Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Procedia CIRP 24 (2014) 130 – 133
www.elsevier.com/locate/procedia

New Production Technologies in Aerospace Industry - 5th Machining Innovations Conference (MIC 2014)

High speed laser micro drilling for aerospace applications

Andreas Stephen[a,*], Geza Schrauf[b], Salar Mehrafsun[a], Frank Vollertsen[c]

[a]*BIAS - Bremer Institut für angewandte Strahltechnik, Klagenfurter Str. 2, 28359 Bremen, Germany*
[b]*AIRBUS OPERATIONS GmbH, Airbus Allee 1, 28199 Bremen, Germany*
[c]*BIAS - Bremer Institut für angewandte Strahltechnik and University of Bremen, Klagenfurter Str. 2, 28359 Bremen, Germany*

* Corresponding author. Tel.: +49-421-218-58017 ; fax:+49-421-218-58063.*E-mail address:*stephen@bias.de

Abstract

To realize a reduced fuel consumption of civil jet transport aircrafts, hybrid laminar flow control (HLFC) is a key technology in aerospace industry. For drag reduction caused by boundary layer suction, small holes at the leading edges of the aircraft wings and tail planes are needed. Much effort has been spend in drilling of small holes into different materials. Nevertheless, the economically drilling of small holes in the range of 50 to 100 µm in diameter on large areas is up to date crucial. Apart from processing time this is also due to the demand of close tolerances in case of suction holes. Additionally, minimization of the thermal distortion when drilling large areas gets more challenging. This paper deals with the transfer of the laser drilling process to an adequate system technology for the fabrication of large suction inserts using a short pulsed fiber laser with a power of 200 W at a pulse repetition rate of 200 kHz. The laser combined with a galvanic scanner and a plane field optic leads to a precise and fast drilling over an area of 100 mm x 100 mm. Using a precise stage several of these drilling fields can be placed side by side to machine the complete panel area. The amount of drilled through-going holes and their roundness as well as the distortion of the panel is influenced by the applied drilling sequence and energy input. As a result, round micro holes down to 30 µm in diameter can be produced with a drilling rate of more than 400 holes per second in 0.8 mm thick titanium sheets.

Selection and peer-review under responsibility of the International Scientific Committee of the "New Production Technologies in Aerospace Industry" conference in the person of the Conference Chairs: Prof. Berend Denkena, Prof. Yusuf Altintas, Prof. Pedro J. Arrazola, Prof. Tojiro Aoyama and Prof. Dragos Axinte

*Keywords:*Hybrid laminar flow control; boundary layer suction; laser drilling; system technology

1. Introduction

Hybrid laminar flow control (HLFC) is an active drag reduction technique. The transition from a laminar to turbulent boundary layer is marked by a sudden increase in the thickness of the boundary layer and a significant change in the local flow behavior. The random variation of velocity and flow direction within the turbulent boundary layer results in an order of magnitude increase in the skin friction compared to that of laminar flow. By sucking a small amount of the air in the external flow through the skin surface, the transition of the boundary layer from laminar to turbulent flow mechanisms can be delayed. As skin friction drag accounts for nearly 50% of the total drag of a civil jet transport aircraft in cruise, technologies that enable laminar flow to be maintained offer the potential for enormous economic and environmental benefit [1].

The design and the manufacture of the suction surface represent one of the most significant engineering challenges concerning HLFC. Various means of producing a skin surface, which will allow air to be sucked through it, have been studied as part of the laminar flow control research that started in the 1940s. The suction surfaces that have been developed can be divided into different categories, one of them is discrete holes drilling by electron or laser beam. Laser drilling has been the preferred technique since the mid-1980s [2]. Ideally, the shape of the hole is cylindrical. Since such holes are difficult to realize by laser drilling, a weak tapering is allowed. For such

Selection and peer-review under responsibility of the International Scientific Committee of the "New Production Technologies in Aerospace Industry" conference in the person of the Conference Chairs: Prof. Berend Denkena, Prof. Yusuf Altintas, Prof. Pedro J. Arrazola, Prof. Tojiro Aoyama and Prof. Dragos Axinte
doi:10.1016/j.procir.2014.08.002

holes the smaller diameter should be outside to prevent dust blocks suction through the holes. This shape of the hole occurs naturally to some extent, as the hole on the beam entry side is always bigger than on the exit side [3]. It is apparent that the parameters of hole size, pitch and skin thickness are not independent of each other and need to be considered together in the design and manufacture of the suction surface.

