CULTURE OF HAND DRAWING IN PREPARING DRAWINGS —USEFULNESS OF PUNCH DRAWING-HAND DRAWING IN MECHANICAL DESIGN AND DRAWING—

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ABSTRACT: Hand drawing of an idea on paper gives clarity to any confusing part and helps us understand the idea more clearly. The act of thinking while drawing with a pencil stimulates our creativity, enabling us to properly evaluate and analyze the points of an idea and to make adjustments to it. Designers should not depend on 3D CAD, a design tool, but should reaffirm the significance of hand drawing, the origin of design, in order to supplement their decision-making and thinking abilities, which are required to produce creative designs. The greatest advantage of hand drawing is that only a pencil and a sheet of paper are needed to express an idea and punch drawing.

Keywords: Mechanical design and drawing, Idea, Punch drawing (rough sketch), Hand Drawing, 3D CAD

1. INTRODUCTION

Solutions for design problems are found through decision-making processes. Therefore, designers should not depend on three-dimensional (3D) computer-aided design (CAD), a design tool, but should reaffirm the significance of drawing by hand, the origin of design, to supplement their decision-making and thinking abilities, which are required to produce creative designs. The greatest advantage of drawing by hand is that only a pencil and a sheet of paper are needed to express an idea and to draw a punch drawing (rough sketch).

This paper is organized as follows: 1) the usefulness of 3D CAD; 2) the convenience of drawing by hand in creating an idea; 3) the culture of drawing by hand in preparing drawings; and 4) the significance of drawing by hand and rough sketching in creating an idea, keeping in mind the relationship between basic education and tools.

2. PROPER ROLE OF 3D CAD

The advantage of 3D CAD is that designers can draw accurate lines and curves as they imagine them without being influenced by their drawing ability and habit. Designers recognize 3D CAD as a design support tool for drawing lines at desired positions while reflecting their images.

However, creative design is essentially something that only man can do and is never achieved automatically. Three-dimensional CAD is only one means to embody an idea generated by a designer's potential, and supports designers in developing their idea through interactive communication with computers. Also, 3D CAD plays an important role in product manufacturing not only as a design tool but also as the core of manufacturing information systems.

2.1 Usefulness of CAD

As a result of the improvement of visual and

graphic expression techniques, the design process of extracting creative factors from a designer's formless idea and expressing the idea on a computer screen using pointing devices, such as a mouse, keyboard, or tablet, will become more efficient by acquiring the skills for operating such devices. In addition, 3D CAD enables designers to model an idea into a 3D shape, to easily select colors and materials in virtual simulations, and to determine the design of the shape within the framework of standards and rules of drawing that have been registered into the system in advance. Moreover, using the zooming and free-rotation functions in preparing drawings, designers can check the model shape from every direction and understand the shape even if they are not accustomed to two-dimensional (2D) drawings.

The sophisticated expression of 3D CAD model data has enabled us to convey information in a more visual and realistic manner and to share information in a very convenient way. However, the amount of information conveyed by 3D CAD model data alone is limited; 2D drawings are still often used for conveying design information. While the utilization of 3D CAD model data is expanding, the fact remains that the design process still depends on 2D projection drawings.

2.2 Changing and evolving tools

The advantages of a 3D shape model are the realness and the clear expression of details. However, a 3D shape model is not the final drawing but merely a supplement for reviewing the entire design. On the other hand, hand-drawn images play a very important role in understanding the total scale of the design. Therefore, designers can achieve a more realistic understanding of their design by placing more importance on drawing by hand, instead of 3D shape modeling, as the final goal of the design process.

Tools must continue to change and evolve with the times, but the basics of techniques do not change over time. Many engineers try to acquire creative and development abilities through technical training, but these abilities are best fostered by keen observation, association, and memory.

3. USEFULNESS OF CONCEPTUAL DESIGN AND ROUGH SKETCH (PUNCH DRAWING)

Conceptual design is the processes of developing new technical elements and the designers' creativity plays a significant role, but the abilities based on experience are of relatively low importance. Design techniques are acquired through repeated prototyping and simulation, and the quality and productivity of development techniques depend on the individual abilities of the designers.

3.1 Process of conceptual design

Newly developed products are put into mass production through the processes of conceptual design and detailed design including the design of functions, layouts, structures, and production plans.

The following are the basic elements of design that should be considered to improve the completeness of conceptual design: 1) required product specifications (functions, operability, and maintainability); 2) required quality characteristics; 3) required cost; 4) required delivery time; 5) required safety; and 6) required environmental friendliness and disposability.

