to their requirements in terms of flexibility and complexity.

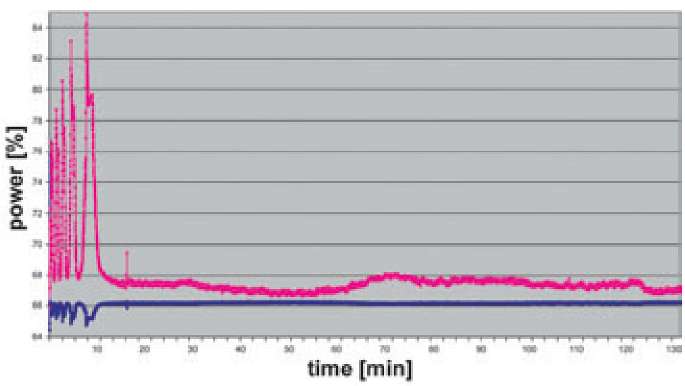

***Figure 8**: Power fluctuations of Synrad 48-2 CO_2 laser (rated power 25 W), regulated and unregulated*

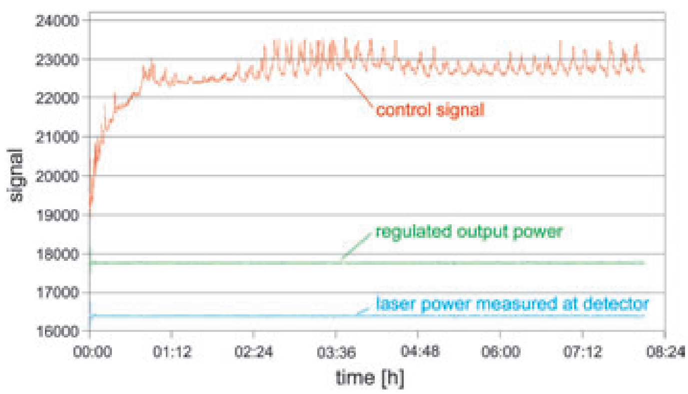

***Figure 9**: Power of Synrad Evo-100 CO_2 laser, measured at detector (blue), regulated power output (green) and activity of the power control unit (red)*

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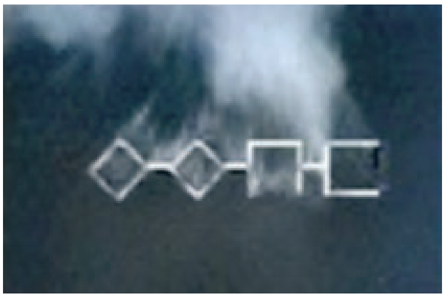

Figure 10: *Cutting spacers*

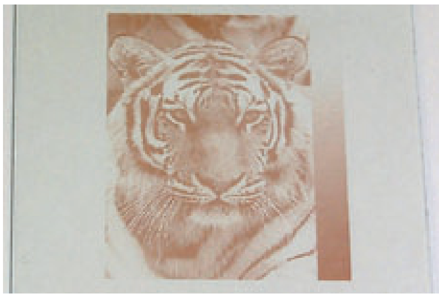

Figure 11: *Marking special doped flat glass*

Figure 12:
Example of industrial MOTF cutting application with external power control and regulation