FULLY AUTOMATIC ROUGHNESS MEASUREMENT "IN MINIATURE"

Klingelnberg now has a new roughness probe that is capable of measuring gear teeth with a module as small as 0.9 mm for carrying out surface measurements on its precision measuring centers. Klingelnberg thus defines a new technical standard for its probes in gearing component roughness measurement – and provides ideal conditions for the measurement of high-precision gearing components such as the ones that are used in modern passenger car transmissions.

Flawless functioning of a transmission depends not only on component geometry, but also on the quality of the functional surfaces of gearing components. Just a few years ago, this aspect of the series production of standard transmissions was not such an important issue. But thanks to new or improved machining technologies extremely smooth surfaces can now be produced cost-effectively, even in large-scale production. Modern manufacturing processes such as barrel finishing and polish-grinding have made a significant contribution in this respect.

Surface properties defined with maximum precision are a key variable, and are frequently also the prerequisite for valuable improvements in drive engineering. Especially in the vehicle industry, and particularly in the electric mobility area, the surface quality of the gearing components is essential: In combination with electric drives, machining takes place at extremely high rotation speeds, resulting in new challenges in transmission and gearing design. But even in conventional drives with a combustion engine, smoother gear teeth can make a significant contribution to the running behaviour. Surfaces with an Rz value of less than 0.5 µm are now used in series production in order to reduce noise, friction and power loss.

As a result, roughness measurement of gear teeth has become significantly more important. In this respect, as well as classic roughness measurement curve evaluation by means of sampling lengths, the industry is making increasing use of material ratio analysis. It offers additional parameters that are useful for assessing surface properties (see Info Box: Roughness Measurement Curve and Material Ratio Analysis).

Trendsetting

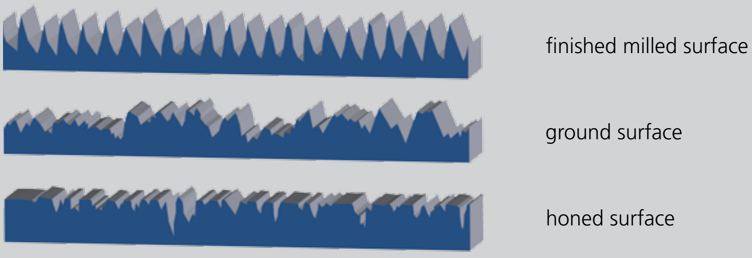
These developments had not yet even emerged in this form ten years ago, when Klingelnberg collaborated with a provider who specialized in surface metrology to develop a roughness measurement system that made optimum recording of roughness parameters possible, particularly on gear teeth. The roughness probes, which are equipped with an integrated rotating mechanism, have been miniaturized to such an extent that they are operated via the standard adapter plate, just like the tactile styluses used to measure geometry in the Klingelnberg 3D measurement system. Similar measuring procedures can therefore be used for roughness measurement as for gear measurement, which ensures that optimum tracing conditions are provided. The tactile stylus and the roughness probe can be exchanged automatically in this

Compact

Roughness Measurement in New Dimensions

Modern manufacturing processes such as barrel finishing and polish-grinding provide increasingly smooth surfaces on gearing components. The precision measuring centers in the P-series enable systematic inspection of component geometry and surface quality in a fully automatic measuring procedure – at Klingelnberg now also for the smallest sizes starting at module 0.9 mm.

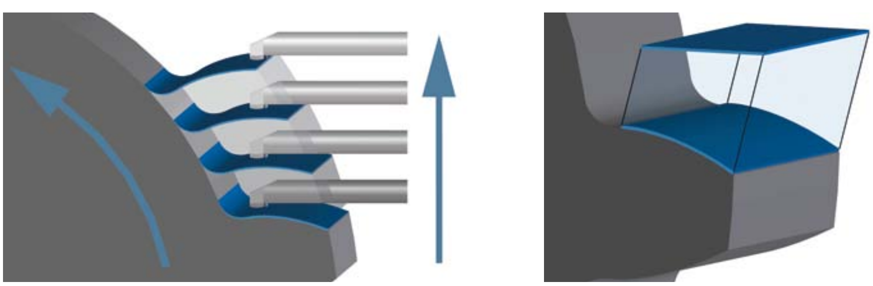
ROUGHNESS MEASUREMENT CURVE AND MATERIAL RATIO ANALYSIS



These three surface profiles illustrate the importance of the material ratio analysis: Although the characteristics of the surfaces are completely different because of the different production processes, the same Ra value was determined in all three cases.

The material ratio analysis, on the other hand, provides clear parameters resulting from the varying material density over the height profile, from the uppermost point on the surface to the transition into the solid material. Characteristics such as high peaks with broad valleys or broad plateaus with narrow grooves are determined via the material ratio parameters Rk, Rvk, and Rpk, as well as Mr1 and Mr2, which differ significantly for the three surfaces.

