Attribute in Formation on Three-Dimensional Annotated Models

-An Example of Training Method in Three-Dimensional Annotated Models for Beginners in Mechanical Design-

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Abstract. 3D CAD is a tool for designers to transform ideas into a shape and examine and finalize such ideas. If techniques related to 3D CAD are effectively used, time and confusion can be reduced and an effective tool for representing design information can be established. Therefore, to establish a new concept of drawings, we should examine the effective use of 3D annotated models. In this paper, (1) fundamental knowledge of machinery is generally examined to design machines using 3D CAD. (2) Improvement in the skills of machine designers is also examined by considering the shape modeling technique using 3D CAD (design = shape determination = ambiguity reduction and shape contriving). (3) The significance of 3D annotated models and the training method for beginners in mechanical design are explained. (4) The actual design process is examined and analyzed, and an example of a practical training method is introduced. To effectively utilize 3D CAD, users must understand its characteristics and fully utilize its functions. Satisfactory learning effects were obtained through design training using 3D annotated models for beginners in mechanical design, who received courses on fundamental knowledge of mechanical design and performed practical design assignments (geometric dimensioning and tolerancing) simultaneously.

Keywords: 3D Annotated Models, Beginners in Mechanical Design, Attribute Information, Practical Design Assignments.

1 Introduction

Concurrent engineering design is the mainstream as a system simultaneously implementing both design and production processes to improve the efficiency of production by starting production simultaneously with the basic designing phase. The advent of three-dimensional (3D) computer-aided design (CAD) and computer -aided manufac-

turing (CAM) has led to the development of the system. Because the improvement in the efficiency of product development and the advancement of designing have been pursued in various areas, the use of 3D CAD has spread along with the improvement of the performance of 3D CAD software, the rich variety of computer functions, and downsizing of computers.

3D CAD enables the establishment of an environment where appropriate users can obtain precise and complete production and technical data in an appropriate form at locations where they require the data in a timely manner at a low cost. That is, 3D CAD realizes speedy and precise communication.

However, products manufactured using 3D annotated models sometimes deviate from those originally intended owing to suboptimization resulting from the use of modeling functions alone. In addition, no methods of presenting and illustrating attribute information (particularly, product characteristics) have been established. The actual state of use of 3D annotated models has been revealed: their use in information transfer from designers to production engineers has been limited to some industries and large companies, and two-dimensional (2D) drawings are mainly used in actual production sites. The disadvantages of 3D annotated models, such as the low compatibility of 3D annotated models among companies caused by the difference in rules and software, much time and effort required for learning 3D annotated models, and inability to use by non-experts, have been pointed out. Therefore, to further spread the use of 3D annotated models, it is desirable to establish a method of presenting their attributes and to introduce 3D annotated models that can be smoothly communicated between designers and production engineers.

In this paper, (1) fundamental knowledge of machinery is generally examined as a prelude to designing machines using 3D CAD. (2) The improvement in the skills of machine designers is examined by considering the shape modeling technique using 3D CAD (design = shape determination = ambiguity reduction and shape formation). (3) The significance of 3D annotated models and the training method for beginners in mechanical design are explained. (4) The actual design process is examined and analyzed, and an example of a practical training method is introduced.

2. Examination of Designing and Transmission of Design Information Using 3D Annotated Models

Drawings are generally received by the staff in post-process and related departments; however, some 3D data are not received. This is because drawings have two roles (storage is not considered here): (1) drawings for the examination of a design and (2) drawings used to convey the design concept of designers to others.

For (1), designers can confirm and examine the design contents by actually presenting the shape of products and parts in drawings. For (2), design concepts that cannot be presented through only the shape of products (*e.g.*, dimensional tolerance, geometric

tolerance, surface texture, surface treatment method, and material) are conveyed to the post-process staff in charge of production technology, mold design and manufacturing, part processing, and inspection of parts and products, in an easy-to-understand manner.

