NEW TECHNOLOGIES

Practical Tolerance Analysis Simulation

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Abstract

In the past, the cumulative tolerance at the development stage for parts assembled together was verified by manual root extraction from the sum of squares in a two-dimensional drawing. Generally, however, the parts of a motor vehicle have a complicated structure, and the variance in three-dimensional space cannot be accurately estimated by the conventional calculation procedure.

Therefore, a project for improving the quality of mass-produced vehicles was established. The project is characterized by arithmetic estimation of the cumulative tolerance in three-dimensional space and prediction of likely defects. This paper outlines our practical tolerance analysis simulation using a three-dimensional CATIA model and its application for developing the COLT PLUS.

Key words: *Tolerance, Simulation, CATIA, Process Capability*

1. Introduction

An automobile is made up of numerous parts, and the manufacture of those parts inevitably involves variations in size. A tolerance is a range of variance specified at the designing stage, but the cumulative sum of tolerances for individual parts may result in gaps, misalignment, faulty assembling, malfunction of moving sections, etc. The aim of tolerance analysis simulation is to clarify the requirements that must be satisfied in order to ensure the required quality of the finished vehicle by calculating the cumulative tolerance for it.

2. Background for introduction of tolerance analysis system

In the past, the cumulative tolerance was manually calculated by root extraction from the sum of squares on a two-dimensional plane (**Fig. 1**), which made three-dimensional positions and revolution hard to analyze. To solve the problem, we decided to introduce a system (3DCS by Dimensional Control Systems) for simulating the cumulative tolerance in three-dimensional space. We also tried to establish a parts installation standard and a positioning method necessary for a three-dimensional product model, which is indispensable for tolerance analysis. We also upgraded drawings so that shape tolerance information could be incorporated.

3. Tolerance analysis procedure

3.1 Analyzed stages and analysis points

The tolerance analysis starts upon starting to design a vehicle and ends when the model is established. The problems detected on the present model and important sections of a new structure were analyzed. The basic

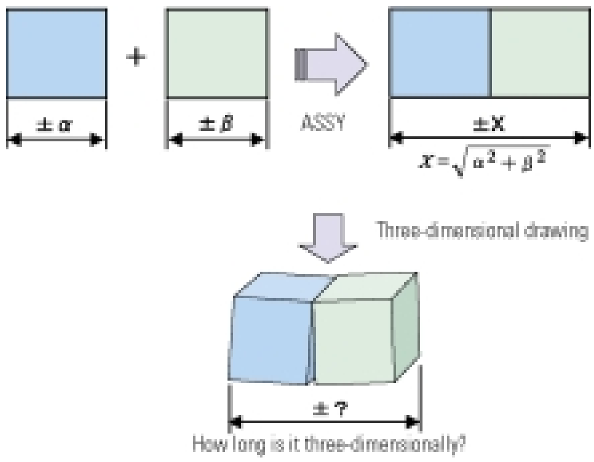

Fig. 1 Problems with analysis of three-dimensional model

coverage is shown in **Table 1**.

In addition, the analysis was conducted for previously developed components and faulty sections of mass-produced vehicles.

3.2 Tolerance simulation process

3.2.1 Preparation of necessary information

The overall flow of tolerance analysis work is shown in **Fig. 2**.

The following information should be prepared:

CAD models of the component parts necessary for the analysis, information on their tolerance, methods of positioning by using a jig or tool, positioning accuracies, assembling procedures, general manufacture tolerances not specified in drawings and the final required accuracies of the sections to be analyzed. If there is a