In laser drilling the combination of the pulse peak power and duration significantly influences the material removal mechanism. The micro-hole drilling processing using nanosecond pulses usually produces holes in metal with acceptable quality, but in general, worse than those by an EDM process because of melting [4]. The material removal rate is usually in the order of 1-10 µm/pulse. The power density of these lasers is in the range of GW/cm^2. Ultra-short pulse lasers operating in the femtosecond or picosecond range produce peak power densities in the range of 10-1000 GW/cm^2. A hole produced with these ultra-short pulses exhibit a clean finish because melting is not significant; however, the material removal rate is usually very low, in the range of 10-200 nm/pulse [5].

Laser drilling presents three different variants. Firstly, the laser trepanning process, which consists in translating the laser beam in circular paths to cut the perimeter of the hole [6]. It is rather a laser cutting process than a drilling process. Secondly, the laser single-pulse laser drilling process is a very fast process, in which all the material is removed in a single pulse [7]. It is mainly used in low-thickness parts or holes with less than 1:10 aspect ratios. Finally, the laser percussion drilling is based on removing material by a sequence of pulses. Each pulse removes a certain volume of material, so that the entire sequence of pulses can achieve deep sized holes with diameters ranging between 25 and 500 µm [8]. One of the main problems in percussion laser drilling is the low repeatability of the process with respect to the geometry of the holes due to burr generated around the hole caused by the melt ejection [9].

2. Experimental

2.1. Laser drilling system

A programmable galvanometer scanner guides the laser beam accurately with a lateral resolution of 1 µm at high speeds up to 3 m/s over the target panel. A beam expansion telescope is integrated to increase the diameter of the beam in front of the scan head before focusing for achieving smaller spot sizes. In a pre-objective 2-axis scanning arrangement, the laser beam passes through and is steered by a set of x and y mirrors that are coupled to galvanometers. The orthogonal arrangement of the x and y mirrors directs the beam down towards the work piece over the length and width of the scan field. Field distortion is compensated with an F-Theta lens (170 mm focal length) after the two-mirror system. This enables both a large scan field (100 mm x 100 mm) and a small spot size (40 to 80 µm depending on the telescope adjustment) at perpendicular incidence of the laser beam. The scan head is mounted on a z-axis to adjust the focal plane with respect to the work piece, see Fig. 1.

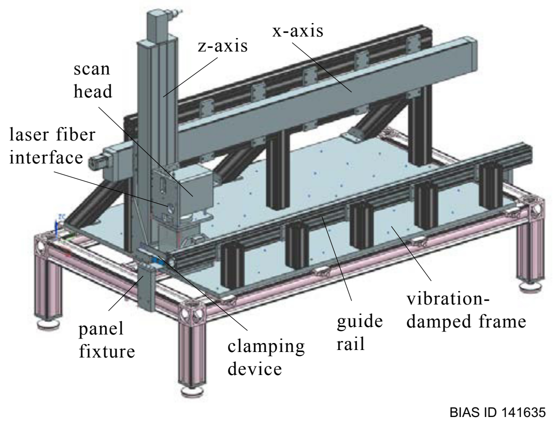


Fig. 1. Laser beam drilling system.

The solid state laser used in this set-up is a pulsed fiber laser (IPG model: YLP-HP-1-30x240-200-200) operating at a wavelength of 1065 nm in its fundamental Gaussian mode at a maximum output power of 200 W. Triggering permits pulsing operation up to 1000 kHz. Since it delivers short pulses switchable between 30 to 240 ns high peak powers of up to 1 GW/cm² can be achieved.

In contrast to common drilling systems, the work piece is fixed in this arrangement. Instead, the z-axis used for the height adjustment of the scan head is mounted on an x-axis with a travel range of 2200 mm. This enables to perforate a panel of 2000 mm length by consecutively adding up to 20 scan fields. A pneumatic clamping device is firmly mounted onto the z-axis, allowing a fixing of the processed panel area in a defined distance to the scan head, see Fig. 2. Furthermore, it also suppresses thermal distortion during processing.

