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Laser micro drilling of wing surfaces for hybrid laminar flow control

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Abstract

Hybrid laminar flow control (HLFC) technology can lead to a significant reduction of up to 10 % of fuel consumption for large passenger aircrafts. A reduction of fuel consumption not only decreases the operative costs but it also reduces the environmental impact of the aircraft. Therefore, areas at the front area of the wings are being perforated by millions of micro holes with diameter of approx. 50 – 100 µm. A part of the airflow is sucked through these holes so that the airflow over the wing surface can be controlled to be laminar instead of turbulent. Another advantage is the anti-icing possibility on cold winter days wherefore hot air is blown through these micro holes before and during take-off and landing. Thus, time-consuming manual anti-icing processes of the wings are no longer necessary.
The challenge is the productive manufacturing of millions of micro holes. Fraunhofer ILT developed a high productive "on-the-fly" laser drilling process with drilling rates of up to 200 holes per second in 1 mm thick titanium sheets. A pulsed singlemode fiber laser source is used in combination with a drilling optic with coaxial process gas supply. Each laser pulse with durations in the range of 500 µs drills one micro hole. The velocity of the relative movement of the drilling optic and the work piece and a constant repetition rate of the laser source of e.g. 200 Hz set the pitch between any two holes. By implementing an interferometric based measurement system for controlling the distance between drilling optic and work piece the process has successfully been transferred to 3D components such as wing demonstrators with internal structures.

Keywords: Laser drilling, hybrid laminar flow control

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1. Introduction

The worldwide air traffic increases continuously. Especially in countries such as India, China or Indonesia the passenger journeys will triplicate until 2034 [1]. Nowadays, approx. 12,000 airplanes are at the same time in the air. Thus, a high amount of environment pollution is generated so that solutions have to be developed to decrease the fuel consumption of airplanes. One method is hybrid laminar flow control. Therefore, the wing leading edge is perforated by several millions of micro holes with diameters of e.g. 60 µm. A part of the air flowing over the wing is sucked in through these micro holes so that the airflow over the wing is laminar instead of turbulent, Fig. 1. By using this flow control up to 10 % of fuel consumption can be achieved due to less drag at the wings. The challenge is the manufacturing of the micro holes. Laser drilling is one promising technology for this task.

