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Applications of dimensional micro metrology to the product and process quality control in manufacturing of precision polymer micro components

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ABSTRACT

Precision manufacturing of micro injection moulded (μIM) components presents challenges in terms of quality control due to the miniaturization of product dimensions and tolerances. This paper addresses product compliance with specifications, focusing on tolerances of dimensions and position on μIM components selected from industrial production. Two systems were analysed: a tactile coordinate measuring machine (CMM) with sub-micrometer uncertainty and an optical CMM allowing fast measurements suitable for in-line quality control. Product quality control capability, measuring uncertainty and calibration guidelines are discussed for both systems. Finally, a new approach for the manufacturing of hybrid micro polymer–metal calibrated objects is proposed.

1. Introduction

A micro product can be defined as having at least two critical dimensions in the sub-mm range [1]. Micro products can be two-dimensional structures (2D) (such as optical gratings), 2D structures with a third dimension ($2^1/_2$D) (for example micro fluidic sensors [2]) and real three-dimensional structures (3D) (for example components for hearing aids). The specification of a micro mechanical component is usually defined on the basis of the desired function of the part, e.g. mating and assembly capability. The specifications are given in terms of maximum deviations from an ideal geometric form, but a downscaling below the defined lower borders of ISO GPS standards may prove to be problematic [3,4]. Compliance with tolerances is described in [5]. In the case of micro mechanical parts the absolute dimensions are small and so are the tolerances [3]. These facts result in at least two challenges: (a) finding a suitable measurement method to actually measure the components; (b) ensuring that the measurement uncertainty is sufficiently small to actually be able to verify the tolerance (see Fig. 1). The consequence in all cases usually is that the measurement uncertainty becomes larger compared to the tolerance interval leaving a much smaller conformance zone for process variations.

The relationship between tolerance, processing capability and metrology methods is particularly challenging in micro technology. References [6,7] describe a categorization of tolerancing based on the type of micro product. One category deals with a downscaling of macro scale principles, and here the use of tolerances is necessary to ensure functionality. A monolithic approach is based on the use of a single substrate, e.g. semiconductor processing, and it is based on the calculated performance deviations during the various process steps. If they are larger than the product tolerances, the parameters of the currently active manufacturing step will be corrected, so that the final product will be situated within the expected product tolerances as defined by the functional behaviour. For micro mechanical components based on a non-monolithic approach (i.e. assemblies of components, usually manufactured in different ways and locations as seen in macro scale manufacturing) detailed knowledge of not only absolute dimensions and geometrical quantities, but also about the uncertainty of measurement is necessary in order to apply [5]. A viable and standardized procedure for uncertainty assessment of CMM measurements at micro dimensional scale is not available yet, especially when the focus is on actual micro products and complex measurements. To this respect, research work has been recently carried out in the field of dimensional metrology using CMMs for micro systems quality control. The uncertainty was calculated on a reference object for a one-dimensional measurand (i.e. flatness) in [8]. The accuracy and precision were calculated for on diameter measurements on a calibrated ring in [9]. Finally, diameter measurements of micro gears were investigated in [10] and the study focused on measuring repeatability. The computation of all the relevant uncertainty contributors of complex micro dimensional measurements on micro products is clearly a challenging task. This paper addresses product compliance with specifications, focusing on tolerance of dimensions and position on micro injection moulded components selected from industrial production. In particular, methods to assess and to subsequently lower the measurement uncertainty based on ISO 15530-3 [11] are presented.

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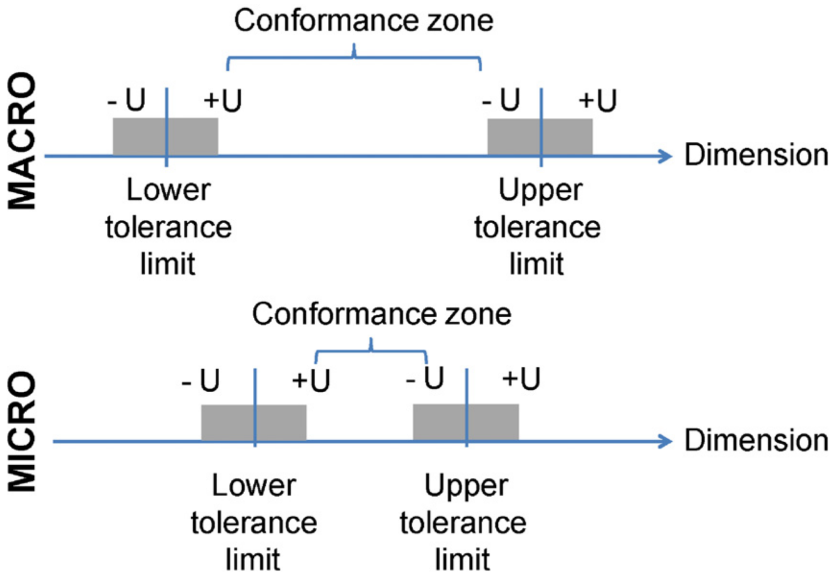

Fig. 1. Illustration of relationship between tolerance and measurement uncertainty. In this representation the measurement uncertainty was kept constant and the tolerance zone decreased.

