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A NEW PROCEDURE FOR DETECTING DEVIATIONS BEHIND AN UNDERCUT BY USING OPTICAL COORDINATE MEASURING MACHINES

Matthias Rückwardt [1], *André Göpfert* [1], *Steffen Lerm* [1], *Maik Rosenberger* [1], *Mathias Schellhorn* [1], *Gerhard Linß* [1]

[1] Technical University of Ilmenau (Faculty of Mechanical Engineering, Department Quality Assurance), Ilmenau, Germany, matthias.rueckwardt@tu-ilmenau.de

Abstract – The field of quality assurance in the industrial production is closely connected to the precise measuring of the products. Several measuring methods are used, like optical, capacitive or tactile ones. There is perennially a pinch for time the measure each needed deviation in a little while, especial when a total inspection is necessary. Optical coordinate measuring machines are especially qualified for this aim, because of their possibility to acquire a lot of measuring points in one measuring step. Because of the blocked optical path, also these machines are finished when the device is located behind an undercut. This is for example the case by the ground of a groove on the inside of a cylinder. Then it is necessary to deflect the beam of the machine as you can see in Fig. 1.

That is the reason why the Department of Quality Assurance from the Faculty of Mechanical Engineering of the Technical University of Ilmenau promoted by the Federal Ministry of Economics and Technology within the framework of the InnoNET program is researching for a new procedure for detecting deviations behind an undercut by using optical coordinate measuring machines. 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 PROBLEM OF TACTILE MEASURING BEHIND AN UNDERCUT

It is always very difficult to measure behind an undercut. As already mentioned tactile coordinate measuring machines are not fast enough for total inspection in the productions process [1]. Furthermore there are other troubles with the tactile touching. First of all a lot of measuring room is need for reaching the area of interest. For this a star or an angulate stylus or even a huge stylus radius has to be used to get to the device under test. This can be quite impossible when the inner diameter of the cylinder does not provide enough space for the geometrical volume of the stylus. Even if adequate space is present a correct measurement is not assured. In case, when the stylus does not get touch to the searched measuring point because of the structure of the object under test, see Fig.2. There will be always an offset between the detected point and e.g. the ground of a groove, depending on the radius (r) of the stylus and the angle (α) of the groove.

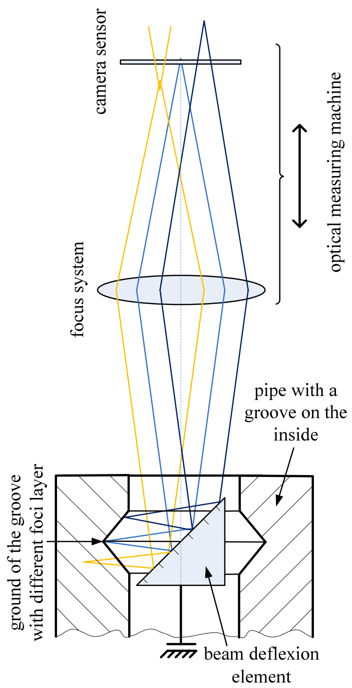

Fig. 1. A principal design to measure behind an undercut by using optical coordinate measuring machines.

As an example, a fine stylus with a radius of 1mm and a typical groove angle (1) of 90° the radial error of measurement is almost b=420µm (2). Naturally this is a systematic error. So the error can be calculated and charged to correct result. But there are many influences on the offset because of different tolerances like: the groove angle is not constant over all or even unknown, the centre of the stylus and the ground of groove will not be on the same level and there are manufacturing inaccuracies.

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

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

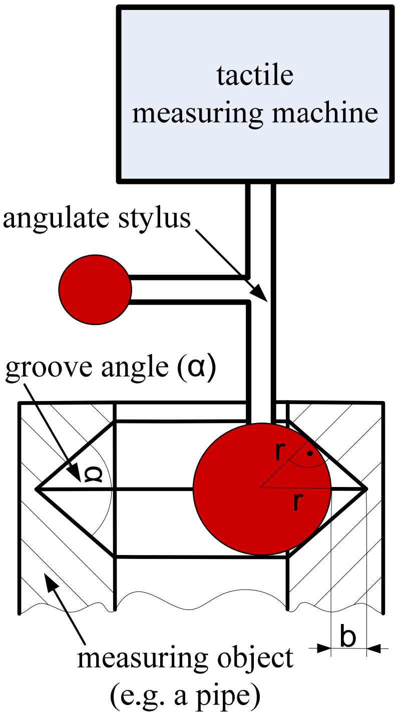

Fig. 2. A principal design to measure behind an undercut by using tactical coordinate measuring machines.

For this reason it is expedient to use optical coordinate measuring machines for detecting deviations behind an undercut. They are able to measure in very small inner diameter of a cylinder with an appropriate beam deflexion element. Furthermore in case of groove measurement light is reflected sufficiently at the ground of the groove back to the camera and the reflections at the shoulder of the groove can not be detected. Therefore only points at the ground will be found.

For keeping the universality for this paper boundary conditions were disregarded and the constructive beam deflexion solutions for special matters are not mentioned here.

