T-SHAPED MICROPROBE AND GAP MEASUREMENT STANDARD FOR INNER MICROSTRUCTURES

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Abstract

To an ever-increasing extent, the constantly progressing miniaturization of components requires a constantly decreasing size of complex internal microstructures such as internal microthreads. These are used in large numbers, among other things in the clock industry and in medical engineering. At the same time, these workpieces are allowed to show only very small tolerances. Thus, it is indispensable to carry out measurements in parallel to the manufacturing of the parts. However, reliable quality assurance for these internal microstructures has been impossible so far.

To overcome this situation, the Physikalisch-Technische Bundesanstalt (PTB) has developed – in cooperation with partners from industry – a complete chain of procedures for the calibration of internal microthreads down to a nominal diameter of 0.7 mm and a lead of 0.175 mm. To determine the most important measurement parameter – the pitch diameter – on microthreads, probe tips with a diameter significantly smaller than 300 µm down to 120 µm are required. For this purpose, a new tactile T-shaped microprobe was designed which has been realized and adapted to a coordinate measurement machine (CMM). An important characteristic of the new design is that the spherical probe tips can be exchanged in the case of wear while the expensive body of the stylus shaft can be re-used.

In addition, a novel measurement standard has been developed to check the gap probing. Whereas common measuring routines in the field of coordinate metrology characterize the spatial probing behavior of a probe under the condition of single-point touching, the new standard allows measurements to be performed in double flank contact. The measurement thus comprises the complete measurement strategy, including self-centering probing. The standard consists of ball pairs which represent one gap, for example, of a screw thread. The ball diameters and the ball distances vary as a function of the thread geometry (diameter, profile angle and pitch). The gap distances which are essential for the determination of the probing behavior were calibrated on a micro-CMM by applying the triangulation method.

Keywords: Microstructures, internal microthreads, tactile T-shaped microprobe, self-centering probing, probe quantification

1. INTRODUCTION

Complex inner microstructures down to 0.2 mm are very often found on technical or medical workpieces. Examples are microplug connections, undercut structures in microbores and microthreads. Within the measurement process these structures are difficult to access and the options for suitable measurement equipment are limited or rather nonexistent.

Based on the demands of German industry PTB has developed a complete chain of procedure for the calibration of complex inner microstructures with partners from industry [1].
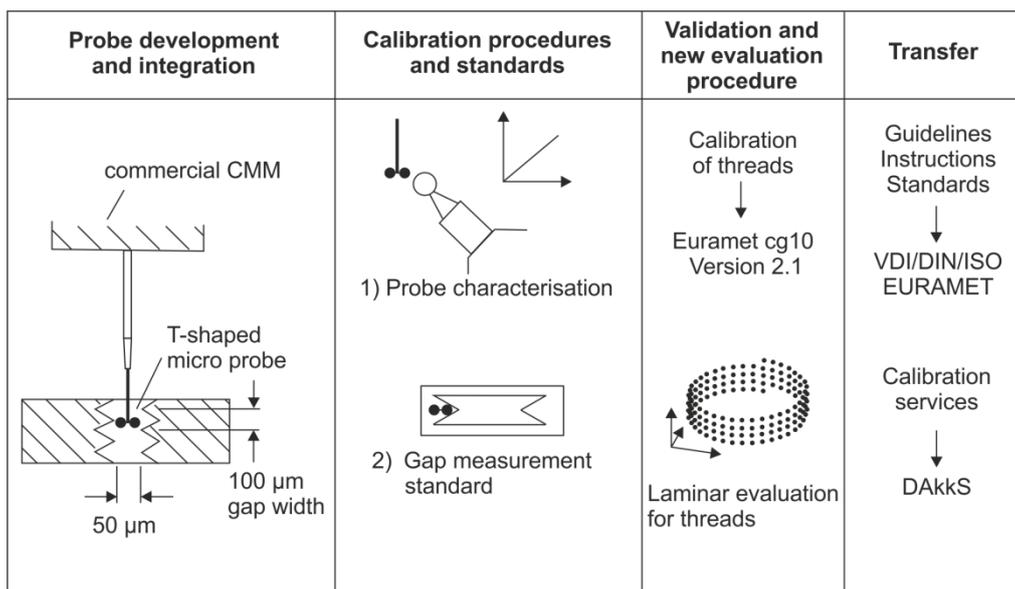

Fig. 1: Complete chain of procedure for the calibration of complex inner microstructures

The developments comprise the design and manufacture of a robust T-shaped microprobe and its integration into a commercial coordinate measuring machine including the adjustment of the probing control process. Moreover, respective measurement procedures and standards have to be developed for the determination of the probe geometry and behavior. The validation measurements are carried out at calibrated inner microthreads, additionally to a new approach for a laminar evaluation. The transfer to industry of these developments is planned by standardization and by the setting-up of calibration services under the supervision of the Germany's National Accreditation Body (DAkkS).

