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Analysis of Variations Control Model for Vehicle Manufacture

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Abstract: Because the body manufacturing quality affects the quality of the vehicle, the control of manufacturing quality plays a decisive influence on the development of the auto industry. As an important factor of manufacturing quality, the research of variations is essential. In this paper, after analysising and comparing of the model used to control the variations of body, which is from traditional to existing, rigid to flexible, we got the optimization model which is based on the model of influence coefficient method. And making a bold speculation about the future research trends in this area, aim to provide useful reference for the future research.

Keywords: The Control of Automobile Body Deviation, Flexible Sheet Assembly, Dimension Chain, Deterministic Analysis, the Method of Influence Coefficient

1. Introduction

Since the birth of the automobile, great and profound changes have taken place in the world and human. After 100 years of development, the automobile industry has experienced from scratch, the rapid development of the process, a substantial increase in annual output, and the technology has greatly improved. But the global automotive manufacturing enterprises are generally facing the problem that the quality of the car body manufacturing, which plays an important role in the impact is not only for China's manufacturer, but also to other countries. At present, the competition of the automobile market is becoming more and more fierce, and the customer's requirements about quality are also more stringent, so it is a major problem to improve the quality of the body manufacturing, and the key to improve the quality of the body is to control and reduce the body variations. Therefore, how to solve this problem is a big challenge for the automobile industry.

2. The Purpose and Significance of the Research on the Variation Control of the Body Manufacture

The manufacturing variations of the body directly affects the performance of the vehicle, such as the wind noise, the sealing, the driving stability and so on. In 1997, the critical survey and assessment showed that the problems of body's quality accounted for more than 40% of the quality of the whole vehicle [1], which was presented by Power J.D., which has been the authority of the quality evaluation of United States. Then, in 2005, Power J.D. investigated the user satisfaction of various parts of the car, which showed us the appearance of the vehicle is the 13%~24% of all the factors, and the car users in many countries are most concerned about the appearance of the car body[2]. In this regard, the domestic and international academic and industrial circles have given a high degree of attention.

At the beginning of the last century, the level of body manufacturing of US is lower than Japan and Germany, especially in the precision of body manufacturing. At that time, the U.S. auto manufacturing variation control in ±2mm above, and the highest level in Europe is ±1.25mm, Japan's best companies are controlled in ±1mm, which lead the three largest auto company of US lost a large number of domestic car market share. Until 1991, Professor Wu Xianming of University of Michigan proposed 2mm project, aim to reduce the body's comprehensive variations, after 3 years, the U.S. auto body quality has been significantly improved, and gradually get back to the original market share[3].

As one of the four major parts of auto car, body plays an important role to the development of the auto industry, mainly reflected in three aspects: Vehicle production capacity is decided by the body's production capacity, the speed of the vehicle replacement is largely determined by the quality of body, the research of body engineering is currently the most active and the most rapid development in the automotive industry. To sum up, the development of China's auto industry is determined by the quality of the body to some extent.

Now, some countries are doing efforts to study and try to improve the quality of the body manufacturing, such as the German Volkswagen Company has implemented the RPS reference point system [4]. And our average level of body's variation is still above±5mm, which is far behind the world level. Therefore, in order to make our auto industry revitalize, it is urgent to carry out the research on the control of the variation of body manufacturing.

3. The Research Status of Body Variation's Source and Control

3.1. Source of Body Variation

Body, as an important part of the car, it is also the carrier of all parts of the entire car. The entire body consists by 300~500 sheet metal stamping parts, with complicated surfaces, and through 50~90 welding and assembling station. Because of its multi-level architecture, there are many intermediate links[5][6][7], and sheet metal forming, automatic assembly line, welding and other technical testing would be related while assembling, it is so complex that all kinds of assembly errors are inevitable.

First, in the design and manufacturing process of the body, the determination of the variation of machining size is a very important link. The source of variations mainly includes the interference between the various parts, variations of the part themselves, welding deformation etc..The integrated variation of the body is formed by coupling, spreading and accumulating in the assembly process.

Second, as the manufacturing process of body is divided into four typical stages, just like trial production, production start, the production of a single shift and shift production, and different stages of production have different characteristics, so the effect of these four stages on the stability of manufacturing is also different.

