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BASIC CONCEPT OF FEATURE BASED METROLOGY

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Abstract: In coordinate metrology, an associated feature (Gaussian associated feature) is calculated from an extracted feature which is determined by a measured data set of CMM (Coordinate Measuring Machine) on a real feature using a least squares method. This data processing flow which is called as "feature based metrology" disagrees with the data processing methods in profile metrology and length measurement. In this report, basic concept of feature based metrology is discussed, such as feature modeling, least squares method and statistical estimation of uncertainty of measurement. Theoretical analysis and simulations for feature based metrology in statistical ways directly imply that basic concept and data processing methods in this report are useful to estimate uncertainty of measurement in coordinate metrology.

Keywords: feature based metrology, coordinate measuring machine, coordinate metrology

1 INTRODUCTION

In coordinate metrology, an associated feature is calculated from a measured data set on a real feature by CMM (Coordinate Measuring Machine). Then, the associated features are compared with the nominal features which are indicated on a drawing (see figure 1). In this data processing, the features are primal targets to calculate, to evaluate and to process [1][2]. Consequently, this process is called as “Feature Based Metrology”. In this report, we discuss the following items to construct the basic concepts of feature based metrology:

(1) methods to calculate geometrical parameters of features,
(2) selection of feature models,
(3) statistical estimation of uncertainty of measurement of features and
(4) calculation method of uncertainty of related features.

From theoretical analysis, simulations and the concept, we construct the data processing methods for feature based metrology. It is implies that these methods and concept in this report are useful to estimate uncertainty of measurement in coordinate metrology.

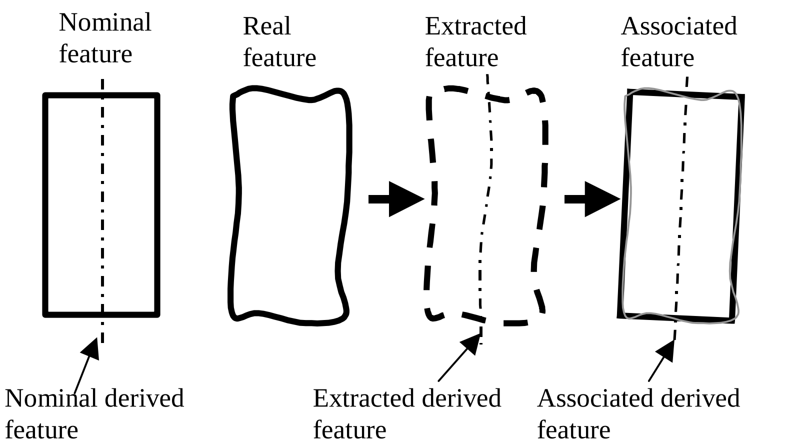


Figure 1. Data processing flow in feature based metrology [1][2]

2 COMPARISON OF FEATURE BASED METROLOGY AND PROFILE METROLOGY

Table 1 shows the comparison of feature based metrology and profile metrology. From this comparison, the major differences between feature based metrology and profile metrology are the number of measured points and the density of measured points. We should note that the number of measured points is small (only 10-20 points) on each feature in feature based metrology. Therefore, we can not calculate geometrical parameters of feature without the model of feature. Furthermore, it is emphasized that extrapolation is used to define a related feature; such as intersection line of two planes which is not be measured directly by CMM. From this, we conclude that the model of features and the evaluation method of uncertainty of measurement are key technical items in feature based metrology.

Table 1. Comparison of feature based metrology and profile metrology.

	Feature based metrology	Profile metrology
Number of measured points	small (10–20 in 3D)	many (1000–10000 in 3D)
Uncertainty of measured points	large	small
Density of measured points	low (discrete sampling)	high (continuous sampling)
Data processing	extrapolate least squares method	filtering
Objects of measurement	parameters of feature	profile
Model of feature	yes	no

3 METHODS IN FEATURE BASED METROLOGY [3][4]

3.1 Calculation of Feature Model [5][6]

Least squares method is normally used for calculating the geometrical parameters of feature from the measured data set. It is because least squares method has better characteristic in robustness under the conditions in table 1 than minimum zone method as the following reasons:

(1) the uncertainty of calculation by least squares method is estimated by statistical way and
(2) the robustness of calculation is good from the small number of measured points.