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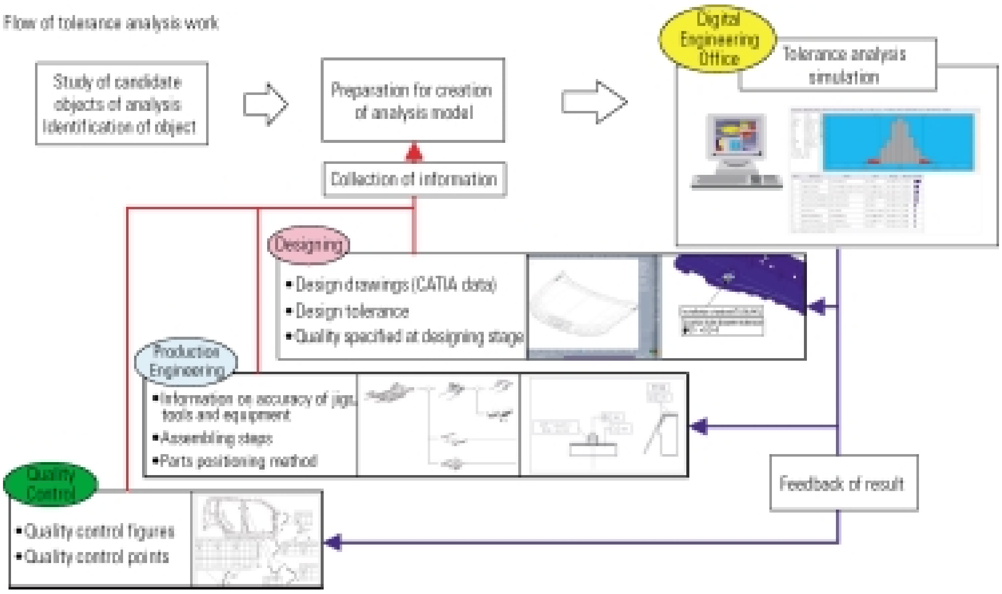


Fig. 2 Tolerance analysis process

Table 1 Examination items and analysis points

Examination Items	• Whether the part is properly installed or not • Whether the fitting meets the appearance criterion or not • Rate of non-conformance to the required specifications • Contribution by specified tolerance/positions
Analysis points	• Installation of front and rear suspensions • Installation of fuel tank • Front and rear exterior • Installation of glasses • Front and rear doors • Installation of steering column • Installation of front and rear sheets

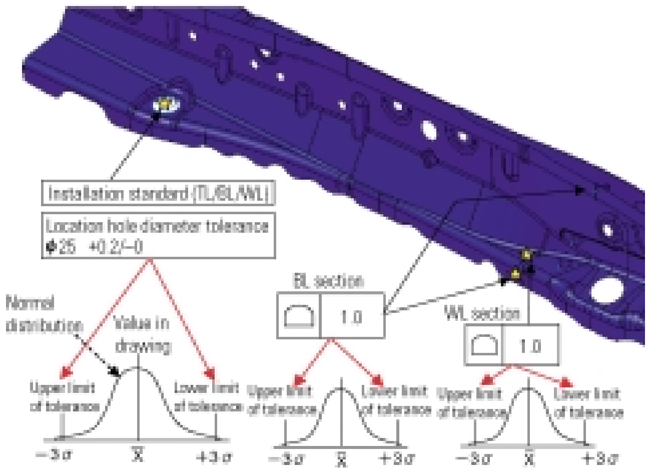


Fig. 3 Tolerance information input

vehicle similar in structure to the one being analyzed, production variance information for the present model as well as the design tolerance may be used.

3.2.2 Creation of tolerance simulation model

Binding-related information was defined for the CAD models for parts based on the tolerance information. A surface tolerance value was specified for both of the surfaces to be joined, and position, diameter and tightening surface accuracies were specified for tightening holes. If binding with a jig was necessary, locater surface accuracy for the jig, position accuracy for the location pin and information on pin diameter tolerance were added (**Fig. 3**). These prerequisite conditions specified are important since the analysis results depend heavily on them.

3.2.3 Tolerance simulation

Variances were generated on the basis of the normal distribution probability with upper and lower limits equal to the tolerance values specified at the time particular values were specified for the parts models. Because of this, all values specified for the CAD models randomly deviated from the reference every time a calculation was made. Such a combination of parts evolved into a finished-product model involving the positional variance of parts.

The distances to and the angles of evaluation points were measured. Typical calculations are presented in **Figs. 4** and **5**.

The variance involved in measurements taken 10 to 1,000 times provides a distribution pattern, which can be compared with the accuracy demanded for a finished product (**Figs. 6** and **7**). The specified elements can be listed in the order of contribution to the pertinent section subjected to measurement (**Table 2**).