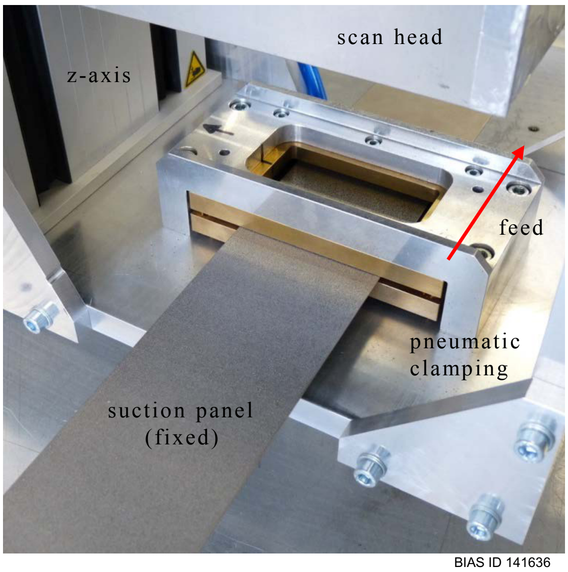


Fig. 2. Pneumatic clamping device.

2.2. Hole analysis

For a non-destructive evaluation of the bore parameters images of drilled holes were recorded by transmitted light microscopy using diffuse lighting, see Fig. 3. The microscopic images were automatically analysed by an edge detection algorithm implemented in a Matlab script. Thereby, the determined diameter depends on the grey value threshold used for the edge detection. To calibrate this threshold to the real diameter a cross-section of the used sample for transmitted light microscopy was prepared, see Fig. 4. As it is nearly impossible to prepare a cross-section exactly in the middle of one micro hole a whole row of drilled holes was analysed. This enables even if the cross-section is tilted the selection of one hole crossed almost in the middle, i.e. the widest one assuming all holes have the same diameter.

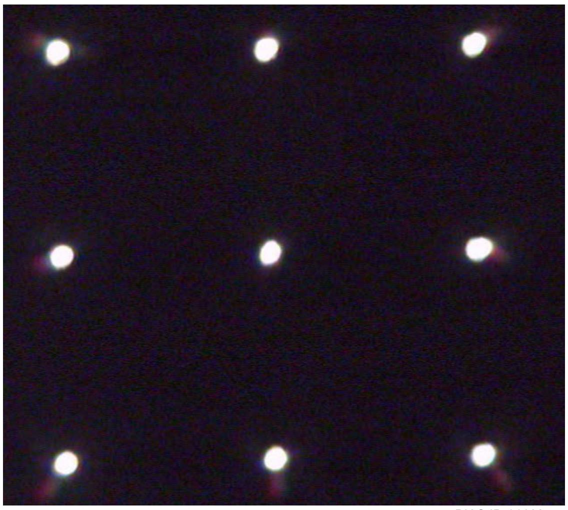
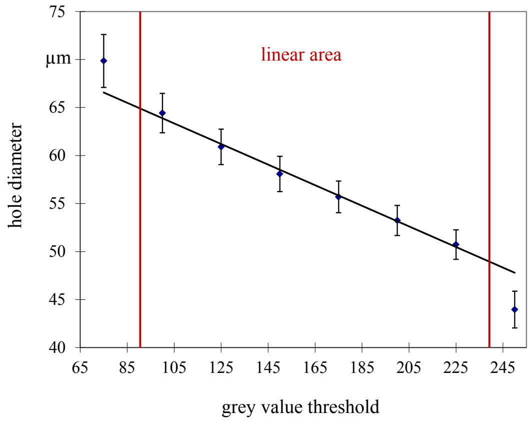

BIAS ID 141637

Fig. 3. Transmitted light microscopy of drilled holes in Ti.

BIAS ID 141638

Fig. 4. Cross-section of laser drilled holes in Ti.

