A Novel Proceeding for Optical Coordinate Measuring Machines to Locate Deviations Behind an Undercut

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Abstract. *The precise measurement of geometrical dimensions represents the basis of quality assurance in the industrial production. Tactile measurement machines are often replaced by optical non-contact measuring procedures to speed up the measurement process and to minimize the effort needed to ensure the product quality. Within a very short time, optical coordinate measuring machines acquiring numerous measuring points. However the feasibility of a measurement depends on the optical path of light. For this reason it is extremely difficult or partly not possibly to measure undercuts. In these cases it is necessary to deflect the beam of light.*

This paper presents a novel proceeding for optical coordinate measuring machines to locate deviations behind an undercut developed by the Department of Quality Assurance at the Faculty of Mechanical Engineering of the Technical University of Ilmenau. The new approaches are described by the example of measurement of an undercut groove on the inside of a cylinder. Therefore several possibilities for beam deflexion, illuminations scenes, foci criteria, minimum of detecting field and the needed optical magnification were discussed.

Keywords: optical measurement, detection of hidden quality features, deflexion of light and camera beam

1. The defficulties of tactile measurement behind an undercut

Dimensional measurements behind undercuts are always very difficult. As described in [1] tactile coordinate measuring machines are not fast enough for total inspection in the productions process. Beyond that there are further problems with the tactile sampling process. For the measurement behind undercuts it is necessary to use a star or angulate stylus to reach the area of interest. This can be quite impossible when the inner diameter of the cylinder is not enough space for the geometrical form of the stylus. Even if sufficient place is present, a correct measurement is not guaranteed. Special problems result for example in the case of the measurement of grooves in particular through the stylus tip radius [Fig.1].

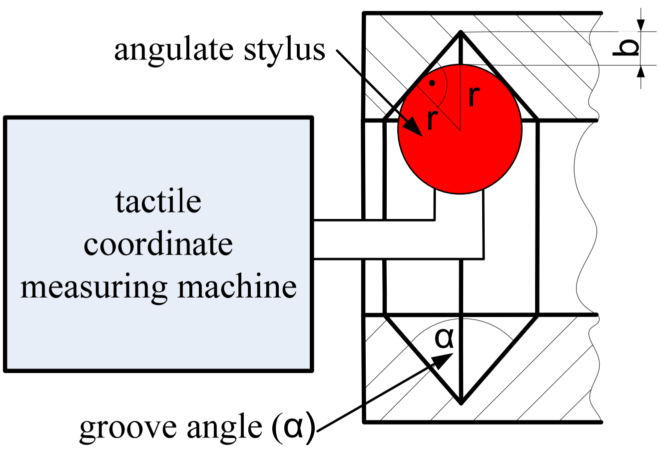

Fig.1 A principal design to measure behind an undercut by using tactile coordinate measuring machines.

For Example a fine stylus with a radius of 500 µm and a typical groove angle α of 90° the radial error of measurement is almost b = 210 µm, [Eq.1],[Eq.2]. Although it is a systematic error and could be corrected, the groove angle can vary and is - in worst cases - unknown.

$$\sin\frac{\alpha}{2}=\frac{r}{b+r} \quad (1)$$

$$b=r\cdot\left(\frac{1}{\sin\frac{\alpha}{2}}-1\right) \quad (2)$$

α groove angle
r radius of the stylus
b error of measurement to the ground of the groove

For this reason it is expedient to use optical coordinate measuring machine for this problem. They are able to measure in very small inner diameter of a cylinder with an appropriate beam deflexion element like a prism [Fig.2]. Due to the general character of this paper boundary conditions were neglected and the constructive beam deflexion solutions for special matters are not mentioned here.

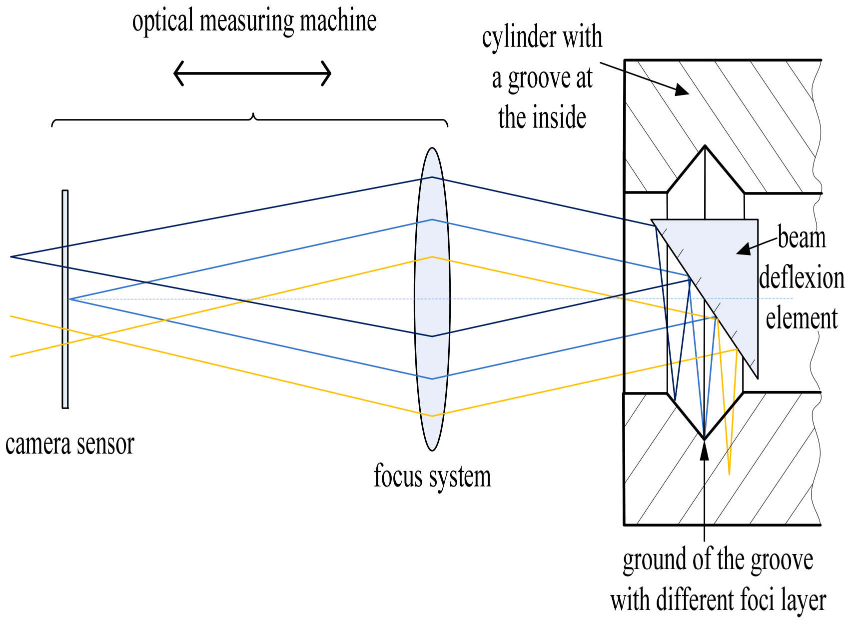

Fig.2 A principal design to measure behind an undercut by using optical coordinate measuring machines.

