# DUAL-FOCUS LASER CUTTING

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## ABSTRACT

A laser cutting technique, named Dual-Focus Laser Cutting, enabling existing and new laser cutting installations to improve cut qualities and process stability as well as extending the thickness range for a number of materials is presented. The technique is based on the use of two stationary focal points, created by a single optical element, rather than the use of only a single focal point created by conventional techniques. The optical element, normally a lens, can be implemented in any old or new laser cutting machine without any changes to the system. A number of advantages related to this cutting technique experienced both in laboratory and under industrial conditions are reported: a high intensity beam can be maintained on the upper surface of the material in order to create the required ignition of the material as well as maintaining a high intensity beam near the bottom material surface suitable for creating a clean kerf all through the material thickness. A number of industrial experiences achieved by industrial end-users on mild steel, stainless steel and aluminium are reported. They illustrate that different cutting machines as well as different materials and material thicknesses can benefit from the new cutting technique.

***IIW-Thesaurus keywords:*** *Laser cutting; Process variants; Laser beams; Process equipment; Nozzles; Steels; Stainless steels; Metallic coatings; Aluminium; Focussing; Optics; Computations; Practical investigations.*

## 1 INTRODUCTION

The laser cutting process is a widely spread industrial technique. Unfortunately, quality and thickness limitations restrict the utilisation of the process, e.g. regarding cutting of steels, within a thickness range up to approximately 15 mm, which has now been the state of the art for several years. However, a big demand regarding increased cutting qualities and the ability to cut thicker materials is still present from the medium and heavy steel industry as well as from the aluminium and die-board (wood) processing industries, etc.

A newly developed laser cutting technique, named Dual-Focus Laser Cutting, enables existing and new laser cutting installations to improve cut qualities and process stability, as well as extending the thickness range for a number of materials. The Dual-Focus Laser Cutting technique is based on the use of two stationary focal points, created by a single optical element, rather than the use of only a single focal point created by conventional techniques. The optical element, normally a lens, can be implemented in any old or new laser cutting machine without any changes to the system. The mentioned cutting technique will be presented.

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## 2 CUTTING THICK MATERIALS, BASIC PRINCIPLES

### 2.1 Focal point position near bottom surface

High-pressure nitrogen assisted laser cutting of stainless steel is in demand from the end-users or customers, due to the excellent cut edge quality. This type of cutting, called fusion cutting, requires cutting gas pressures in the range up to 20 atm., depending on the material thickness to be cut. In order to avoid the formation of burrs/dross on the lower part of the cut edges, it is generally known that the position of the focal point must be as close as possible to the bottom surface of the material, which means in the bottom of the kerf. However, the beam intensity level on the upper surface still has to be capable of igniting/starting the process. By this defocusing technique a wider kerf is created, which is required in order to obtain the pressure drop needed through the kerf to blow out the melted material efficiently. Furthermore, the high beam intensity in the bottom of the kerf prevents the burrs/dross from each cut edge to fuse together, which otherwise will lead to problems regarding the separation of the parts. However, as the material thickness increases, it becomes impossible to maintain the position of the focal point in the bottom of the kerf, as the beam intensity level then drops below the required level for igniting the material, thereby starting the cutting process. Quality problems typically arise at thicknesses above 10 mm using e.g. a standard 3 kW laser and a lens focal length in the range 7-10 inch. Even the cutting of stainless steel thicknesses below 10 mm are often meeting undesirable quality variations.

### 2.2 Focal point position near top surface

Oxygen-assisted laser cutting of mild steel is called exothermic cutting, as oxygen reacts chemically with the material being cut. Due to the relatively low melting point of the oxides and lower viscosity of the molten material, as compared to the conditions for nitrogen-assisted stainless steel cutting, it is relatively easy to clean the kerf efficiently with a lower oxygen pressure, typically in the range up to 5 atm., even in material thicknesseses up to 10-15 mm. For the cutting of mild steel it is generally known that the focal point is positioned near the upper surface of the material in order to obtain the required ignition and process stability to achieve an acceptable cut quality. The process requires a sharp and highly intense focussing on the surface in order to obtain sharp edges and to avoid uncontrolled so-called self-burning in the kerf edges. However, as the material thickness increases the process becomes more and more oxygen-controlled like the flame cutting process. Uncontrolled self-burning is of main concern as well as problems arises due to a remarkable dross formation leading to problems regarding the separation of the cut edges. Cutting highly reflective materials like aluminium also requires that the focal point be close to the upper surface in order to achieve and maintain a high intensity on the material. For this reason similar difficulties as described for stainless steel are present regarding the achievement of a dross-free quality.

