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ROUGHNESS MEASUREMENT OF PRECISION GEAR TEETH

Improved finish requirements to reduce surface distress failures have led to the need for accurate and standardized measurement of tooth flank roughness.

OVER THE PAST 25 YEARS, INDUSTRIES SUCH AS POWER generation, aerospace, automotive, and others have continuously increased the operational demands of gearboxes. The precision gears used in these highly loaded, low-speed or high-speed gear applications are susceptible to surface distress failures. Consequently, tooth flank roughness finish has become a key parameter for gearbox designers, manufacturers, and operators. Failure modes such as micropitting, macropitting, scuffing, and wear are all dependent on these flank finishes. Assuming that all appropriate gear design, manufacturing, and lubrication criteria have been utilized, it is the flank finishes that will determine the gearboxes' susceptibility to surface distress failure.

BACKGROUND ON FLANK FINISHING

Prior to the 1990s, a precision ground gear flank could be finished to an Ra of roughly 20-32 µin. Additional flank finishing operations, such as honing or lapping, could achieve Ra finishes of roughly 12-20 µin.

With the application of the ISF® Process to gears, starting in the mid 1990s, finishes of Ra ≤ 4 µin have become widely commercialized. Initially, there were concerns that superfinished gears would not retain lubricant on the smooth tooth surface and that the superfinish would therefore be a detriment. Over the years, there have been many discussions regarding the overly used yet scientifically uncertain "oil pocket theory." This theory suggests that deep grinding "valleys" must be left on the flanks to carry lubricant through the contact zone. Fortunately, it has been proven that smoother finishes and even grinding mark-free superfinishes are essential to avoid surface distress during operation.

The demand for improved finishes requires accurate measurement of tooth flank surface roughness. Yet, to this day, flank roughness measurement is often inaccurate and lacks standardization. The following sections describe how to accurately measure tooth flank surface roughness on the gear manufacturing shop floor using an internationally standardized approach.

SHOP FLOOR PROFILOMETER

A profilometer is an instrument for measuring surface texture. Surface texture is separated by the instrument's filter into its "waviness" (long wavelength) and its "roughness" (short wavelength). Here, this discussion focuses on the tooth's roughness.

For shop floor measurements, a diamond-tip contact stylus profilometer is the appropriate instrument. There are a number of suitable instruments available from recognized profilometer manufacturers. A well-equipped profilometer system will include the contact head with an articulated holder, the controller/processer unit, and a data storage computer and/or printer. Also included with the profilometer should be spare styluses, calibration pads, and a clamping device. See Figure 1 for a schematic of a typical contact stylus profilometer. The skidded-type stylus is recommended when only roughness measurements will be taken. Handheld profilometer units are not recommended due to their inherent inaccuracy linked to the operator's hand movement during measurement.

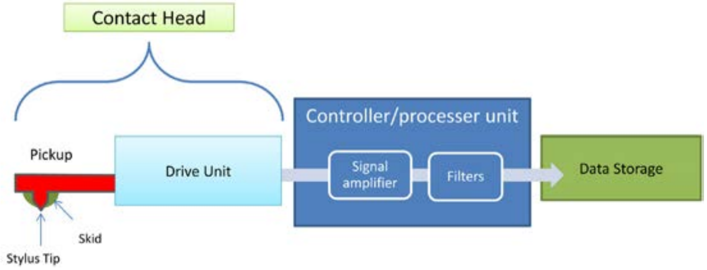

Figure 1: Contact stylus profilometer

The instrument selected must be capable of making roughness measurements that can comply with ISO-4287 (1997), ISO-4288 (1998), and ISO-3274 (1996) standards. With experience and care, compliance to these international standards will ensure that measurements will be accurate and reproducible.

MEASUREMENT STANDARDS

Surface texture filtration is a complex subject and is beyond the scope of this discussion. For those interested, ISO-16610 is a family of standards on this subject. Fortunately, for precision gears, a simple Gaussian filter meets the ISO requirements. As such, shop floor contact stylus profilometers should be equipped with and take measurements using an ISO-approved Gaussian filter.