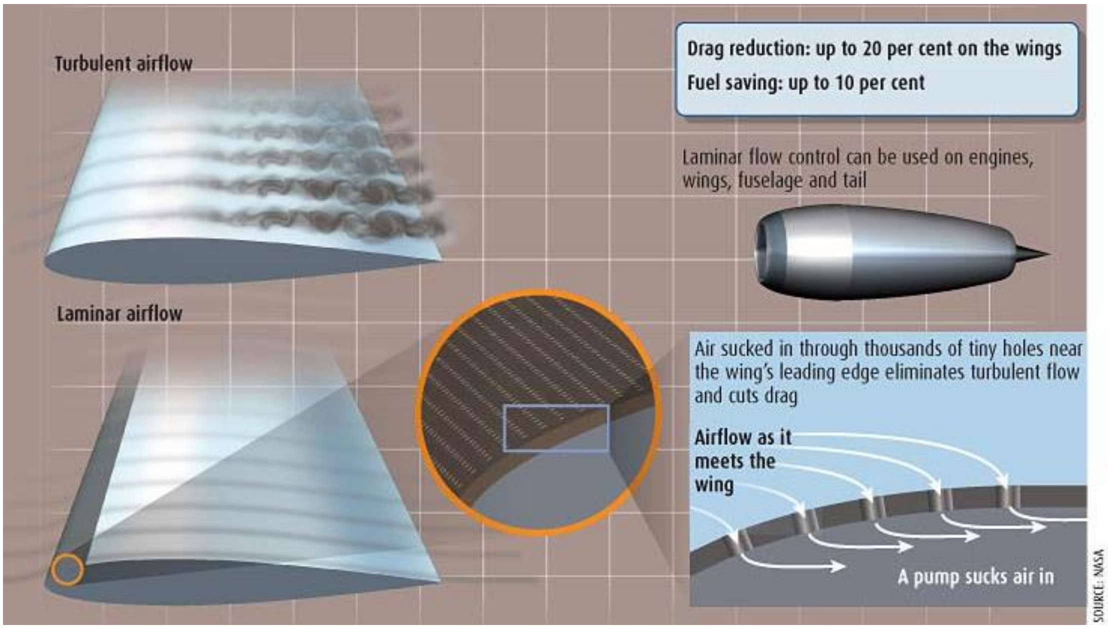

Fig. 1. Schematic of hybrid laminar flow control [1]

2. Experimental setup

As millions of micro holes have to be drilled, only a high productive drilling process has to be used. Therefore, a melt-dominated drilling process using QCW single mode fiber laser radiation is suitable. A QCW single mode fiber laser source from IPG Photonics YLR-150/1500-QCW has been used in combination with a drilling optic from Precitec with both 100 mm collimation and focusing length, Fig. 2. Maximal possible pulse peak power of the laser source is 1.5 kW at pulse durations between 0.1 and 10 ms and repetition rates of 1 up to 500 Hz. Based on the optical setup a focal diameter of approx. 12 µm is achieved. Furthermore coaxial process gas is necessary to expel the melted material out of the holes. As the work piece consists of 1 mm thick titanium, Argon has to be used as process gas because titanium reacts very exothermic with oxygen.

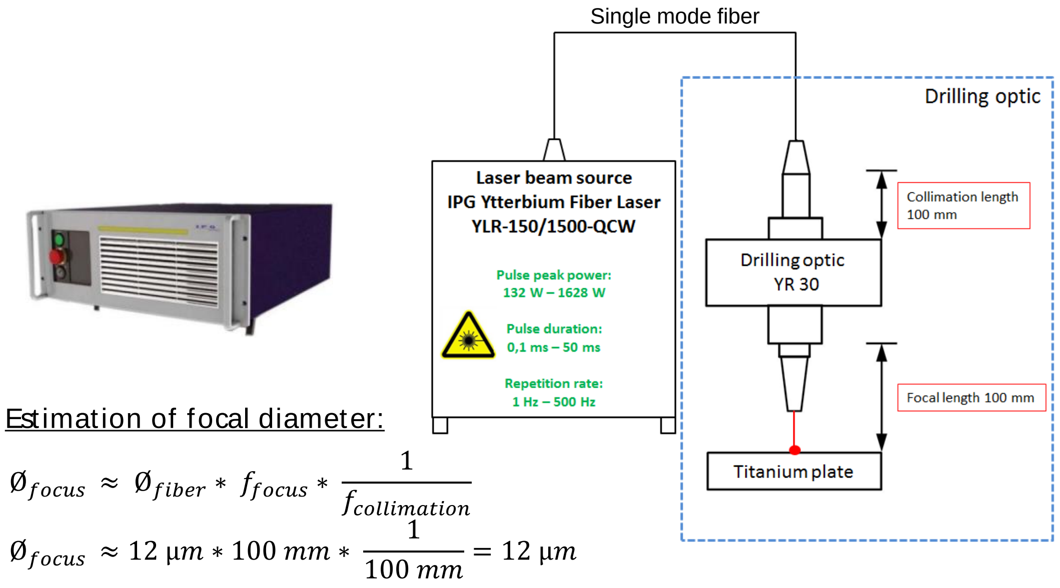

Fig. 2. Schematic of the setup of equipment

The drilling process is performed “on-the-fly”. The laser source emits pulses with a fix repetition rate and the optic is moved with a constant velocity over the workpiece, Fig. 3. The pitch between any two holes results of the combination of repetition rate and velocity.