## 3 NEW DEVELOPMENTS - DUAL-FOCUS LASER CUTTING

### 3.1 Cutting with two focal points

A new technique under development is based on a single transmitting or reflecting optical element creating two fixed focal points at two different positions separated from each other in the direction of the materials thickness to be cut (Fig. 1). The optical element includes a concentric circular centre surface area creating a focal point located near the bottom material surface. Depending on the dimension of this area/diameter a certain controlled amount of the laser beam power is joined to this focal point. The outer ring area of the optical element focuses the second part of the laser power close to the upper material surface. A number of advantages are related to this special “Dual Focus Laser Cutting” technique. For cutting mild steel, stainless steel or aluminium a high-intensity beam can be maintained on the upper surface of the material in order to create the required ignition of the material, as well as maintaining a high-intensity beam near the bottom material surface, suitable for creating a clean kerf all through the material thickness. The technique expands the so-called parameter window within which high quality cuts can be carried out. In other words, cutting thicker materials

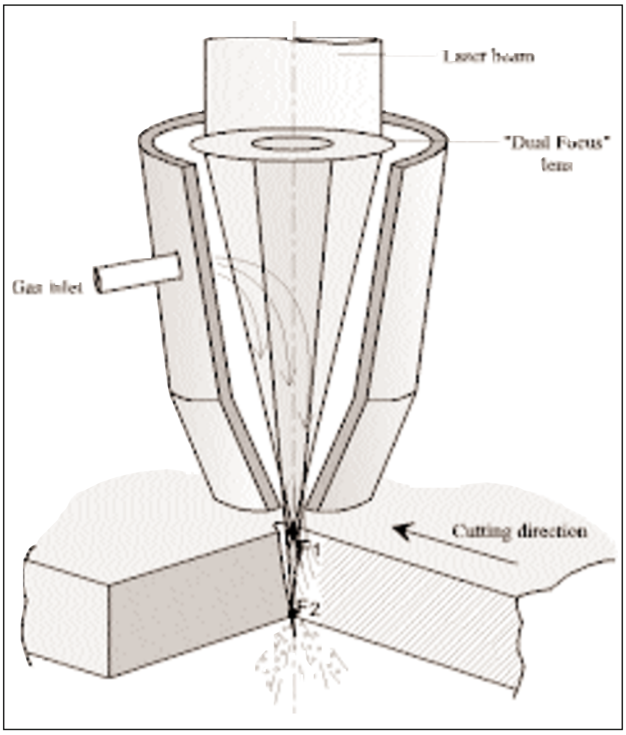


**Fig. 1. Dual-Focus Laser Cutting. Basic principles.**

becomes less sensitive and the possible thickness capable of being cut with a certain power level is increased.

### 3.2 Improved piercing technique

Normally, piercing implies problems related with the formation of spatter ejected against the cutting nozzle and the optics. Often these sensitive parts are damaged through the piercing operation. A special piercing technique is made possible by the Dual Focus Laser Cutting technique. The piercing operation based on the use of the focal point F2, normally positioned at the bottom surface of the material during cutting assures a safe distance from the material surface to the nozzle tip.

### 3.3 Smaller nozzles, reduced gas consumption

Due to the nature of the beam propagation related to the Dual-Focus Cutting technique, reduced diameter cutting gas nozzles can be used, as illustrated in Fig. 2. As mentioned earlier, high-pressure nitrogen cutting of e.g. stainless steel requires that the focal point position be close to the bottom surface during cutting. Depending on the material thickness to be cut, the required nozzle diameter must normally be extended considerably to obtain a suitable beam clearance. At cutting pressures in the region of 20 atm. the consumption of gas is very high, typically 40 - 60 $m^3$ per hour. Nozzle diameters are typically in the range 2-3 mm. The Dual-Focus Laser Cutting technique allows corresponding nozzle diameters in the range 1 - 2 mm, typically reducing the gas consumption by 30 - 40%.

