Developments on Laser Drilling in Gas Turbine Blades

Authors

Thomas Beck, Jens Dietrich
Siemens PG
Huttenstraße 12
10553 Berlin, Germany
phone: +49 (0)30 3461 2841
e-mail: beck.tb@siemens.com
Website: www.siemens.com

Keywords

Drilling, Ablation, Surface Functionalization

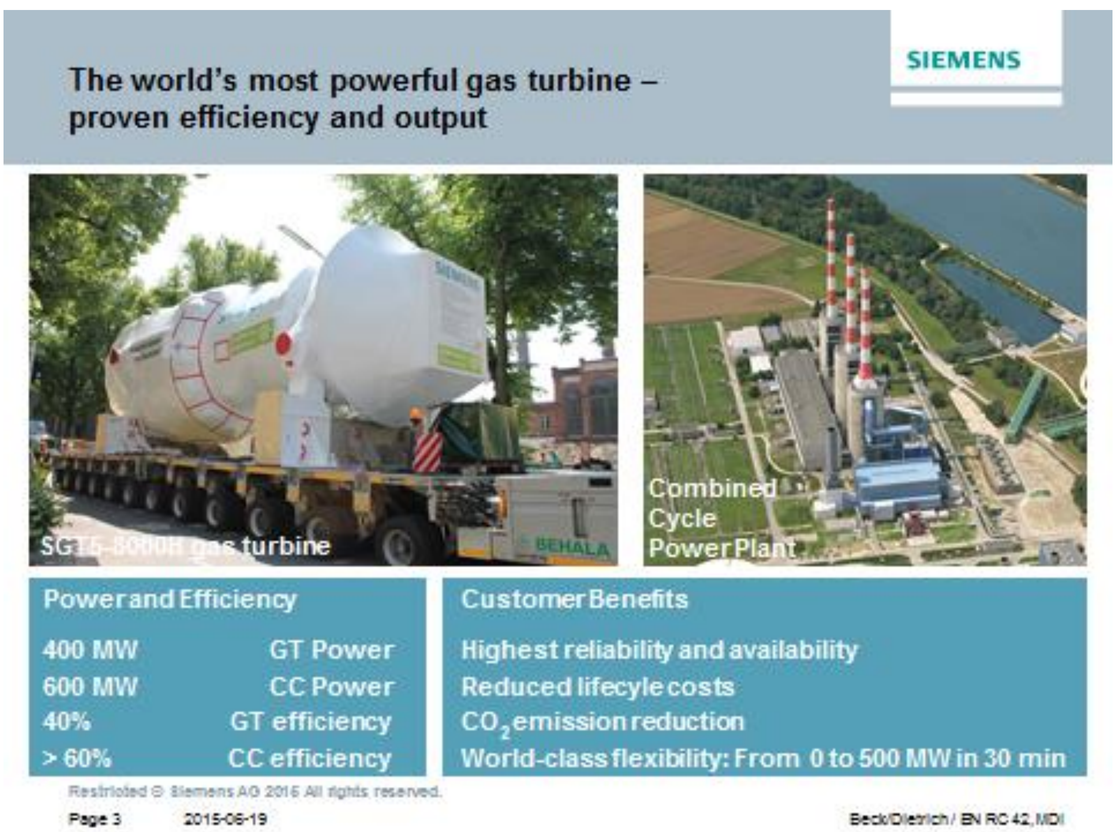
Abstract

Drilling applications represent about 5 % of the industrial laser materials processing applications. Cooling holes in gas turbines for aircrafts as well as for power plants are one of the main applications. The improvement of productivity has led to several drilling strategies with respect to laser sources (thermal drilling and ablation drilling), the beam handling, beam distribution, and handling of the work piece, all of which contribute to the over-all efficiency of the process and a high productivity.

We present the successful development and implementation of a combination of laser systems with different pulse durations for drilling complex 3D geometries. Additionally an overview on actual fields of development is presented.

