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Laser tracker performance quantification for the measurement of involute profile and helix measurements

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ABSTRACT

Standard-conforming measurements for a large involute gear were performed with a manually operated laser tracker system and the corresponding task-specific measurement uncertainties were estimated. Especially, readers using laser trackers for inspecting large involute gears will get information of a taskspecific measurement performance for the first time, which significantly differs from the laser tracker machine specification. To ensure unambiguous and repeatable measurement results, user-friendly auxiliary tools are used, which allows the operator to probe the measurement points according to existing guidelines and standards. Measurements were taken on a robust and highly accurate large involute gear measurement standard of the Physikalisch-Technische Bundesanstalt (PTB) under laboratory conditions. The size of this gear measurement standard complies with those gears used in wind power plants. The external gear materializes a left and a right hand gear as well as a spur gear. The obtained results of profile, helix and surface measurements are presented. These research activities were carried out at the PTB in the department of coordinate metrology.

1. Introduction

The first tracking laser interferometer was developed in 1986 by Lau, Hocken and Haight in order to fulfill the need of positioning measurements for industrial robots [1]. In the past few years, performance of laser tracker systems has been strongly improved. Applications have become popular in the field of industrial large-scale metrology and assembly. Compared to the well-known automatic coordinate measuring machines (CMMs), which are usually located at a fixed position in a measurement room, the laser tracker can be considered as a portable, frameless coordinate measuring machine. Measurements can be performed by an operator who manually moves a reflector to a target point. The locations are recorded in spherical coordinates. Laser trackers enable direct measurements on machine tools or on the shop floor close to the assembly facilities. Thus, laser tracker measurement technique has also become interesting in the field of gear metrology throughout the past few years. However, information considering achievable task-specific measurement uncertainty is missing so far. This is the reason why laser tracker users tend to get a first impression about the ability of laser trackers for gear measurements from the laser tracker's specifications.

Considering the structure of a gear, it is impossible to use a spherical reflector to touch all the surface points directly. On the one hand, the laser beam will be shaded, on the other hand the spherical reflector usually is too large to put into a gear gap. However, most laser tracker systems are equipped with a handheld measuring device. Those are, for instance, the T-Probe (Leica) [2], the I-Probe (API) [3], and the RetroProbe (Faro) [4]. These devices enable the use of laser trackers to measure both, the hidden points on the reference cylinders to determine the gear axis and the points on the gear flanks. Nevertheless, neither

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information about the measurement strategies nor information on the achieved measurement accuracy is available in the field of gear metrology so far. According to the existing guidelines and written standards for the typical gear measurands, such as profile, helix and pitch, the measurement points are to be taken close to the specified tracks on the gear flanks [5]. For the estimation of task-specific measurement uncertainties, the usual practice is to carry out measurements on a calibrated gear measurement standard and to compare the measurement results against the calibrated results. However, due to the manual probing by the use of a laser tracker, the number of measurement points will be significantly smaller compared to automatic measurement processes and recommendations given in guidelines and written standards. This discrepancy mainly affects the parameter of form errors. The form errors of the gear measurement standard measurements, used for this investigation, lie in a range of a few micrometers. Hence, this effect can be considered negligible.

2. Measurement auxiliary tools

In order to realize standard-conforming measurements for involute gears using laser tracker systems, user-friendly auxiliary tools presented in [6] were used. The important tools are named HaLi-Inv-Template and HaLi-Hel-Tape (Fig. 1). The combination thereof allows easy manually marking of all locations of measurement points for profile, helix and pitch on both flanks of the gear. These two auxiliary tools provide guidance for the operator to probe the surface points along specified tracks on involute flanks, according to technical regulations specified in existing involute gear standards and guidelines.