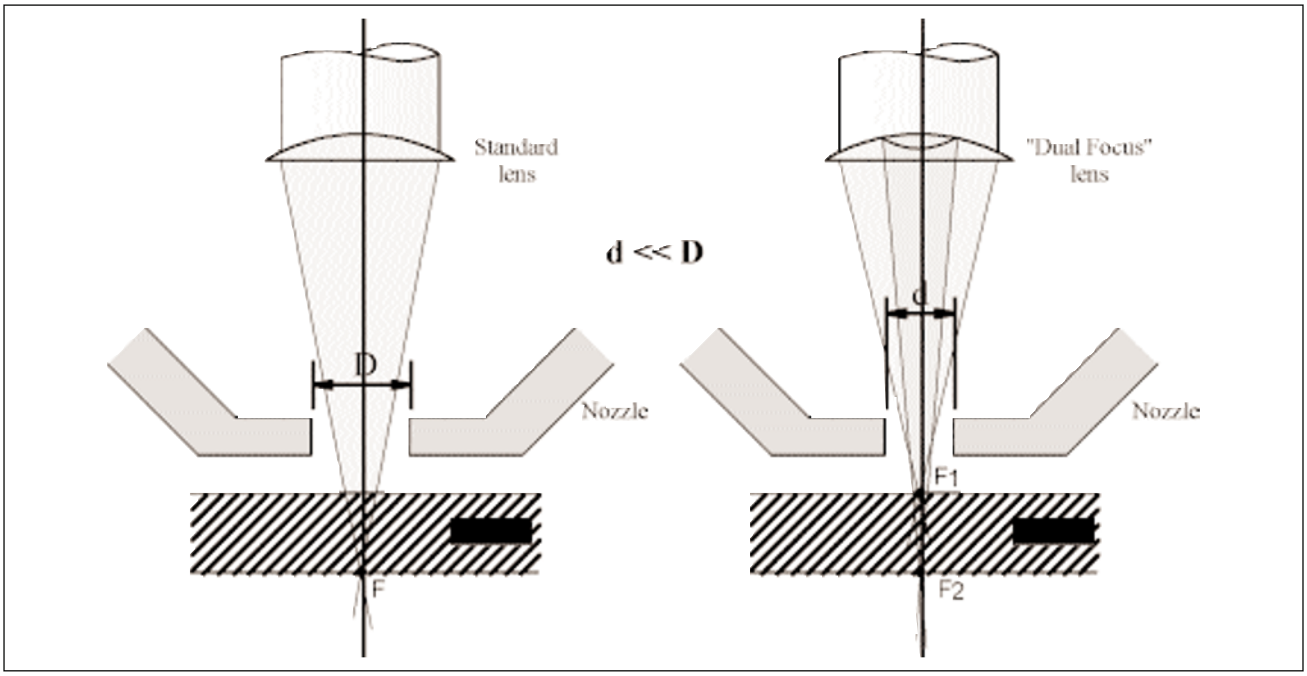


**Fig. 2. The Dual-Focus Laser Cutting technique requires smaller nozzle diameters, as compared to the standard technique.**

### 3.4 “Flying optics” cutting machines

The majority of laser cutting machines are either based on stationary optics, often in combination with a stamping unit, and moving material or based on a so-called “flying optics” system and a stationary material to be cut. “Flying optics” systems often suffer from focal point instability. This is caused by the often very long beam paths in the system, in which case the basic beam divergence influences the focal point position relative to the cutting nozzle tip. This focal point position sensitivity often introduces a difference in the cutting quality depending on the actual position in the system related the actual distance from the laser source. The Dual-Focus Laser Cutting technique has shown much less sensitivity related to the focal point position due to the fact of having 2 focal points in action. For example, it was found that the vertical focal point position tolerance for cutting 13 mm stainless steel, was within 4 mm using the Dual-Focus Laser Cutting technique. The corresponding standard lens technique only showed a tolerance within 1 - 2 mm. It is therefore obvious that the Dual-Focus Laser Cutting technique is not only a technique for cutting thick section materials but that it will be advantageous even in thin sheet cutting, especially for “flying optics” cutting machines.

## 4 OPTICAL CALCULATIONS FOR DUAL-FOCUS LENSES

### 4.1 Gaussian beams

Modelling $CO_2$ laser beam propagation through space and optical components is a physical optics problem. That is, it requires to consider the wave nature of light. This complicated problem, can however be considerably simplified by various approximations, such as scalar wave diffraction theory, Fraunhofer diffraction and Fresnel diffraction. When applied to laser beams and

