euspen's 16th International Conference & Exhibition, Nottingham, UK, May 2016
www.euspen.eu

Length determination on industrial polymer parts from measurement performed under transient temperature conditions

Giuseppe Costa, Daniel Madruga, Leonardo De Chiffre, Hans Hansen

Department of Mechanical Engineering, Technical University of Denmark (DTU), Building 427, Produktionstorvet, DK-2800 Kgs.Lyngby, Denmark

Email: giucos@mek.dtu.dk

Abstract
A way to reduce the cost of metrology in manufacturing is to perform dimensional verification directly in the production environment, avoiding a long and expensive acclimatization phase. In this work the effect of a transient temperature state, typical of the production environment, was investigated on commercial polymer parts. Two points length measurements were performed before the stabilization of the temperature and length at standard conditions was estimated. The experiments consisted of synchronized measurements of length and temperature of the part over several minutes during the cooling phase, from 27 °C to 20 °C approximately. The length variation was measured by means of an inductive probe and the temperature with an RTD surface sensor. The frame of the system was composed by elements in Zerodur and Invar to minimize the thermal deformations of the structure. Uniform temperature in the part was assumed. The reference length at 20 °C (L_{20}) was calculated with an a posteriori regression of the data from the complete cooling curve. A prediction of L_{20} was then performed exploiting partial segments of the curve. Several segments with different time spans and starting points were evaluated. The procedure was repeated 5 times on 5 nominally identical parts. An expanded uncertainty (k=2) below 2µm was evaluated for the predicted length at 20 °C.

Keywords: dimensional measurement, production environment, temperature

1. Introduction

Quality control and metrology are becoming more and more important in modern manufacturing industries with a consequent impact on the overall costs of the final products. An important part of these costs is due to the preparation of the part to measure, i.e. the temperature acclimatization. In order to reduce the impact on costs and production time of the measuring process the measurements can take place directly in the production environment and the uncertainty due to the uncontrolled thermal state can be reduced by monitoring the temperature field of the measuring system. In this work a commercial polymeric part is heated up and its dimension and temperature are measured simultaneously during the cooling phase. The dimension of the part at the conditions stated in the ISO standards [1] is then estimated with a regression of the experimental data. The purpose of the work is to validate measurements performed under non stationary conditions and estimate the influence of the measuring procedure, in particular the measuring time. The experiments emulate a realistic industrial situation where the part comes from the production process at a higher temperature than the ambient which again is typically higher than the reference temperature (20 °C). A previous work dealing with measurements in production environment has been performed on metallic part [2].

2. Experimental work

2.1. Equipment

The experimental setup is depicted in Figure 1. The metrology frame consists of parts made of Zerodur and Invar to minimize the thermal deformations. The variation in length of the part is measured with an inductive displacement probe (TESA GT 22HP) with a resolution of 0.1 µm and a MPE of (0.07 + 0.4·L) µm (L in mm). The frame holds the inductive probe and a fixed stainless steel rod both provided with a spherical tip. During the measurement the polymer part is placed in between these two components. The temperature of the part is measured with a calibrated contact resistance sensor (Omega SA1-RTD) with a resolution of 0.01 °C and calibration uncertainty of 0.02 °C. A temperature controlled heating plate is used to heat up the polymer part. The experiment is performed in a room at (20 ± 0.5) °C.

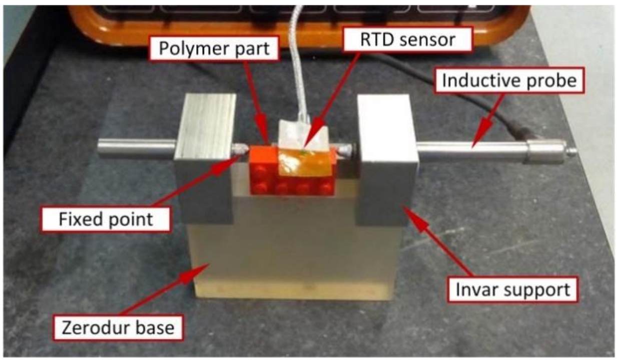

Figure 1. Experimental set up.

2.2. Procedure

The part is firstly heated to a temperature above 30 °C then the temperature sensor is attached to the top surface and the part is positioned on the fixture. Length variation and temperature are acquired simultaneously with a sampling rate of 1 Hz as soon as the temperature decreases below 27 °C. This step is meant for minimizing temperature gradients in the part. The procedure is repeated five times for five nominally identical parts resulting in a total of 25 repetitions.

The experimental curves of length and temperature are shown in Figure 2 and Figure 3.

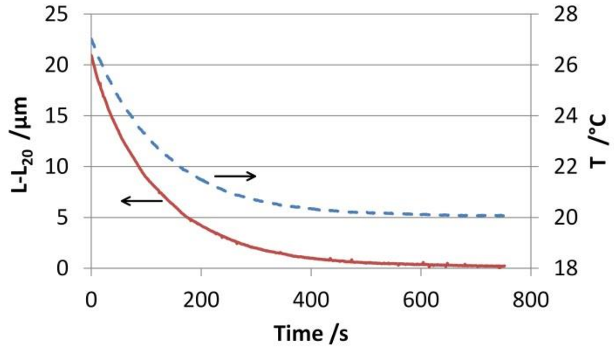

Figure 2. Length valuation *L*-L_{20} (continuous line) and temperature variation T (dashed line) vs time for one repetition.

