Application Note for Industry

Cooling Holes Inspection

with NOVACAM™ SURFACEINSPECT™ 3D Metrology System

Keywords: film cooling holes, cooling air holes, diffuser, trailing edge cooling slots, tip cap cooling holes, blade platform cooling holes, metering hole, rib turbulators, rotor blades, stator blades, drill offset, 3D inspection, defects, dimensions, surface roughness, thermal barrier coating, TBC, non-contact, non-destructive inspection, aerospace, power generation, NDT, robot tools, end-of-arm tooling

Introduction

Film cooling is a key functional aspect of turbine blade design that keeps the temperature of jet engine turbines and land-based gas turbines at an acceptable level. In modern jet engines for example, turbine stage inlet temperatures exceed the melting points of the blade materials. To avert heat-related turbine blade failure, multiple small-diameter holes are drilled into the hollow blades to discharge cooling air from the blade interior onto its surface. These cooling holes are typically machined using lasers, electrical discharge machining (EDM), or, occasionally, electro-chemical machining (ECM).

Since the efficiency of cooling holes depends on their final shape, inclination angle, and spacing, they must pass tight quality controls–both during blade production and during engine reconditioning. Current testing procedures, such as overall air flow measurements through the blade, leave much room for improvement.

NOVACAM SURFACEINSPECT system now offers powerful capabilities and valuable insight to the cooling holes inspection process. Equipped with a non-contact optical scanner, the system acquires and assesses the 3D geometry of cooling holes in both aerospace and power generation sectors. It does so at high speed, with micron precision, and with unprecedented versatility in terms of setup.

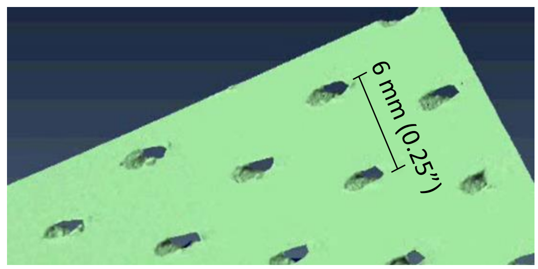

Figure 1: Surface of a combustion chamber liner featuring cooling holes (acquired by SURFACEINSPECT system)

Surface Acquisition

Based on low-coherence interferometry, the SURFACEINSPECT system acquires high-precision 3D topography of surfaces in a point-by-point manner with speed of up to 100,000 3D points per second. The resulting 3D surface point cloud (e.g., Figure 2) gives micron-precision geometry of surfaces, which can be analyzed for roughness, defects, or any GD&T criteria required by the user.

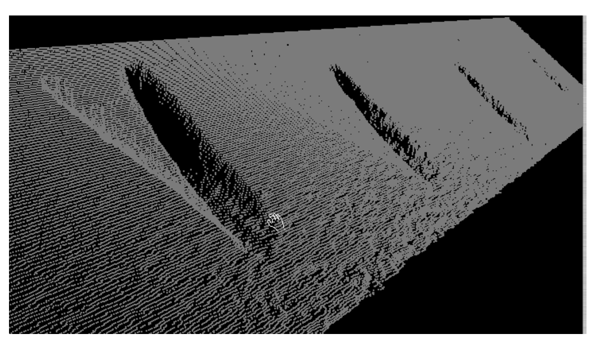

Figure 2: Jet-engine turbine blade with cooling holes (point cloud acquired by SURFACEINSPECT system)

What Aspects of Cooling Holes Are Important?

Cooling hole geometries have grown more complex over time to improve their functional effectiveness. Scientists and manufacturers are on a constant mission to fine-tune their shape, their distribution, and their inclination angles to optimize engine performance. Micron-level inspection brings significant value to this effort.

On the basic level, the SURFACEINSPECT system confirms the **presence** and exact **location** of each cooling hole. However, many additional parameters can be determined from the acquired 3D point cloud.

For example, the **shape of the diffuser opening**, a key aspect of the cooling hole functional efficiency, can be visualized (see Figure 3).