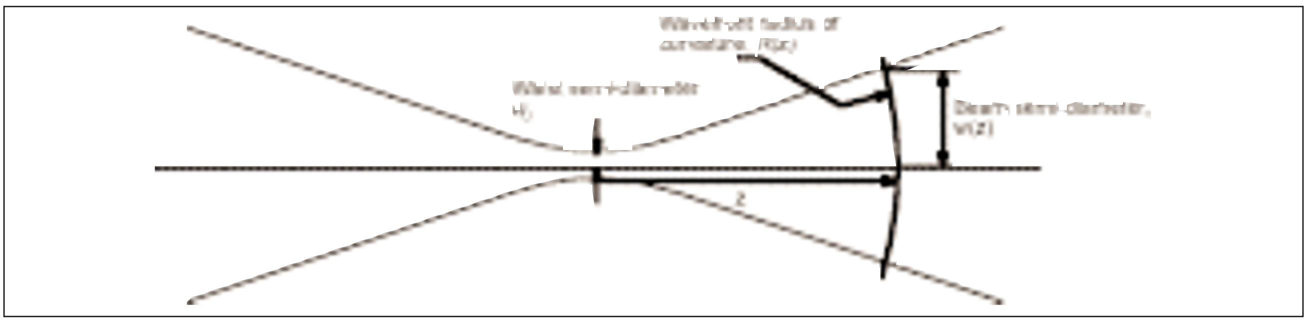


**Fig. 3. Gaussian beam definitions.**

Definitions:
$w_0$ = waist semi-diameter
z = distance from waist
w(z) = beam semi-diameter a distance z away from the waist
R(z) = wavefront radius of curvature a distance z away from the waist
$\lambda$ = wavelength
P = laser power
r = radial distance from axis.

free-space modes, the end results are some equations, with which the reader is probably familiar:

$$w(z) = w_0\sqrt{1 + \left(\frac{\lambda z}{\pi w_0^2}\right)^2} \quad (1)$$

$$R(z) = -z\left[1 + \left(\frac{\pi w_0^2}{\lambda z}\right)^2\right] \quad (2)$$

These enable the semi-beam diameter and wavefront curvature radius to be computed for a distance z away from the waist, see figure 3.

As written, they apply to the fundamental mode $TEM_{00}$ that has a Gaussian intensity profile at any location in z. This intensity profile is probably again familiar, equation 3. A little less familiar, however, would be the "complex amplitude" profile equation 4.

$$I(r) = \frac{2P}{\pi w^2(z)} e^{-2(r/w(z))^2} \quad (3)$$

$$A(r) = \left(\frac{1}{w(z)}\right)\sqrt{\frac{2P}{\pi}}\, e^{-(r/w(z))^2} e^{i\left(\pi r^2/\lambda R(z)\right)} \quad (4)$$

This can be broken into two parts, amplitude and phase:

$$\textit{Amplitude, } a = \left(\frac{1}{w(z)}\right)\sqrt{\frac{2P}{\pi}}\, e^{-(r/w(z))^2} \quad (5)$$

$$\textit{Phase, } \phi = \pi_r^2/\lambda R(z) \quad (6)$$

So $\textit{Complex\_amplitude, } A(r) = Amplitude.e^{iPhase} = ae^{i\phi}$ (7)

and $\textit{Intensity, } I(r) = Amplitude^2 = a^2$ (8)

The Gaussian beam propagation equations (1) and (2) above are valid provided that the Gaussian profile is not altered (e.g. from beam clipping at an aperture) or that aberrations are not introduced by an optical system. This would result in the amplitude and phase terms (5) and (6) respectively being changed. Normally, this is avoided. However, with Dual-Focus lenses there is a deliberate alteration to the phase term in order to redistribute the beam energy. Consequently, once a laser beam has passed through a Dual-Focus lens there is no guarantee that the above Gaussian beam equations will accurately predict how the beam propagates.

To get an idea of how the energy distribution around the foci depends on the lens and beam parameters, it is necessary to take a step back to more fundamental diffraction theory.

## 4.2 Non-Gaussian beams

Fundamental diffraction theory is covered in a number of books on general optics [8, 9]. However, for those readers with a non-optical background, the following is a brief description of the problem.

Figure 4 shows a plane defined by the $x_1$ and $y_1$ axes at z = 0. In that plane the amplitude and phase as expressed by equation (4) are known. Given this, the diffraction problem involves calculating the amplitude and phase at another plane (defined by the $x_2$ and $y_2$ axes) a distance z away. For Dual-Focus lenses, the first plane would be located immediately after the lens and the second plane at some place of interest around the foci. Of course, to build up a complete picture of the intensity distribution at the foci it is necessary to repeat the procedure for many second planes.