Due to this, parts of complicated shape can be analyzed three-dimensionally, and information not obtained in the past such as variance distribution, spec-

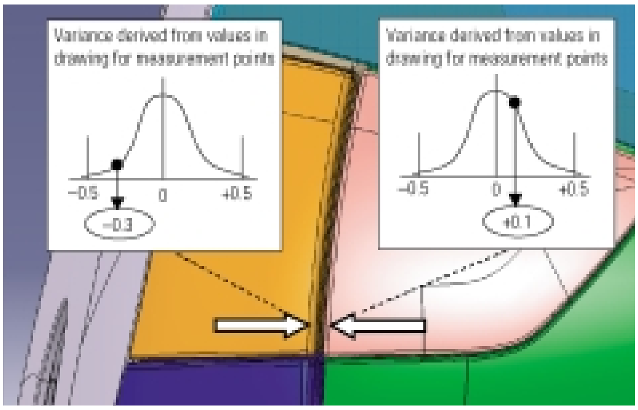


Fig. 4 Gap measurement

out rate and the contributions of elements of variance can be identified visually.

3.3 Result of analysis and planning for countermeasures

If the distribution (expected variance) of the section evaluated in **Fig. 7** was narrower than the required accuracy range (from the lower limit to the upper limit), the design was judged acceptable. If wider, those factors judged to be responsible were identified according to the contributions (**Table 2**) and analyzed, and countermeasures were planned, while noting the following aspects:

Review of the structure and the specified tolerance, review of the parts positioning method and the assembling procedure, proposal of an adjustment-making structure, improvement of the accuracy of individual parts, review of the accuracy control range for subassembly, review of the preferential control points, etc. Simulation is performed again based on the new tolerance and control values, and the effect of the action is checked. If the requirements are satisfied, the tolerance values in the drawing and the equipment are adjusted accordingly.

4. Typical applications

4.1 Vehicle height analysis for COLT PLUS

A study was undertaken to find out a way to provide a vehicle height that does not exceed the limit and can be accommodated in a multilevel parking garage, in compliance with a request, and a measure was taken to provide such a vehicle height actually. As wide variance of vehicle height was foreseen for COLT PLUS at the designing stage, the actual height variance of finished vehicles was verified by tolerance analysis as part of the study at the vehicle development stage.

4.2 Result of analysis

Fig. 8 presents a model in which tolerance values are incorporated after parts causing vehicle height variance of the COLT PLUS are identified at the verification stage. The lightest and heaviest models (the weight depends on the combination of options) were prepared.

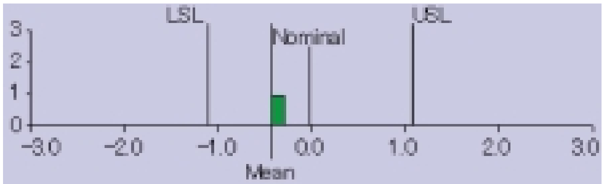


Fig. 5 Measurements (first)

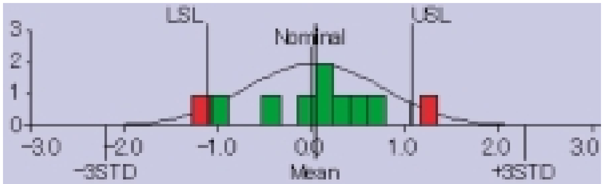


Fig. 6 Measurements – cumulative (tenth)

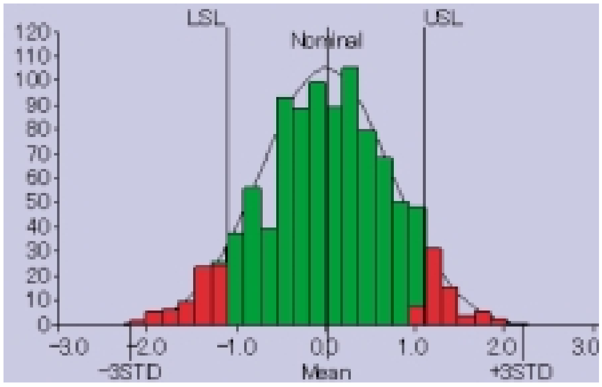


Fig. 7 Measurements – cumulative (thousandth)