2. Finding the parameters to measure behind an undercut with an optical coordinate measuring machine

In the field of this research the main focus lay in the determination of the optimal measuring parameters. This covered optical magnification, illuminations scene, focus criteria and minimum of detecting field to find plenty enough and stable measuring points on the ground of a groove which is found on the inside of different cylindrical elements. Different extreme cases for the optical measurement were examined. The selected units under test covered different material classes for example metal with high reflexion character, plastic in different colours and surface roughness and even transparent plastics. The transparent objects represent a special challenge for optical measurement. That is because of the fact that detected measuring points can, as desired, part of the ground of the groove but in addition they could occur through material inclusions, reflexions on a particle or dust or at the backside of the groove. With problematic measuring parameters it is possible that no detectible reflexion occur. On account of this the results of transparent object will be named.

A typical optical measuring machine has got an uncertainty of measurement of 4 up to 5 µm and a confocal incident light, as in [2]. The presented results were accomplished on the optical coordinate machine UNI-VIS 250 from Mahr OKM GmbH Jena. With a planar mirror, which is placed at an angle of 45° to the optical axis, it is possible to detect the ground of the groove. By using different magnifications and foci criteria variable areas of interest (AOI) are placed on the ground of the groove to find detectable points. The measurements were ten times repeated.

Table 1. Researched parameters for finding the fewest standard deviation for the z-coordinate (in ascending order in µm).

parameter			**tranpsrent cylinder**	
size of AOI (µm)	**magnifi-cation**	**foci-criteria**	**standard deviation**	**range (max.-min.)**
40x40	5x	scattering	0,56	1,60
80x80	5x	scattering	1,79	4,80
80x80	5x	noise	1,95	5,30
40x40	3x	noise	2,23	6,70
100x100	3x	scattering	2,28	7,60
80x80	5x	contrast	2,30	6,60
80x80	1x	scattering	2,53	8,80
80x80	3x	scattering	2,63	9,00
100x100	5x	contrast	2,70	9,20
40x40	5x	contrast	2,71	9,60
40x40	3x	scattering	2,82	8,00
40x40	3x	contrast	3,25	10,50
80x80	1x	noise	3,48	11,00
80x80	3x	contrast	3,59	13,10
40x40	5x	noise	3,66	11,90
100x100	1x	scattering	3,81	13,30
100x100	3x	contrast	3,87	11,80
100x100	1x	noise	3,92	13,70
100x100	1x	contrast	3,93	12,50
40x40	1x	scattering	4,59	12,60
80x80	1x	contrast	4,69	14,30
40x40	1x	noise	4,74	15,50
100x100	5x	noise	4,77	14,30
40x40	1x	contrast	4,88	16,80
80x80	3x	noise	5,07	16,00
100x100	5x	scattering	6,31	18,20
100x100	3x	noise	8,37	29,50

The encountered coordinates, especially the z-coordinate recovered during the focusing, is needed to get the diameter of the groove by using a coordinate transformation into a polar coordinate system. Thus, the standard deviations and the ranges of the z-coordinate are listed in Table 1 for all measurements to find the best parameter. As seen there, it is possible to get very stable results with a standard deviation under 1 µm.

But therefore it is necessary to heed some parameters. A higher magnification depends on a smaller AOI, because resolution is rising and the field of view shrinks. Thus more details are visible whereby its more difficulty for the focus algorithms to detect accurate an point. As consequence several small AOIs should be used as a large AOI to detect those quality features.

It is very interesting that the contrast focus criterion does not provide the best results although it is so often used in machine vision. Theoretical the focus point depends only on the object-wide because the frequency content of the image does not change, see also [2]. But on average the scattering criterion is about 1 µm better than the contrast criterion. So it is the best in the test with also the lowest range for the maximum to the minimum.

3. Conclusions

Optical coordinate measuring machines are faster and so more appropriate than tactile in the productions process for total inspections. With a beam deflexion element precision measurements behind an undercut are possible. Therefore it is shown here that a standard deviation under 3 µm can be easily reached. The best parameters for this aim are a high magnification with a small sized AOI from about 40 x 40 µm in combination with the scattering focus criterion.

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References

[1] H.-J. Gevatter, U. Grünhaupt, Compendium for measurement and automation technology, Handbuch der Mess- und Automatisierungstechnik in der Produktion, Springer, Berlin, 2006.

[2] S. C. N. Töpfer, Automated edge probing for high resolution optical geometric measurement, Automatisierte Antastung für die hochauflösende Geometriemessung mit CCD-Bildsensoren, Ilmenau University of Technology, Dissertation, 2008