Computations of this nature are usually done with some approximations, which can save large amounts of time; treating light oscillations as scalar quantities rather than vectors is an example. Another such approximation applicable to Dual-Focus lenses is that the problem is "rotationally symmetric": the z-axis in figure 4 being the axis of symmetry. Yet another, though not obvious approximation, is that the calculations largely fall within the realm of the "Fresnel approximation". When these are applied, the amplitude and phase in the two planes are related by the following equations:

$$A_2(r_2) = \frac{2\pi_e^{2\pi i z/\lambda}}{i\lambda z}\, e^{i\pi r_2^2/\lambda z}\int_0^\infty A_1(r_1) e^{i\pi r_1^2/\lambda z} J_0(2\pi_{r2r1}/\lambda z) r_1 dr_1 \quad (9)$$

$A_1(r_1) = a_1e^{i\phi}1$ and $A_2(r_2) = a_2e^{i\phi}2$ (10)

And where the intensity is then,

$$I_2 = a_2^2 \quad (11)$$

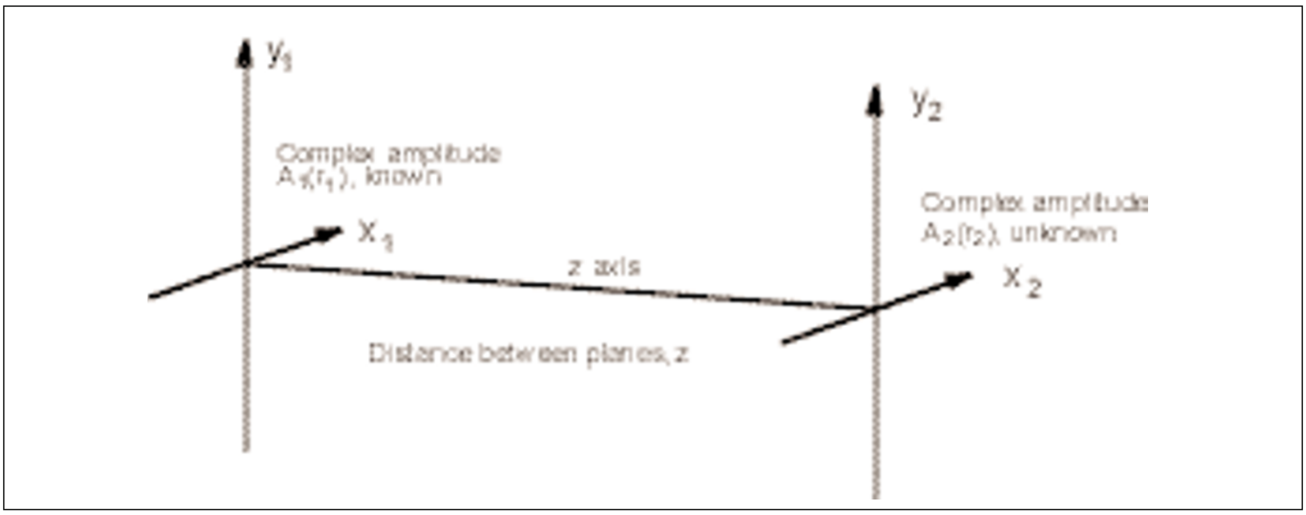


**Fig. 4. Diffraction problem. Computing the complex amplitude in plane 2 from the known complex amplitude in plane 1.**

where $\lambda$ is the wavelength (10.6$\mu$m) and the $J_0(\ )$ are Bessel functions of zero-order. This is still a formidable computation, especially as it needs to be repeated several thousand times just to build up a single picture. Obviously, the only practical way of doing this is by computer. Before equation (9) is used, it is first necessary to determine the amplitude and phase just after the lens (plane 1). We achieve this by ray tracing through the inner and outer regions of the lens. The phase, including any contributions from aberrations, is found from the optical path length along each ray. By modelling the mode structure of an incident beam it is then possible to determine the amplitude. One complication that results here, is that by the time the inner and outer portions of the beam leave the lens, they have started to overlap. It is necessary to look more closely at this region to determine the amplitude and phase that results from the interference of the two beams. Quite often it can result in a spike or dip of the intensity pattern.

Once the ray tracing has been completed with the amplitude and phase found on plane 1, then equation (9) is used repeatedly for many z and $r_2$ values to build up a picture of the foci. Some examples are now given.

