Application Note
for Industry

Surface Characterization and Roughness Measurement

with NOVACAM™ Non-Contact 3D Metrology Systems

Keywords: surface roughness, surface quality, 3D industrial inspection, long-stroke profilometry, long profiles, roughness parameters, 3D metrology, NDT, non-contact profilometry, optical profilometry, circumferential or axial roughness profiles in hard-to-reach spaces, high-aspect-ratio surfaces

Introduction

Manufacturers in high-precision industries require precise and reliable indicators of surface quality. Traditionally, surface roughness measurements are acquired in quality control laboratories. However, measurements right on the production line are often preferable, since there they can provide timely feedback on a coating or manufacturing. NOVACAM 3D metrology systems provide this capability. Unlike microscope-type profilometers, they measure roughness with fiber-based optical probes, making them suitable even for production environments. The small, rugged probes:

- Scan surfaces from a standoff as long as 68 mm (standard probes) or more (non-standard probes)
- Acquire 2,100 or 100,000 3D points per second. For instance, a 4 mm roughness profile is measured in < 5 sec at 2.1 kHz, and in < 1 sec at 100 kHz.
- Measure even hard-to-reach surfaces, such as inside diameters of tubes & bores (Figures 1 & 2), slots, blade surfaces, bottoms of blind bores, etc.
- Are immune to ambient light & air perturbations

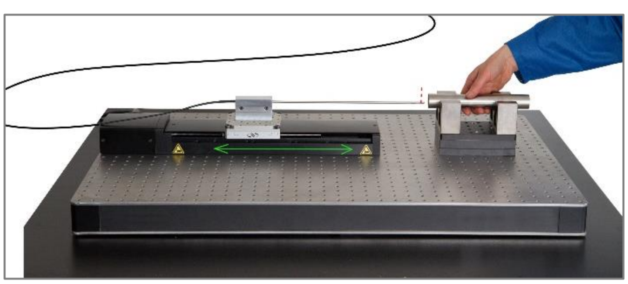


Figure 1: NOVACAM fiber-based optical profilometer probe, integrated with horizontal motion, automatically acquires a roughness profile inside a machined bore

- Can be integrated with robots, gantries or precision stages, enabling fully automated roughness measurement solutions.

How Surface Roughness is Measured

Based on low-coherence interferometry, NOVACAM 3D metrology systems use infrared light: the system non-contact fiber-based scanning probe acquires data in a point-by-point and collinear manner. The system interferometer converts optical interference data into high-precision height measurements. Roughness software then automatically analyzes the height data and removes waviness from the calculated overall roughness (Figure 3).

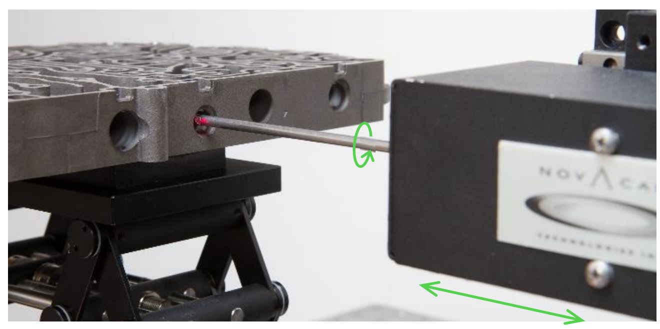


Figure 2: NOVACAM BOREINSPECT™ rotational scanning probe measures roughness and 3D geometry inside valve body bores

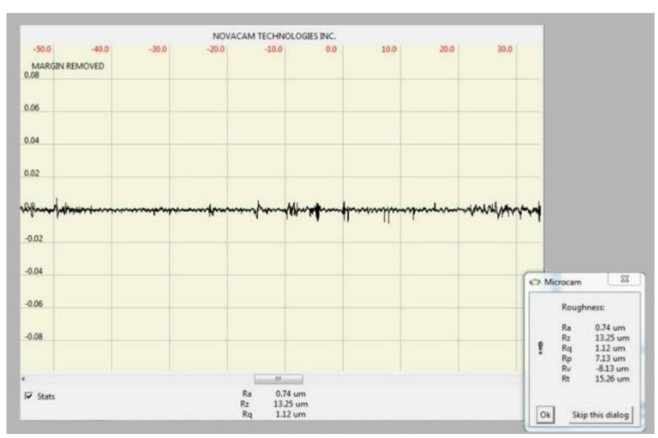


Figure 3: Linear roughness profile and roughness measurement parameter values from inside a machined bore

SYSTEM PARAMETERS for ROUGHNESS MEASUREMENT

- **Precision (or repeatability) of measurement** = typically 0.5% to 6% of roughness value.

