Virtual datum based on least uncertainty criterion for cross-axis motion measurement

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Cross-axis translational motion of a carriage on a machine tool is important factor for machine accuracy. Two-point method, one of the self-check, uses two displacement sensors and separates cross-axis motion includes non-repeatable motion from straightedge profile. Profile measurement of a large-scale workpiece is in demand in industry. This measurement requires large sampling points and it amplifies influence of sensor's random error. The authors already proposed two-point method based on the least uncertainty criterion. In this article, characteristics of the estimated cross-axis motion uncertainty in spatial frequency domain is discussed. Uncertainty of hardware datum is smaller under specified spatial frequency, f_b, and that of two-point method is smaller over f_b. The relationship between standard deviation of the sensor's noise, σ_n , that of the hardware datum profile, σ_f and f_b is clarified.

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1. Introduction

Cross-axis translational motion of a carriage on a machine tool is important factor for machine accuracy. Cross-axis motion is often estimated using a hardware datum, e.g. a straightedge or a laser beam. Furthermore, virtual self-check methods that separate the cross-axis motion from hardware datum error are well-known [1-3]. For example, two-point method, one of the self-check, uses two displacement sensors and separates cross-axis motion includes non-repeatable motion from straightedge profile.

Profile measurement of a large-scale workpiece is in demand in industry. This measurement requires large sampling points and it amplifies influence of sensor's random error. Multi-probe methods generally take difference of sensor's outputs to separate cross-axis motion. Since it works as high-pass filter, the cross-axis motion signal is distorted. Then, integration or inverse filtering is used to recover the cross-axis motion. Therefore, influence of the sensor's random error tends to be large at low spatial frequency domain.

The authors already proposed two-point method based on the least uncertainty criterion [4]. When standard deviation of the hardware datum profile and sensor's random error are given, suitable weights of the weighted addition are derived to obtain estimated cross-axis motion with least uncertainty. However, the hardware datum profile often has dominant spatial frequency. Therefore, error separation and control of random error amplification don't work sufficiently.

In this article, characteristics of the estimated cross-axis motion uncertainty in spatial frequency domain is discussed.

2. Principle

Fig.1 shows the schematic diagram of the software datum using two displacement sensors. Two displacement sensors on a carriage scan along a straightedge and cross-axis motion is estimated using weighted addition and inverse filtering.

Generally, the combined standard uncertainty of the cross-axis motion includes the uncertainty of hardware datums that are the straightedge profile f(x) and random noise of the sensors. Then, power of the uncertainty of the estimated cross-axis motion after inverse filtering, $u(w_1, w_2)$, can be described as follows[4]:

$$\left\{u\left(w_1, w_2\right)\right\}^2 = \left\{\frac{w_1 + w_2}{\left|G\left(j\omega\right)\right|}\right\}^2 \sigma_f^2 + \frac{\left(w_1^2 + w_2^2\right)}{\left|G\left(j\omega\right)\right|^2}\sigma_n^2 \tag{1}$$

where σ_f is standard deviation of the straightedge profile and σ_n is standard deviation of the sensor's random noise. Parameters w_1 and w_2 are

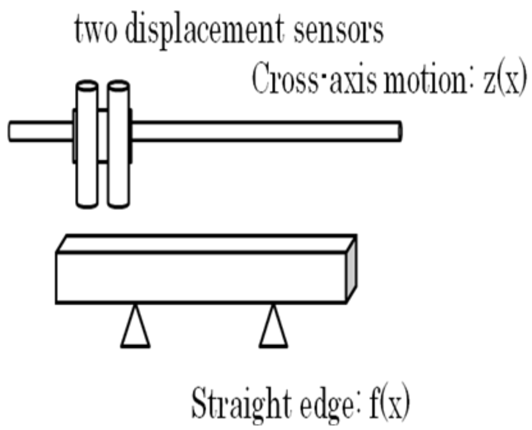

Fig.1 Two-point method

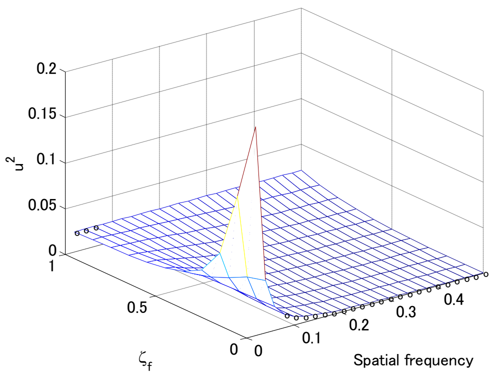

Fig.2 Relationship between Spatial frequency, ζ_f and power of uncertainty signal

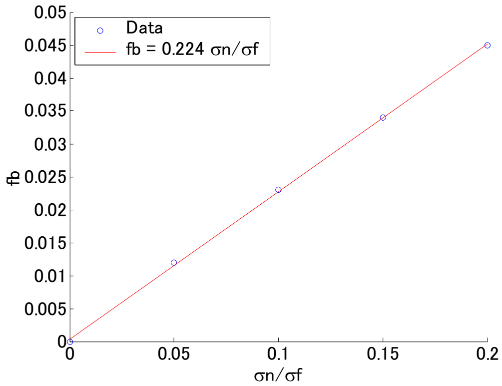

Fig.3 Relationship between σ_n / σ_f and f_b

the weights of the weighted addition. Furthermore, G(jω) is the transfer function of the weighted addition as follows:

$$G(j\omega) = w_1 e^{j\omega} + w_2 \tag{2}$$

3. Power of uncertainty signal

When $(w_1, w_2) = (1, 0)$, it corresponds to the hardware datum. On the other hand, $(w_1, w_2) = (1, -1)$, it corresponds to the conventional two-point method.

Fig.2 shows the relationship between spatial frequency of the cross-axis motion, ζ_f $(=w_1+w_2)$ and Eq. (1). Hardware datum method, $\zeta_f = 1$, still includes the error of the straightedge, but it does not amplify the sensor's random error. Conventional two pint method separates the error of the straightedge, but it amplifies the sensor's random error at the low spatial frequency domain. In Fig.2, a black circle shows the least power point at every spatial frequency. Power of the uncertainty of hardware datum method is smaller than two-point method under 0.07 lobes/measured length. On the other hand, it is larger over 0.07lobes / measured length. Here, this boundary spatial frequency is described as f_b.

When σ_n / σ_f is given, f_b can be derived using Eq. (1). Fig.3 shows the relationship between σ_n / σ_f and f_b. Circles show the derived f_b and line is least squares by first order polynomial. The graph shows that f_b is 0.023 lobes / sampling interval at $\sigma_n / \sigma_f = 0.1$. Then, when sampling number is 10 or 100, f_b is 0.23 or 2.3 lobes/measured length.

4. Conclusions

In this article, characteristics of the estimated cross-axis motion uncertainty in spatial frequency domain is discussed. Uncertainty of hardware datum is smaller under f_b and that of two-point method is smaller over f_b. The relationship between σ_n / σ_f and f_b is clarified.

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