Introduction

Drawing on the latest scientific and technical advances worldwide, the SIEMENS gas turbine plant in Berlin builds gas turbines for power plants that are due to their high efficiency especially economical and environmentally friendly. The latest product innovation is a gas turbine called the SGT5-8000H. This power pack has an output power of 375 MW, which is definitely a world record. Gas turbines represent a unique blend of classic heavy machine construction and modern production technologies. Not only the turbine as a whole, but also every blade is a technical masterpiece combining highest precision and performance. There are about 2,400 blades in a gas turbine, each of which is subjected to extreme stress during operation. gas at a temperature of 1,400 ° C impinges on the blades at a speed of 100 m/s. this forces the blades to rotate at 50 or 60 revolutions per second (velocity at the tips of the blades is supersonic). Yet, even in these extreme conditions the blades stay cold. This is achieved through an innovative production technique that makes perfect air-cooling possible. The optimization of air distribution has benefited from the ability of lasers to drill small (typical diameters of 0.4–1.2 mm) cylindrical holes at 15–90 º into the curved blade surfaces. Laser systems for those deep penetration drillings (up to 25 mm) are operated with pulse durations in the millisecond range. Addition, most of the exit holes are shaped to enable a film cooling effect. These shaped holes with individually optimized three-dimensional geometries are generated by a laser ablation process with typical pulse durations of roughly 100 ns. With a specific combination of these large pulse durations one can also produce holes in complex coated turbine blades. Up to four different metallic and ceramic coatings shield the blades from thermal stress and from high temperature corrosion, while all of these layers as well as the base material have different physical properties.



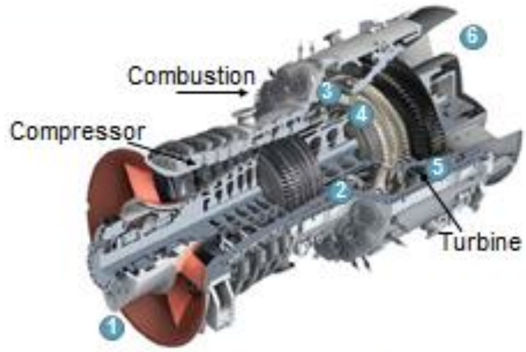
Laser Drilling

Incremental improvements in laser process and control technologies have led to substantial increases in the number of cooling holes in turbine engines. Fundamental to these improvements is an understanding of the influence of process parameters on drilling hole quality and drilling speed. Laser drilling makes it possible to machine both very small and precise holes in various shapes and orientations in a wide range of materials. These holes can be tapered or shaped to enhance the amount and direction of air flowing through them, thus improving the blade’s cooling characteristics. Hundreds or thousands of cooling holes can be drilled in one part with a single setup.

Laser drilling of cylindrical holes in turbine engine components generally occurs through melting and vaporization of the material due to absorption of energy from a focused laser beam. For laser drilling pulsed systems are used, with pulse durations depending on the hole characteristics – for turbine blade drilling typically in the millisecond regime. The pulse energy required is fundamentally determined by the material thickness, composition, and the desired hole diameter. Higher pulse energies provide faster drilling rates but can also decrease hole quality. For pulse generation flash-lamp pumped Nd:YAG lasers are used. Their power is limited by the duty cycle at which a laser can operate without degradation of performance. laser drilling of turbine blades is accomplished using average powers of about 200–400 W. the pulse length is chosen to optimize the hole quality, typically ranging from 0.5 to 2 milliseconds. A laser beam penetrates only a few hundred nanometers into metal. The process transferring energy deep into the material is heat conductivity, causing an energy transport in the direction of the laser beam. Depending on the intensity, different kinds of processes occur; for metals vaporization takes place above 10^7 W/cm^2, melting at about 10^6 W/cm^2, and only below 10^5 W/cm^2 only heating occurs. Whether melting or vaporization is more dominant in a laser drilling process depends on many factors, with laser pulse duration and energy playing important roles. Typically, Gaussian shaped pulse intensity distributions are applied, causing vaporization in the hole center and melting in a surrounding layer . To remove material by melting requires only about 10–20 % of the energy needed to vaporize the same volume, because of the 10 times higher specific vaporization energy compared to the melting energy. When a flash-lamp pumped Nd:YAG laser is used, mainly melting occurs and the process creating a hole is melt expulsion. Although typically coexisting with vaporizaion, melt expulsion dominates the scene in this case. It arises as a result of the rapid build-up of gas pressure within a growing bore cavity created by evaporation. When a molten layer forms and the pressure gradients acting on the surface due to vaporization are sufficiently large to overcome surface tension forces, the molten material is expelled from the hole.

