Process Analysis of Machining Process with Various Geometrical Characteristics

Fumiko Ogawa^{*1}, Taishi Tamai¹, Hironobu Kawamura¹, Ken Nishina²

1. Nagoya Institute of Technology: Gokiso-cho, Showa-ku, Nagoya, Aichi, 466-8555 Japan
2. Aichi Institute of Technology: 2-49-2 Jiyugaoka, Chikusa-ku, Nagoya, Aichi, 464-0044 Japan

**fumiko_ogawa@outlook.jp*

Abstract:

This paper proposes a method for analyzing geometrical characteristics, especially for improvement of manufacturing machining process. The definition of the geometrical characteristics in the GPS (Geometrical Product Specifications) standard defined as ISO 1101 are the value of difference from geometrically correct points, lines and planes as the datum, and it is aggregated property of multiple factors. This aggregated property of the geometrical characteristics is for conformity evaluation of the product functional requirement, and may not be appropriate to use for the improvement the manufacturing process. The geometrical characteristics have resolution structure and/or hierarchical structure. To elusive the causal mechanism and their relationship, and to use the causal mechanism for improvement of the manufacturing process, the geometrical characteristics should be resolved on their coordinate position, or should be observed the hierarchical structure. And as the first step, observation of the actual shape of the feature is also useful to analyze. Through the case study, this paper proposes the efficient procedure of process analysis of the geometrical characteristics.

Keywords

Geometrical characteristics, Causal relationship, Boring process, Machining, Measurement

1. Introduction

Recently, due to diversification of customer needs and development of machining technology in the manufacturing industry, the feature of the product is becoming more complicated. And, measurement technology, such as coordinate measuring machine (CMM), has also been developed. That helps to quantify various and complicate feature more than ever. Meanwhile, the geometrical tolerances, they are characteristics expressing the functional requirements of mechanical parts, are aggregated characteristics of the complex feature. This is sometimes a problem in terms of improvement of design and manufacturing process.

Machining accuracy of a certain part is collection of some geometrical characteristics, and it is considered that these geometrical characteristics have mutually influence each other from the technical point of view. There is a hierarchical structure between some of the geometrical characteristic based on the datum area, line or surface. There are also causal relationships. However, the causal relations cannot be elucidated by the geometrical characteristics defined in ISO 1101 [1] or JIS B 0021 [2]. Because these geometrical characteristics originally have information such as coordinate and direction, and some of them also have distinctive distribution. In the definition of the current geometrical characteristics, since it represents the absolute value such as the difference between the maximum and the minimum value, it becomes characteristics which is composited information of positive/negative value or the direction. In order to make use the quality information obtained from the machining process results for the upstream process improvement, it is necessary to have information of position coordinate and directionality in the geometrical characteristics. Thereby elucidating the mechanism for creating quality can be shown.

In case of machining process with geometrical tolerance, when linking the process information obtained from the machining process to the improvement of the upstream process, there are mainly two points of view of improvements such as design stage and the manufacturing process. For design improvement, it is considered whether it is possible to manufacturing, tolerance design for cost reduction, verification of ease of manufacturing,

etc. [3]. For manufacture improvement, it is considered to secure stable processes, to solve problems, to pursuit higher accuracy, and to understand the process capability in the factory.

This paper proposes a method for analyzing geometrical characteristics, especially for improvement of manufacturing machining process. A case study of boring process is introduced as an actual example. This aims to verify the usefulness for improvement of the manufacturing machining process by elucidating the causal mechanism in each geometrical characteristics in this actual process.