2. FINDING THE PARAMETERS TO MEASURE BEHIND AN UNDERCUT WITH AN OPTICAL COORDINATE MEASURING MACHINE

In the field of this research the main focus was on finding optimal parameters: This included 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. Diverse extreme cases of machine vision are under test. The different measurement objects are out of several classes of material. Fore example metal with high reflexion character, plastic in different colours and surface roughness and even transparent plastics are used. The transparent objects display the main challenge in optical measuring. Due the fact that it is not garantated detected the points are on the ground of the groove, in the material, because of a reflexion on a particle or dust or at the backside of the groove with its likewise well refection characteristics. Also it is possible that there is no detectible reflexion. On account of this the results of transparent object will be named.

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

A typical optical measuring machine has got an uncertainty of measurement of 4 up to 5 µm and a confocal incident light [2]. The presented results were accomplished on the optical coordinate machine UNI-VIS 250 from Mahr OKM GmbH Jena [3]. 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 a reproducible points. The measurements were ten times repeated.

The encountered coordinates, especially the z-coordinate recovered during the focus ride, 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 around 1µm.

But therefore it is necessary to heed some parameters. A higher magnification depends on a smaller area of interest, because resolution is rising and the field of view shrinks. Beyond more minutiae are detectable in a huge area, so it is not possible for the focus algorithm to detect each time the same point beside all the others in the area. Consequently several little AOIs should be used as one large one for finding the 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 [2]. But on average the scattering criterion is about 1µm better than the contrast. So it is the best in the test with also the lowest range for the maximum to the minimum [3].

3. OPPORTUNE ILLUMINATION FOR THE SUPPORT OF THE MEASUREMENT

In some cases it is essential to illuminate the measuring scene, for example by scanning in large pipes when the confocal light is not powerful enough. Therefore in a next step the research is focused on a ring light with 8 separately controllable LED-segments. With this ring light it is possible to light the measuring object form each direction, see also in Fig. 3.

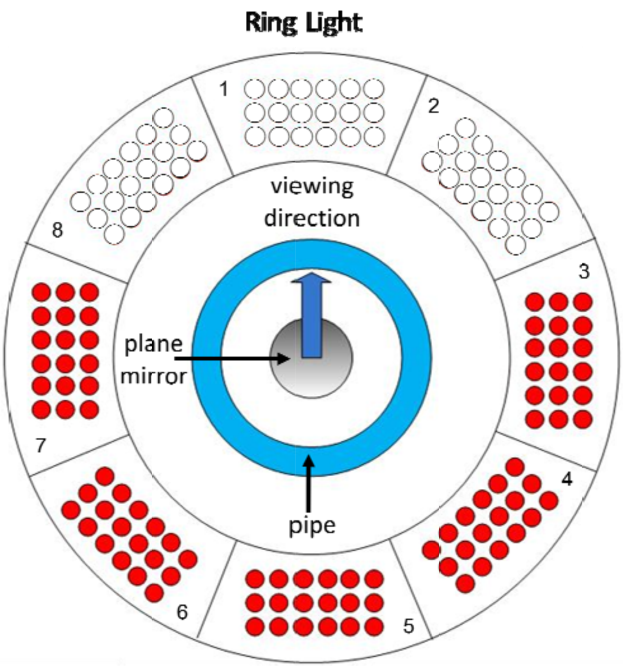

Fig. 3. A principal illumination scene to measure in a pipe with a ring light out of 8 separately controllable LED-segments (red=on, white = off).

In this test the planar mirror is in a depth of the pipe that without illumination no point is detectable, because of the missing light. The different segment of the ring light are turned on, as seen in table 2, and when there are points they are measured ten times with the parameters form part 2 of this paper to get the standard deviation and range.

The planar mirror always offers a small viewing direction for the camera to the area of interest in the pipe. To get enough light there, there are two possibilities. First of all the light from the ring light can be reflected direct over the mirror to the pipe. That is the case, if segments 1,2,8 or 1,2,3,7,8 are on, but this does bring catastrophically results. There is still not sufficient light in the pipe. This is the same when the light comes from the side.

So the better way to illuminate the pipe is by indirect reflection or diffuse scattering. For this purpose all segments can be turned on or still better the area of interest is illuminated from the opposite side of the viewing direction. See also table 2, when the segments 4,5,6 or 3,4,5,6,7 are on. Know for example the diameter of the pipe can be detected with a standard deviation in one point of about 2,8µm.

Table 2. Standard deviation of the measured points with different light segments of the ring light (in µm).

on segments	standard deviation	range (max.-min.)
5	5,97	19,22
4,5,6	4,46	13,2
3,4,5,6,7	2,79	9,07
6,7,8	no point	no point
3,7	no point	no point
3,4,6,7	32,54	104,55
2,3,6,7	no point	no point
2,3,4,6,7,8	14,45	46,67
1,2,3,4,5,6,7,8	6,86	19,79
1	no point	no point
1,2,8	176,67	574,25
1,2,3,7,8	22,42	72,13

4. CONCLUSIONS

Optical coordinate measuring machines are faster and so more appropriate than tactile in the productions process for total inspections. Especial because they are able to measure behind an undercut with a beam deflexion element. Therefore it is shown here that a standard deviation under 3µm can be easily reached. The best parameters for this aim are a high magnification with a middle sized AOI from about 40x40µm in combination with the scattering focus criterion.

Normally devices under test are huge which required a large field of view. But even with a magnification of 1x and a area of interest size of 80x80µm a standard deviation of 2,53µm is attainable. This is sufficient for most measuring tasks.

Furthermore, if it is necessary to illuminate the object under test with a ring light, this should happen from the opposite side of the viewing direction to get enough light to the area of interest.

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