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Accuracy and Repeatability of Thread Measurements Using Replication Techniques †

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Abstract: One of the important problems in verifying the dimensional and geometrical accuracy of products is measuring in difficult-to-reach places. One of the non-destructive measurement methods is the indirect measurement, using the replication technique. This study aimed to determine whether the error values of the measurements with the use of replicates depend on the thread parameter being checked. Two types of replica materials were used in the study—one in initial liquid consistency, and the other in paste form. The replicas obtained were cut into slices. Their profiles were measured on an iNEXIV VMA-2520 metrology system. The thread parameters measured were: thread angle, thread height, pitch and root radius. To assess the accuracy of the replica measurements, the results obtained were compared with the values from the direct measurement of the thread. The repeatability of the replicas in the context of measuring a given parameter was examined using the analysis of means. Irrespective of the replica material used, the largest errors in comparison with direct measurement were recorded for the thread angle. Measurements of this parameter were also characterized by the lowest repeatability. For the other parameters analysed, the relative error was usually less than 1.5%.

Keywords: replica; thread masurement; indirect measurement

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1. Introduction

Developments in machine tools, cutting tools, tooling and Computer-Aided Engineering (CAE) programs are making it possible to machine parts with increasingly complex geometries. At the same time, this generates new challenges in measuring it. One of the problems of modern metrology is the measurement of workpiece geometries in difficult-to-reach places. One solution is to verify the tool that performs the dimension/feature in question, without directly measuring the feature on the product. In some cases, it is possible to measure a given feature after the component has been cut. Such tests are then, of course, destructive. Another solution can be the use of a replication technique, which can significantly reduce testing time. In this method, an imprint (replica) is made with a certified plastic compound, which reproduces the tested geometry as its negative. This replica—is then measured. During the measurement, attention should be paid to the hardness of the replica and its tendency to deform. Very often, measurements of replicas are carried out using non-contact methods. The replica method can also be useful when measuring very large components that, for example, do not fit on the measuring device.

When selecting the appropriate compound for a specific application, consideration should be given to, among other things, the complexity of the geometry under investigation—how much difficulty the replica material has in penetrating the surface in question; the place of application—in line with or against gravity; the required final hardness of the replica and its elasticity - parameters that affect the ability to remove the replica from the part of the measurement under investigation and the choice of measuring tools. Replication techniques have been successfully applied to replicate both macrogeometry [1–3] and microgeometry [4] and surface topography [5–9]. However, each application requires studies to select the appropriate type of compound, to know the limitations of using the replicates in question, and to determine the degree of repeatability and estimate the magnitude of indirect measurement errors using them [3,10,11].

2. Materials and Methods

The tests were carried out for the M14x2 6 g thread. This is the thread used for loose threaded joints. The thread tested was an external thread, so that its profile could be measured using the direct method—without the use of replicas. PLASTIFORM's two-component compounds were used to make the replicas, the properties of which are shown in Table 1. The two components of the replicas chemically harden when mixed. They then form a resilient substance that fills the surface well and allows its geometry to be reproduced. Both compounds are designed to make a semi-flexible impression to measure the cross-section on a profile projector.

Table 1. Properties of replica compounds.

Property	PLASTIFORM M70	PLASTIFORM F50
Initial consistency	Pasty	Fluid
Final consistency	Semi-flexible	Semi-flexible
Final hardness in Shore A	70	50
Maximal removal constraint	5%	10%
Setting time (20 °C)	4 min	8 min
Precision	0.01 mm	0.001 mm
Direct measurement	No	No
Possibility to cut to obtain a profile	Yes	Yes

The replicas were made according to the recommendations given by the manufacturer. Ten replicas were made with each compound. A 1 mm thick slice was then cut from each replica with a double-bladed knife. The thread profile of the replicas was measured on a Nikon iNEXIV VMA-2520 CNC video metrology system. The profile vector function was used. The profile was measured with a sampling step of 0.05 mm. The thread profile was also measured using the direct method—i.e., without using replicas. In this way, 3 thread sections were measured, spread every 120° around the thread axis. Measurements of the replica profiles did not provide information on the position of the thread axis. For this reason, it was not possible to determine all thread parameters, e.g., diameter dimensions. The following thread parameters were analyzed in the study:

- pitch P (nominal value $P = 2$ mm),
- thread height $h3$ (nominal value $h3 = 1.227$ mm),
- root radius R (nominal value $R = 0.289$ mm),
- thread angle α (nominal value $\alpha = 60°$).