### 4.3 Example computations

Based on the above calculations and formulas it is possible to obtain a sequence of plots for a Dual-Focus lens as e.g. illustrated in Fig. 5. Each case has 4 plots. The top two are the intensity along the z-axis, with the left being logarithmic and the right linear. The bottom graphs show a 2-D map of the intensity with z and $r_2$, again logarithmic and linear. The vertical $r_2$ scale is greatly expanded, so that in reality the high intensity region is a narrow strip about the axis. The value "2h" is the diameter of the central portion of the lens focussing the power inside this region into the lower focal point. In the case of 2 h = 0 the Gaussian beam equations (1) and (3) produce the same results. Subsequent plots can be done for increasing 2 h values. When 2 h is equal to the lens diameter we have a normal lens again, but with a focal length F + dF. The sequence shows the development of the second focus and decline of the first. The logarithmic scale allows both the low and high intensity features to be seen. Figure 5 shows this case when 60% and 70% of the power is transmitted through the 2 h area. For a series of plots with a 2 h value increasing form zero to full beam diameter the first changes to be seen are that the isophotes (lines of constant intensity) start to become asymmetric and that a low intensity second focus appears further out than the dF value stipulates. As more power is directed into the second focus, it moves towards the geometrical optics location. Over 70% of the power has to be directed to the second focus before both foci have the same intensity, see Fig. 5. This proportion is similar for other lens designs.

## 5 INITIAL LABORATORY EXPERIENCES

A number of Dual-Focus lenses were initially manufactured by a European optics manufacturer. The design of the lenses covered first hand a limited number of combinations between power distribution in the two focal points as well as distances between the two focal points. Basic experimental work was based on a 2.8 kW $CO_2$-laser with the beam mode designation TEM01*. Materials tested were stainless steel, mild steel, aluminium and wood.

Stainless steel in the thickness range up to 13-15 mm as well as aluminium in the thickness range 8-10 mm have been cut free of burrs/dross using the high-pressure nitrogen cutting technique. Cutting wood materials in the thickness range 40-50 mm also showed a clean, straight and perpendicular cut quality. The Dual-Focus Laser Cutting technique allowed nozzle distances up to 1.5 mm. Further, it allowed even smaller diameter nozzles to be used. In general, the Dual-Focus Laser Cutting technique showed that the thickness capability, for a certain power level, regarding the cutting of stainless steel has been extended by 20-30% still obtaining burr/dross-free qualities, as compared to the standard lens technique.

Low-pressure oxygen cutting of mild steel has so far been tested up to 20 mm of thickness based on stan-

2 h = 12.18 mm, 60% of beam power within 2 h.

2 h = 13.97 mm, 70% of beam power with in 2 h.

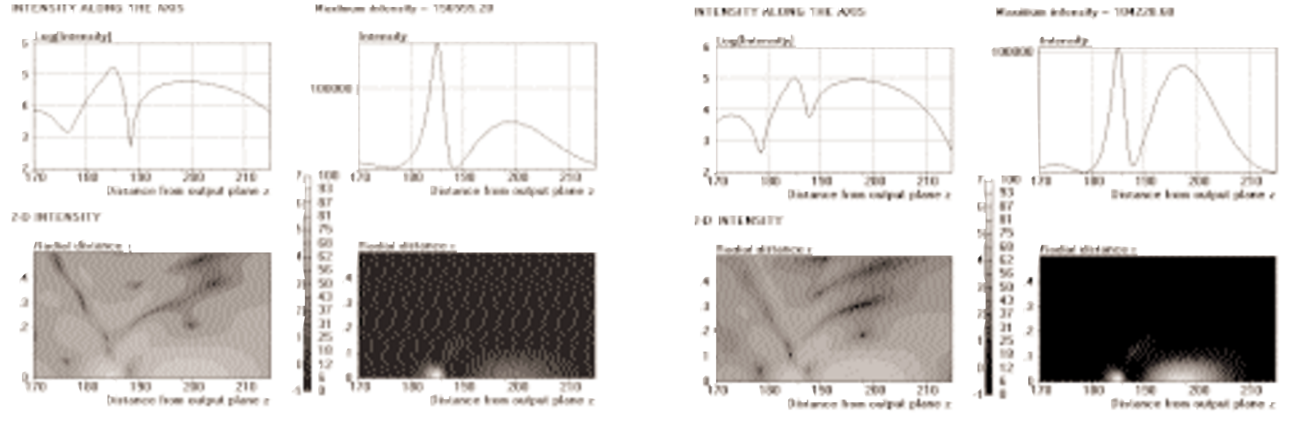

**Fig. 5. Example computations for a 15DFA190-125-XXX Dual-Focus lens in a 3kW $CO_2$ $TEM_{00}$ beam with $1/e^2$ diameter of 18 mm. XXX represents the "2 h" diameter.**

dard nozzles. Basically, it was found that the cutting process became more stable compared with the use of a standard lens, especially in the thick section area. In this region, which means thicknesses above 10 mm, the process becomes oxygen controlled. The Dual-Focus distribution of the energy in the kerf seems to be beneficial as it somehow “takes the heat of the oxygen” in terms of reducing the tendency to the well-known phenomena of uncontrolled self-burning of the material, which is disastrous for the cut quality. The process also becomes more independent of chemical composition of the steel, as well as primer and paint do not influence in the same way as seen known related to standard lens cutting.