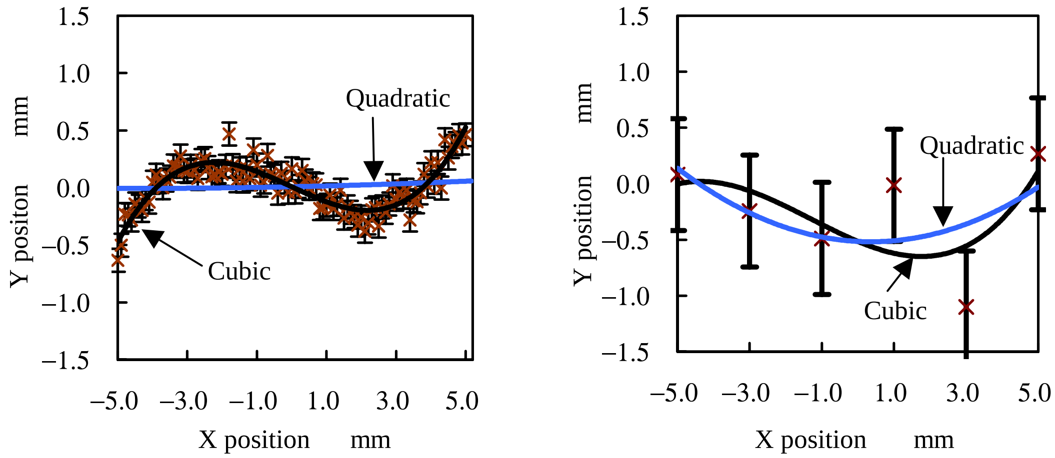
When the number of measured points is small, the deviation and the confidential zone size of calculated feature by minimum zone method is larger than that by least squares method. In addition to this, the uncertainty of measurement on coordinate metrology and feature based metrology is evaluated from the deviation and the confidential zone of size calculated features. From this, we can understand that least squares method is suited to coordinate metrology and feature based metrology.

3.2 Selection of Model

Using least squares method, how to select the model of feature is one of the key issues. Figure 2 indicates the selection of model for a data set of cubic equation with random errors. When the number of data is large and the error is small, the selection of model is easy to determine that the curve is quadratic or cubic using χ^2 testing (see figure2 (a)). However, when the number of data is small and the error is large, approximation is difficult to determine an appropriate model of the curve (see figure 2 (b)). The selection of model from measured data set is difficult in feature based metrology. This is because the condition of measurements in feature based metrology is similar to that in figure 2 (b).

From this, we have to select the model of feature from the nominal feature or other information from designing and machining in machine shop as follows:

（1） use the same model of nominal feature, when no other information of measured feature;
（2） use the lower degree model, when no information in frequencies of form deviation of the measured feature (see 3.3); and
（3） use the model of nominal feature with form deviation, when the frequency characteristic of form deviation of measured feature is known from information of profile measurements or information of machine tool on the machine shop.



(a) (b)

Figure 2. Approximate curves of measured profile which is generated by cubic equation ($y = 0.01\,x^3 - 0.15$) with random errors. (a): number of data is 101 and standard deviation is 0.1. (b): number of data is 6 and standard deviation is 0.5.

3.3 Uncertainty of Feature [7]

The uncertainty of each measured point is defined by error analysis of CMM and probing system, and the results of profile measurement on each feature. From the uncertainty of measured point, the uncertainty of measured feature can be calculated statistically using following equations.