When the bore diameter is determined the corresponding grey value threshold can be calculated. This is done by using the dependence of the calculated diameters on the grey value threshold. An analysis of the frequency distribution of the grey values shows that they are constant distributed between 90 and 240. This area can be associated with the edge region, where the diameter changes linearly, see Fig. 5. In this case the natural bore diameter of 50 µm corresponds to a threshold of 230. When the algorithm is calibrated using this threshold the bore diameters in every lateral direction for every drilled hole can be detected automatically in a non-destructive way. Therewith, the diameter and its tolerance, the roundness and the reproducibility can be analysed for the drilling result.



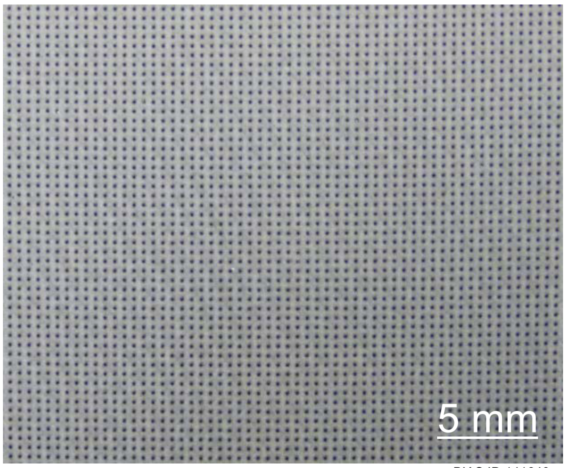
BIAS ID 141639

Fig. 5. Calculated bore diameter versus threshold used for edge detection.

3. Results

The aim of the work carried out was the fabrication of perforated metallic panels made of 0.8 mm thick titanium for aeronautical applications, i.e. suction surfaces for hybrid laminar flow control, by short-pulsed laser percussion drilling. Preferably, burr formation at the bore edge and thermal distortion of the panel should be most extensively suppressed. These investigations include the evaluation of bore diameters, reproducibility, roundness and efficiency.

The evaluation of efficiency showed that with the used laser the highest drill rates can be achieved at pulse duration of 120 ns applying an average laser power of 200 W and a pulse repetition rate of 200 kHz. This equals the maximum pulse energy of 1 mJ for the laser. Under these conditions 500 pulses must be applied to drill through the 0.8 mm thick titanium, which equals 2.5 ms or 400 holes/s. The achieved suction surface at beam entrance is shown in Fig. 6.



BIAS ID 141640

Fig. 6. Suction surface; hole distance 0.5 mm, beam entrance side.

For a suppression of the thermal distortion a combination of two strategies were applied. Firstly, a pneumatic clamping device prevents any movement of the panel in the area of the scan field and dissipates the heat efficiently from that zone. Secondly, the drilling sequence is designed so that the panel is mostly uniformly heated. This is performed by drilling in a first step a hole-pattern with 2 mm distance, than adding the holes for a pattern with 1 mm distance, and finally achieving the required 0.5 mm hole-distance. This result in a slight thermal distortion of the panel with a deviation in height less than 1 mm over several centimeters, see Fig. 7.

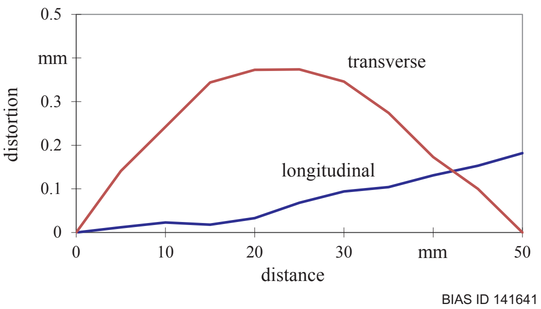


Fig. 7. Distortion of the panel, beam exit side.

Beneath drilling rate and panel distortion, quality is an essential aspect for suction surfaces. Today's fiber lasers offer the possibility to drill fast at even high qualities. Fig. 8 shows micro drillings former achieved with a Nd:YAG laser (0.6 mm Ti) and now with a fiber laser (0.8 mm Ti) at the same wavelength and pulse duration, applying the same energy but at higher possible repetition rates with the fiber laser. However, melted material at the side walls can be observed with nanosecond pulses. On the basis of analyzed 100 holes an average diameter of 50 µm with a tolerance of 5 µm can be observed for the drilling conditions using the fiber laser, see Fig. 9.