## 6 INDUSTRIAL EXPERIENCES

A few hundreds of these lenses have now already been tested and accepted by many industrial end-users, mainly throughout Europe but also in the US. Although developments and tests have been carried out successfully on a laboratory basis, most of the very important practical experience has been gained in relation to tests and production work carried out on end-user premises, giving important feedback to be used for lens design optimisation work.

Most of the experiences have so far been performed on industrial “standard” cutting machines. However, other types of generally known cutting machines on the market are also subjects for tests currently and in the future. Some industrial experiences based on stainless steel and mild steel cutting are presented hereafter.

### 6.1 Dual-Focus laser cutting of stainless steel

To illustrate some of the feedback from industrial experience, a case from a Danish company, Linco Trading A/S, cutting stainless steel on their two laser cutting machines shall be described. Both laser cutting machines are based on “flying optics”. The “old” one is cutting with a power level of 1200 watt at the point of processing. The working area is 2 * 4 $m^2$. This machine suffers from too much “beam divergence”, as it is not equipped with a compensating telescope. There is a beam diameter change from 16 to 22 mm (86%) in the working area. This means that the vertical focal point position relative to the material surface is changing depending on the actual location of the cutting head in the working area, thus affecting the cutting performance/quality. In some areas the quality is good, in other areas it is poor. The second “new” machine is cutting with a power level of 2200 watt at the point of processing. The working area is 1,5 * 4 $m^2$. A telescope is equipped on this machine to compensate for beam divergence effects. The beam diameter is fairly constant in the working area, approximately 18 mm (86%). Table 1 shows a summary of the results experienced

**Table 1. Summary of results obtained by comparing a standard 7,5’’ lens to a Dual-Focus lens.**

| Machine type | Stainless steel. Thickness, m.m. | Standard lens, 7.5’’ | Dual-Focus lens, 15DFA190-100-060 |
|---|---|---|---|
| **Bystronic. 2 * 4 m²** | 1 | Everywhere in the area.<br>No dross. | Everywhere in the area.<br>No dross. |
| | 2 | Everywhere in the area.<br>No dross. | Everywhere in the area.<br>No dross. |
| **1200 Watt at the workpiece** | 3 | Possible in half area due to beam divergence.<br>Dross attachment.<br>Cutting speed, 800 mm/min. | Everywhere in the area.<br><br>No dross.<br>Cutting speed, 1200 mm/min. |
| **No telescope for divergence compensation** | 4 | Not possible. | Everywhere in the area.<br>No dross.<br>Cutting speed, 800-900 mm/min. |
| **Bystronic. 1.5 * 4 m²** | 5 | Everywhere in the area.<br>Dross.<br>Cutting speed, 13-1500 mm/min. | Everywhere in the area.<br>No dross.<br>Cutting speed, 1700 mm/min. |
| **2200 Watt at the work-piece** | 8 | Everywhere in the area.<br>Severe dross.<br>Cutting speed, 450 mm/min. | Everywhere in the area.<br>No dross.<br>Cutting speed, 700 mm/min. |
| **Including telescope** | 12 | Not possible. | Everywhere in the area.<br>Limited dross attachment.<br>Cutting speed, 200 mm/min. |

Related other data: Thickness’ up to 4 mm: Nozzle diameter ø 2.0.
Thickness’, 5 - 12 mm: Nozzle diameter ø 2.5.
Nitrogen pressure 12 bar measured in the cutting head.

by comparing a standard 7,5'' lens to a Dual-Focus lens based on the same focal length. Using a standard lens, the "old" machine was just capable of cutting a maximum of 2 mm with an overall good quality. 3 mm is only possible to cut with good quality in half of the working area. 4 mm thickness is not possible. Using a Dual-Focus lens a good quality is obtained in the whole working area up to 4 mm material thickness. Further, the cutting speeds were increased by 30-50%. Using a standard lens, the "new" machine was just capable of cutting maximum 8-10 mm. In the thickness range above 5 mm the quality is characterised by a dross attachment which needs to be machined away afterwards. Two persons were occupied for this activity. Using a Dual-Focus lens a good quality without dross attachment was obtained in the whole working area up to 8 mm material thickness! Even 12 mm thickness was cut at an acceptable quality, which was out of the capacity of the machine when using the standard lens. Further, the cutting speeds were increased by 20-30%.