Equation (1) shows an observation equation, a regular equation and a least squares solution, where **A** is Jacobian matrix, **p** is a parameter vector and **S** is an error matrix.

$$\begin{aligned} &\text{observation equation: } && \mathbf{d} = \mathbf{A}\mathbf{p} \\ &\text{reguler equation: } && \tilde{\mathbf{A}}\mathbf{S}^{-1}\mathbf{A}\mathbf{p} = \tilde{\mathbf{A}}\mathbf{S}^{-1}\mathbf{d} \\ &\text{least squares solution: } && \mathbf{p} = (\tilde{\mathbf{A}}\mathbf{S}^{-1}\mathbf{A})\tilde{\mathbf{A}}\mathbf{S}^{-1}\mathbf{d} \end{aligned} \tag{1}$$

Using the propagation law of error to least squares method, the error matrix of parameter $\mathbf{S}_p$, and the error matrix of observation $\mathbf{S}_m$ are calculated as equations (2) and (3) respectively. The matrices $\mathbf{S}_p$ and $\mathbf{S}_m$ indicate the variations of the parameters and the values of observation equations at each position.

$$\mathbf{S}_p = (\tilde{\mathbf{A}}\mathbf{S}^{-1}\mathbf{A})^{-1} \tag{2}$$

$$\mathbf{S}_m = \mathbf{A}\mathbf{S}_p\tilde{\mathbf{A}} \tag{3}$$

Figure 3 shows an example of error analysis form twelve measured points on a flat plane. Middle plane is least squares plane, the upper and the lower planes are the upper and the lower limits of confidential zone of feature respectively. We note that the upper and the lower limits of confidential zone is equal to the range of the uncertainty of measured feature. Using equation (3), the uncertainty at the position out of measuring range also can be calculated.

Figure 4 displays the confidential zone for extrapolation of a least squares line and a least square cubic curve for the same data set which is generated from the cubic curve with large random errors. In the case of large random errors, the range of confidential zone of the simple model (least squares line) is smaller than that of the complex model (least squares cubic curve) at the position out of measuring range. This directly demands that the simple model is suited to feature based metrology with extrapolation.

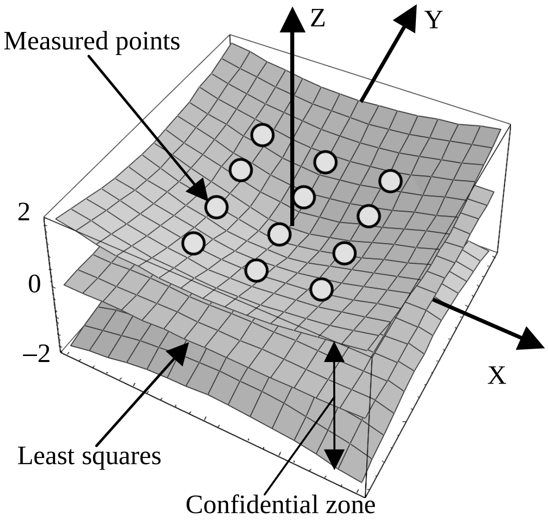


Figure 3. Confidential zone of measure plane; number of measured points is 12 and standard deviation of each measured point is 1.0.