2. PROBE DEVELOPMENT AND INTEGRATION

The new T-shaped microprobe [2] consists of a robust clamping body which is manufactured by a microerosion process and two microspheres with diameters down to 100 µm. The probe design has been optimized, so that the clamping force of the body on the probe spheres is as large as possible to ensure a stable position of the probe spheres in the body. Due to the stable position of the probe spheres a reliable probing and thus a lower measurement uncertainty is achievable in particular in the self-centering probing mode. To achieve this goal, two different materials were tested and the shape of the clamping body was varied. To optimize the design, finite element analyses were carried out. Figure 2 shows an example of a result of such a design optimization.
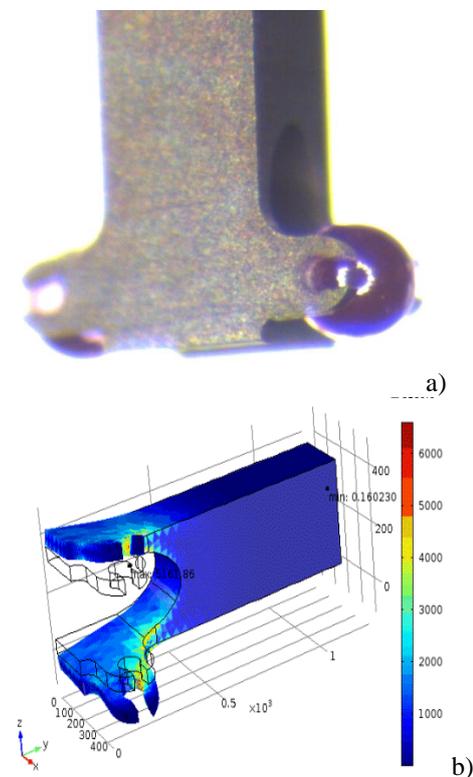

a)

b)

Fig. 2: a) Realized T-shaped microprobe with sphere diameters of 290 µm; b) Distribution of tensions during insertion of the probing spheres

The integration of the probe spheres in the body was carried out at PTB. For that purpose, an optical coordinate measuring machine (Werth Video Check HA) was equipped additionally with translation stages so that the microspheres can be precisely aligned with the clamping body and inserted straight into the slot without damaging the filigree construction (Figure 3).
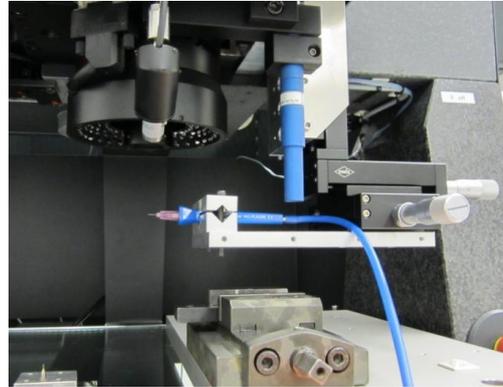

Fig. 3: Assembly fixture for the insertion of the microspheres in the clamping body

3. CALIBRATION PROCEDURES AND STANDARDS

In general, the probe characterization on CMMs is carried out on a reference sphere. For the new T-shaped microprobe the probing area on such a sphere is restricted due to the special design of the probe. In order to achieve a maximized probing area a reference sphere with a small diameter of 1 mm is needed. Nevertheless, only a small area, can be probed during the characterization process, which leads to an incomplete description of the probe geometry and behavior.