*Other observations:*

During standard lens cutting, piercing was carried out first on all specimens. Metal deposits around the pierced holes were machined away manually before cutting out the specimens in order not to damage the nozzle tip during cutting. This procedure is a very time-consuming activity. The thicker the material becomes, the major this problem becomes. When using the Dual-Focus technique for piercing, no significant metal deposits is produced on the upper surface, which means that cutting can proceed succeedingly after every pierced hole.

### 6.2 Dual-Focus laser cutting of mild steel

This example covers the experiences achieved by a Danish end-user, Sjørring Maskinfabrik A/S, cutting mild steel in thicknesses up to 15 mm. In this case experiences were made in thicknesses 8, 12 and 15 mm. Also comparisons between different steel grades and primer conditions were experienced. As noted in the following test report (Table 2), the main problem using the standard technique is the uncontrolled exothermic reaction between material and oxygen (burning). Problems typically occur in relation with narrow geometries, 90 degree and sharper corners, small hole diameters, too drastic changes in the cutting direction, when passing already kerfs or passing major scratches in the surface, when the primer thickness variation is too large, when passing painted areas e.g. plate ID-numbering or minor disturbances of any art in the process. The above mentioned problems causes time waste and destruction of many components/material, which means a lowered productivity and expensive components.

Similar experiences were achieved with the same materials in 8 and 15 mm thickness.

## 7 CONCLUSION

A new laser cutting technique, named "Dual-Focus Laser Cutting", has been presented. The technique is based on a single transmitting or reflecting optical element creating two fixed focal points at two different positions spaced from each other in direction of the materials

**Table 2. Results obtained with 12 mm zinc-primed mild steel.**

**Material: 12 mm zinc-primed mild steel.**
**SSAB St.2144: C 0.17 Mn 1.54 Si 0.49**
**Dillinger St.2144: C 0.137 Mn 1.58 Si 0.428**
**Domex 355MCB: C 0.07 Mn 0.50 Si 0.01**
**Machine: Bystronic. Laser power, 2800 watt.**

| | Lens | Focus | Nozzle diam. | Nozzle distance | Gas pressure | Speed | Comments |
|---|---|---|---|---|---|---|---|
| **Standard** | 7.5'' | 0. pos. at matr. surface | 1.5 mm | 0.7 (mm) | 02 / 0.4 atm | 1000 mm/min | – Domex generally showed to be the best material to cut in terms of stability and cut edge quality.<br>– Dillinger is practically impossible to cut.<br>– Uncontrolled exothermic reaction between material and oxygen (burning) is the major problem.<br>– Problems cause waste of time and destruction of many components/ material, hence a lower productivity and expensive components. |
| **Dual-Focus** | 15DFA 190-150-060 | F1: 0 mm<br><br>F1: upper focus | 1.5 mm | 0.5 mm | 02 / 0.4 atm | 1100 mm/min | – Quality OK, no dross, no post treatment of components.<br>– Problems regarding uncontrolled burning practically eliminated.<br>– Speed increased by 10%.<br>– All 3 steels can be cut. Domex still gives the smoothest cut edge quality. |

thickness to be cut. A number of advantages are related to this cutting technique. For cutting mild steel, stainless steel or aluminium a high intensity beam can be maintained on the upper surface of the material in order to create the required ignition of the material as well as maintaining a high intensity beam near the bottom material surface suitable for creating a clean kerf all through the material thickness. The following advantages have been experienced through tests carried out in laboratory and under industrial conditions:

– Increased thickness capability.
– Increased cutting speeds.
– Improved cut quality.
– Improved piercing technique.
– Improved process stability.
– Less sensitive regarding focal point position.
– Advantageous for "flying optics" systems, even for thin sheet cutting.
– Allows smaller cutting gas nozzles, leading to reduced gas consumption.
– To be implemented in every existing as well as new laser cutting machine.

Optical calculations for Dual-Focus lenses have been carried out by V & S Scientific. These illustrate the relation between the intensity profiles in the foci region. Such calculations are important in terms of understanding the beam propagation behaviour and the process experiences. A number of industrial experiences achieved by industrial end-users are reported. These examples illustrate that both different cutting machines as well as different materials and material thicknesses can benefit from the new cutting technique. At FORCE Institute the development of the new cutting technique is an intensively ongoing process. Further activities related to the Dual Focus laser cutting technique will be to optimise the relationship between foci distances and power distribution as well as evaluating the tolerances involved for these parameters. Also phenomenological studies in order to understand the process/melt dynamics will be carried out. Another important subject related to the new technology is the development of tailored gas nozzles to further improve the laser cutting process.

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