- ISO-4287 is the international standard for the definitions of surface roughness. For tooth flank roughness, Ra, Rz, and Rmr are key parameters to be specified and measured with precision gears.
- ISO-4288 is the international standard covering how to measure surface roughness. This standard establishes the setup requirements for the profilometer and the procedures on how to take the roughness measurements.
- ISO-3274 is the international standard for defining the capabilities and requirements of contact stylus instruments and the stylus tips.

Combining the key elements of these three ISO standards can be consolidated into the simple reference chart in Figure 2 for precision gear roughness measurement. This chart shows the international standard for cutoff length (filter), evaluation length, cutoff ratio, and stylus tip size for the typical range of surface roughness found in precision gears. A chart such as this should be posted with all profilometer instruments in order to assure that measurements are taken consistently and correctly.

A properly equipped shop floor profilometer may look similar to Figure 3. Here, it is set up to measure a wind turbine planet tooth flank. Figure 4 shows the measurement results, following the ISO standards, of the superfinished wind turbine gear.

Profilometer Measurement Set-Up Selection Guide

ISO 4287 (1997) / 4288 (1996) / 3274 (1996)

Non-periodic Profile				Cutoff Lc mm (in)	Cutoff Ratio Lc/Ls	Minimum Evaluation Length, Le mm (in)	Max tip radius µm
Ra µm (µin)		Rz µm (µin)					
>	≤	>	≤				
0.006 (0.2)	0.02 (0.8)	0.025 (1)	0.1 (4)	0.08 (0.003)	30	0.4 (0.02)	2
0.02 (0.8)	0.1 (4)	0.1 (4)	0.5 (20)	0.25 (0.01)	100	1.25 (0.05)	2
0.1 (4)	2 (80)	0.5 (20)	10 (400)	0.8 (0.03)	300	4 (0.16)	2*

Figure 2: Profilometer setup guide *For surfaces with an Ra > 20 µin, a tip with a radius of 5 µm can usually be used without significant differences in the measurement result.

Turbo Datawin-NT 1.
Measuring conditions

Assessment length	1.50 mm
Lc (Cut Off)	0.250 mm
Lc / Ls:	100

Ra	0.05 µm
Rz	0.39 µm
Rmr(0.400µm)	100.0 %
Rmr01(10.0 %)	0.03 µm
Rmr02(20.0 %)	0.07 µm
Rmr03(30.0 %)	0.09 µm
Rmr04(40.0 %)	0.10 µm
Rmr05(50.0 %)	0.12 µm
Rmr06(60.0 %)	0.13 µm
Rmr07(70.0 %)	0.15 µm
Rmr08(80.0 %)	0.17 µm
Rmr09(90.0 %)	0.20 µm
Rmr10(100.0 %)	0.40 µm