  Example: for a surface profile with measured Ra = 3.07 µm (119.6 µin.), repeatability (1σ) over 10 measurements was found to be 65.7 nm (2.6 µin.), which is equivalent to 2% of the Ra value.

- **Finest Ra measured** 0.05 µm (2.0 µin.)*
- **Ability to measure** Ra > 10 µm (390 µin.)
- **Standoff** can vary from 0.5 mm to 68 mm for standard probes and can go higher for non-standard probes

**This limit depends on the probe selected for the application*

Why Look Beyond Ra?

Average roughness (Ra) is a commonly used roughness parameter, yet it is frequently inadequate for describing the specific character of material roughness. This is because surfaces with identical Ra but dissimilar character may exhibit different properties when it comes to:

- Maximizing or minimizing contact with neighbouring substance or material
- Ability to retain or shed fluids
- Ability to resist certain kinds of wear
- Ability to resist pressure and stress cracking.

For a more detailed evaluation of surface roughness character, NOVACAM system software calculates additional roughness parameters (Ra, Rz, Rq, Rp, Rv, Rt). For an even wider range of linear and area roughness parameters (Rsk, Rku, Rz, Sa, Sq, Ssk, Sku, Sy, Sp, St, Sy, Sz, etc.), the 3D point cloud data may be analyzed with third party roughness calculation software, such as MountainsMap® or TrueSurf®.

Example: Characterizing a Fuel Cell

Sample fuel cell plates were scanned and imaged with NOVACAM OPTICAL 3D PROFILOMETER system. Since fuel cell surface properties impact the fuel cell efficiency, they must be kept between specified target parameters. To capture more precise roughness characteristics, the system was used to generate a height map (Figure 4), a 3D representation of the sample (Figure 5) and several relevant roughness parameters (Table 1).

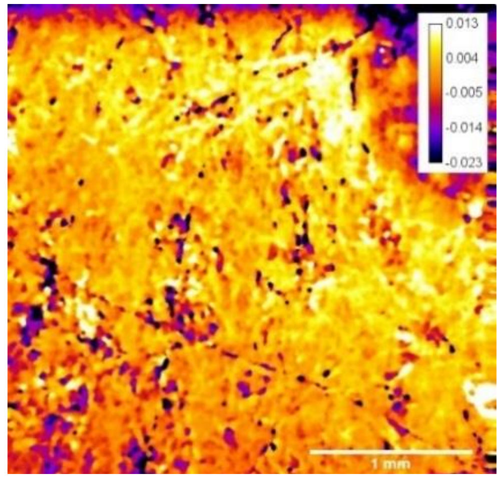


Figure 4: Height map of a 3 mm^2 sample of a fuel cell plate

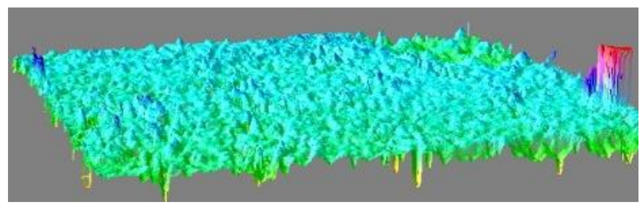


Figure 5: 3D representation of a 3 mm^2 sample of a fuel cell

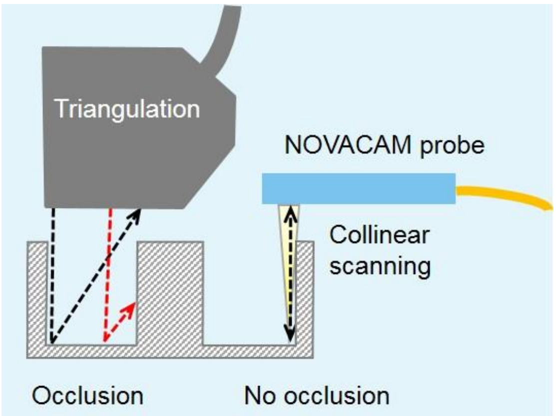
Table 1: Fuel cell linear roughness parameters