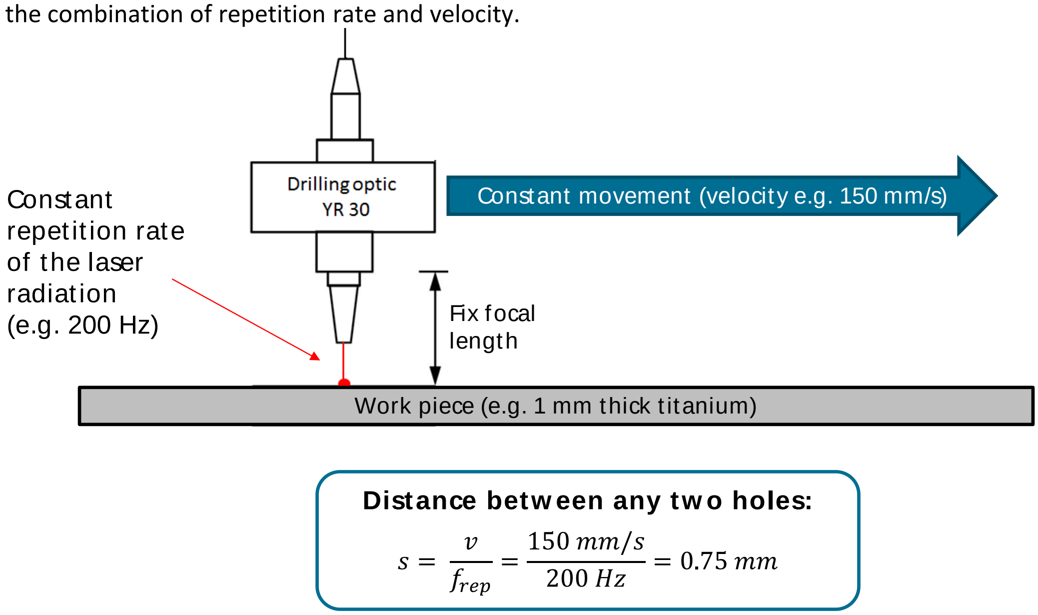

Fig. 3. Schematic for laser drilling “on-the-fly”

3. Experimental results

3.1. Development of the drilling process

A variation of pulse peak power is shown in Fig. 4 with the effect on hole entry and exit diameter. The resulting holes are conical with a diameter of 75 µm using a pulse peak power of 800 Watt. Increasing the pulse peak power up to 1500 W leads to negative conical holes where the hole entry diameter (60 µm) is smaller than the hole exit diameter (90 µm). As the focus of the laser radiation is set to the upper surface of the work piece and the Rayleigh length of the laser radiation is very short (0.2 mm) , the hole geometry shows the caustic of the laser radiation. For the application of hybrid laminar flow control negative conical holes are beneficial so that the pulse peak power of 1.5 kW will be used for all further experiments.