Table 2 Degrees of contribution

Index	Tolerance	Point	Part	Percent	Graph
1	Profile_Spring_LH	5(Group)	RR_SUS_2WD_1	[illegible]	
2	Profile_Roof	CENTER(Group)	BODY_2WD_1	[illegible]	
3	Linear_Spring_LH	2(Group)	FR_SUS_1	7.23 %	
4	Profile_Sp_Body	1_SP_RH(Group)	BODY_2WD_1	4.29 %	
5	TORSION_ARM_TO_HUB	TA_HUB_RH	RR_SUS_2WD_1	3.76 %	
6	Linear_Spring_RH	2(Group)	FR_SUS_1	2.59 %	
7	Linear_Tie_1_RH	1(Group)	RR_SUS_2WD_1	2.01 %	
8	Position_Rh_Body	2_RH_RH(Group)	BODY_2WD_1	1.59 %	
9	Profile_Upper_Spring_Pad_LH	6(Group)	RR_SUS_2WD_1	1.34 %	
10	Profile_Lower_Spring_Pad_LH	SP_LW_RH(Group)	RR_SUS_2WD_1	1.34 %	
[illegible]					

Weight variance was converted into figures representing spring length.

The combination of options which gives the minimum weight and maximum height resulted in the specified value being exceeded (**Fig. 9**). By analyzing the degrees of contribution, we ascertained that the manufacture variance of the length of the spring for the suspension is a major factor and that the vehicle height can be brought to the specified level by changing the spring

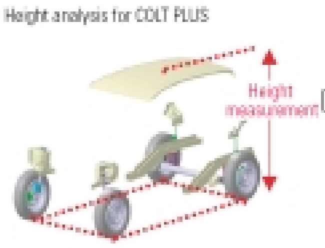


Fig. 8 Creation of analytical model

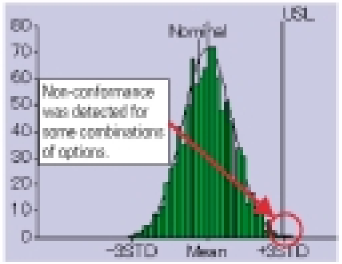
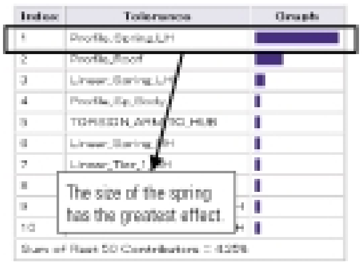


Fig. 9 Result of analysis

Table 3 Determination of degrees of contribution



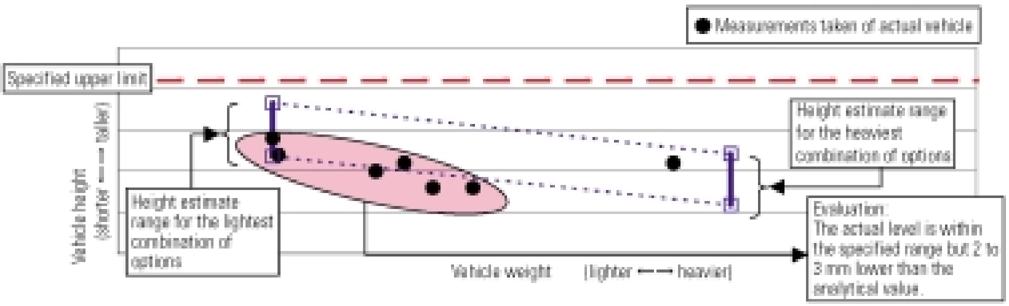


Fig. 10 Comparison of analytical and actual figures (relationship between vehicle hight and vehicle weight)

length appropriately. Therefore, we judged this change as a countermeasure (**Table 3**).

By comparing the results of the analysis and actual measurements, we found that the vehicles examined did not exceed the upper limit and that the analysis results closely agreed with the reality (**Fig. 10**). The height is measured on the inspection line for mass-produced vehicles, and appropriate action is taken to detect non-conformances without fail on that line.

5. Remaining tasks

There is a demand for analytical output closer to the actual variance range. To improve the analytical accuracy, we hope to verify agreement between the simulation results and the reality, and to prevent or eliminate problems attributable to the restrictions in analysis software (limited number of points at which parts are fixed together, inability to determine distortion and deformation because the model is calculated as rigid, etc.).

6. Conclusion

We wish to ensure the production process capability by reflecting the necessary and sufficient conditions, thus enabling accuracy verification factors to satisfy the design specifications, to the design drawings and production preparations. We will also work to stabilize product quality.

Finally, we sincerely thank those concerned inside and outside the Company for their assistance.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