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Contact Deformations under the Influence of Measurement Force

Anita Avisane*, Didzis Avisans

Institute of Mechanical Engineering, Riga Technical University, Ezermalas str. 6k – 418, Riga LV-1006, Latvia

Abstract

The common measurement error when measuring the component geometrical dimensions using universal contact measurement instruments is caused by different factors, such as error of the measurement instrument, personal reading errors, effect of surface roughness on the measuring line deviation, influence of contact deformation measurement force, and others. The present article examines one of these factors, i.e. contact deformations under the influence of measurement force. To make precise measurements it is essential to find out the effect of roughness of measured components. High roughness creates additional measurement errors. It is particularly important in the measurement of thin components, flexible materials and films. Flexible bodies in the meaning of this article are components of different shape and sizes made of rubber-like materials. This article studies principles of error formation based on the deformation of surface roughness and basic material.

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1. Introduction

Nowadays all the time increasing production of polymers and growing application of products made of polymers, also in the field of mechanical engineering causes a necessity to increase the production precision and efficiency. Rapid and high precision control of component sizes furthers the increase of production process precision and efficiency. Up to now there are no polymer material component measurement and measurement error detection methods which fact makes the choice of correct measuring devices for definite materials difficult. Development of such methods and their introduction into practice allows making precise and good quality control, reducing the necessity for ungrounded high product tolerances. When making measurements components made of highly elastic materials are exposed to deformations under the effect of deformation measurement force. Until now this issue has

* Corresponding author. Tel.: +371 67089701.
E-mail address: anita.avisane@rtu.lv

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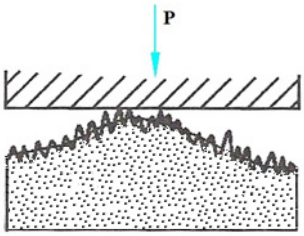
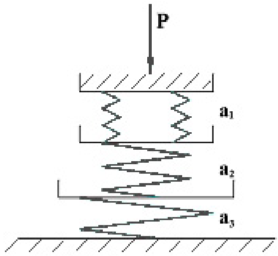
not been studied sufficiently. There are numerous and different sources of literature mentioning particle deformations, but deformations during their measurement process and their effect on measurement precision have not been studied. In such cases one has to consider also deviations arising as a result of surface roughness deformations. The permitted values of measurement mistakes are assumed 20% to 35% of the allowance value. A standard comprises 15 measurement maximum permitted error lines, depending on rated sizes and production allowance. For sizes from 1 to 500 mm the allowed measurement limit errors $[\Delta_{mer}]$ are given in ISO 1938:1981 Standard and need not be calculated.
This paper can be used as a basis for the development of definite elastic material component measurement or measurement error determination methods, when taking measurements by definite measurement instruments.

2. Contact circuit

For precise determination of total measurement error affected by the applied force surface deformation should be divided into three parts. The first part is roughness deformation, the second part is subsidence of these roughnesses and the third – deformation of basic material. Schematically in the form of a spring it is shown in Fig.1.



a)



b)

Fig.1. Scheme of contact: a) whole scheme; b) scheme of spring principal.

Thus total surface deformation can be calculated by summing up the calculated deformations of all three constituent parts:

$$a = a_1 + a_2 + a_3, \quad (1)$$

where
a_1 – deformation of surface irregularities.
a_2 – subsidence of the surface irregularities.
a_3 – deformation of base material.

3. Calculation of surface roughness deformation

Studies of contacts of rough surfaces are connected with roughness deformation. Roughness deformation is very crucial in the determination of measurement errors. One essential parameter affecting roughness deformation and used in the solution of contact tasks is the height of surface roughnesses. The height of rough surface roughness is counted off from the midline (in case of a profile) or median plane (in case of 3D surface), which means that maximums of random process or random function are determined.

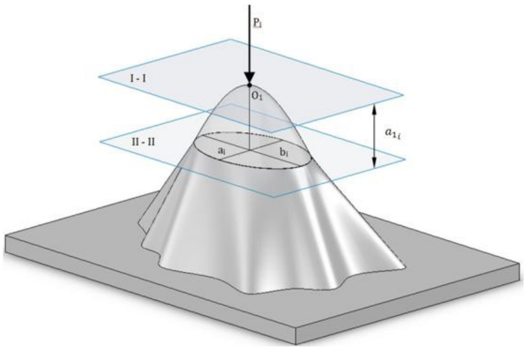


Fig. 1. Deformation of free–choice surface peak.