2. Properties of geometrical characteristics and proposal analysis method

GPS (Geometrical Product Specification) standard is defined by ISO 1101, which aims to avoid the drawing's ambiguity. GPS is a generic name of various standards concerning the definition and instruction methods of the geometrical specification of machine parts, which is defined to exclude imperfections and ambiguities of the dimensional tolerance, geometrical tolerance and surface texture. This contains what is necessary for the geometrical definition of the workpiece. ISO 1101 / JIS B 0021 defines the geometrical tolerance and describes the explanation. The definition of the geometrical characteristics in the GPS standard are the value of difference from geometrically correct points, lines and planes as the datum. Therefore, the geometrical characteristics are indicated only by a positive (absolute) value (See Fig.1). But in some case, this value may not be appropriate for process improvement, such as evaluation of the process capability or improvement for defectives.

Fig.1 Definition of geometrical characteristics in ISO 1101

Therefore, this paper proposes following two points;

1. It is necessary to observe the correlation and variation by resolving into position coordinates and directions when looking at variations of total characteristics including elements of multiple variables such as geometrical characteristics.
2. There is a hierarchical structure in the relation between the geometrical characteristics, and it is necessary to elucidate the hierarchical structure for the upstream process.

As for 1, Nishina et al. (2005) [4] argues that information such as position coordinates and direction is necessary as a method of evaluating process capability. However, it was not verified using actual examples, was only the argument. For 2, it is described on "interrelationship of geometrical tolerance" in Section 17 of JIS B 0021, but since there are only a few papers analyzing this hierarchical structure by using actual examples, so this paper covers the case study. From the statistical and technical point of view, this paper demonstrates that resolving the geometrical characteristics into position coordinates and directional accuracy after clarifying the hierarchical structure leads to elucidate of the causal mechanism.

3. Geometrical characteristics in boring process case

The case study of this paper is the process that bore a hole in a cylindrical feature with a boring machine. The left diagram of Fig.2 shows the model diagram at the time of boring process. This includes four geometrical tolerances, i.e. the circularity and the perpendicularity of the cylindrical hole, the flatness and the parallelism of

top and bottom surfaces of the workpiece itself. Regarding the perpendicularity representing the degree of tilt of the cylindrical hole in this case, when the center of the circle on the upper surface of the cylinder is set as the reference point (origin), the perpendicularity of the cylindrical hole is the difference between upper and bottom center coordinate position of the circle, as shown on the right side of Fig. 2.

Fig.2 Left: Model of Boring Process / Right: Definition of Perpendicularity in this case

As the case study, examples of resolution structure and hierarchical structure are shown in order 1 to 3 as shown in Table 1.

Case 1 shows the resolution structure of geometrical characteristics which resolves circularity and perpendicularity into coordinate and directional accuracy.

Case 2 shows the hierarchical structure of geometrical characteristics which has a comprehensive regulated relation between flatness and parallelism.

Case 3 shows the hierarchical structure having the dependency relations related to flatness as the datum and perpendicularity and also resolution structure of perpendicularity.

Resolution Structure	Hierarchical Structure
Case 1 : Circularity and Perpendicularity	Case 2 : Flatness and Parallelism
Case 3 : Flatness and Perpendicularity	

Table 1 Three actual cases in this research

The measurement data used in this case were from the actual machining process, and the shape and coordinate of the machined area and the related part was measured in each step of the machining process from the heat treatment to the final step.

4. Case study

4.1. Resolution structure (Circularity and Perpendicularity)

Originally, circularity has data for one round of circle. As shown in Fig. 1 of Chapter 2, in the current standard, circularity tolerance means the smallest distance in radii when the circular feature is in two geometrical concentric circles [5]. For this reason, there is lack of information on the position where the highest point is and where the

bottom point is.

Also, perpendicularity in the current standard (which can be considered as the position in this case) is the value obtained by the Euclidean distance. So the variation in the x direction and the variation in the y direction are not always the same. Furthermore, positive/negative direction and angle information of tilt are also lacked.