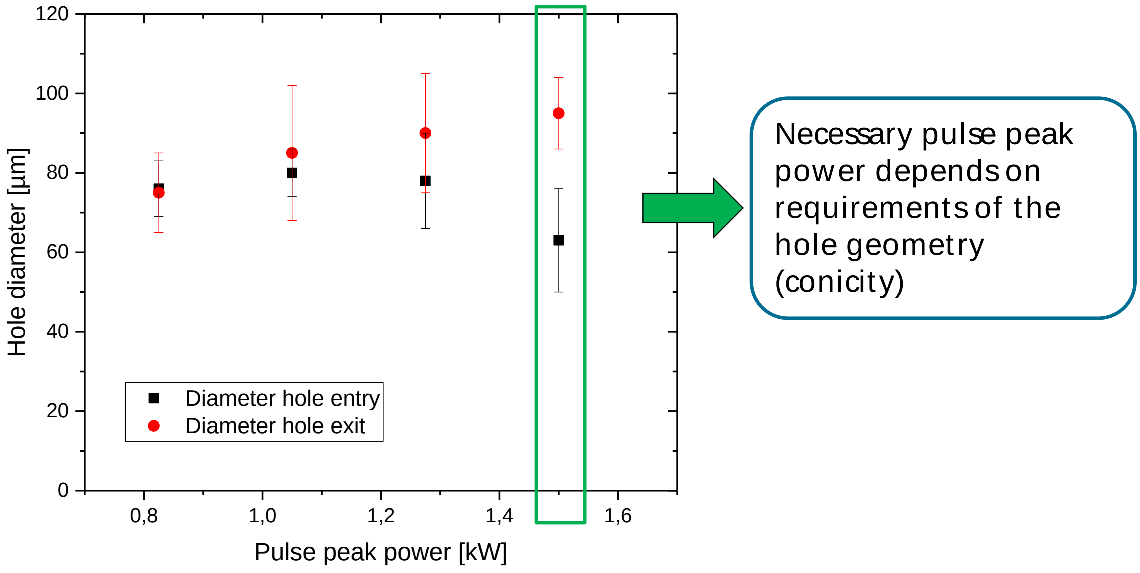

Fig. 4. Hole entry and exit diameter in dependence of the pulse peak power

The hole entry and exit diameter as well as the percentage of clogged holes in dependence of the pulse duration are shown in Fig. 5. If the pulse duration is smaller than 0.25 ms, up to 30 percent of the drilled holes are clogged. This is based on too less time for sufficient material removal out of the holes. An increase of pulse duration larger than 0.25 ms leads to an increase of hole diameter. Thus, 0.25 ms is defined as a suitable pulse duration and will be used for all further experiments.

A variation of the repetition rate during on-the-fly drilling is combined with a suitable adaption of the velocity of the relative movement between drilling optic and work piece. Repetition rates up to 200 Hz are suitable so that the result are holes with a high roundness. By a further increase of the repetition rate, elongated holes occur due to a too long movement range during the single laser pulses.

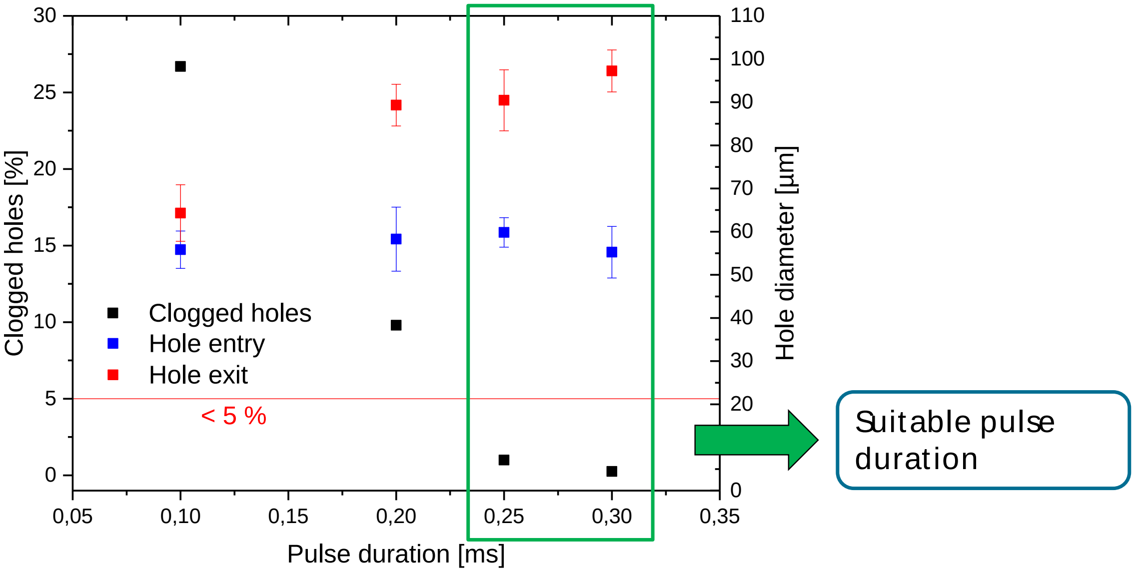

Fig. 5. Hole entry and exit diameter in dependence of the pulse duration

The resulting holes are shown in Fig. 6. Due to the repetition rate of 200 Hz, 200 holes can be drilled in one second.

