Effect of measurement conditions on three-dimensional roughness values, and development of measurement standard

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Abstract. Friction or corrosion behaviour, fatigue lifetime for mechanical components are influenced by their boundary and subsurface properties. The surface integrity is studied on mechanical component in order to improve the service behaviour of them. Roughness is one of the main geometrical properties, which is to be qualified and quantified. Components can be obtained using a complex process: forming, machining and treatment can be combined to realize parts with complex shape. Then, three-dimensional roughness is needed to characterize these parts with complex shape and textured surface. With contact or non-contact measurements (contact stylus, confocal microprobe, interferometer), three-dimensional roughness is quantified using the calculation of pertinent parameters defined by the international standard PR EN ISO 25178-2:2008. An analysis will identify the influence of measurement conditions on three-dimensional parameters. The purpose of this study is to analyse the variation of roughness results using contact stylus or optical apparatus. The second aim of this work is to develop a measurement standard well adapted to qualify the contact and non-contact apparatus.

1. Introduction
Some characterizations of roughness are investigated with different apparatus. Three-dimensional (3D) roughness was characterized on two samples (a ring and a tube) and the first standard of measurement developed in this current study [1,2,3]. The influences of measurement conditions on roughness parameters are analysed, for contact and for non-contact measurements: in terms of step of scanning and size of area [4]. Roughness values are compared after two measurements on the same place inside the tube. The nomenclature is given on the table1. These measurements were performed using a stylus contact profilometer and a confocal sensor. The standard of measurement is created with a specific geometry to enable qualification of roughness with different instrument.

Table 1. Nomenclature.

| (X, Y, Z) | Lateral coordinates of point on the surface and vertical measurement coordinate on the surface |
| (A, B) | Big radius of ring, about 70 mm and respectively, small radius of ring, about 13 mm |
| (C, D) | Radius of the tube, about 10 mm, and respectively, thickness of the tube, about 1mm |
| St | Maximal height, μm |

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2. Influences of measurement conditions
The influences of measurement conditions are analysed after contact and non-contact measurement. All the apparatus used are equipped with a stylus or a point sensor. The relevant techniques used in this current study qualify Z, the altitude position of points on the surface characterized for each position (X,Y), with specific associated steps. The system of coordinate is established on the reference of the apparatus, associated to the motion in X and Y directions.

2.1. Contact measurements
The first sample is a ring. The figure 1 shows the geometry of this sample, with a radius A of 70 mm and with a radius B of 13 mm. Some measurements were done on the torus of the ring using the contact device SURFASCAN 3D to analyse the variation of the 3D surface characterization. The vertical resolution of the inductive transducer is 4 nm. The radius of the stylus used is about 2 μm and the angle of the edge is about 60°. The measurements were done on the torus on an area about 8 mm × 4 mm. These measurements were done with a step in X direction about 4 μm and in Y direction about 4.4 μm.

The least mean square plane associated to the measurement points is characterized. Then, the correction of the defect of parallelism between the surface and the reference of measurement is corrected using the appropriate rotations. The effect of F-Filter was analysed with different length of spline. The shape involved was distorted. Then, no F-Filter was used for treatment, but a cropping was done, in order to reduce the zone analysed (without perturbation by the shape). The L-filter, a 3D Gaussian regression filter with a cut-off about 0.8 mm is applied [5]. The S-filter, a 3D Gaussian regression filter with a cut-off about the double of the lower step was applied. No significant evolution on parameters are analysed with and without S-filtering. Then, the L-filter is used such as simplified and sufficient treatment combining with cropping. The roughness parameter values are obtained using the Surfascan software. The value of Sa, the arithmetic roughness is about 0.14 μm. Height parameters are calculated using the definition given on the papers referenced [2,3,4] for the Sa, Sds, Sq, Ssc, Ssk, Sku, Sdq and Sdr. The Sz and St parameters are defined only in the references [3,4]. For each parameter analysed, the normalized results are given in the figure 2. The reference values are that obtained on the more precise measurement corresponding to the measurement with the smaller steps. 2, 3, 5, 7 and 10 multiplies the smaller steps. The influence of the size of the area of the measurement is investigated; normalized results are given in the figure 3. The reference values are that obtained on
the more precise measurement corresponding to the measurement with the bigger area about 4 mm x 4 mm. The smaller areas are squares with a length about 2 mm and 1 mm.

Figure 2: Influence of the steps acquisition on the normalized values of 3D roughness parameters, done using contact apparatus.

Figure 3: Influence of the size of the acquisition area on the normalized values of 3D-Roughness parameters, measurement done using contact apparatus.

2.2. Non contact measurements
The second sample is a tube. The figure 3 shows the geometry of this sample, with a radius C of 10 mm and with a thickness D of 1 mm. Some measurements were done using the confocal chromatic sensor on the device Altimet 3D to analyse the variation of the 3D surface characterization. The vertical resolution of the optical pen is 3 nm. The lateral resolution of the optical pen is 3.3 μm. The measurements were done inside the tube, on an area about 2 mm², with a step about 10 μm in the both directions X and Y.

Figure 4: Measurement on a tube with a 3D confocal apparatus.

The shape was cut-off using a F-Filter with length of spline about 0.8 mm. The L-filter, a 3D Gaussian regression filter with a cut-off about 0.8 mm is applied [5]. The S-filter, a 3D Gaussian regression filter with a cut-off about the double of the step was applied. No significant evolution on parameters are analysed with and without S-filtering. Then, the results are obtained by combining F-filtering, L-filtering and rotation of the least mean square plane. The roughness parameter values are obtained
using the Surfascan software. The value of Sa, the arithmetic roughness is about 0.34 μm. For each parameter analysed, the normalized results are given in the figure 5. The reference values are that obtained on the more precise measurement corresponding to the measurement with the smaller steps (10 μm). 2, 3, 4 and 6 multiplies the smaller steps.