3.2. The Research Status of Deviation Control of Vehicle Manufacturing

We need to through a few steps in order to maximize realize the expected requirements of manufacturing variations. Firstly, based on the theory of stream of variation (SOV) [8][9], the propagation law of variation during assembling is revealed. Then determine the source of variation based on the variation of size during manufacturing, and implement the variation control when manufacturing. Finally set up the analysis model of assembly variation, via to analysis the model we can describe the relationship between the assembly variation and other source variation more clearly and accurately.

The current model of variation analysis is divided into two categories: rigid and flexible. The method of establishing the model is shown in table 1.

Table 1. Method of assembly deviation model.

Modeling method			Force of the triangle rule	Engineering Mechanics Basics
Rigid model	Dimension chain model	According to the geometry size and assem-bly of parts, the relationship between the closed loop and the space dimension of the ring is established, and through the linear solution	Form closure	Kinematics
	Deterministic model	According to the relationship between the parts in the deterministic positioning, the relationship between the deviation of the parts and the fixture location deviationis is established		
	Direct finite element method	Using the finite element tool, the assembly process of the parts is analyzed and the res-ults are obtained		
	Influence coefficient method	Using the finite element analysis, the relati-onship between the assembly and the man-ufacturing deviation of the parts assembly is obtained	Form closure	
Flexi-blemodel	Flexible static analysis	Combined with the finite element analysis, the coordinate points of the parts are processed by static contact method, and the relationship between the material and the geometric covariance is analyzed	Force closure	Dynamics

3.2.1. The Rigid Model of Body Manufacturing Variation Control

In the traditional assembly variation analysis, the method is based on the theory of rigid body variation accumulation, the widely used methods are: Worst Case [10], Root Sum Squares [11] and Monte Carlo Simulation [12] [13]. The Worst Case method is one of proposed by Greenwood at first, it applies to one dimensional assembly, but as a result of the analysis, it is necessary to give a very strict limit to the size of the parts in order to meet the requirements of the final assembly size, so it will increase the cost of production. Therefore，in actual practice it usually for the composition of the small number or need to ensure ensure this completely inter-changeable. The tolerance value of a single part is consistent with the statistical distribution law according to statistical method, and then using of probability theory to determine the tolerance of the assembly size according to the distribution of parts size, one of the more commonly methods are root-mean-square. Because

of the shortcomings of the extreme value method which are extremely difficult to overcome, the application is very poor. Now most method of tolerance allocation is based on statistical method. At the beginning, Parkson put forward the viewpoint of statistical tolerance allocation based on the perspective of statistical tolerance [14]. He takes the cost as the objective function, and puts forward a set of calculation formula of program. Then Lee W.J and Woo T.C considered variations as random variables that are consistent with a certain distribution rule, and put forword reliability index based on the second order moment [15]. Later, Jiangxin Yang, who come form Zhejiang University, made a further study on the basis of the former, and presented a method for the reliability of the four degree of the reliability index of the design method [16]. The following will be targeted at several typical models to analyze.

(1)Dimension chain model

The dimension chain model[17][18][19] obtain the explicit or implicit function relationship between the closed loop and the ring by establishing the assembly dimension chain, then based on the extreme value method or statistical method, the mapping model between the assembly deviation and the parts is studied. The model will divided the variation of the assembly process into three categories: the deviation of the parts, the geometric characteristics of the parts and the adjustment of the assembly motion. The closed loop is the adjustment of the assembly motion, but also the final assembly variation.
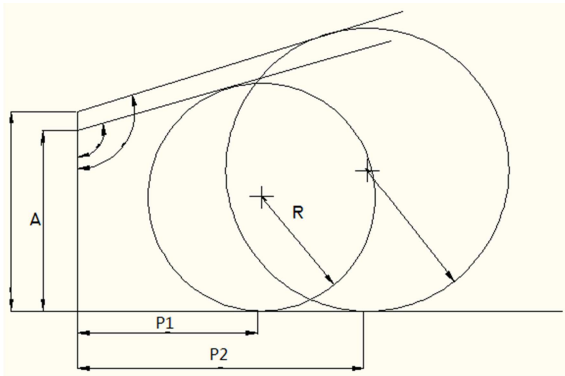