We sometimes have the false perception that 3D data have both characteristics (1) and (2) of drawings. The reality is, however, different. Conventional 3D data are sometimes insufficient as the design information used to convey the design concept of designers to the staff in production technology, manufacturing, and test departments. As a result, even if 3D drawings, which require more time and effort than 2D drawings, are prepared, 2D drawings are inevitably necessary.

3D annotated models indicate 3D drawings containing design information without 2D drawings attached. 3D annotated models consist of 3D models (3D shapes) representing the shape and characteristics (annotations and attributes) of a product as well as drawings representing annotations of product characteristics and management information that are separated from the 3D models as independent information.

For example, product shape consists of information including the shape and coordinate system. Product characteristics include information such as the dimensions, dimensional tolerance, geometric tolerance, surface texture, surface treatment method, material, hardness, specifications, annotations, itemized notes, quality control standards, reference standards, name/number of parts of the product, and name/number of parts of reference drawings. Management information includes, for example, name/number of parts, the number of parts used, approval seal and date, and history of design change.

The conventional drawing method for 2D drawings is not applicable to 3D annotated models. However, the standards of 3D annotated models have not been established and are different among various design sites. Therefore, it takes time for the staff at the production site to understand the design concept and intention from the drawings, which may lead to the production of products that deviate from the concept of designers.

Without the establishment of unified standards of the drawing method among companies, 3D annotated models will remain difficult to use and they will not become commonplace.

2.1 Lack of Information Other than Shape that are Indispensable for Manufacturing

In 3D data, information that is not represented by shape, such as standards of precision, processing method, and conformity, is not included. In addition, 3D data lack annotations regarding shape and enlarged and cross-sectional views of important regions that are required to convey design concepts more flexibly and accurately.

2.2 No Unified Rules

Depending on the type of information added to 3D data, the development of additional functions of the software will be required. Unlike printed drawings, tools for data

browsing will also be required. Because of the lack of unified rules, 3D models are caught in a vicious circle; that is, they have not been widely spread as a tool for conveying design information and thus limited development of the software.

2.3 Representation of Attribute Information

How can product characteristics and management information be represented? For example, to specify geometric tolerance, geometric characteristics that can be tested are selected and directly reflected on the surface of the 3D shape together with related data. Here, median values are basically used as the dimensions of a 3D model; otherwise, the fact that median values were not used is noted in annotations.

3 Advantages of Developing 3D Annotated Models

Designing using 3D CAD has become popular in companies. The advantages of 3D annotated models are summarized below.

(1) Easy understanding of the shape of products

With 3D annotated models, users can (i) understand the shape of products easily, (ii) convey the information about the shape of parts to the production site more concretely and easily, and (iii) understand the details of products upon receiving an explanation, even though they may have little knowledge of drawing.

(2) Realization of concurrent engineering based on front-loading

The schedule for the evaluation and analysis of products can be moved up before prototype production (front loading) by preparing electronic data using 3D annotated models, leading to reductions in time and cost in the production of prototypes. In addition, various tasks can be performed in parallel, leading to the improvement of the quality of products and marked reduction in the time required for product development.

(3) 3D tolerance analysis software

3D tolerance analysis software can be implemented by preparing electronic data of drawing from 3D annotated models. The 3D tolerance analysis software can three-dimensionally analyze the variation in assembly by directly inputting the tolerance data into the 3D data. Optimization of the indication of tolerance using the results of sensitivity evaluation is possible, which enables the users to visually confirm, for example, the fit between a hole and an axis.

4 Basic Requirements for 3D Mechanical Design

In discussing how the talent of manufacturing is cultivated, the important keywords are people's interest in various phenomena and their desire to solve the underlying mechanisms. The cycle of interest, discovery, and thrill promotes an inquiring mind to search for the essence of an object. For example, some people like to unscrew bolts and disassemble machines. This simple impulse is one of the important qualities for design engineers in the initial phase.

To foster excellent design engineers, basic knowledge in engineering, flexibility of ideas, and imagination are required. One of the concerns of design engineers who carry

out designing for the first time is how to deal with issues that can be solved on the basis of the experience and sense of balance of experienced designers. Things that are obvious to experienced designers, although fundamentally simple issues, are difficult for beginners to unravel no matter how much they ponder.

