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Monitoring of the thermal deformations on polymer parts using a vision system

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Abstract
Dimensional measurements in production environment are affected by non-controlled temperature conditions. In the case of polymer parts the high thermal expansion coefficient leads to significant dimensional changes. In order to achieve high accuracy in dimensional measurements, thermal deformations must be monitored and the measurements compensated. In this investigation thermal deformations on polymer parts are monitored using a vision system consisting of a camera equipped with telecentric lenses focused on the surface of the part. The magnification of the optics and an axial illumination allow appreciating the surface texture and surface details on the parts. A set of images is acquired at varying temperature. Digital image correlation with subpixel resolution is performed on images to estimate the displacement of the surface features. The effectiveness of the calculation is related to the quality of the surface features caught by the camera. Experimental tests are performed on a commercial ABS (Acrylonitrile Butadiene Styrene) part. Two series of pictures are acquired in different locations of the part during a cooling period of 10 minutes. Traceability of the method is established through a calibrated artefact for optical microscopes. Displacement measurement uncertainties lower than 0.5 µm have been documented.

Dimensional Metrology, Vision System, Image Processing

1. Introduction

When measurements are carried out in an industrial production environment, temperature variations both in the ambient and in the part lead to a significant increase of the measurement uncertainty. The effect is very strong when measuring polymer parts due to high coefficients of thermal expansion. The current trend in industrial metrology focuses on reducing the waiting time before the measurement, necessary for temperature acclimatization, to the point of measuring during a transient state [1-2].

This work deals with the study of a non-contact technique to assess thermal deformations to be used to compensate errors due to the transient temperature condition. The studied technique uses a simple vision system to collect pictures and a digital image correlation (DIC) algorithm to extract displacements information. DIC is a technique widely used in experimental solid mechanics to measure mechanical and thermal strains [3]. In this work the surface displacements due to temperature variations are measured on a prismatic part made of ABS (Acrylonitrile Butadiene Styrene) through acquisition of picture of the surface and application of a DIC algorithm. A measurement uncertainty is then estimated.

2. Experimental set up and procedure

The experimental set-up is depicted in Figure 1. The ABS sample is placed in a positioning fixture composed by a plane and fixing pins. In the length direction a floating pin is opposed to a fixed point. A spring on the floating pin helps the positioning of the part and imposes the part to shrink (or expand) in the same direction during cooling (or heating up). The measuring area is located close to the floating point thus the rigid movement of the measuring area is maximized and results as the sum of the local displacements along the length. The images are acquired with a CCD camera with a 572x764 pixels sensor and equipped with telecentric lenses with a 2x magnification. The telecentric lenses limit the unwanted zoom variations caused by out of plane displacement. The part is illuminated with a coaxial light to increase the contrast of the surface features observed by the camera. The field of view of the camera is approximately 2×3 mm.

The experiment scope is to acquire pictures of the same surface detail at different temperature conditions of the part. Using DIC it is then possible to extract the translation of the features and estimate the deformation of the whole part.

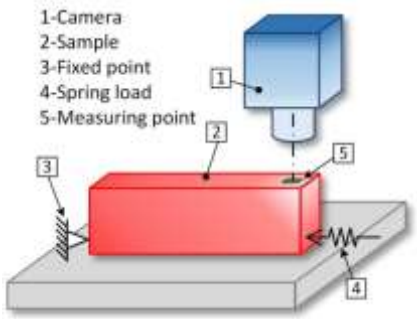


Figure 1. Experimental setup for optical surface displacement measurement

To produce several temperature conditions, the part is heated up on a separate heating plate and placed in the fixture. 20 pictures are taken during the following 10 minutes of cooling.

For reaching a high accuracy of the DIC results, the surface pictures should resemble a random speckle pattern. In this work however the surface considered presents only residual

marks from the machining. A loss in performance of the DIC is therefore expected and accepted with the advantage of avoiding surface treatment, i.e. painting of speckle patterns. The experimental procedure is repeated twice considering two different areas, A and B, in order to evaluate the influence of different surface appearances. Surface B contains also a portion of a surface detail (see Figure 2).

The experimental setup is placed in a controlled temperature room with temperature of (20±1) °.