The thread parameters were determined in NX 1984. From each measured profile, five values of the characteristic were determined.

3. Results and Discussion

Figure 1 presents graphs showing the mean values and standard deviation of the thread height $h3$, pitch P, root radius R and thread angle α determined from profiles measured directly on the thread and using replicas made with F50 and M70 compounds.

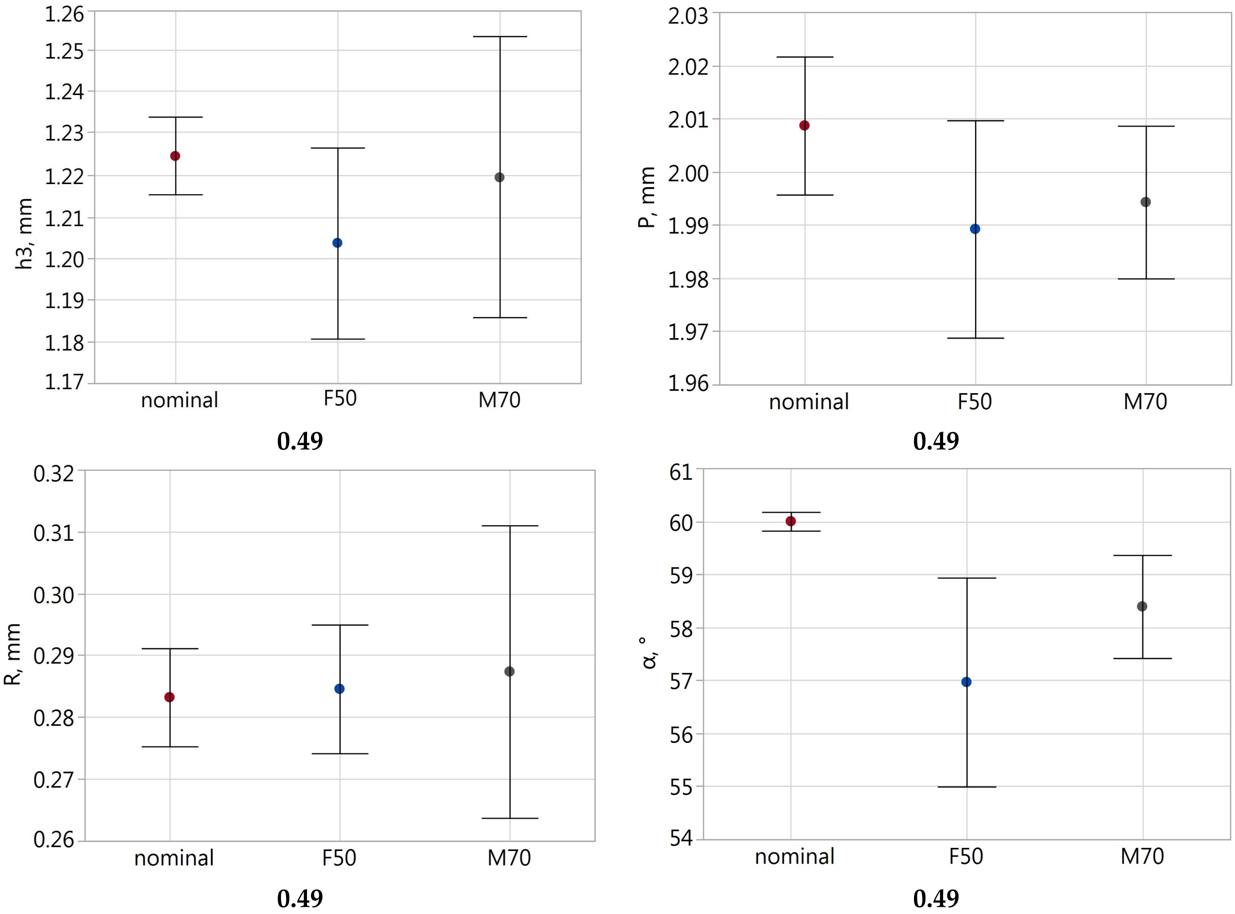

Figure 1. Values of thread height *h*3, pitch *P*, root radius *R* and thread angle *alpha* measured directly and using F50 and M70 replicas.

It can be observed that the variability of the results obtained for direct measurements is usually significantly lower than for measurements with replicas. To compare the mean values measured directly and by means of replicas, the relative error *RE* (Figure 2) was determined. For 3 of the 4 parameters considered, a smaller *RE* was obtained with the M70 compound. The largest error was observed in the measurement of the thread angle. For the M70 material, the average relative error was on average less than 1.5% for the other parameters, and less than 1% for most single measurements.