2. Case description

Micro injection moulding is a process which enables the mass production of polymer micro components. In addition to the previously mentioned definition of micro products, a further categorization applies to the specific case of polymer micro products. In particular, micro injection moulding (μIM) is referred to the production of parts having [12,13]: (a) weight in the range of milligrams as well as overall dimension, functional features, and tolerance requirements that are effectively expressed in terms of micrometers (e.g. micro gears); (b) overall dimensions in the macro range, weight in the order of grams, tolerance requirements that are effectively expressed in terms of micrometers down to nanometres (e.g. lenses [14]) and/or areas with micro features having critical dimensions in the micro- and nanometre range (e.g. digital versatile discs). The selected product for the present investigation is a component for micro mechanical application, i.e. belongs to the 'a' category. Particularly, it is a toggle for a hearing aid application made of liquid crystal polymer (LCP) with a part weight of 35 mg (see Fig. 2). The component is produced in batch sizes of several hundred thousands parts per year using conventional injection moulding equipment having a rather small plasticizing screw (diameter 15 mm) and a mould with micro cavities machined by micro die sinking electrical discharge machining (EDM).

Four different measurands have been selected for the investigation: outer diameter (*D*), inner diameter of the hole in the middle of the part (*d*), concentricity of the two circles (*C*), and the height (H) of the pillar placed at the bottom of the component and visible in Fig. 2. Nominal dimensions and related tolerances are as follows: $D = 5.400 \pm 0.030$ mm, $d = 1.550 \pm 0.020$ mm, $C = 0.020$ mm, $H = 0.380 \pm 0.030$ mm. The currently employed quality control involves manual measurements performed on digital dial gauge for height measurements and an optical measuring microscope. Internal audit described in [15] highlighted the limitations of the current quality control procedure: inconsistency between technical drawings and metrology software set-up, instrument verification rather than actual instrument calibration for the intended measuring task, poor measuring method standardization due to manual execution. It is calculated that the ratio (U/T) between the measuring uncertainty (U) and the tolerance (T) to be verified is not suitable for the considered measuring tasks (it varies between 27% and 66%) and therefore is leaving a very limited conformance zone available for tolerance verification (from a maximum of 19 μm in case of the inner diameter to a minimum of no conformance zone for the concentricity). On the contrary, it is recommended that the U/T ratio shall be less than 10% or, at least, lower than 20% [16]. Moreover, manual measurements are time consuming and have a very low repeatability (which represents 90% of the final measuring uncertainty). The need for automated and more repeatable measuring systems with a lower uncertainty is clear and different solutions are presented in this paper. In particular, in Section 3 uncertainty assessment of measurements on polymer objects with a high accuracy tactile CMM based on ISO 15530 [11] are described. Subsequently, these calibration data are employed in Section 4 to calculate the uncertainty of optical CMM

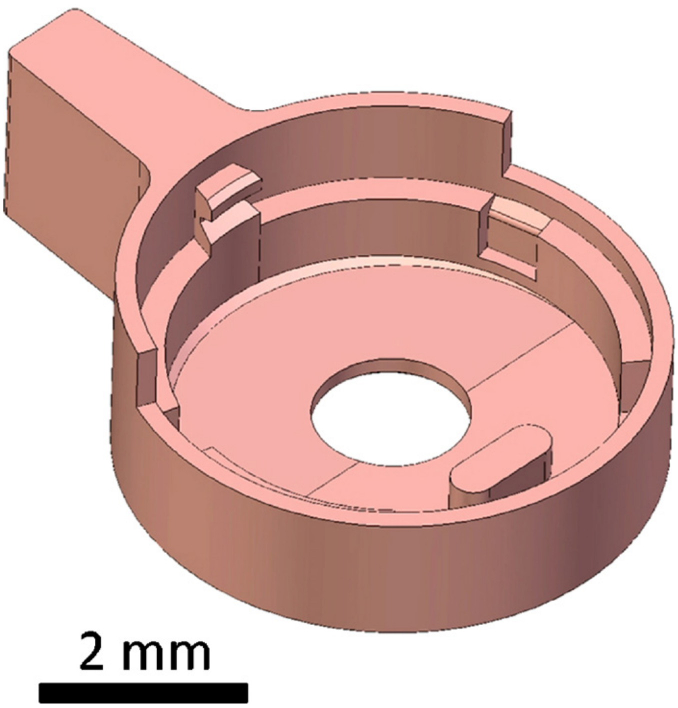

Fig. 2. Polymer micro injection moulded component (toggle for hearing aid application).