Novel Method of Non-contact Out-of-roundness Measurement with Air Gauges

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Abstract

In the paper, a new concept of the out-of-roundness measurement of the inner cylindrical surfaces based on reference method is presented. The novel measuring tool for three-point measurement consists of three independent air gages. The specific design of the air gages ensures its improved static and dynamic properties: multiplication of 0.5 kPa/µm in the displacement range from 20 to 120 µm, and time constant of 0.006 s.

To determine the time constant of the air gauges, two laboratory set were used, one for the sine input, and other for the step input. Investigations proved that the behaviour of small chamber air gages with piezoresistive pressure transducers could be considered the first-order dynamic system. Even though the time constant is back-pressure-dependent (i.e. it changes from the beginning of the measuring range to the end), and is different for rising and for falling pressures, its values ensure fast enough response for the out-of-roundness measuring task. The devoted software designed for that purpose, enabled to determine the coefficients of identification and to reproduce actual profile from the measuring data. The analysis proved that the final results stay in conformity with the results gained from reference methods (differences less than 10%). The conclusion is that the proposed method provides fast, cheap and accurate device for out-of-roundness measurement with tolerances of 10-15 µm.

1 The measurement equipment

The use of pneumatic gauging for measurement of small displacements or small differences in length offers a number of advantages: non-contact inspection, higher resolution, ease of use, purging of contamination, and resistance to fouling [1]. The novel method was designed to provide an accurate and fast non-contact measurement of the inner diameters.

It is based on the complete automatic set, where the detail is placed manually (Fig. 1, left). The measuring head goes up from lower part of the set, and perform the measurement in three intersections (bottom, middle and top) turning around 360º (Fig. 1, right). The novelty of the method consists of following: the measuring head contains three independent air gauges (Fig. 2), it is placed on the flexible rod (a floating head), and it is based on original algorithm designed for analysis of three independent signals to determine the roundness of the measured detail.

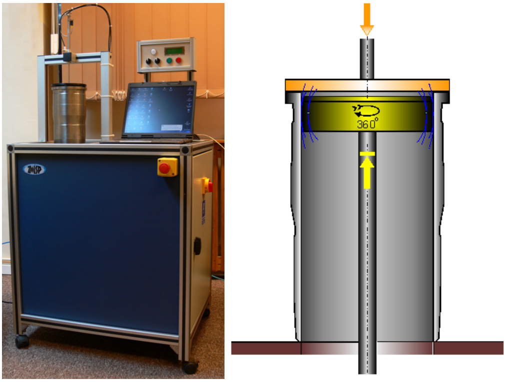

Figure 1: The *Geoform* equipment (left) and the scheme of measurement (right)

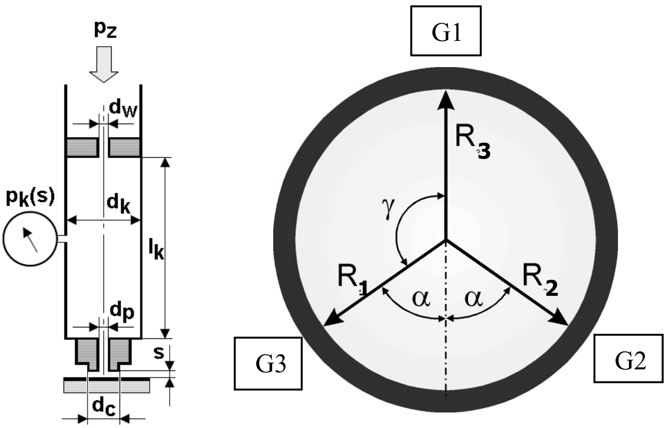

Figure 2: Single air gauge (left) and position of three such gauges in the measuring head (right)

2 Dynamics of the applied air gauges

It was proved that the reduction of an air gauge measuring chamber volume improves its dynamical properties [2]. Dependent on the geometrical parameters d_p, d_w, d_c, d_k, l_k, the dynamic characteristics of an air gauge could become close to the first-order system with time constant T smaller than 25-30 ms. For the *Geoform* device the measuring chambers with T=0.006 s were manufactured, and the nozzles were chosen to provide multiplication of 0.5 kPa/µm in the measuring range of 100 µm.

The thorough examination revealed the dependence of the time constant on the actual back-pressure $T=f(p_k)$. The normalized function $T/T_{max}=f(p_k/p_{k\ max})$ is presented in the Fig. 3 for smallest examined chambers with volume V_{k2}=0.251 cm^3 and the largest ones V_{k9}=3.921 cm^3. In the *in situ* measurement during the machining, the knowledge on the expected change in T is crucial, but in measurement of such feature like roundness, it is enough to know the maximal value of T.

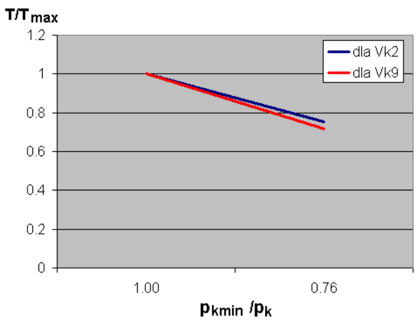

Figure 3: Normalized function $T/T_{max}=f(p_k/p_{k\ max})$

3 The simulations and reference measurement

The devoted software enables to determine the coefficients of identification and to reproduce actual profile from the measuring data. To obtain information on conformity of the obtained results with true values, a set of simulations and reference measurement was carried out. The initial model was prepared for the tests of algorithm, and the measurement was simulated. The possible errors were generated like: angle displacement of air gauges, random error of the roundness, amplitudes of certain harmonics [3]. The simulations proved that those factors do not affect the results of measurement in sufficient way, and are omitable.

The method was tested by means of comparative analysis with the result of measurement with Talyrond 365 device made by Taylor-Hobson. The method accuracy $DP = \left|\overline{\Delta}_{MP} \pm u_p s\right| \cdot 100\%$ was calculated for mean difference $\overline{\Delta}_{MP}$ between n measurement results, with coefficient u_p of normal distribution for P=0.95, and standard deviation s. After 100 repetitions with different cylinders, the *DP* factor was calculated as 9.40%. The results of examinations are presented in the Table 1.

Table 1: Results of statistical comparative analysis of Geoform device with Talyrond

Number of samples *n*	100	Standard deviation *s*	0,031
Mean value $\overline{\Delta}_{MP} = \frac{1}{n}\sum_{i=1}^{n_s} \Delta_{MP_i}$	0,088	Confidence interval for the single measurement $\left(\overline{\Delta}_{MP} - u_p s; \overline{\Delta}_{MP} + u_p s\right)$	0,088±0,060
Confidence interval for the above mean $\left(\overline{\Delta}_{MP} - u_p \frac{s}{\sqrt{n}}; \overline{\Delta}_{MP} + u_p \frac{s}{\sqrt{n}}\right)$	0,0880±0,0060	Accuracy of method *DP*	9,40%

The result is highly satisfactory, especially when considering incomparably lower price and faster work of the tested device.

The conclusion is that the proposed method provides quick, relatively cheap and reasonably accurate device for measurement of inner cylinders with out-of-roundness tolerances of 10-15 µm.

References:

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