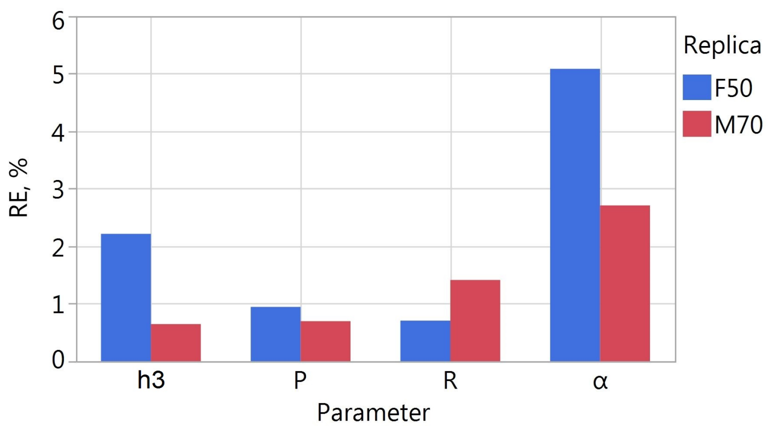

Figure 2. Relative error *RE* values of thread parameters depending on the replica compound used.

The variability of the parameters determined expressed by the standard deviation presented in Figure 1 includes the variability of the value of a given characteristic within one replica and between replicas. The repeatability of the replicas was investigated using an analysis of means (ANOM). This analysis takes into account how the value of a given characteristic for a given replica changes in relation to the mean determined for all replicas. An example of the results of ANOM for the parameter *h3* is shown in Figure 3. The number of exceedances of the control limits is summarised in Table 2.

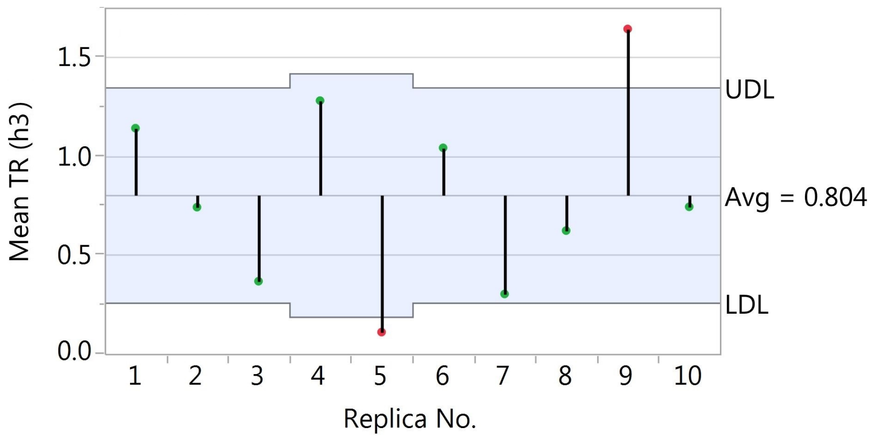

Figure 3. Results of analysis of means (with significance level 0.05) of the parameter *h3* measured using replicas made with F50 compound.

Table 2. The number of exceedances of control limits per number of profiles measured directly (nominal) or on replicas.

Parameter	Nominal	M70	F50
h3	1/3	1/10	2/10
P	0/3	0/10	0/10
R	1/3	0/10	1/10
α	0/3	6/10	7/10

A lower number of exceedances was recorded for the M70 compound. The thread angle measurements were characterised by poor repeatability - the average values for more than half of the replicas fall outside the control limits. It should be noted that even in the case of direct measurement, the values observed for the different cross sections may have differed.

4. Conclusions

The tests carried out showed that indirect measurements, with the replicas, of the thread angle have low repeatability. This parameter is sensitive to axial misalignment of the cut section of the replicas. In the case of linear parameters such as pitch, thread height and root radius, the lower error in comparison to direct measurements was due to the use of M70 compound, which originally had a paste-like consistency. This material has a higher final hardness compared to F50 and an associated lower maximum removal constraint. It should therefore be noted that in the case of an internal thread, there may be more problems with the removal of M70-type replicas.The parameter 'precision' stated by the manufacturer (Table 1) relates rather to the ability of the mixture to penetrate the surface, and in the application analysed this parameter did not prove to be significant. The improved surface penetration ability of the F50 replica meter had no beneficial effect on the values of the analysed thread parameters.

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