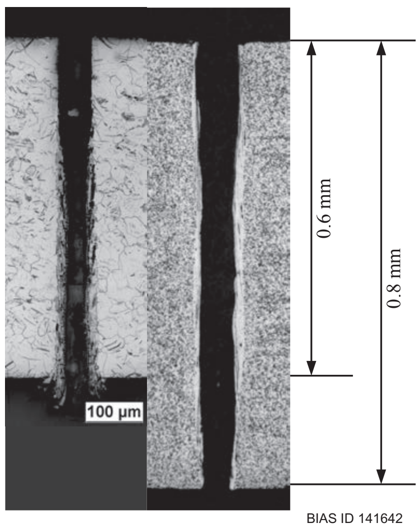


Fig. 8. Micro hole drilled in (left) 500 ms; (right) 2.5 ms.

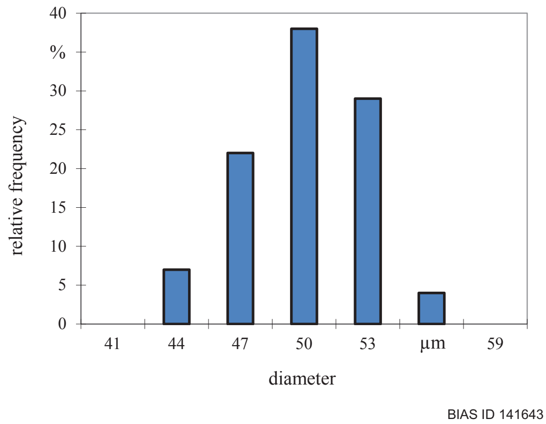


Fig. 9. Relative frequency of the realized bore diameters achieved with the short-pulsed fiber laser (120 ns, 200 W, 200 kHz).

4. Conclusion

In the manufacture of suction surfaces for aviation by discrete hole drilling both economical (hundreds of holes per second without thermal distortion) and qualitative (small holes with close tolerances in thicker sheets) aspects must be considered. Today's short pulsed fiber lasers can meet these demands if the system and processing technology will be adapted and optimized.

Acknowledgements

The authors gratefully acknowledge the support of the Clean Sky Joint Technology Initiative within the 7th Framework Program of the European Union (GA n°338546).

References

[1] Schrauf G. Status and perspectives of laminar flow. The Aeronautical Journal 2005;1102:639-44.
[2] Young TM, Humphreys B, Fielding JP. Investigation of hybrid laminar flow control (HLFC) surfaces. Aircraft Design 2001;4:127-46.
[3] Li L, Low DKY, Ghoreshi M, Crookall JR. Hole Taper Characterisation and Control in Laser Percussion Drilling. CIRP Annals 2002;51: 153-6
[4] Li L, Diver C, Atkinson J, Giedl-Wagner R, Helml HJ. Sequential Laser and EDM Micro-drilling for Next Generation Fuel Injection Nozzle Manufacture. CIRP Annals 2006;55:179-182.
[5] Tu J, Paleocrassas AG, Reeves N, Rajule N. Experimental characterization of a micro-hole drilling process with short micro-second pulses by a CW single-mode fiber laser. Optics and Lasers in Engineering 2014;55:275–83.
[6] Ashkenasi D, Kaszemeikat T, Mueller N, Dietrich R, Eichler HJ, Illing G. Laser trepanning for industrial applications. Physics Procedia 2011;12: 323–31.
[7] Schulz W, Eppelt U, Poprawe R. Review on laser drilling: I. Fundamentals, modeling, and simulation. Journal of Laser Applications 2013;25:012006.
[8] Arrizubieta I, Lamikiz A, Martínez S, Ukar E, Tabernero I, Girot F. Internal characterization and hole formation mechanism in the laser percussion drilling process. International Journal of Machine Tools & Manufacture 2013;75:55-62.
[9] Ng GKL, Li L. The effect of laser peak power and pulse width on the hole geometry repeatability in laser percussion drilling. Optics and Laser Technology 2001;33:393-402.