A View into the Gas Turbine - 0,5 mm Diameter Cooling holes in a 440 t heavy Gas Turbine

SIEMENS



1. Air suctioning into compressor
2. Compression to 20 bar
3.
4. Heating up by 16 burners
5. Turbine entrance temperature is above 1500° C
6. Turbine blades change the thermal energy in a rotating movement (3000 rounds/min => supersonic speed

Turbine exit temperature is about 600° C (hot enough to load a steam turbine => CC: Combined Cycle)


Turbine blade assembly


Turbine blade during laser drilling

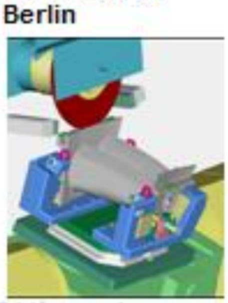

Laser drilled 1. stage blade

Cross Section of a laser drilled Turbine blade

Main Process Steps in Gas Turbine Blade and Vane Manufacturing

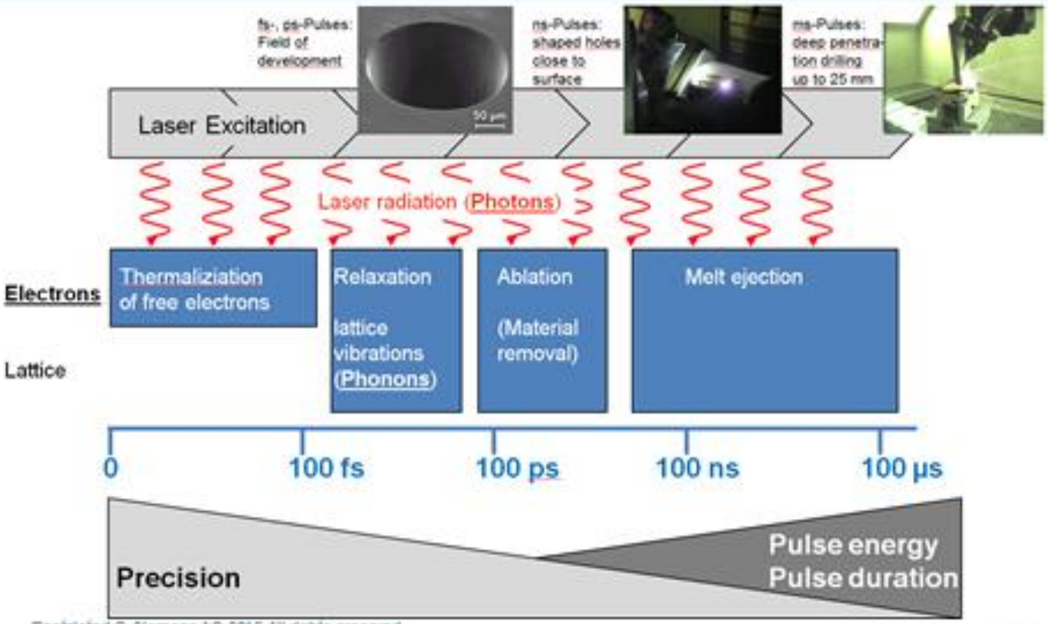
SIEMENS

Casting	→	Machining	→	Coating	→	Drilling
Ni- and Co-Based Alloy - SX - DX		- Grinding - Milling - EDM		- CVD - VPS (LPPS) - APS - HVOF - EB-PVD		- Laser - EDM, ECM **Assembly** - Welding - Brazing - NDE (FPI, airflow
Casting Houses (External Vendors)		**Siemens Gas Turbine Plant Berlin**		**TACR** (Turbine Airfoil Coating & Repair, 100 % Siemens)		**Siemens Gas Turbine Plant Berlin**