Therefore, a task-specific probe characterization increasingly gains in importance. This contains also the examination of the double flank contact which is required for some gap measurements, e.g. the diametrical dimension over balls for gears or the pitch diameter for threads. The probing angle α leads to larger acting forces F_N than the preset probing force F which affects the flattening of the probing sphere (Figure 4). The deviation caused by flattening in the measurement direction $w_{v0}(F_N)$ can be calculated by the equation (1), wherein $w_0(F)$ is the respective deviation affected by a single point probing in normal direction [3].

$$w_{v0}\left(F_N\right) = w_0\left(F\right) \cdot 0.5^{2/3} \cdot \sin^{-5/3}\left(\frac{\alpha}{2}\right) \qquad (1)$$
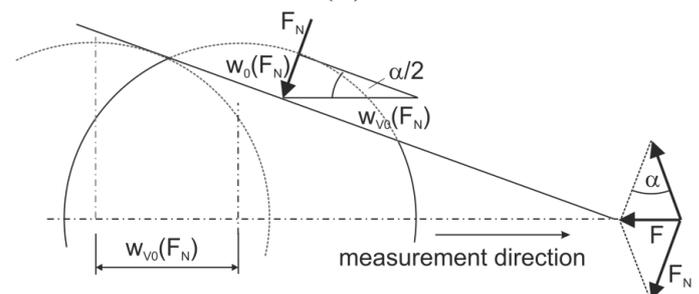

Fig. 4: Principle of gap measurement

To overcome that problem, PTB developed a gap measurement standard [4]. The principle of the standard is that at least two calibrated precision spheres (e.g. of ruby or ceramics) are mounted on a thermally invariant base plate (such as Invar) so that one or two gaps are formed. Figure 5 shows a possible variant in which the four precision spheres form the measurable gaps. Depending on the radius of the probing sphere r_i a calculable length L results. The dimensions of the standard (radius of the precision spheres R_i and distance between the spheres a) have to be specified in such a way that the probing angle α under which the probing sphere with radius r probes the precision spheres is equal to the probing angle of the measurement task. For metric threads the probing angle corresponds to the thread profile angle with $\alpha = 60\,°$. The dimensions are evaluated according to equation (2) and Figure 5.

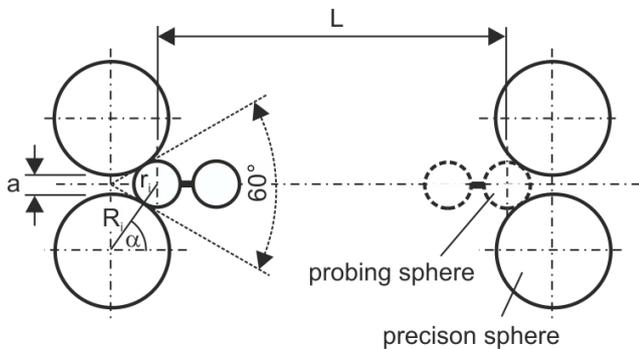$$a = 2 \cdot \left(R_i \cdot \sin\alpha + r_i \cdot \sin\alpha - R_i \right) \qquad (2)$$

Fig. 5: Principle of the gap measurement standard

The gap measurement standard shown in Figure 6 has been designed for thread pitches from 1 mm to 6 mm which are most commonly used in thread metrology. To use the standard for substitution, the similarity criterion must be complied with. In addition to the probe angle α, this also applies to the length to be measured L.
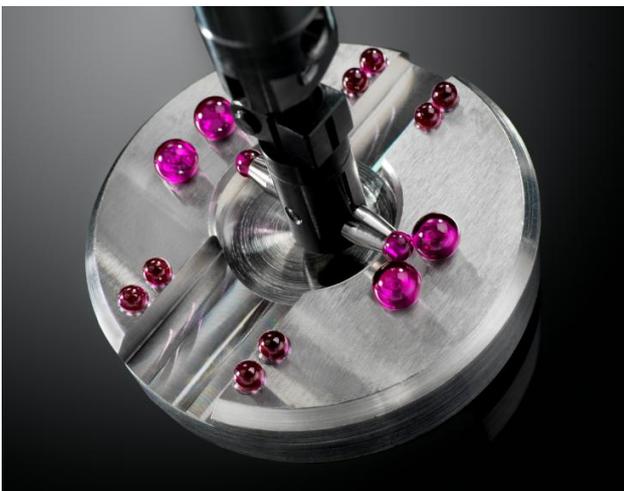

Fig. 6: Example of a gap measurement standard for common thread sizes

Table 1: Dimensioning examples of common thread sizes

Thread pitch P in mm	Probe sphere radius r in mm	Sphere radius R in mm	Distance a in mm	Probe angle α in °
1.00 … 1.75	0.3 … 0.5	1.5	0.3	67 … 55
2.00 … 3.50	0.6 … 1.0	1.5	0.9	70 … 51
4.00 … 6.00	1.15 … 1.75	2.5	1.9	71 … 55

4. VERIFICATION AND NEW EVALUATION PROCEDURE

The first test measurements with the T-shaped microprobe were performed on gauge blocks and gauge rings to confirm the stability and repeatability. The differences in the measurement results were not more than about 0.1 µm and were thus in the range of measurement results that have also been achieved with conventionally bonded probes.