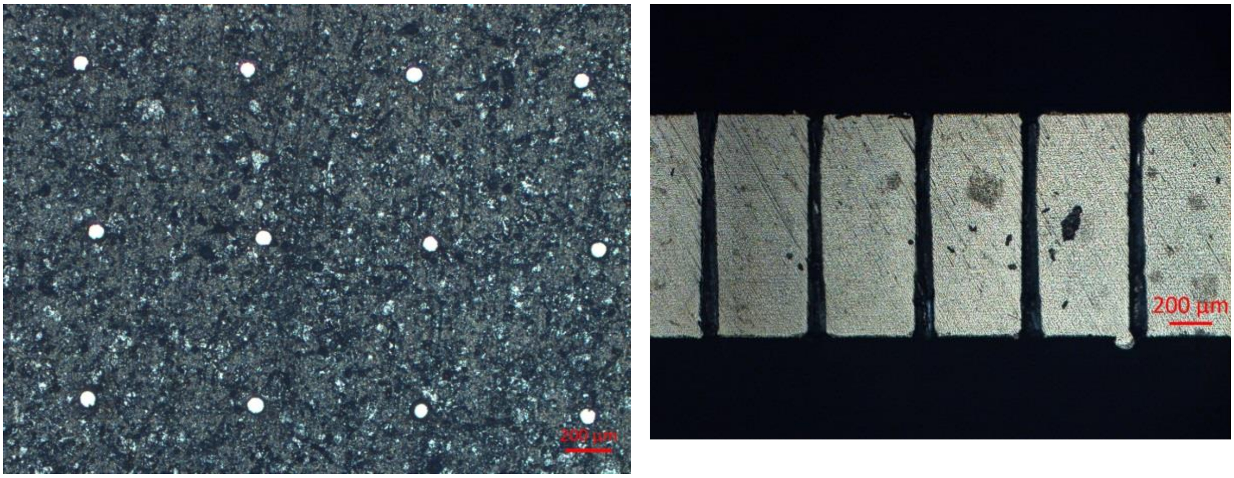

Fig. 6. Top view of the micro drilled holes with through light (left) and longitudinal section of the holes (right)

3.2. Transfer to 3D components

Finally, large 3D wing leading edge structures with lengths up to 3 m shall be micro drilled. Thus, a possibility to transfer the process to 3D components has to be developed. Therefore, a 6-axis gantry system with traveling lengths of 2,5 x 2,0 x 1,5 m (X x Y x Z) from Reis has been used. The NC-programs are generated by a suitable CAD-CAM coupling. As the Rayleigh length of the laser radiation is very short (0,2 mm), a fast working online distance control system between the process gas nozzle of the drilling optic and the work piece has to be implemented. An interferometric working measurement system based on optical coherence tomography (OCT) is most suitable as the measurement wavelength of 1550 nm is not influenced by spatters or possible plasma of the drilling process. The measurement signal is processed so that an additional z-axes controls the distance between work piece and drilling optic precisely.

4. Conclusion

Hybrid laminar flow control leads to significant reduction of fuel consumption of air planes of up to 10 %. The necessary micro holes can be drilled by using QCW single mode fiber laser radiation. As the process can be performed “on-the-fly”, up to 200 holes per second can be drilled using one laser source and drilling optic. A further increase of productivity can be achieved by using several laser sources and drilling optics. As 3D components such as wing leading edges with dimensions of e.g. 3 m can have tolerances and the Rayleigh length of the single mode laser radiation is very short (0,2 mm), an online distance control system between drilling optic and work piece is mandatory. OCT-based systems are suitable as the measurement signal is not influenced of spatters or plasma.

References

[1] IATA Air Passenger Forecast Shows Dip in Long-Term Demand, 26.11.2015