Fig. 1: Roughness probe and plug connector: In addition to the sensor technology, a precision swivel device is also integrated into Klingelnberg's extremely compact roughness probes. The roughness probes can therefore be operated on the adapter plate like the tactile styluses, and can be changed automatically. An especially convenient feature is the automatic plug-in.



Figs. 2 and 3: Owing to the optimized measurement and tracing strategies of the skidded surface finish gage, the curved surface behaves like an ideal plane relative to the roughness probe – illustrated here with a sample profile measurement on an involute gear.

Now even the finest structures on barrel-finished gear teeth can be inspected and analyzed on the P-series precision measuring machines with the utmost precision – using a fully automatic procedure.

process, making it possible to carry out a fully automatic complete measurement – consisting of gear measurement, dimension measurement, shape measurement, position measurement and roughness measurement in a single clamping. Reproducibility of 0.01 µm is achieved with the precision CNC-controlled measuring procedures.

A Milestone

The integration of this roughness measurement system into the overall concept of precision measuring machines was truly a milestone: For the first time, Klingelnberg was able to perform roughness measurements on gear teeth in a fully automatic process. Patents were granted to Klingelnberg for this development in 2014 and 2015. "We combined our gear measurement expertise and our roughness measurement know-how, but it was difficult to predict where it would all lead us," said Jan Häger, project manager for software development, recalling the development phase. "In the beginning, we had to work really hard on convincing our customers. However, the roughness measurement system that we developed is now highly appreciated and in great demand."

That which differentiates the Klingelnberg system from many other roughness measuring equipment even now is the possibility of carrying out systematic measurement using a fully automatic procedure in a shop-floor environment. The Klingelnberg system is now being successfully used in several hundred P-machines all over the world.

Why Have a Separate Technical Solution?

It is no simple matter to measure the roughness of gearing components using other established technologies. In the specialist literature and the roughness measurement standards, skidless surface finish gages (or reference plane probe systems) are often recommended or required. But the use of these systems is problematic because of the involute curvature of the tooth contour of gear teeth in the preferred measuring direction. The tracing conditions sometimes shift quite significantly due to this curvature – particularly when extended traversing lengths are used. On the whole, the following disadvantages occur when using these systems:

- Optimum tracing of the diamond needle in the normal direction is only ensured in one part of the trace length.
- This effect causes errors during filtering, which must be compensated for.
- The large amount of stylus deflection that occurs requires an appropriately large measuring range, which can limit the resolution of the measuring signal.
- The setup for gear teeth measurement is time-consuming and error-prone.
- It is often impossible to make systematic serial measurements under constant conditions.
- The systems are sensitive to vibration.

"Under laboratory conditions and for reference measurements, these systems are undoubtedly the method of choice," is the assessment of applications engineer Thomas Serafin. "But in combination with gear measurement and integration in the P-machines, our main objective was to develop a user-friendly, rugged solution that was insensitive to vibrational effects and designed for use on the shop floor." The skidded surface finish gage developed by Klingelnberg meets these requirements while also allowing complex motion sequences with up to four machine axes.

Advantages of a Skidded Surface Finish Gage

With a skidded surface finish gage measuring movements are controlled in such a way that a linear motion of the skid and stylus needle is produced relative to the surface. The integrated swivel device automatically positions the diamond needle and the skid in optimal alignment with the surface. Compared to measurement using reference plane probe systems, the advantages are as follows:

- The diamond needle optimally traces the entire measuring path in the normal direction relative to the surface, irrespective of the measuring length.
- The contact force of the diamond needle can be kept to a minimum, since the significantly greater contact force of the skid ensures that the entire probe system has a secure contact with the surface.
- The involute curvature is fully compensated for by the generative motion of the measurement, resulting in almost complete linearization of the scan on the gear surface (see Fig. 2 and 3).
- The deflection of the skid is recorded independently of the deflection of the diamond needle via the deflection of the 3D tracer head.
- The diamond needle registers only the surface roughness. This makes it possible to use a small measuring range with an extremely high resolution.
- By amplifying and evaluating the differential signal between the skid and the diamond needle, vibrational influences are decoupled extremely effectively.
- The diamond needle is embedded in the shaft of the skid to protect it from damage.

"Make-or-Break" Points in Development

In order to be able to immerse into small gear tooth spaces, Klingelnberg selected a special skid design for the probe that it introduced back in 2012 for modules from 1.6 mm and above, making it possible to have a slim design and also large

HIGHLIGHTS IN BRIEF

All precision measuring centers in the P-series can be equipped with a high-precision roughness measurement device.