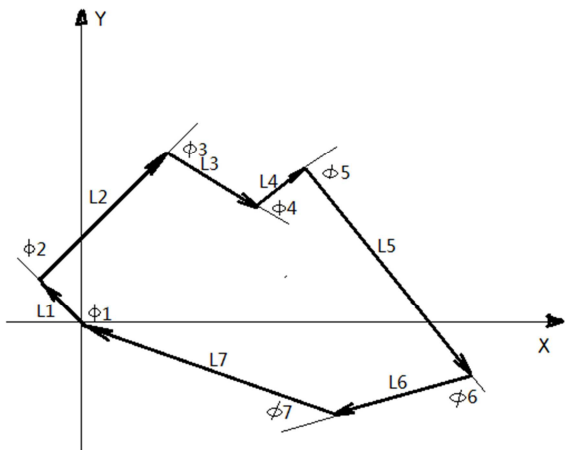**Fig. 1.** *Closed loop of dimension chain model.*

Fig. 2. *Assembling vector ring of dimension chain model.*

As shown in Figure 1, P1 is the assembly adjustment, the mapping relationship between A and R is studied by establishing the dimension chain model. The method of calculating the dimension chain model has the extreme value method and statistical method.

For two-dimensional assembly dimension chain, the vector loop vector is projected onto x, y and rotation direction, as shown in Figure 2, the constraint equation can be obtained.

$$H_x = \sum_{i=1}^{n} L_i \cos\left(\sum_{j=1}^{i} \varphi_j\right) = 0 \qquad (1)$$

$$H_y = \sum_{i=1}^{n} L_i \sin\left(\sum_{j=1}^{i} \varphi_j\right) = 0 \qquad (2)$$

$$H_\varphi = \sum_{i=1}^{n} \varphi_j = 0° \, or \, 360° \qquad (3)$$

And then use direct linearization method [20] [21] (DLM), calculating constraint equations of the Taylor expansion, to obtain the sensitivity coefficient matrix of variations of assembly and parts.

$$\{\Delta H\} = \left[A\right]\{\Delta X\} + \left[B\right]\{\Delta U\} = \{\Delta \theta\} \qquad (4)$$

The variables in the formula are presented as follows: $\{\Delta H\}$ ——variations of assembly clearance；$\{\Delta X\}$ ——variations of part；$\{\Delta U\}$ ——Assembly motion adjustment (closed loop)；$\left[A\right]$ ——First order partial derivative of part variation；$\left[B\right]$ ——First order partial derivative of motion adjustment.

$$\{\Delta U\} = -\left[B\right]^{-1}\left[A\right]\{\Delta X\} = \left[S\right]\{\Delta X\} \qquad (5)$$

For three-dimensional space model, the relationship between the length of the assembly vector ring and the diagonal line needs to be expressed by the translation matrix and rotation matrix of homogeneous transformation.

But because of the limitation of dimension chain model. When the parts assembly relations are more complex, there will be a variety of assembly features. Namely, while a part is assembled with multiple parts simultaneously, assembly dimension chain relationship is difficult to extract, dimension chain generation is more difficult. Therefore, the model is generally used only for parts of the connection between the simple situation.

(2)Deterministic analysis model

The deterministic analysis model [22] [23] mainly focuses on the influence of the position deviation and the deviation of fixture location in the process of workpiece positioning, mainly used for fixture design. Deterministic positioning, that is the space of parts and components of 6 degrees of freedom fully bound. In this aspect research should be Asada and by earlier [24], they studied the problem of the deterministic localization and the complete constraint. After that, Sayeed

and Demeter [25] developed a software that can automatically determine the geometric parameters of the point, so that the positioning can satisfy both the deterministic and the complete constraints. Carlson [26] and Wang [27] use the surface contact model to study the problem of deterministic positioning, complete constraint and positioning accuracy. As a continuation of the research, the theoretical basis of the deterministic positioning and complete constraints is the kinematics, the main method are as follows: Helix theory and coordinate transformation. The deterministic model can be divided into two kinds of point contact model and surface contact model according to the contact between the location block and the workpiece.