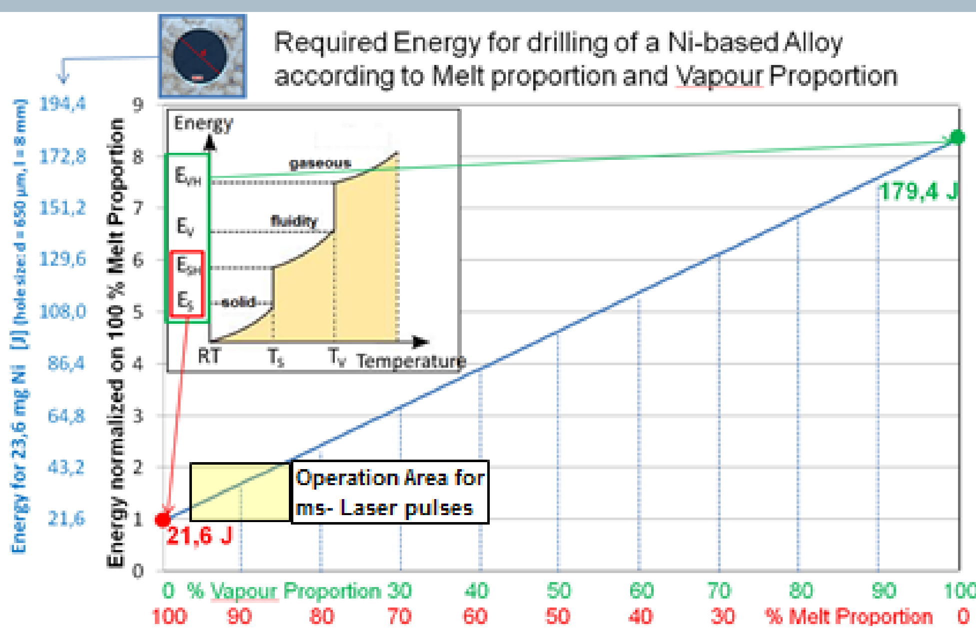
SIEMENS

Laser Radiation – Material interaction during Laser Drilling



SIEMENS

Melting and Vaporization Energy during Millisecond Laser Drilling



Maxium Drilling Depth and Economical Achieveable Aspect Ratios during Laser Drilling

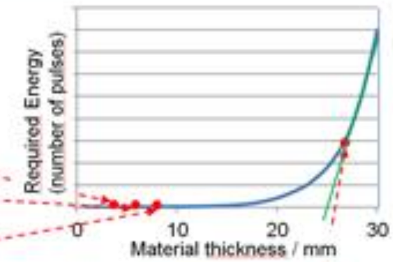
SIEMENS

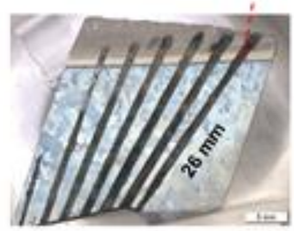
Pulse Para.:
t_P = 0,6 ms
E_P = 9 J
P_P = 15 kW

Number of required laser pulses for drilling of 10 samples for 3 different material thicknesses

Drilling depth [mm] \ Number of pulses	2	3	4	5	6	7	8	9	10	Aver-age
4		3	7							3,7
6					9	1				6,1
8							2	8		8,8

Drilling depth [mm]	required pulses	required Energy [J]	Energy p. length [J/mm]
4	3,7	33,3	8,3
6	6,1	54,9	9,2
8	8,8	79,2	9,9





Equipment for ms- and ns-Laser Pulses for Shaped Formed Diffuser Cooling Holes

SIEMENS