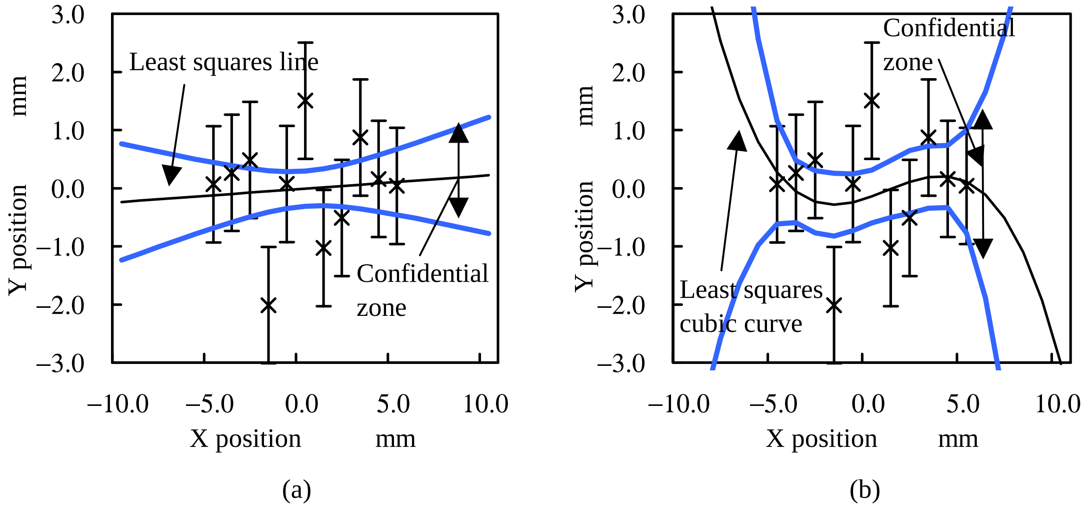


Figure 4. Extrapolation of feature by approximate of (a) linear equation and (b) cubic equation; number of measured point is 11 and standard deviation is 1.0.

3.4 Calculation of Related Feature [8]

Figure 5 displays calculation concept of relationship between an intersection line and two planes which cross at angle α. The confidential zone (uncertainty) of the intersection line is calculated from the confidential zones of tow planes and angle α as equation (4). Where s_1 and s_2 are the uncertainty of two planes, s_s is the uncertainty of intersection line.

$$s_s = \frac{\sqrt{s_1^2 + s_2^2}}{\sin \alpha} \quad (2)$$

Thus, the uncertainty of the related features such as intersection lines, intersection points and intersection circles can be estimated using this concepts and calculation.

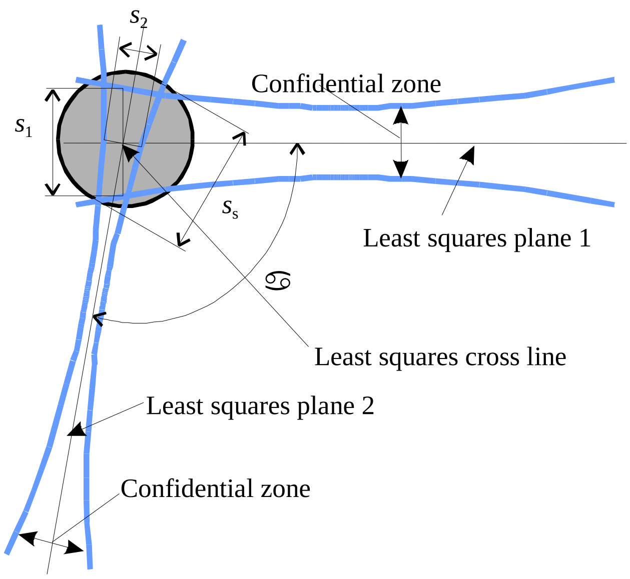


Figure 5. Confidential zone of cross line by two plane features with confidential zones.

4 PROCESSING FLOW IN FEATURE BASED METROLOGY

From the methods of feature based metrology discussed in section 3, the uncertainty of measurement in feature based metrology is calculated using following five steps:

(1) measuring several points on each feature by CMM,
(2) selecting the model of each feature by information of drawings, design or machining,
(3) calculating the geometric parameters and size of confidential zone (uncertainty) of each feature,
(4) calculating the geometric parameters and size of confidential zone (uncertainty) of related features,
(5) comparing and evaluating the geometric parameters and the uncertainty of measurement of each feature with dimensions and tolerance zones indicated in drawings.

5 CONCLUSION AND FUTURE WORKS

In this report, we have placed basic concept of feature based metrology which is used in coordinate metrology and constructed the data processing flow of it using CMM. From theoretical analysis, we reach the following conclusions:

(1) least squares method is suited to calculate the geometric parameters and the uncertainty of features,
(2) simple (low degree) model is fitted to the model of feature in the condition of feature based metrology,
(3) calculation method of the uncertainty of feature is presented using least squares method and statistical evaluation,
(4) calculation method of the uncertainty of related feature is also presented.

The future works in feature based metrology as follows:

(1) how to define uncertainty of each measured point in CMM,
(2) how to select the model of each feature; evaluating function of selection,
(3) how to evaluate of the results of measurement; how to compare geometric parameters and tolerancing,
(4) how to decide the strategy of measurement using feature based metrology.

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