For point contact model, the following points should be noted in the model hypothesis: fixtures and parts are kept rigid, position block and work piece for point contact, clamping force can be controlled. Before analysis, we should build the constraint equations of the fixture for the position of the parts at first, and then analyze and determine whether the components are in a deterministic position, finally through the constraint equation of Taylor expansion or deduction, and slove the mapping relation of parts variation and position variation.

These methods are only suitable for the rigid body parts, and the statistical characteristics of the assembly deviation are determined by the geometrical relationship and the movement relationship of the parts. However, taking into account that the body is composed of hundreds of thin sheet parts with a large flexible assembly, the traditional assembly method can not be fully applied to the body assembly deviation analysis, so we put forward the analysis model of the flexible sheet.

3.2.2. Research on the Deviation Control of Flexible Sheet Assembly

Firstly, based on the regression analysis of the data of the measurement of the flexible plate assembly, in 1980, Takezawa [28] put forward the hypothesis of the rigid body based on the assumption that the deviation of the accumulated theory is not suitable for the car body parts assembly deviation analysis, he also proved that the Addition theory of Variance is no longer suitable for flexible sheet assembly, he also opened a prelude to the study of the assembly deviation of the flexible sheet at the same time. After that, the scholars of Michigan university combined with the finite element method and the traditional theory in 1990, he took the lead in the assembly of the car body flexible sheet parts of the theoretical research. In 1995, Liu [29] proposed a model of one dimensional cantilever beam element with bias element method, which was used to calculate the assembly deviation. But the model will be simplified to one dimension of the cantilever beam, which is focused on the theoretical analysis and the accuracy is not high, so it is still necessary to improve. In 1997, Hu [30] proposed the theory of variation flow, and considered the structural and statistical analysis of the components, and the assembly of the two new forms of parallel and series. In the same year, Hu and Liu [31] used the finite element analysis method to establish a model of mechanical deviation simulation for two or three dimensional free surface sheet, and

proposed the effective method of influencing coefficient (MIC). In 1998, Liu and Hu[32] combined with mechanical model and statistical method, and analyzed the influence of different welding joints (such as lap, butt joint, glue) on the assembly variation. In recent years, Du Sheliang and Lin Zhongqin [33] proposed the application of bionics, attempt to solve the problem of poor adaptability and robustness of the traditional automobile manufacturing deviation control, they hope that the influence factors can be simulated by using bionic element. Then achieve the purpose of controlling the deviation of the vehicle body by analyzing the stress and strain in the finite element method.

At present, it is still a finite element method, static analysis method and influence coefficient method to study the assembly deviation analysis method for the flexible sheet parts of the body. Among them, the most widely used model is based on the influence coefficient method. Afterwards, based on this model, many scholars have carried on a more thorough research. For example, Long [34] established a simulation method of the rigid motion and flexible deformation when analysising the difference between flexible and rigid assembly in the positioning principle, assembly mechanism and the variation transmission, the method is considered to be considered for the fixture deviation. Georg and Frank [35] also analyzed the influence of welding sequence on the assembly variation of the application of MIC. In addition, Lindkvist [36] and Dahlstrom also proposed a method to establish the contact model in MIC. Xing Yanfeng [37] used MIC analyze the influence of fixture location deviation on the assembly deviation in the process of assembly. Next, we will describe the representative model.
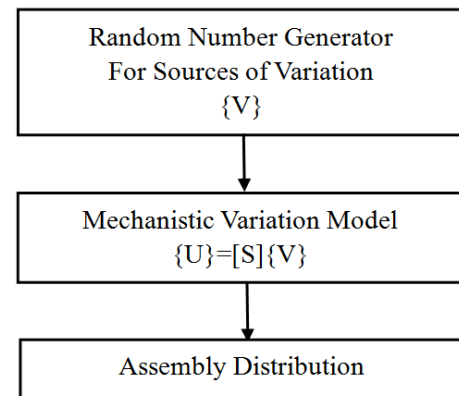
(1) Analysis model based on MIC

Fig. 3. *The process of assembly variation analysis with MIC.*

The MIC[38][39], which is based on the linear elastic deformation of the flexible thin plate element, combined finite element analysis with statistical analysis, then established linear relationship between the variation of the assembly and the input variation, and obtained the method for the sensitivity matrix of assembly parts to the deviation of parts. Based on the assumption of flexible parts, the relationship between the deviation of the assembly and the deviation of the parts is established (Figure 3 shows the assembly variation flow chart

with MIC), which is based on the position of the flexible part of the body. The establishment of the entire linear relationship only runs the two time finite element analysis, which successfully overcomes the disadvantages of the large amount of the multi-assembly sample finite element simulation.