Roughness indicator		Measurement
Ra	Average roughness	0.01 mm
Rq	Root mean square roughness	0.01 mm
Rsk	Skewness	-0.05 mm
Rku	Kurtosis	13.03
Rv	Maximum profile valley depth	-0.06 mm
Rp	Maximum profile peak height	0.09 mm
Rt	Maximum height (distance from highest peak to lowest valley)	0.16 mm

Watch Your Step: Measuring High-Aspect-Ratio Surface Features

High-aspect-ratio features such as steps, grooves, sharp edges, steep slopes, and blind holes present a measurement challenge for many profilometers. However, NOVACAM systems are well suited to measure such surfaces because their probes scan in a collinear manner – i.e., the emitted and reflected light signals travel along the same axis. This capability means that for some applications they will provide a more thorough measurement coverage of high-aspect-ratio features than is possible with triangulation technologies or contact styluses (Figure 6).

Figure 6: Collinear scanning allows for better measurement coverage of high-aspect-ratio features than offered by triangulation technologies.



As an example, in the semiconductor sector, NOVACAM systems measure CMP pad surfaces, which are patterned with small, steep-walled grooves (Figure 7).

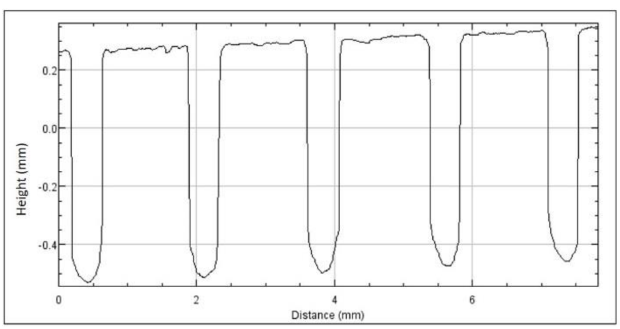


Figure 7: Profile of a CMP pad surface shows high-aspect-ratio channels that are used for slurry distribution. Profiles may be analyzed for 3D geometry or roughness.

When Roughness is a Chore: Roughness Measurement in Hard-to-Reach Spaces

Fiber-based probes also facilitate 3D surface metrology inside hard-to-reach spaces such as tubes, bores, barrels (Figure 8), cylinders, O-ring grooves, precision rivet holes, blisks on engine compressors, fir tree slots, and inside surfaces of turbine disk blades. Roughness acquisition in tight spaces is accomplished by either simple probe displacement along the Z-axis or by rotating either the inspected object or the probe.

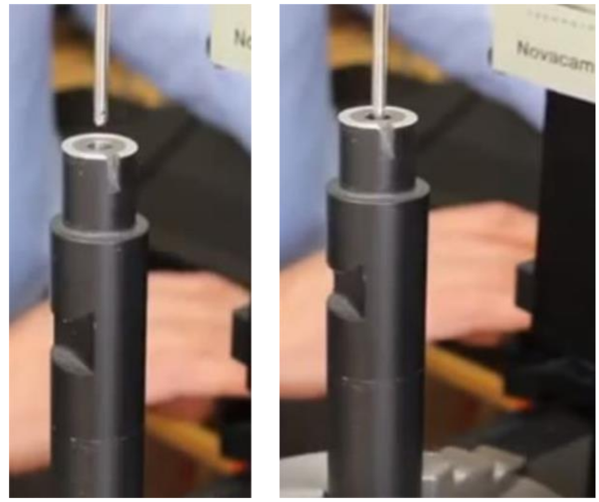


Figure 8: Small-diameter side-looking TUBEINSPECT system probe about to enter a barrel, and then scanning the inside