For roughness contact N.M. Belyaev's solution can be used – for contact of ellipsoid surfaces, where we assume on body as an ideal hard plane. Deformation a_{1_i} of one freely chosen surface roughness peak can be determined as follows [1]:

$$a_{1_i} = \frac{3}{2} K(e) \frac{P_i \cdot \theta}{b_i}, \quad (2)$$

where

$P_i = \dfrac{P}{N(\gamma)}$ – force, applied to free – choice surface peak, P – force applied to the surface, $N(\gamma)$ – amount of roughness peaks on the level γ;

$K(e)$ – first order elliptic integrals;

$e = \sqrt{1 - \dfrac{{a_i}^2}{{b_i}^2}}$ – eccentricity of contact area;

b_i – large semi-axis of the one roughness peak's contact area (Fig. 2).

a_i – small semi-axis of the one roughness peak's contact area (Fig. 2).

$\theta = \dfrac{1-\mu^2}{\pi \cdot E}$ – constant of material property (where μ - Poisson's ratio, but E – modulus of elasticity).

Surface roughness height, according to the studies described in previous publications [2, 3, 4], are determined by using asymptote of Rayleigh distribution law. In its turn surface roughness deformations are calculated by multiplying the obtained deformations of one surface roughness peak by the number of roughnesses per a field unit. To make use of the data of obtained equations possible in the solution of engineering tasks theoretical parameters are replaced by standard parameters used in practice St, Sa and RSm. The surface roughness deformations are calculated as follows:

$$a_1 = St - 2\sqrt{2\pi} \cdot Sa \cdot \left(1 - \frac{3}{2\sqrt{2}} \cdot \frac{q}{E} \cdot \frac{RSm}{Sa}\right), \quad (3)$$

where

St – surface total height is a height between the highest peaks Sp and the deepest valley Sv and it is determined by relevance: $St = Sp + Sv$;

Sa – arithmetical average deviation from the surface mid-plane;

q – pressure on the surface, the perpendicular force that is applied on unit of the area;

RSm – mean spacing of the profile irregularities.

Simplifying this formula in the solution of engineering tasks we can write:

$$a_1 \approx St - 5Sa \cdot \left(1 - \frac{q}{E} \cdot \frac{RSm}{Sa}\right), \quad (4)$$

4. Subsidence of Surface Roughness

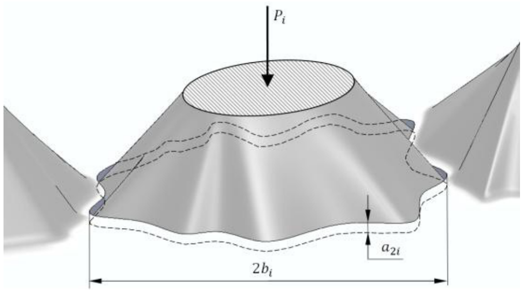


Fig.2. surface roughness subsidence.

During the measurement process and determination of measurement error, besides the roughness deformation, one should consider also roughness subsidence and in some cases even deformation of basic material. To determine roughness deformations and subsidence one must know geometrical parameters of roughnesses and their elastic properties. According to studies by L.A. Galin [5] this roughness subsidence can be determined according to the following formula:

$$a_{2_i} = \frac{K(e) \cdot \theta \cdot P_i}{b_{2i}} \tag{5}$$

where
b_{2i} – large semi-axis of the of the elliptic surface (Fig.2).

The calculation of the surface roughness subsidence can be calculated by the similar scheme as the calculation of the surface roughness deformation. It would make easier for further solving the engineering solutions by making more simple equation:

$$a_2 \approx 0.1 \cdot RSm \cdot \frac{q}{E}. \tag{6}$$

According to a similar scheme as for the determination of surface roughness deformation, simplifying this formula for the solution of engineering tasks the following equation was obtained:

$$a_3 = \frac{q}{E} \cdot h\,. \tag{7}$$

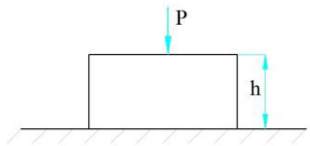


Fig.3. Deformation of the base material.

5. Total surface deformation

The total surface deformation under the effect of measurement force is being determined using the following expression:

$$a \approx \frac{q}{E} \cdot \left[h + 1.1 \cdot RSm + \frac{E}{q}(St - 5 \cdot Sa)\right]. \tag{8}$$

This equation allows predicting measurement error for each contact measurement measuring instrument under the effect of measurement force, which in its turn allows evaluation of the suitability of the chosen measuring instrument for measuring definite material component. The allowed values of measurement error are assumed 20%

to 35% from the allowance value. In cases when the calculated measurement error for the instrument with the smallest pressure on the surface exceeds the allowed measurement error, for the measurement of the given component the contactless measurement method should be chosen.

Conclusions

The coherence of the determination of surface roughness deformation a has been obtained, comprising surface grain orientation (texture), characteristic quantities of physical mechanical properties of component to be measured and pressure on the contact area under the effect of measurement force. Thus we can conclude that by the help of this equation we can determine the effect of both the measurement force and surface roughness on the measurement error. By determining the measurement error we can increase both the measurement precision and production efficiency, which in its turn complies with the objective set forth by today's ecologists – to reduce the amount of raw materials of polymer materials and their wastes.

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