- Fully automatic roughness measurement of gear teeth starting at module 0.9 mm, as well as shafts and plane surfaces
- Evaluation of roughness parameters according to DIN EN ISO 4287 (Ra, Rz, Rt, Rmax)
- Evaluation of material ratio parameters according to DIN EN ISO 13565-2 (Rk, Rpk, Rvk, MR1, MR2)
- Extremely high resolution of 7 nm
- Integrated motorized swivel device for automatic alignment of the diamond needle with a diamond tip radius of 2 µm or 5 µm
- Optimal tracing conditions by use of measuring procedures similar to gear metrology
- Extremely simple handling by means of integration in the normal measuring process
- Precise measurement, even in the shop-floor environment

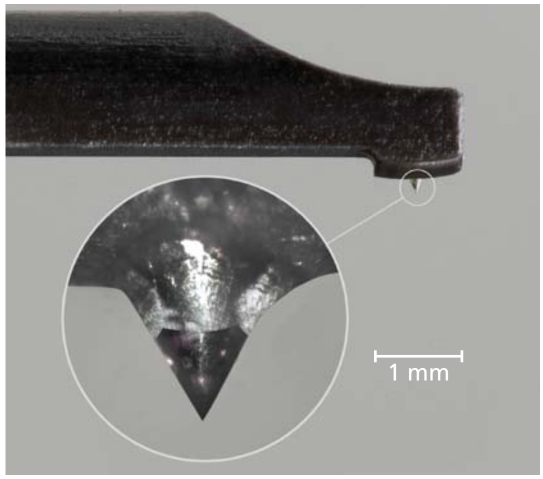
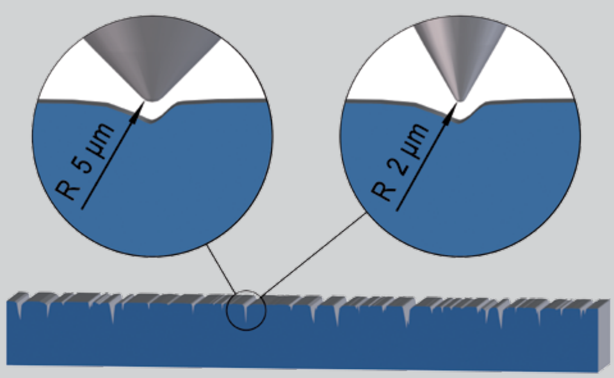


Fig. 4: A blow-up image of the new roughness probe for gear teeth starting at module 0.9 shows the skid in relation to the diamond needle. Despite the extremely small dimensions of the overall system, a ratio of 1:1000 was achieved between the tip radius and the skid radius. This roughness probe comes equipped with the 2µm/60° diamond needle as standard.

MINIATURIZATION OF THE PROBE: TIP RADIUS OF 2 µm



Barrel-finished gear teeth fulfill the most demanding of requirements: They exhibit an extremely high material ratio – thanks to their surface quality featuring broad plateaus and extremely slender striae. This is a challenge for metrology.

In height profile representations, significant vertical scaling relative to the surface is typically used, as in this example. This makes the striae, which are just 0.5 µm to1.5 µm deep, appear very narrow and seemingly impossible to measure using a 90° diamond tip. The magnified view shows the actual relationship between the narrowest stria and the diamond needle. Using of the 60° diamond needle with a 2 µm tip radius which is now also available further improves the tracing situation in such cases.

skid radii. The optimum frictional properties that this provides and the strongly integrating effect on the surface provide a high degree of measuring signal quality. In addition to the version with a 5µm diamond tip, the probe is now also available with a diamond with a tip radius of 2µm and a 60° angle.

Now starting at module 0.9 mm

The challenges were several times tougher for the latest development of the new roughness probe for gear teeth from as small as module 0.9 mm (see Figure 4). This was an innovation that Klingelnberg introduced for the first time at Control 2016 in Stuttgart at the end of April this year.

A specially developed design now ensures that the biggest possible proportion of the gear tooth surface is traced, even with extremely small gear teeth. In order to be able to achieve deep immersion into tooth spaces with a space width of 1 mm, the skid and the diamond needle underwent further miniaturization. However, thanks to the sophisticated design it was still possible to have large skid radii in both the longitudinal and the transverse direction. An extremely short distance between the diamond needle and the skid was also achieved, so that the biggest possible proportion of the short evaluation length that is available with small gear teeth can be registered.