For an authoritative verification of the new T-shaped microprobe, comparison measurements at a calibrated thread ring gauge with a size of M3 were carried out. The determination of the pitch diameter of parallel thread gauges by mechanical probing was to be undertaken according to the calibration guide EURAMET cg-10 [3]. The measurements were performed with a probing sphere with a diameter of 290 µm so that the calibration was just possible with a conventional bonded T-shaped probe. The measurement results and the deviations between both results are shown in Table 2. The obtained measurement values are comparable within the measurement uncertainty.

Subsequently, measurements were carried out on internal microthreads with sizes of M0.7 x 0.175, M0.9 x 0.175 and M10 x 0.175 which were measurable for the first time.

Table 2: Results of the comparison measurement on a thread ring gauge M3x0.5

	Calibration with conventional bonded T-shaped probe (∅ 290 µm) in mm	New T-shaped microprobe (∅ 290 µm) in mm	Deviation in µm	Measurement uncertainty of the calibration in µm
Pitch-diameter	2,6554	2,6548	-0,6	2,5
Minor-diameter	2,4325	2,4317	-0,8	2,0
Lead	0,5000	0,5001	+0,1	1,0

In addition to this known approach of thread analysis also a new mathematical approach has been developed for the laminar description of rotationally symmetrical flank surfaces. By winding up the measurement points recorded on the flank surface, a plane is obtained which is mathematically easy to describe in case of metric threads because of the constant slope. After the application of best-fit algorithms, laminar-related thread parameters can be derived. These parameters include among other things periodical pitch errors, crowning or local defects. An example is shown in Figure 7 at a thread plug gauge M64 x 6 in size. In addition to the above described conventional 2D parameters, a periodic error can be detected

in the laminar evaluation, which was not detectable with the traditional measurement and evaluation strategy.
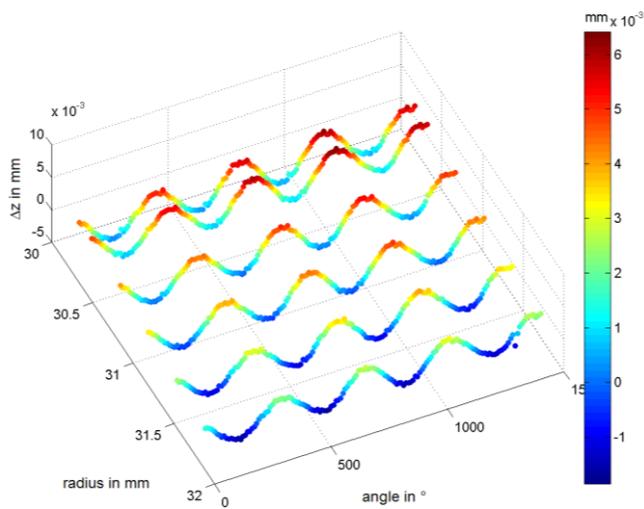

Fig. 7: Laminar evaluation of a flank surface of a thread gauge plug

5. CONCLUSION

Based on the demands of German industry, PTB has developed a complete chain of procedure for the calibration of complex inner microstructures with partners from industry.

The developed T-shaped microprobe allows tactile measurements of inner structures for gap spaces down to 100 µm. Significant applications are measurements of internal microthread geometries for dental implants or microgears used in the clock industry. The patented probe shaft design easily allows the mounting and dismounting of the two probing spheres by guaranteeing sufficient clamping forces. The T-shaped microprobe can easily be assembled and mounted on commercial CMMs and operated by using standard software.

In order to consider the task-specific double flank contact measurement, a new gap measurement standard was developed which minimizes systematic errors.

In addition, a new measurement strategy allows the laminar evaluation of thread flanks.

With these three developments the main research fields in metrology "measurement tools", "measurement standards" and "evaluation software" are covered. Hereby, the basis is established for new measurement capabilities for internal microstructures. Currently, transfer activities to industry are under way. Both of the following are aspired, the commercial manufacturing of the T-shaped microprobe as well as the transfer to accredited laboratories to expand their service offer. In addition, the developments will be proposed and discussed in the respective guideline and standard committees.

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[4] Patent 10 2014 201 508.1: „Normal und zugehörige Verfahren"