In designing, many things cannot be determined from only standards and logical calculation. I endeavor to answer seemingly naive questions from beginners simply and by citing examples. If I can draw out "I see" from them, I feel that they have learned and understood a new piece of knowledge.

4.1 Comprehension of Drawings

It is said that, recently, beginners in mechanical design have been unable to comprehend drawings. Also, customers have pointed out that beginners in our company lack the ability to comprehend drawings. To solve this problem, the total period of technical training was reduced by 5% and training in hand drawing was introduced. During this training in hand drawing, the beginners are required to model the shape of products three dimensionally in their mind. By introducing technical training that includes tasks at which beginners are unskilled, they learn to understand ambiguous portions of blueprints, pictures, and drawings.

Along with the trend of global standardization, the marked amendment of Japanese Industrial Standards (JIS) and the establishment of new standards have recently been carried out. In particular, in the field of mechanical drawing, the changes in parameters such as surface texture and their description method have brought about confusion. Therefore, users should acquire comprehensive and practical knowledge, technology, and skills concerning the dimensions and tolerance of mechanical drawings required to understand production drawings.

4.2 Origin of Mechanical Design

The abilities of designing unknown products, pursuing the method of manufacturing, and embodying them should be developed. In other words, designers create rough sketches to represent the dimensions and mechanisms of products on the basis of the specifications of products in the initial phase of designing. In addition, designers should continuously seek the design requests from customers and create rough sketches to find clues for better products. These processes are the origin of designing and it is considered that 60% of designing is finished when these processes are complete.

4.3 Passing on of Skills

The passing on of invisible techniques from one person to another is essential for the development of our company, a group made up of design engineers showcasing such technique. In the framework of outsourcing, individual engineers can cultivate the skills in a given workplace. However, the skills of individual engineers will be buried among day-to-day work and will not be passed on to junior colleagues as an intellectual property of the company. Therefore, it is necessary to intensively collect information and establish a management system that enables continuous information collection.

Our company started tackling this issue around 1997 and has established a substantial system.

5 Application of 3D Annotated Models

As described above, 3D annotated models indicate 3D drawings containing design information without 2D drawings attached. In this section, I will discuss the method of designing using 3D data, along with practical design processes.

5.1 Planning Phase

In the planning phase, the contents of designing work are determined in accordance with the entire plan formulated on the basis of the requests from customers. In this phase, the basic specifications, budget, schedule, and assignment of roles among the staff are determined.

If the product is newly designed, the use of 3D CAD is not necessary in the planning phase. However, these days, many designs are based on resemblance using conventional techniques rather than other techniques requiring new element testing. Therefore, young designers can understand the type of design, the level of satisfaction of specifications realized by the design, and the required cost by referring to existing 3D CAD data that were previously developed for similar or appropriate designs. Even for mid-ranking designers, reconfirming the concept that previously designed products are also important.

5.2 Conceptual Design Phase

In the conceptual design phase, the concept of design including shape and mechanism that one considers in one's mind is given on rough sketches. The inaccurate points will become clear by drawing rough sketches. By drawing many rough sketches to remove such inaccurate points one by one, one can obtain an ideal concept of design.

Rough sketches are not intended to convey accurate information to others. It is time-consuming to represent the concept that one considers in one's mind while considering how to model them using a 3D annotated model. Therefore, it is better to create rough sketches by hand drawing while paying attention to the following points: (1) Do the functions satisfy the specifications? (2) Is the mechanism simple and optimal? (3) Are the driving and power transmission methods optimal? (4) Is the static strength satisfactory? (5) Is the balance of shape appropriate? (6) Are the dynamic characteristics considered?

5.3 Basic Design Phase

In the basic design phase, the concept developed in the conceptual design phase is embodied in a planning drawing. Several inconvenient issues will become clear by creating a planning drawing. At this point, the concept is sometimes found to be unfeasible. In this case, another concept is developed from the beginning. While solving inconvenient issues, designers create planning drawings again and again to obtain a final

planning drawing.

