Inverse problems of measurement with application on specification of surface profile

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Introduction:
A contradiction of the specification of free-form surface is pointed out. The inverse problem of measurement (IPM) is defined based on the representational measurement theory. By using the concept of IPM, a desired property of specification limits is derived and a correction for the contradictory situation is proposed.

Specification and measurement of surface profile

The upper and lower specification limits (USL and LSL) of a free-form surface profile defined in ISO 1101 are two curves enclosing circles of certain diameter \( r \), the centers of which are on the nominal surface profile (see figure 3a). For an actual surface profile \( l \), if all the points \( l \) are within the tolerance zone, i.e. \( \text{USL} \leq l \leq \text{LSL} \), \( l \) is within the spec.

The canonical method of measuring surface profile is contact measurement by moving a tactile stylus along the surface to be measured to obtain the locus of the centre point of the stylus tip.

Figure 1. working principle of measuring surface profile with a tactile stylus

With \( S \) as the stylus, the locus \( l \) is the division of \( l \) and \( c \) can be estimated by the motion of \( E_1 = E_2(l) = E_2(l) \). The combination of \( D_0 \) followed by \( E_2 \) is a closing filter \( C_1 \), \( D_0 \).

A Contraction of the Specification of Free-form Surface

Due to the extreme property of closing filter, the estimated profile is always above the actual profile (see figure 1). Hence when an actual surface profile coincides with the USL (within spec.), the measurement result (within error) would, however, be out of spec., which contradicts with the ideal situation.

Figure 2. A correction of the tolerance zone of surface profile

Representational model of measurement

Representational measurement theory allows measurement to be defined as the assignment of numbers to attributes of objects in such a way as to describe them (Fischler, 1982). Here measurement can be considered as a mapping \( \mathcal{M} \) from the measured objects to the measured values.

For the measurement of a attribute, one or more empirical relations would be defined between the measured objects. E.g. \( \mathcal{M} \) is a very general empirical relation.

The set of the measured objects with the empirical relations, \( R_0, R_1, \ldots, R_n \), can be taken as a mathematical object \( \mathcal{M}(R, R_0, \ldots, R_n) \), called an empirical relational system (ERS). E.g., the ERS of length (or mass, force) \( (M, \leq, \geq) \) where \( \leq \) is a preorder, \( \geq \) a composition operation.

Measurement: a measurement is possible only if there exists a structure-preserving mapping from the ERS to a specified empirical relational system (ERS). E.g. the NRS representing the length as \( (R, \leq, \geq) \). The numbers in the NRS are the values of the measured (quantity to be measured).

Inverse problems of measurement

Inverse problem is a general framework of problems that infer information from observations (Salrier, 2009). In many cases, the measurements are not directly observable; they can only be inferred from the observed data of some related proxy quantities.

Definition: inferring the values of the measurements from the observed data is the inverse problem of measurement (IPM). In forward mapping is the characteristic function of the measurement process, \( L = \mathcal{M}D \).

Inverse problems of measurement

The measurement of contact surface measurement

A correction of the specification of measurement

A proposed solution

- Correcting the curve of LSI from \( l \) to \( l' = C_{l}(l) \) (see figure 2b), where \( C_{l} \) is the closing filter with the structuring element \( S \).

The diameter of element \( S \) is assumed to be smaller than the diameter \( r \) of the stylus to avoid the inherent property of closing filter that the desired property is satisfied after the correction.

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*Contact: [email protected], +44 1484 471285