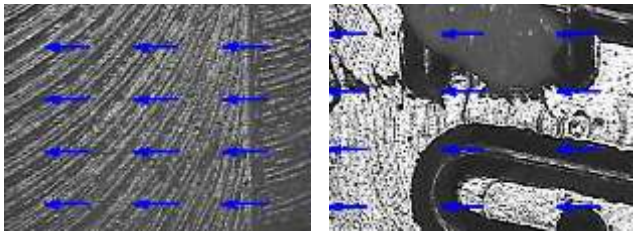
3. Data analysis

The first image of each series (at higher temperature) is used as reference. The DIC is performed between each picture and the reference picture as follows:

- Definition of small subsets equally distributed over the image. The subsets can be considered subjected to rigid deformation only. A global analysis using the whole picture would increase the calculation accuracy due to the higher number of surface details to correlate. However it would also increase the computational time and make the method not suitable for online calculation.
- Comparison of corresponding subsets using a 2D cross correlation method [3].
- Subpixel registration performed by fitting the neighboring of the maximum of the correlation coefficient function with a 2 dimensional Gaussian curve [3]; an effective resolution of 0.05 pixels is used.
- Creation of a displacement field by assigning the displacement calculated for each subset to the central pixel of the subset.
- Calculation of the average value of the displacement field.

Four different subset sizes are introduced to study the variability due to the calculation algorithm. The sizes considered are: 31×31, 61×61, 91×91 and 121×121 (dimension in pixels). A global analysis is performed to estimate a reference displacement value.

A set of 20 data points is calculated for each combination of picture and subset size (8 cases). It represents the shrinking of the polymer part during the measuring time.



A B

Figure 2. Details of the surfaces considered. The arrows indicate the displacement field calculated with the DIC algorithm.

4. Results and uncertainty estimation

The displacement field shows a linear variation with the pixel position, in agreement with a uniform temperature distribution on the considered surface. It is therefore possible to perform a linear regression of the displacement against the spatial position. The standard deviation of the regression residuals gives an estimation of the repeatability of the calculation.

The influence of the calculation method is considered as the average value of the differences between the estimated displacements and the reference displacement calculated with the reference global analysis.

The uncertainty of the DIC output (displacement in pixels d_{px}) is considered as the combination of the component due to repeatability u_{rep} and the influence of the calculation method u_{met}:

$$u_{d_{px}} = \sqrt{u_{rep}^{\ 2} + u_{met}^{\ 2}} \qquad (1)$$

Traceability is ensured with a calibration procedure of the camera sensor.

A calibration procedure is performed using the chessboard pattern present on a calibrated standard for optical microscopes produced by Alicona GmbH. The average pixel dimension is estimated by counting the number of pixels corresponding to a grid pitch. The distortions caused by the optics are considered negligible since the methodology focuses on local relative displacements of small areas.

The calculated average pixel size s_{px} is 4.07 µm with a standard uncertainty u_{spx} of 0.01 µm, estimated including the contributions from the procedure and the uncertainty stated in the calibration standard certificate.

The surface displacement expressed in micrometer $d_{\mu m}$ is therefore:

$$d_{\mu m} = s_{px} \times d_{px} \qquad (2)$$

Consequently the combined uncertainty of $d_{\mu m}$ is:

$$u_{d_{\mu m}} = \sqrt{s_{px}^{\ 2} \times \left(u_{rep}^{\ 2} + u_{met}^{\ 2}\right) + d_{px}^{\ 2} \times u_{s_{px}}^{\ 2}} \qquad (3)$$

The major uncertainty contribution is represented by the uncertainty of the DIC calculation u_{dpx}. As an example the expanded uncertainty (k=2) for a nominal displacement of 35 µm is listed in Table 1 for the different cases considered.

Table 1 Expanded uncertainties (k=2) for a displacement of 35 µm

	U /µm	
subset size /pixel	Surface A	Surface B
31×31	0.83	0.86
61×61	0.56	0.49
91×91	0.52	0.42
121×121	0.38	0.39

The two surfaces give similar results in terms of uncertainty despite their different texture. The performance of the DIC calculation improves when using wider subsets. An expanded uncertainty lower than 0.5 µm has been reached using a subset size of 121×121 pixels.

5. Conclusions

The measurement of the thermal displacements of a polymer part has been performed using a digital image correlation algorithm with subpixel registration. The effect of the surface appearance and the calculation method are studied and considered in the uncertainty. Surface texture doesn't affect significantly the uncertainty of the method. An expanded uncertainty lower than 0.5 µm has been documented.

Acknowledgements

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