This new roughness probe provides ideal conditions for measuring the high-precision gear components that are used in modern passenger car transmissions. ◆

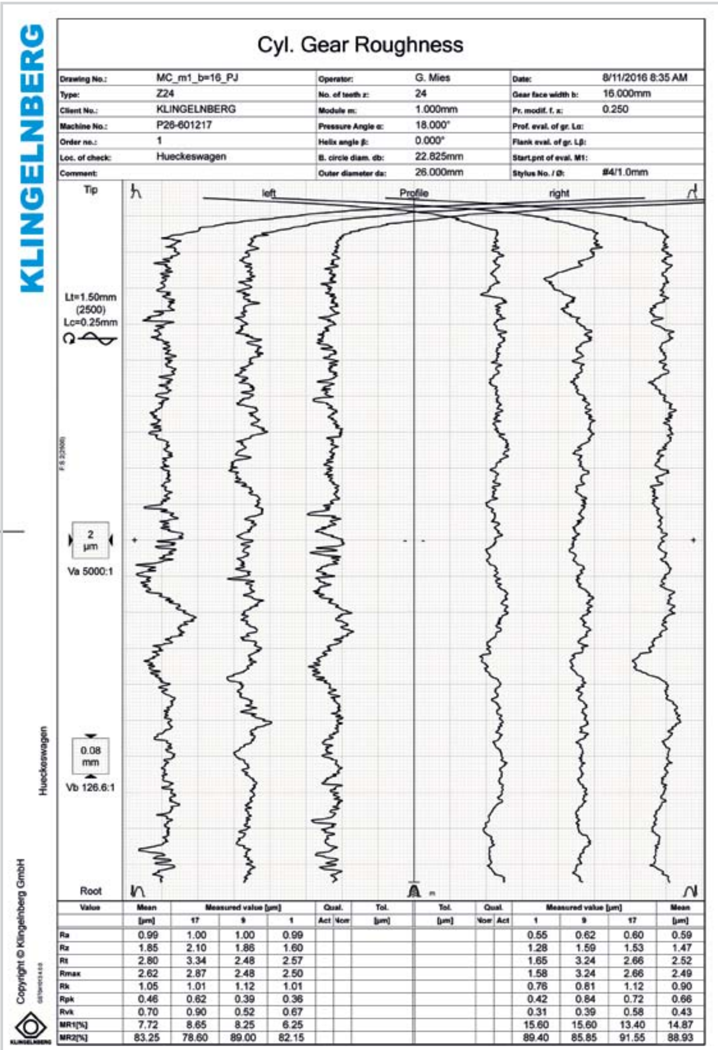


Fig. 5: The measurement results are output in an extremely clear way, with the display of the measurement curves and the selected parameters in table format, in a layout similar to that used for geometry measurements on gear teeth. The roughness parameters are evaluated according to DIN EN ISO 4287 (Ra, Rz, Rt, Rmax). The material ratio parameters are evaluated according to DIN EN ISO 13565-2 (Rk, Rpk, Rvk, MR1, MR2).

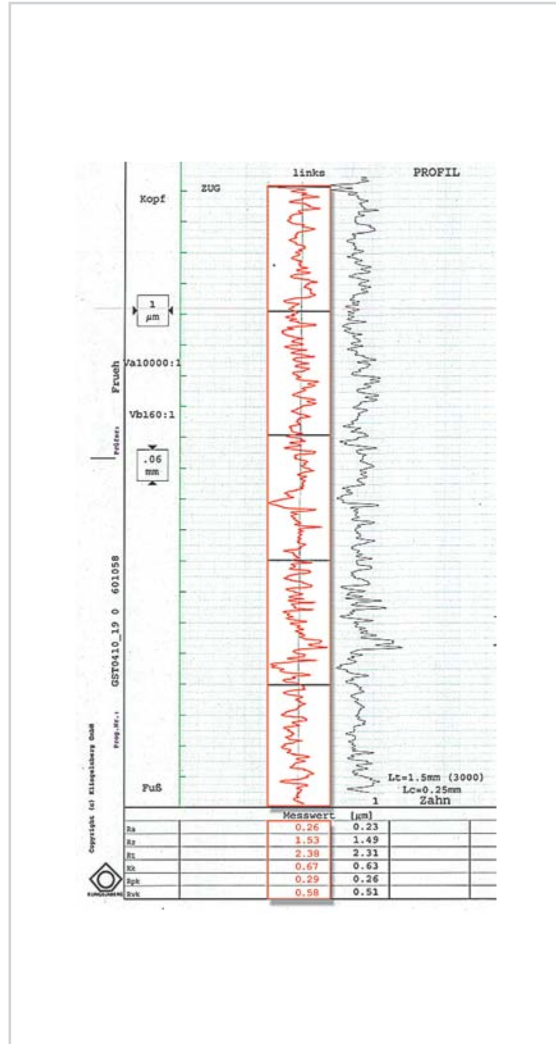


Fig. 6: Comparison measurement: This comparison measurement conducted by a customer shows the outstanding correspondence between the measurement performed using a reference plane measurement system (in red) and the Klingelnberg measurement (in black). This is true not only for the parameters, but also for the characteristic of the two measurement curves.

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