The influence of the size of the area of the measurement is investigated; normalized results are given in the figure 6. The reference values are that obtained on the more precise measurement corresponding to the measurement with the bigger area about 1 mm x 2 mm. The smaller areas are squares with a length about 1 mm.

![Figure 5: Influence of the steps acquisition on the normalized values of 3D-Roughness parameters, measurement done using non-contact apparatus](image1)

![Figure 6: Influence of the size of the acquisition area on the normalized values of 3D-Roughness parameters measurement done using non-contact apparatus.](image2)

2.3. Influences on results

On the results given in the figure 2 and the figure 5, only five of the ten parameters are strongly influenced by the step when measurement is done with contact profilometer and confocal sensor. Firstly, the value of the skewness, Ssk, seems to be very instable. The values of the spacing parameter, Sds and the hybrid parameters Ssc, Sdq decrease more than 40 % when the step is divided by two; Sdr decrease more than 60 %. In the same case, the values of local amplitude parameters St and Sz decrease no more than 20 %. For the two parameters Sa and Sq, the behaviour is not the same for the ring and the tube. The results given on the ring sample with the contact apparatus produce almost similar values of these two parameters. Less than 20% of decrease can be observed on the Sa and the Sq values, when the step is divided by ten. The increase of the Sa and the Sq values are about 20 % in the case of a non-contact measurement on the tube, when the steps are divided by three.

On the results given in figure 3 and figure 5, only three parameters are strongly influenced by the size of the area scanned in the case of contact or non-contact measurements when the size is divided by two or fourth. The values of the St, Sz and Ssk are significantly affected. The variation of Sa and Sq values are less than 1.1 % in the case of a non-contact measurement on the tube. No more than 1% of variation can be observed on the Sa and Sq values, when the area is divided by fourth, for the results given on the ring sample with the contact apparatus. These values are strongly disturbed when the size is divided by sixteen.
2.4. **Optimal method of measurement with accuracy**

Previous analyses clearly indicate that the results on Sds, Ssc, Sdq and Sdr values are very influenced by the step of the scanning. The area size is not so influent. It will be interesting to develop an optimal method in order to quickly qualify the roughness. A first measurement with smallest steps, on a small area, can allow identifying the stable parameters: for example, such as Sa and Sq, for the results obtained on the ring. Then, the optimal step of scanning can be used to perform a series of measurements. In every case, measurement with the smallest step will enable to determine precisely hybrid parameters Ssc, Sdq, Sdr and Sds.

2.5. **Influence of the apparatus**

The tube defined on figure 2 was measured with a step of 10 μm in a previous study [6], with contact profilometer and confocal sensor. The conditions of measurements are given on the table 2. In the figure 7, the values of some 3D-Roughness parameters, calculated after contact measurement, are used to define the reference and there are compared with values obtained using confocal sensor. Variations can be observed on all the values characterized by the two techniques. The values of average parameters, as Sa and Sq, present a variation more than 40 %. Then, it seems to be necessary to measurement a standard, in order to precise the values of roughness.

| Table 2. Conditions of contact and non-contact measurement inside the tube. |
|--------------------------------|---------|---------|
| Measurement conditions         | Contact | Confocal|
| Area, mm²                     | 4       | 2       |
| Step in Y and Y directions, μm | 10      | 10      |
| Stylus radius or spot size, μm | 2       | 3,3     |

![Figure 7: Influence of the apparatus values of 3D-Roughness parameters, measurement done using contact profilometer and non-contact confocal instruments](image)

3. **Development of a standard of measurement**

Some standards are developed to verify the roughness but on plane samples. Others standards can be used to verify the capability of the apparatus only at the scale of macrogeometry [7]. In fact, all the previous analysis conducted us to develop a specific measurement standard of roughness with a complex shape. Then, the identification of properties needed for this part is done. This standard must allow quantifying roughness using different instruments. The geometry is defined with a complex and specific shape: with concave and convex curvature. A measuring range about three hundreds micrometers is selected: optical apparatus, as interferometer or confocal sensor must enable to measurement this part. Then, dimensions are computed in order to allow the measurement on a maximal area about 4 mm x 4 mm. The first sample was turned on a bar of 35NiCrMo16, with
hardness about 40 HRC. Turning process is chosen in order to create different roughness levels due to different feedrate values. The drafting is given in figure 8(a).

A protocol of manipulation was established when the first measurements were performed with this standard. The figure 8(a) indicates the specific position of the measurement, in the middle of the sample. A method is developed to allow a precise positioning of the sample on the apparatus plate: the axis of the sample needs to be parallel to the X motion of the table (figure 8(b)). After the first measurement on the standard, an improvement of this component is needed. The standard presents a shape defect. Some investigations with mill-turn machining will be conducted in next months in order to reduce this defect. On the other hand, the protocol must be adjusted in order to precise the treatment of measurement data. First analysis had shown a significant influence of the shape filters on the roughness results.

4. Conclusion
A standard of roughness is developed; a protocol of measurement is defined in order to quantify the roughness parameters. In the next year, a new standard will be used to investigate with a campaign of inter-comparison on different instruments. The results obtained will improve the knowledge of influence factors on values of roughness parameters. Maybe specific and optimal method of characterization will be defined.

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