At this point, all types of information, including methods for driving, control, detection, processing, and assembly, as well as the mechanisms and dimensions, are incorporated in the planning drawing. In addition, various factors, including the place of use of the product, electric power supply site, and surrounding environment, should be examined. Insufficient examination of these factors may sometimes render the planning drawing unusable.

In the basic design phase, a 3D annotated model of actual size and shape, along with the planning drawing, is created for use in design review. Through design review, customers can confirm the image of the completed product at an early stage, which will facilitate the improvement of sales and services.

5.4 Detailed Design Phase

In the detailed design phase, assembly, manufacture, and parts drawings are created on the basis of the planning drawings. Parts drawings should indicate instructions for manufacturing so that the manufacturing department and subcontractors can manufacture parts properly; therefore, parts drawings should not include points that may lead to misunderstanding. In parts drawings, the following items are clearly presented: (1) dimensions of each part (*e.g.*, dimensional tolerance, fit, surface texture, and geometric tolerance), (2) material, (3) processing method and procedure, (4) number of parts (production or purchase), (5) name of manufacturer, model, basic specifications, and main dimensions of commercial product, and (6) total weight.

Information on attributes is added to the 3D annotated models developed in the basic design phase. However, as I explained above, it is difficult to add all information on attributes to 3D annotated models. Therefore, the information on attributes that cannot be presented by 3D annotated models is added using external software. Assembly drawings are used so that designers can (1) examine the feasibility of the assembly of parts and problems that may be expected to arise during assembly before the parts are actually assembled and (2) provide instructions regarding the sequence of assembly and the points to be noted to those who perform the assembly. The dimensions of the entire product and main dimensions of mechanical parts should be included in the assembly drawings. Assembly drawings are created by assembling 3D annotated models created from the parts drawings. Assembly drawings are easily created using 3D CAD. When using the function of removing discrepancies, which is the greatest advantage of 3D CAD, users can confirm the origin of errors of, for example, hole deviation, that is, whether it is caused by a mistake in assembly or that in the parts drawing.

6 Training Method and Contents for Beginners in Mechanical Design

In general, beginners in mechanical design depend on their intuition gained from 3D models. In the absence of 3D models, their spatial imaginative power decreases. In

addition, their basic skills related to the mechanical subjects decline because of the reduction in the contents of mechanical courses given at educational institutions, leading to the decline in the ability to understand drawings and in the amount of knowledge on materials and basic engineering. We revised the educational contents to be compatible to both virtual and real spaces by analyzing the characteristics of 3D shapes. We also aim to improve the quality of engineering education, including rapid prototyping, 3D plotting, designing, and evaluation of prototypes.

We first developed standard forms of training. By thinking outside of the stereotypical concept based on drawings, we need to consider the new ideal method of information transmission. To this end, we must clarify the information required for manufacturing and examine the method of conveying such information by representation using 3D data.

Table 1 lists an example of the contents of training courses developed in cooperation with an education institution in 2011. The contents are under consideration so no definite achievements have been obtained thus far. However, according to the responses to a questionnaire, the attitude of beginners in mechanical design toward designing and designed products has become positive. For example, one beginner submitted a comment on an assignment: “In each process of manufacturing from the examination of structures, determination of shapes and dimensions, analysis to verify functions, creation of the shape of products by controlling machine tools, to the evaluation of products, all or some processes can be reflected in 3D models and the relationships among processes, which were originally less related, were clarified.”

Table 1. Example of contents of educational training for beginners in mechanical design

1. Scope of application 2. Definition of terms 3. Mode of 3D annotated models
4. Management information of 3D annotated models,
5. Details of presentation method of product characteristics,
6. General notes for creation 7. Development of annotated assembly models
8. Tolerance of models —omitted—
20. Columns for title and history 21. Method of data management

7 Examples of Practical Training Method for Beginners in Mechanical Design

Designers in our company are assigned to a department related to automobiles, where parts and products are basically designed using 3D CAD models. Also, home electric appliances are mainly designed using 3D CAD models. Therefore, in our company, beginners in mechanical design are trained by effectively using our own mechanical training sheets in an environment where interference and operation checks with 3D CAD assembly are possible.