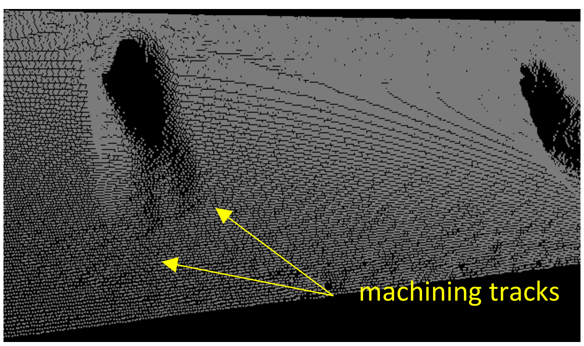

Figure 3: This cooling hole diffuser opening reveals the dual channel shape created by drilling

A **portion of the cooling hole inner diameter (ID)** is obtained from the same data set (Figure 4).

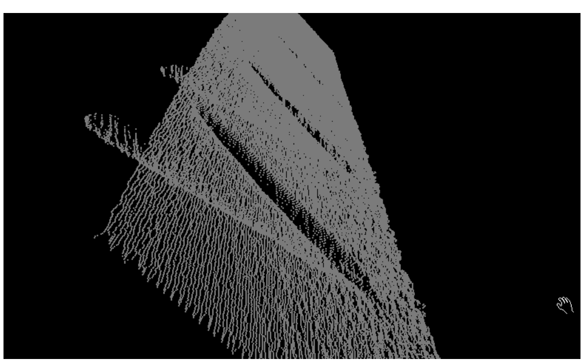

Figure 4: The partial surface of cooling hole ID is shown as protruding below the turbine blade surface

The **geometrical center** and the **inclination angle of the through-hole** (i.e., the angle of drill penetration through the blade surface) are determined by fitting a cylinder to the acquired portion of the cooling-hole ID (Figure 5).

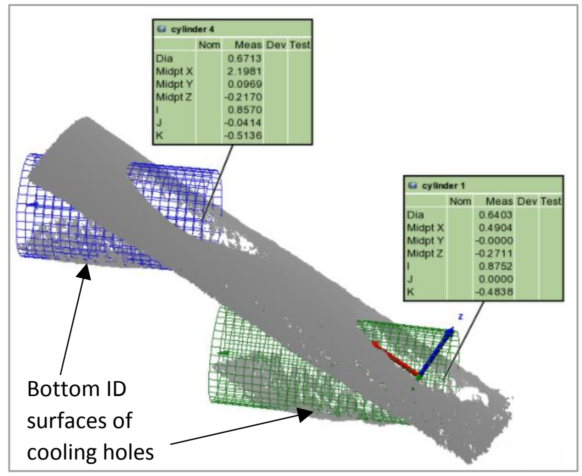

Figure 5: Fitting a cylinder to each partial through-hole profile is used to determine the center and inclination angle of each cooling hole

From the acquired profile, **waviness** and **roughness** of the cooling hole bottom surface can be calculated (Figure 6).

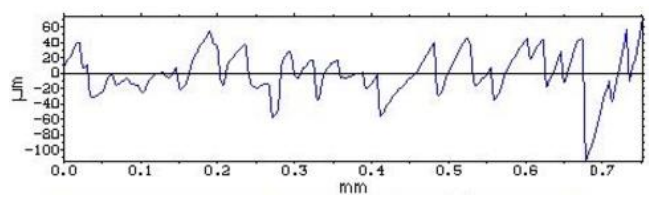

Figure 6: Roughness graph of the acquired bottom ID profile of a cooling hole. The scanned profile represents a length of 0.7 mm.

When **a larger portion of the cooling hole ID** is needed than that acquired from a single scan, this can be achieved by progressively adjusting the relative angle of the scanner lens and the blade surface; the resulting ID profiles are then combined into a more complete image of the through-hole.

Finally, **dimensional variability** of the cooling hole can be assessed by comparing its inner diameter surfaces to the CAD model.

Valuable Process Insight

Due to their complex design and multi-step manufacturing process, turbine blades and vanes are high-cost engine components by the time they reach the stage of being drilled with cooling holes. This applies to all engine surfaces with cooling holes, whatever the industry.

The high cost of these components is why any cooling hole machining issues must be detected and corrected fast–so as to avoid the high cost of scrap at this stage. Examples of machining issues are out-of-spec inclination angles or incorrect offsets between the metering and diffuser sections of the cooling hole caused by drill misalignment. With high-speed and high-precision cooling hole measurements supplied by the SURFACEINSPECT system, manufacturers gain a powerful tool for fast problem diagnosis and mitigation of out-of-spec machining.