Since circularity and perpendicularity targeted in this case are the machining accuracy simultaneously obtained by the boring process, it is conceivable that they are related to each other from technical point of view. In the conventional evaluation method described in JIS B 0021, correlation coefficient value is 0.0614 as shown in Table 2 (a), it is considered circularity is almost uncorrelated with perpendicularity. But in another view, since perpendicularity is represented by the Euclidean distance, it can be analyzed by dividing perpendicularity into x and y coordinate. Therefore, circularity and perpendicularity were respectively checked whether there are various patterns or characteristics of the coordinate position and the direction. As the result, regarding the circularity, it was found that the elliptical shape, as shown by the red line in the left diagram of Fig.3. Perpendicularity was also checked the tilt direction, and it was observed that there was tendency to tilt as shown in the right diagram of Fig.3.

Fig. 3 Left: Actual Shape of Circularity / Right: Plot of Perpendicularity (N=30)

Based on these information, perpendicularity was resolved into the x and y coordinate and analyzed again. The correlation coefficient of the circularity and y direction of perpendicularity is -0.4183 as shown in Table 2 (b). Further, from the view of actual circularity shape, information was extracted from the bulging direction (circularity: 90 to 120 rad) and from the indentation direction (circularity: 270 to 300 rad). As the result, stronger correlation between the circularity of the bulging/indentation shape and the perpendicularity after resolving as the x and y coordinate can be found as shown in Table 2 (c).

(a) Correlation coefficient value between Circularity and Perpendicularity

Correlation coefficient value	Circularity
Perpendicularity	0.0614

(b) Correlation coefficient value between Circularity and Perpendicularity x and y axis

Correlation coefficient value	Circularity
Perpendicularity x axis	0.2402
Perpendicularity y axis	-0.4183

(c) Correlation coefficient value concerned Circularity shape

Correlation coefficient value	Circularity (90 to 120 rad)	Circularity (270 to 300 rad)
Perpendicularity x axis	0.3019	-0.1878
Perpendicularity y axis	-0.4944	0.3392

Table 2 Correlation Analysis between Circularity and Perpendicularity

By resolving the geometrical characteristics, it was found that the tilt of the perpendicularity affected to the shape of circularity. In particular, it was found that, as the perpendicularity was more tilted in the $-y$ direction, the circle radius increased. Factors the perpendicularity is tilted can be considered that the main spindle of the machining tool is tilted, or the workpiece itself is tilted due to the factor of inclining shape of flatness or parallelism (Fig.4). From this example, it was confirmed that it led to elucidate the causal mechanism between the geometrical characteristics by resolving the perpendicularity as the coordinate and evaluating the circularity with a pattern of shapes rather than only the difference of the maximum and the minimum radii value.

Fig. 4 Left: Model in case of tilted Spindle / Right: Model in case of inclining the workpiece

4.2. Hierarchical structure (Flatness and Parallelism)

As mentioned in Chapter 2, the comprehensive regulatory relationship of geometrical characteristics is described as "interrelationship of geometrical tolerance" in Section 17 of JIS B 0021. In the case of flatness and parallelism, the parallelism which is the orientation deviation of the target feature regulates the flatness which is the shape deviation of the same surface. But the parallelism cannot be regulated by the flatness tolerance. In other words, if the parallelism is regulated, the flatness is also regulated at the same time. Although this interrelationship may be better from the standpoint of guaranteeing quality, when improving, it needs to be considered that resolving geometric characteristics hierarchically, not that comprehensive interrelationship.

In this case, since flatness of the bottom surface of the workpiece is the reference surface for machining and measurement, when measuring the parallelism, it is needed to understand information of the shape such as undulation of the measurement surface. When measuring the parallelism without considering the undulation of this reference surface flatness, the correlation becomes almost uncorrelated as shown in Table 3. The parallelism with considering the undulation of the reference surface, stronger correlation coefficient 0.754 was observed.

The relationship between the flatness shape and the inclination direction of the parallelism cannot be observed unless measuring the parallelism with considering the shape of the flatness. This case study shows that the parallelism accuracy can be improved more by controlling the shape of the flatness, and it is necessary to elucidate the hierarchical structure.