7.1 To Improve 3D Space Recognition Ability

The space recognition ability of beginners in mechanical design has been declining even though they can operate a 3D CAD system to some extent. They are given an assignment written on an A4 sheet every morning to develop their hand drawing skills. The assignment is as follows.

(1) Imagine a machine part and draw two isometric drawings by freehand in an empty space on the paper.
(2) On the basis of the above isometric drawings, create a 2D drawing freehand by third angle projection.
(3) On the basis of the above 2D drawing, create an isometric drawing freehand.
(4) From the 2D assembly drawing, create a parts drawing.

7.2 Contriving of Shapes

In designing, the requirements of products are sometimes satisfied by the shape of the products. Therefore, beginners in mechanical design are trained to refer to past examples of contriving shapes as information for determining the shape of products.

7.3 Use of Examples of Determining Ambiguities in Designing

The 3D design of mechanisms cannot proceed without the determination of ambiguities in the design by the designers themselves. The factors that satisfy the design conditions include functions, price, material, production capacity, and ambiguities. We provide examples of the reasons behind the determined shape of products to beginners to improve their design skills.

7.4 Design Skills and Know-How

Learn-by-doing training in which beginners observe, touch, and feel objects is necessary. To this end, we provide (1) practical training using originally developed mechanical training exercises and machine element library and (2) training to actually experience the weight, smoothness, hardness, movement, and mechanism of real products rather than a virtual product. Furthermore, practical training based on the know-how accumulated in the field will lead to the development of effective human resources.

3D CAD is a method of realizing technologies related to drawing. The transition from 2D design to 3D design is not easy. To smoothly carry out the correct procedure of 3D mechanical design, we propose to follow each of the steps below.

(1) Learn the minimum necessary commands required in designing
(2) Learn the procedure of modeling in 3D design
(3) Design products in a style similar to that used in 2D CAD
(4) Examine the design style that can make full use of the functions of 3D CAD with a minimum amount of knowledge
(5) Use 3D CAD in actual designing
(6) Improve the procedure to increase productivity by utilizing the functions of CAD on the basis of experience in actual designing

The key here is how rapidly one can perform steps (1)–(6). The work required for

passing on technology from one person to another and accumulating know-how as a permanent asset cannot be achieved through the efforts of only one sector. The basic concept of the technical support system is that people support other people; in particular, the senior staff should back up the young staff.

The use of 3D design will be more widespread in the future. To obtain the maximum effects of 3D design, it is important to establish work processes appropriate for 3D design and to set these processes in place.

Any excellent breakthrough concept would be useless if it is not conveyed as information. Furthermore, no matter how excellent the concept is, it could not be realized if it is not refined to improve the accuracy and if it lacks necessary information. Therefore, the accumulation of design documents that support design technology that can accommodate environmental changes in manufacturing and lifelong training for designers are necessary.

Designing is achieved on the basis of inspiration, intuition, feeling, and creativity of designers. To embody the conceptual plan of a design, conceptualization of the design representation using drawings is needed. The basic concept of designing is to create drawings that satisfy the specifications of products and optimize the cost. Lastly, it is important to prepare an environment where people can exercise their abilities because people are a valuable resource.

8 Conclusions

The average quality of design has been improved by designing using 3D annotated models compared with conventional designing methods. However, in reality, the load of designers has adversely increased.

The long-established culture of drawings has further advanced because of the spread of 3D CAD. If the standardization of 3D annotated models proceeds, designers may become free from creating supplementary drawings. Note that the original rules for 3D annotated models established in a company cannot be used unless suppliers and other companies also agree to use these rules. Therefore, it is desirable that in-house standards become industry standards and, in turn, national standards, although realizing this will be difficult.

The skills of design engineers that companies demand are diverse. In addition, the degree of expectation (requirement of abilities) changes with time. The demand for 3D design skills required for 3D CAD will increase now and in the near future with regard to the improvement of design quality and efficiency. Design, which is the foundation of all industries, is a world of planning and creating and constantly requires new sense and technical innovation.