At first, the MIC only consider parts of the material properties, geometry and the deviations of parts, through the efforts of many scholars, and gradually establish a consideration includes a fixture locating errors and welding torch deviation effect of reasonable MIC, as is shown in Figure 4, based on the linear relationship between the assembly deviation and the source of the deviation, the assembly calculation is carried out using this model.
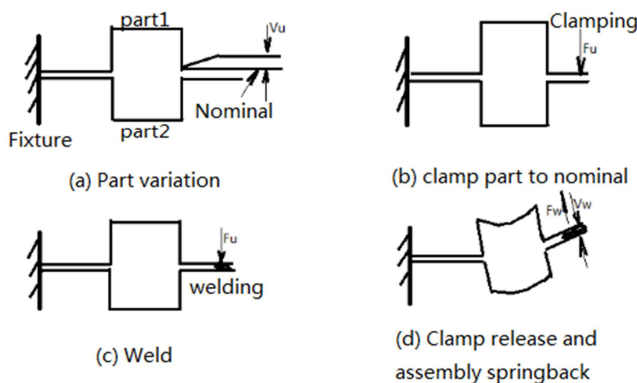

Fig. 4. The model of flexible assembly variation.

Although the MIC is easy to understand, the operation is relatively simple, it also has its own limitations, which is based on linear small deformation assumption [40], can not be considered in the case of material nonlinearity. Neglecting the influence of welding heat distortion. Therefore, in order to get more accurate and efficient results, this model has to be improved.

4. The Development Trend of Deviation Control for Vehicle Body Manufacturing

With the development of lightweight and energy saving and emission reduction projects, the body structure is undergoing tremendous changes in the material and the form. For example, in aspect of using high strength steel, light metal materials, composite materials, etc.[41].In the form of using aluminum alloy frame structure, component integration and structural optimization[42]. However, in order to achieve this goal at the same time, it has put forward higher requirements for the body manufacturing technology, especially for the body deviation control research is a great challenge.

At present, there are two main types of tolerance control management in foreign countries: the technology of tolerance management and the experience of Japan and South Korea as the representative of the United States and Europe. That is to say, Europe and the United States enterprises mainly through the use of some software, such as 3DCS, Analyst VisVSA and

so on to analyze the tolerance and thus ensure the quality of the body, that is, through the software simulation to achieve assembly, is conducive to the implementation of Synchronous Engineering. Then compared the scheme, to achieve the optimization objective. However, Japan and South Korea is to achieve this goal by summing up the experience in the production practice. Compared to Europe and the United States, but the reliability of the enhanced, but the cost has increased, and time consuming, it is not conducive to the implementation of Synchronous Engineering. According to this analysis, the future trend of software analysis should be the dominant position.

Because the body is connected with resistance spot welding technology which has the nature of high efficiency, low cost and automation. Although Liu and Hu [41] has researched three kinds of welding form, such as lap joint, butt joint and fillet. When facing the connection will soon emerge of new materials, for the current welding technology will be a challenge, so the corresponding variation control will produce greater difficulties.

5. Conclusion

Control of body manufacturing deviation is to control the body manufacturing quality, and the ultimate goal is to control the body manufacturing quality. To achieve this goal, we must have advanced detection means and effective data processing method to do the foundation, then use a sufficiently accurate model and algorithm analysis integrated data to control and reduce manufacturing deviation.

In this paper, we analyzed some typical models of variation analysis, such as: dimension chain model, deterministic model, direct finite element model, and the model of influence coefficient method, then evaluated and compared their advantages and disadvantages. It can lay the foundation of the analysis model of flexible deviation, and it will play a more and more important role in future research.

At present, we must have a more in-depth study of the variation analysis model to get a more perfect variation control method, and participate in the international auto industry actively, and to explore the control of the body to explore the more effective way to control the body variation.

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