Evaluation Method for Stability of Manufacturing Process Based on Fuzzy Norm Method

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Keywords: Manufacturing process；Stability；Measurement uncertainty；Fuzzy norm method；Evaluation.

Abstract. For the manufacturing system adjusted, there still is the uncertainty in the manufacturing process which is part of poor information problem with probability distribution unknown. The statistical evaluation methods depend on information with known probability distribution, which can not used to realize to evaluate the stability of the manufacturing process. Hence it is urgent to solve the problem above. Firstly, the output experimental data in the manufacturing process are selected to establish the membership function according to the fuzzy norm method. Under the given confidence level, the measurement uncertainty of the experimental data can be estimated to characterize the uncertainty of the manufacturing process. Then the relative error of the measurement uncertainty can be obtained, which can evaluate the stability of the manufacturing process. Therefore, based on the fuzzy set theory, an evaluation method for the stability of the manufacturing process using the fuzzy norm method is proposed to make up for the deficiency of the statistical methods.

Introduction

Considering the cost of production, the qualified rate of the products should be controlled meanwhile ensuring the quality of the products[1]. It can directly affect the quality of the products whether the manufacturing process is stable or not. Thus, it is significant to study the stability of the manufacturing process after the adjustment of the machine tool[2-4].

Measurement uncertainty is a characteristic parameter of measured results which can be used to describe the dispersion degree of the measured values for a property of the products reasonably[5]. The measurement uncertainty is mainly obtained using statistical methods and the measurement uncertainty in some cases also is estimated using the fuzzy set theory[6-10]. Because of complex structures, probability distribution of the system is unknown. An evaluation method for the stability of the manufacturing process using fuzzy norm method is proposed.

Evaluation Model for Stability of the Manufacturing Process

Collection of the Measured Data. Suppose that the output workpiece performance under investigation is represented as a random variable *x*. The workpiece is regularly subjected to sample, it can be obtained that the measured values on a certain performance of workpieces. Each extraction contains *N* continuous workpieces and it is a total of *M* extractions. It can be obtained that the measured data which constitute the measured data sequence *X*

$$X = (X_1, X_2, ..., X_m, ..., X_M); m = 1,2,..., M \tag{1}$$

where X represents the measured data sequence of the workpiece performance; X_m represents the mth measured data sequence in X, M is the number of X.

The mth measured data sequence X_m in the mth extraction can be expressed as

$$X_m = (x_1, x_2, \ldots, x_n, \ldots, x_N); n = 1,2,\ldots,N \tag{2}$$

where x_n represents the nth measured data in X_m, N is the number of X_m.

Establishment of the Membership Function. The measured data sequence X_m is ordered from small to large, constructing a new data sequence X_I, as follows

$$X_I = (x_1, x_2, \ldots, x_i, \ldots, x_N); x_i \le x_{i+1}; i = 1,2,\ldots,N-1 \tag{3}$$

Define the difference sequence Δ_i of adjacent measured data to be

$$\Delta_i = x_{i+1} - x_i \ge 0 \tag{4}$$

The smaller the difference value Δ_i is, the thicker the distribution of x_i is; otherwise, the larger the difference value Δ_i is, the thinner the distribution of x_i is.

According to Eq. 4, the linear membership function is used to describe the probability density function of the manufacture system, as follows

$$r_k = 1 - (\Delta_k - \Delta_{\min})/\Delta_{\max} \tag{5}$$

where r_k represents the probability distribution factors.

If the maximum probability distribution factor is $r_{\max}$, x_k is changed as X_v and the number k is changed as v. If there are mass $r_{\max}$, X_v and v are obtained by the arithmetic mean of $r_{\max}$.

Let the discrete values

$$h_1(x_k) = r_k; k = 1,2,\ldots,v \tag{6}$$

$$h_2(x_k) = r_k; k = v, v+1,\ldots,N \tag{7}$$

Make two polynomials

$$f_1(x) = 1 + \sum_{l=1}^{L} a_l (X_0 - x)^l; x \le X_0 \tag{8}$$

$$f_2(x) = 1 + \sum_{l=1}^{L} b_l (x - X_0)^l; x \ge X_0 \tag{9}$$

to approximate the discrete values $h_1(x_k)$ and $h_2(x_k)$, respectively. The membership functions $f_1(x)$ and $f_2(x)$ can be obtained. L is order of the polynomials in Eq. 8 and Eq. 9. If L is 3 or 4, the membership function is generally close to high precision of the discrete values. X_0 is the true value of the measured data.

Suppose that

$$\mu_{1k} = f_1(x_k) - h_1(x_k); k = 1,2,\ldots,v \tag{10}$$

$$\mu_{2k} = f_2(x_k) - h_2(x_k); k = v, v+1,\ldots,N \tag{11}$$

The ∞-norm is defined as

$$\|\mu\|_\infty = \max_{k=1}^{N} |\mu_k| \tag{12}$$

Then, make a_l meet

$$\min_{a_l} \|\mu_1\|_\infty \tag{13}$$

and make b_l meet

$$\min_{b_l} \|\mu_2\|_\infty \tag{14}$$

The coefficient a_l and b_l can be determined to obtain the membership function $f_1(x)$ and $f_2(x)$, as show in Fig. 1.

The true value X_0 is estimated using the maximum membership degree, as follows

$$X_0 = x\big|_{f(x)=1} = X_v \tag{15}$$

where $|_{f(x)=1}$ represents that it is at the membership function $f(x)$=1.