Table 3 Correlation Analysis between Flatness and Parallelism

4.3. Resolution and Hierarchical structure (Flatness and Perpendicularity)

There are two types of geometrical characteristics that are single feature and related feature. The difference between single feature and related feature is whether it needs to have related datum to designate geometrical tolerance. If the geometrical tolerance is not related to the datum, it is a single feature. In other hand if the geometrical tolerance is determined in relation to the datum, it is the related feature. Datum is defined as "the theoretically exact geometrical standard set to regulate the tolerance zone when indicating the geometrical tolerance to the relevant feature" [6]. The orientation and location deviation of the related feature are set based on the datum.

In this case of boring process, the perpendicularity of the cylindrical hole is machined and measured based on the assumed datum surface that is the bottom side surface of the workpiece (Fig.5). Therefore, the perpendicularity of the cylindrical hole could be easily affected by the shape of this datum surface, and there should be a correlation between flatness and perpendicularity.

Fig. 5 Example of Relationship between Geometrical Characteristic and the Datum Feature

The correlation coefficient between the flatness of the bottom surface of the workpiece and the perpendicularity of the cylindrical hole in the boring process is shown in Table 4. It was not observed the correlation between the flatness and the perpendicularity. However, as in Section 4.1, when resolving the perpendicularity as x and y axis, it was observed that between flatness and y axis of perpendicularity was particularly correlated. And, when plotting

on x and y coordinate, the inclination of the perpendicularity shows deviation on x direction and variation on y direction, as shown in Fig.6. Therefore, it is assumed that the deviation of x direction affects to the perpendicularity, and the flatness as the datum surface before machining affects to the y coordinate of the perpendicularity hierarchically.

For this reason, information of the actual datum shape in the machining step should be required for machining process improvement.

<p>N=20, Correlation coefficient value = 0.0175</p> <p>Flatness</p>	<p>N=20, Correlation coefficient value = 0.0072</p> <p>Flatness</p>	<p>N=20, Correlation coefficient value = 0.7194</p> <p>Flatness</p>
Flatness and Perpendicularity	Flatness and Perpendicularity x axis	Flatness and Perpendicularity y axis

Table 4 Correlation Analysis between Flatness and Perpendicularity (x and y axis)

Fig.6 Plot of Perpendicularity on x and y Coordinate Position

5. Concluding remarks

The purpose of this research is to propose the new analysis method of the geometrical characteristics to be useful for improving the manufacturing process. And with using the case study of the boring process in a machining manufacturing, it is elucidated the causal relationship between the multiple geometrical characteristics, and verified usefulness of this proposal method. Through three examples of boring process, it was shown that close relationship of multiple geometrical characteristics and those factors, and the causal mechanism can be elucidated

by analyzing geometrical characteristics from the view of resolution structure and hierarchical structure. In addition, based on the hypotheses established in this research, as the result of experiments using the test pieces, the tilt of main spindle of the boring tool was examined, and resulted in improvement.

As shown this case study, the aggregated value of geometrical characteristics may not be appropriate to use for the improvement the manufacturing process. It should be elucidated the deviation mechanism with analyzing the actual shape of the feature and the resolution/hierarchical structure of multiple geometrical characteristics, and it will lead to clarify where the problem in the manufacturing process and improve it.

As the future issue, this proposal method would be applied and verified in other case or other geometrical characteristics which is not shown in this paper, and all of the geometrical characteristic would be tried to organize as the same method.

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Author's biographical notes

Fumiko Ogawa is a doctor course student at Department of System Management and Engineering. She is a member of JSQC. Her areas of research include Manufacturing Engineering and its Quality.

Taishi Tamai is a master course student at Department of Industrial Engineering. He is an associate member of JSQC. His area of research includes Data Analysis.

Hironobu Kawamura is an associate professor at Department of System Management and Engineering. He is a member of JSQC. His areas of research include Quality Control and Applied Statistics.

Ken Nishina is a professor at Department of Business Administration. He is a member of JSQC. His areas of research include Quality Control and Applied Statistics.

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