Still later on in the engine lifecycle, during engine maintenance and reconditioning, SURFACEINSPECT system provides insight into:

- the type and extent of surface wear or damage to cooling holes caused by engine operation and
- the quality of reconditioned cooling holes.

Tough Enough to Help Automate Inspection on the Plant Floor

Being fiber-based and modular, the optical scanner of the SURFACEINSPECT system (Figure 7) is deployable right on the plant floor–it is not limited to lab environments. As needed, it operates at a distance (as long as several meters) from the interferometer enclosure and is easily integrated as either a robot end-effector or as a vision component in automated or semi-automated systems on the plant floor. It can be integrated as a vision component in CNCs (high-precision EDM/laser drilling machines).

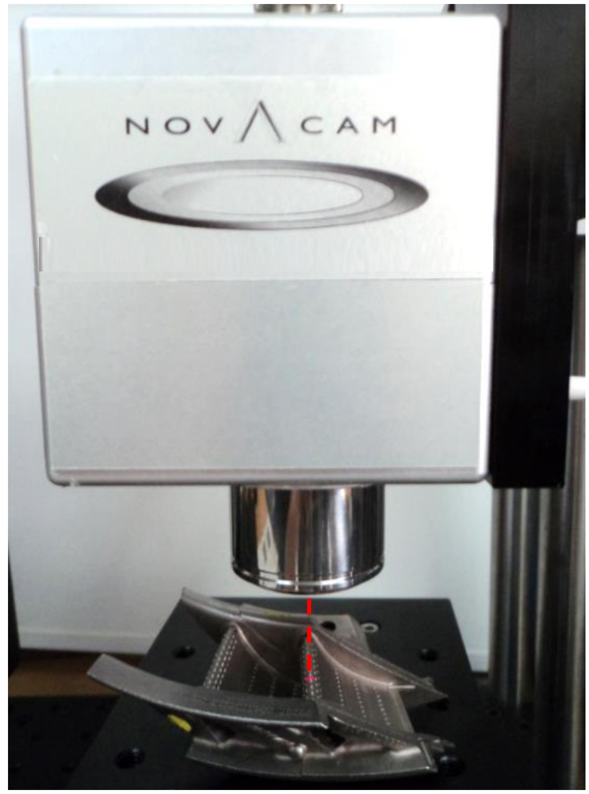

Figure 7: The SURFACEINSPECT system galvo scanning probe inspects cooling holes on the outer surfaces of a stator blade (nozzle guide

Notably, the SurfaceInspect scanner enables 3D metrology anywhere, even in harsh (very hot, high pressure, cryogenic, or radioactive) environments.

Cooling holes inside tight spaces? No problem!

Unique in the industry, and unlike microscope-like instruments, the SURFACEINSPECT system can also be configured to measure surfaces in hard-to-reach spaces. While the SURFACEINSPECT system galvo scanning probe is the fastest scanning option, a small-diameter rotational scanning probe can also be added or substituted to acquire cooling holes in tight space such as, for example, on the inner surfaces stator blades (Figure 8).

Figure 8: A rotational scanner probe inspects cooling holes on the inner surface of a stator blade.

Conclusion

Engine turbine robustness is of the highest priority in both the aerospace and in power generation industries. In support of this priority, helping ensure the efficacy of engine film cooling mechanism, NOVACAM SURFACEINSPECT system brings important inspection capabilities to the cooling hole inspection process: high precision, high speed, and high setup flexibility.

SURFACEINSPECT system components are listed below.

SurfaceInspect system components

Component	Physical aspect	Deployment area
MICROCAM™-3D or 4D interferometer	19" rack-mountable instrument	plant floor / control room
computer workstation	mini desktop-size PC or laptop	plant floor / control room
galvo scanner	surface-scanning galvanometer probe*	on lab inspection stations or directly on the plant floor as: - robot end-effector - 3D inspection instrument in drilling /EDM machines, etc.

*For cooling hole inspection inside hard-to-reach spaces, alternative small-diameter probes, with probe diameters as small as 0.5 mm (0.02") are available.

Detailed technical specifications are available upon request.

Novacam encourages technicians and engineers in charge of machining and inspecting cooling holes to contact us to discuss your applications and particular challenges.

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