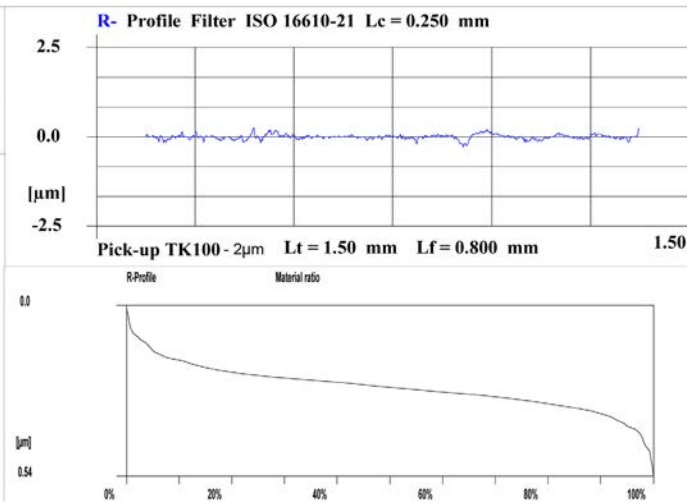

Figure 4: Planet gear measurement results

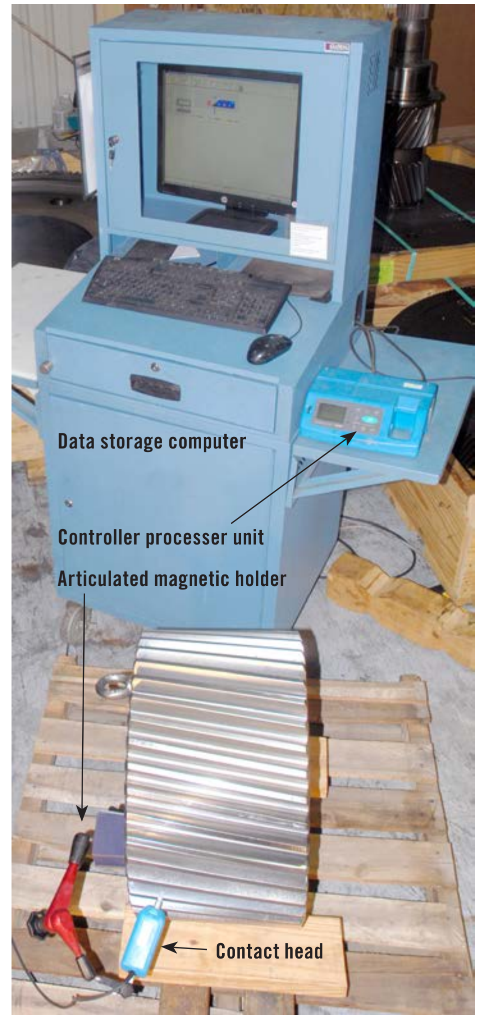

Figure 3: Shop floor profilometer measurement of a wind turbine planet tooth flank

PROFILOMETER TIP ANALYSIS

The recommended profilometer is a rugged instrument capable of thousands of roughness measurements without developing problems and should require only annual or even bi-annual calibration to maintain functionality.

However, the diamond-tip styluses are the delicate components within the profilometer system. They will become dirty, worn, or damaged through regular use. Spare styluses are essential to maintain the capability of a profilometry system. Regularly scheduled checks of the stylus via a calibration pad measurement are the fastest way to verify its condition while on the shop floor. If a diamond tip is dirty, worn, or damaged, the measurement across the calibration pad will not match the pad's roughness. Dirty, worn, or damaged tips will typically result in an inaccurately smooth roughness measurement, thus dangerously misleading. When this occurs, the stylus must be cleaned and retested. If this does not solve the problem, the stylus must be taken out of service for further investigation and possibly returned to the manufacturer for repair.

Figures 5, 6, and 7 show examples of the diamond-tip styluses and the associated calibration measurements.

Most precision gear roughness measurements require a 2-micron tipped stylus as per ISO. However, a 5-micron tip is permitted on surface roughness of Ra > 20 µin, provided that the larger tip size is noted, since the measured difference is small. Obviously, a 5-micron tip is much more durable compared to a 2-micron tip.

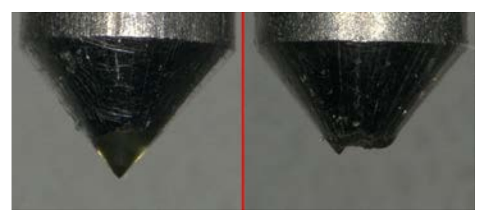

Figure 5: Good stylus tip (left) and a damaged stylus tip (right)

Profile: R [LC GS: 0.8 mm]	
Ra	0.410 µm
Rz	1.670 µm

Good 2µm tip on nominal 0.4µm patch
(Ra within 10% of nominal)

Figure 6: Good tip analysis

Profile: R [LC GS: 0.8 mm]	
Ra	0.331 µm
Rz	1.431 µm

Broken 2µm probe on nominal 0.4µm patch
(Ra not within 10% of nominal)

Figure 7: Damaged tip analysis

CONCLUSION

It has been shown that a diamond-tip contact stylus profilometer is capable of accurately and consistently measuring precision gear flank roughness by following the ISO-4287, ISO-4288, and ISO-3274 standards. With experience and care, this shop floor profilometer will consistently measure precision gear tooth flank roughness to verify compliance to design specification.

ABOUT THE AUTHOR: Mark Michaud, president of REM Surface Engineering, is a leading expert in the field of isotropic superfinishing of engineered metal components. During his 35-year career at REM, he has worked in research, operations, sales, and management. Michaud has been granted over 100 patents, published numerous technical articles, and given lectures in the United States, Europe, and Asia. Mark has degrees in chemistry from Reed College and an MBA from the University of Hartford. He can be reached at mmichaud@remchem.com. ISF is a registered trademark of REM Chemicals, Inc.