Several models of fiber-based optical probes meet the needs of such applications:

- **Side-looking probes** acquire linear profiles of inside diameters as narrow as 2.5 mm. Figure 9a) depicts a side-looking probe.
- Both **forward-looking** and **side-looking probes** acquire profiles inside blind holes, slots, or grooves. Figure 9b) depicts a forward-looking probe, and Figure 6 depicts a side-looking probe.
- **Rotational side-looking probes** acquire ID profiles that are linear, circular, or spiral. With these probes, roughness may be measured both along axial and circumferential profiles of inside diameters.

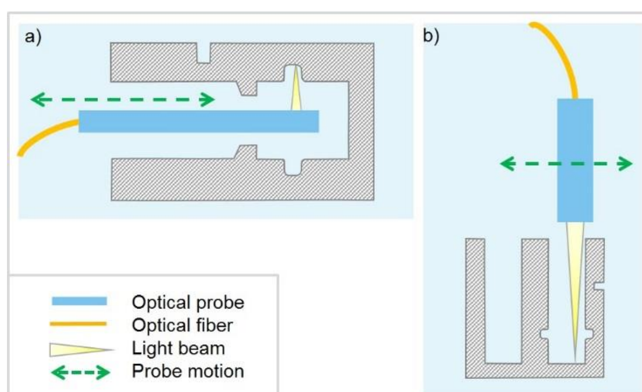


Figure 9: Non-contact 3D profilometry in hard-to-reach spaces:
a) Side-looking probe acquiring a profile on an ID wall
b) Forward-looking probe acquiring a profile on the bottom of a blind hole

Don't Hesitate, Automate!

NOVACAM 3D metrology systems are designed for easy measurement automation and plant-floor deployment. Their capabilities include:

- **User-configurable scan definitions** that may be invoked automatically through a programmable logic controller (PLC) or interactively by operators
- **Long profile measurement capability.** In the production context, the acquired profile is automatically analyzed by roughness software and logged for retrieval by process control software.
- **An application programming interface (API)** for system integrators and OEMs to accommodate a wide variety of online and offline applications. Exported results may be integrated with data loggers and statistical process control software.
- **Easy integration of fiber-based probes** with precision stages, gantries, slides, or robot arms – for automated plant floor inspection stations
- **Immunity to environmental factors** such as ambient lighting or air perturbation
- **Ability to measure even in hostile environments** with extreme temperature/pressure or radioactive

.

Additional Advantages

- **Measurement versatility** – the same probes that measure roughness can measure 3D geometry, chatter, thickness (in case of semi-transparent materials) and defects.
- **No damage to surfaces** with non-contact probes
- **No need for consumables** – non-contact probes do not wear out or break tips
- **Ability to scan surfaces that are** reflective or nonreflective, smooth or rough, stationary or moving
- **Option to time-multiplex several probes with a single interferometer.** With probes measuring at different locations (one probe measuring at a time), this setup lowers the overall cost of inspection stations.

Conclusion

Novacam encourages technicians and engineers in charge of roughness measurements to contact us to discuss your application.

NOVACAM™ 3D metrology systems for roughness measurement

System	Type of optical probe	Roughness measurement
OPTICAL 3D PROFILOMETER™ system	Front-looking or side-looking probe	On most surfaces – easy or hard-to-reach
TUBEINSPECT™ system	Side-looking probe combined with rotational motion for measured part	On inside and outside diameters of tubes that may be rotated
BOREINSPECT™ system	Side-looking rotational probe	In hard-to-reach spaces
SURFACEINSPECT™ system	Galvo (raster) scanner probe	On open surfaces or on the bottoms of blind slots and holes
EDGEINSPECT™ system	Galvo (raster) scanner probe	On edge radii, or on inside corners

- All NOVACAM 3D metrology systems include MICROCAM™-3D/4D interferometer (19" rack-mountable instrument) and a mini desktop-size PC or laptop that hosts NOVACAM data acquisition software and, typically, data analysis software.
- Learn more about NOVACAM 3D metrology systems here: https://www.novacam.com/products/

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