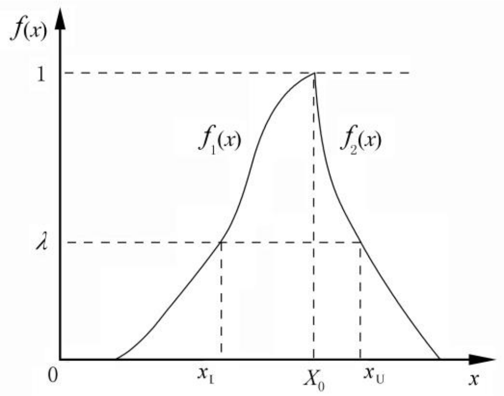

Figure 1. Membership function

Estimate for the Fuzzy Uncertainty of Measured Data. According to the fuzzy set theory, the manufacturing system is fuzzy. There is a transition interval in the manufacturing process from true to false or from false to true. The transformation law of the overall characteristics of the manufacturing system can be expressed by a characteristic function $G(x)$, as follows

$$G(x) = \begin{cases} 1 & (\text{true})\lambda \geq \lambda^* \\ 0 & (\text{false})\lambda < \lambda^* \end{cases} \tag{16}$$

where $G(x)$ represents the characteristic function which can describe the variations of the manufacturing system; λ represents the level of $G(x)$, $\lambda \in [0,1]$; λ^* represents the optimal level of $G(x)$.

The change interval of the measured data is assumed to be $[x_L, x_U]$. x in the interval $[x_L, x_U]$ is available and its value is 1 (true); x out of the interval $[x_L, x_U]$ is not available and its value is 0 (false).

Let the level $\lambda=\lambda^*$, and make λ^* meet, respectively

$$\min \left| f_1(x) - \lambda^* \right|_{x=x_L} \tag{17}$$

$$\min \left| f_2(x) - \lambda^* \right|_{x=x_U} \tag{18}$$

The optimal fuzzy uncertainty U_{λ^*} of the measured data can be expressed as

$$U_{\lambda^*} = x_U - x_L \tag{19}$$

According to the measurement uncertainty, the optimal fuzzy uncertainty U_{λ^*} can be used to characterize the measurement uncertainty of the measured values.

The confidence level P of the workpiece performance can be defined as

$$P = \frac{\int_{x_L}^{X_0} f_1(x)\mathrm{d}x\big|_\lambda + \int_{X_0}^{x_U} f_2(x)\mathrm{d}x\big|_\lambda}{\int_{x_L}^{X_0} f_1(x)\mathrm{d}x\big|_{\lambda=0} + \int_{X_0}^{x_U} f_2(x)\mathrm{d}x\big|_{\lambda=0}} \times 100\% \tag{20}$$

where $|_{\lambda=0}$ represents that is at the level λ=0 and Eq. 20 should meet $0 \le P \le 1$.

The confidence level P is affected by λ and L according to Eq. 20. λ and L are adjusted to satisfy P. In practical, optimizing that L = 3, then adjusting λ to meet P. The optimal fuzzy uncertainty $U_{\lambda*}$ at the optimal level λ^* can be obtained.

Evaluation Method for the Stability of the Manufacturing Process. The property characteristic of the manufacturing system generally changes slightly in a relatively short time in actual normal manufacturing process. Thus the measured data sequence X_1 is selected as the intrinsic sequence X_1 of the manufacturing process, characterizing that the stability of the manufacturing process is best in this stage.

With the accumulation of running time of the manufacturing system, mass factors are likely to cause a variety of disturbances, which can affect the stability of the manufacturing process. To evaluate for the stability of the manufacturing process, the measured data sequences X_2, X_3,…, X_m,…, X_M are selected as the evaluation sequences X_2, X_3,…, X_m,…, X_M of the manufacturing process. It is obtained (M−1) groups of the evaluation data sequences because of M extractions.

Using the fuzzy norm method, the optimal fuzzy uncertainty $U_{1\lambda*}$ of the intrinsic sequence is estimated and the optimal fuzzy uncertainties $U_{2\lambda*}$, $U_{3\lambda*}$,…, $U_{j\lambda*}$,…, $U_{(M\text{-}1)\lambda*}$ of the evaluation sequences are obtained as well. The basic of $U_{1\lambda*}$, the optimal fuzzy uncertainties of the evaluation sequences are compared with $U_{1\lambda*}$, to evaluate the stability of the manufacturing process.

In order to effectively evaluate the stability of the manufacturing process, the relative error $\mathrm{d}U_{j\lambda*}$ of the optimal fuzzy uncertainty between the evaluation sequences and the intrinsic sequence, can be defined as

$$\mathrm{d}U_{j\lambda^*} = \frac{U_{j\lambda^*} - U_{1\lambda^*}}{U_{1\lambda^*}} \times 100\%;\ j = 2,3,...,M \tag{21}$$

where $U_{1\lambda*}$ represents the optimal fuzzy uncertainty of the intrinsic sequence; $U_{j\lambda*}$ represents the (j−1)th optimal fuzzy uncertainty of the evaluation sequence.

According to Eq. 21, the relative error $\mathrm{d}U_{j\lambda*}$ can be obtained to describe that the variation degree of the uncertainty of the manufacturing process, which can realize evaluation for the stability of the manufacturing process.

Summary

Based on the fuzzy set theory, it is put forward an evaluation method how to evaluate the stability of the manufacturing process using the fuzzy norm method. The evaluation method can make up for the deficiency of the statistical methods in the aspects of evaluating for the stability of the manufacturing process.

Acknowledgements

This project is supported by National Natural Science Foundation of China (Grant Nos. 51475144, 50375011 and 50675011).

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