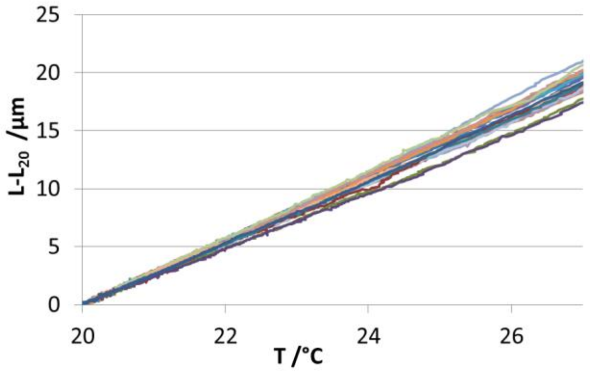

Figure 3. Length variation vs temperature variation for all the repetitions.

3. Data analysis

The first step of the data analysis is the definition of the reference length. For each repetition the length at 20 °C is extracted from the regression of the whole experimental curve (see Figure 3). Several regression models are compared (linear and quadratic) showing a low variability of the extracted values. The average value over the different models is considered as reference length (L_{20}). The experimental data are then referred and zeroed on this value.

The second step is the estimation of the length at 20 °C ($L_{20,est}$) from partial segments of the experimental curve. Segments with different time spans (30, 60, 90, 120, 240, 300 s) and different starting points are considered. Assuming a linear relationship between length and temperature and a homogenous temperature field, $L_{20,est}$ can be calculated using a linear regression. All the estimated lengths are then grouped depending on the segment size and the starting temperature to assess the influence of measurement procedure and the deviation from the ideal stationary case. The average error (difference between L_{20} and $L_{20,est}$) and its standard deviation are calculated for each group with same segment size and starting temperature. The average error represents the deviation from the assumed model and its standard deviation can be assigned to the repeatability of the experimental procedure and method.

4. Uncertainty budget

The expanded uncertainty of $L_{20,est}$ is estimated according to :

$$U(L_{20,est}) = k \cdot \sqrt{(2 \cdot u_L)^2 + (2 \cdot \alpha_T \cdot u_T)^2 + {u_m}^2 + {u_{rep}}^2}$$

Where: u_L is the uncertainty on the length measurement calculated from the MPE value of the probes; u_T is the uncertainty on the temperature measurement calculated from the calibration uncertainty of the temperature sensor; α_T is the average coefficient of thermal expansion calculated from the experimental data representing the sensitivity factor of the temperature uncertainty; u_m is the uncertainty of the estimation model, i.e. the error L_{20} - $L_{20,est}$; u_{rep} is the uncertainty due to the repeatability of the calculation, i.e. the standard deviation of the average error L_{20} - $L_{20,est}$; k is the coverage factor, set equal to 2. The components u_L and u_T are multiplied by 2 since they influence both the values of L_{20} and $L_{20,est}$. Table 1 depicts the estimated uncertainty for the different data segments.

Table 1. Expanded uncertainty of the estimated length (values in µm).

		Length of data segment /s						
		30	*60*	*90*	*120*	*180*	*240*	*300*
Starting temperature /°C	*21*	0.73	0.57	0.48	0.43	0.40	0.38	0.38
	22	1.05	0.66	0.55	0.48	0.42	0.39	0.37
	23	0.99	0.64	0.60	0.55	0.45	0.40	0.38
	24	1.24	0.68	0.52	0.50	0.45	0.40	0.38
	25	2.40	0.99	0.59	0.53	0.50	0.44	0.40
	26	2.02	1.67	1.01	0.67	0.54	0.48	0.43
	27	2.93	1.97	1.56	1.18	0.74	0.59	0.50

The uncertainty decreases for temperature closer to 20 °C and for longer data sets. The influence on the temperature is attributed to the distance from the reference temperature and to the non-uniform temperature field in the part.

5. Conclusions

A set up and a procedure for length measurement in a production environment have been developed. The dimension at the reference conditions can be estimated with a linear regression from continuous measurements of length and temperature of the part under non stationary thermal conditions. For measuring time longer than one minute an uncertainty lower than 2 µm has been achieved.

The determination of the optimal sampling time that balance accuracy improvement and measuring time require the knowledge of the thermal state of the part since the uncertainty depends on both temperature and time of the measurement (as shown in Table 1).

According to the results, a marked temperature variation during the measurements ensures a solid identification of the length-temperature relationship and therefore a better prediction of the length at 20 °C. Otherwise the background noise may lead to higher uncertainty.

Future work will involve the implementation of more temperature sensors on the part and on the frame to handle non-uniform temperature fields.

References

[1] ISO 14253-2 2011

[2] De Chiffre L, Gudnason M M and Gonzalez Madruga D 2015 Dimensional Measurement with submicrometer uncertainty in production environment *in Proceedings of the 15th International Conference of the EUSPEN*. pp. 163-4.