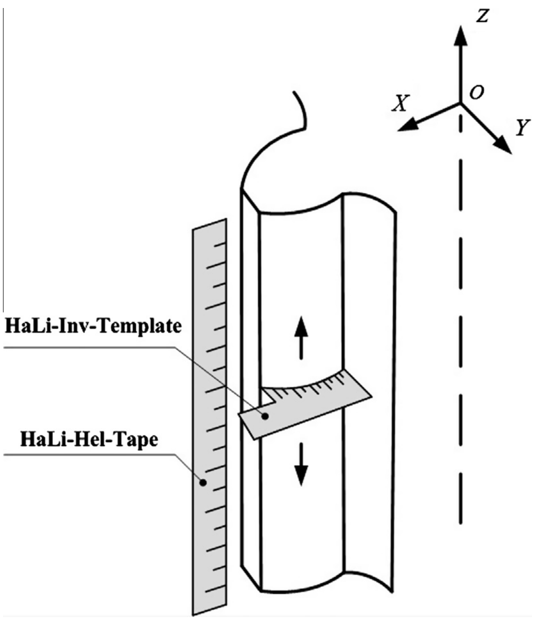

Fig. 1. Schematic diagram of the HaLi-Inv-Template and the HaLi-Hel-Tape.

The HaLi-Inv-Template indicates the measurement points in a transverse plane. As a complement, the HaLi-Hel-Tape allows to mark the positions along a helix in a cylindrical plane which is concentric to the gear axis. It should be noted that the HaLi-Inv-Template and HaLi-Hel-Tape need to be individually designed according to the parameters of the measured gear. The base circle is considered as the most important parameter for the HaLi-Inv-Template, whereas the helix angle is most important for the HaLi-Hel-Tape.

An example of a HaLi-Inv-Template for the left flank of a spur gear is illustrated in Fig. 2. It shows a segment of an external spur gear with $z = 38$, $m_n = 25$ mm, and $\alpha_n = 20°$. The scales on the HaLi-Inv-Template indicate the profile position in length of roll from 100 mm to 220 mm in grid spacing of 5 mm. It is clearly visible that the point density at the root is higher than the density at the tip. This effect can be explained by the gear kinematics and the corresponding measurement and evaluation strategies.

The most important form information of the HaLi-Inv-Template is based on the base circle of the gear. According to Euler [7,8], this is the only reference value responsible for the involute curvature. In addition, information on the module, the number of teeth, the pressure angle as well as the helix angle is specified in the drawings of gear design. In this example, the pitch diameter of the gear is indicated on the HaLi-Inv-Template as a small circle. However, it must be noted that these gear data must be seen as an example. Other parameters allow the same base circle to be represented according to the following equation:

$$d_b = m_t \cdot z \cdot (\cos \alpha_t), \quad (1)$$

where d_b denotes the base circle diameter, m_t is the transverse module, z is the number of teeth and α_t is the transverse pressure angle.

The design of this HaLi-Hel-Tape only depends on helix angle and face width of the gear. The HaLi-Hel-Tape shows information on helix angle and position of the gear datum. The scale grid spacing is not less than 5 mm in order to guarantee sufficient information while providing user-friendly handling during probing. An example of HaLi-Hel-Tape for the spur gear of face width $b = 100$ mm

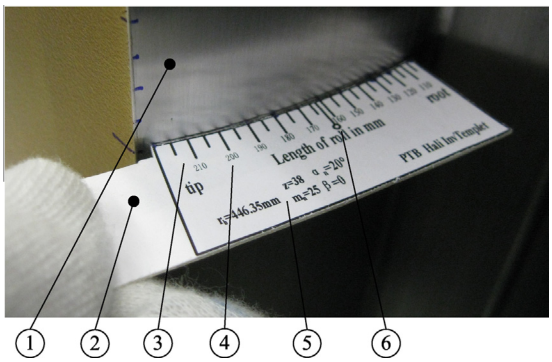

Fig. 2. Top view of the HaLi-Inv-Template for the left flank; 1. gear tooth, 2. handle, 3. scales, 4. length of roll, 5. gear parameters, 6. pitch circle.