The mission of conceptual design is to transform an obscure image in the mind of a designer into a concept drawing of a product and to explain how to meet the required quality and cost target, what kind of parts to use and how to assemble them.

If designers use 3D CAD when they are still formulating an idea for the conceptual design, they may want to first clarify the shape of a product because of their nature as designers. However, this is not the original course of conceptual design. Designers then may start

detailed design while paying little attention to the concept. When we see vendors smoothly "modeling" parts in their demonstration, it appears that they are skillfully "designing" them. However, it is not that they have a clear intent to "design" them but that they only "produce shapes". The "ability of modeling" and the "ability of design" are two different spheres.

The first step of conceptual design is to draw a rough sketch, on the basis of which designers can gradually expand an image and select ideas. Rough sketching has a significant role in conceptual design. However, we are often surprised to find that many young designers today do not or cannot draw a rough sketch. They cannot imagine a 3D model although they routinely use 3D CAD for design.

The 3D CAD model of a part is not the expression of an image in the mind of designers but only the results of modeling a shape without detailed consideration.

Namely, they design the details to adjust the appearance of the shape after viewing and understanding the obtained model. This is not the proper course of conceptual design.

Hand-drawn drawings and materials can be prepared in a shorter period of time than those prepared using CAD. They are flexible and helpful in figuring out the cost. Also, the 3D images are easily understandable even to nondesign department members so that more constructive opinions can be exchanged in design reviews. If design reviews take place after a design is almost completed using CAD, designers may not like to have their design questioned by others and therefore may expend much effort in defense against the opinions from other departments. As a result, design reviews are not constructive but merely argumentative.

When the conceptual design is expressed in a rough sketch, designers can deal with a considerable change in the design because they have not completed the detailed design using CAD. This takes some mental pressure off the designers. As a result, the designers themselves can provide more constructive opinions in design reviews and also accept opinions from other departments.

Having such composure of mind is the key for designers to create good-quality products. For this reason, the first step of conceptual design is to expand an image by drawing a rough sketch.

3.2 Usefulness of rough sketch

At an initial phase of design, designers draw a rough sketch that expresses the specifications and structure of a product. Also, they always look for hints for the invention and design of new products in the requests from customers and turn them into rough sketches.

Designers tend to casually doodle, that is, to draw a rough sketch, on a sheet of paper nearby, particularly when they encounter difficulties in generating an idea. Rough sketching is the process of seeking a "hint" for generating an idea while doodling several lines and three-dimensional shapes with casual strokes of a pencil.

The necessary abilities in drawing by hand are not techniques but the intuition and sensibility to produce a kind of ambiguity. Strictness is not required to draw a rough sketch, in which we can jot down or draw a flash of inspiration or idea and freely reflect our intention. A blank piece of paper does not display helpful icons or tell us anything at all, and that is why it is the right environment for generating a creative idea.

Through the repeated process of drawing lines and erasing undesired lines while unconsciously controlling the angle of the pencil, we ceaselessly combine *contradictory elements such as existence and nonexistence and* fullness and emptiness, waiting for them to fuse together. In time, the lines start to look different, as if they are alive. A cycle of one idea followed by another will be established at that time. Lines show unlimited possibilities; a line drawn spontaneously will lead to a new line,

resulting in a more innovative idea. Designers attain an ideal image by reviewing drawings and making modifications to them.
An idea that starts with a rough sketch is gradually developed into a schematic. The development of a true design through the process of making a clear sketch using a combination of painting and projection techniques and expanding on the details is the real joy of drawing by hand.

4. CULTURE OF DRAWING BY HAND

4.1 Advantages of drawing by hand in preparing drawings

The ability to imagine the structure of an object is necessary for understanding an actual 3D shape on the basis of 2D drawings. The interpretation of drawings is required when an object has an unfamiliar shape with which we are unused to dealing. In such a case, pictorial analysis and sketches of each part of the object will provide us with an outline and image of the object. Then, we need not try to memorize all the details of the drawings. The designer's intention is conveyed more concretely by hand-drawn drawings than by written descriptions and conversation.
Although the concept of design and drawing is the same in drawing by hand and 3D CAD, their roles are partly overlapping and partly distinct. Both analog and digital versions have their own benefits.
Drawings have various functions, but the most significant function is the conveyance of information; this subordinates any other function. The preparation of drawings therefore includes very spiritual aspects. The acts of drawing lines and shapes and writing to convey some information to others must be associated with the desire that the intended meaning be correctly understood by the recipients.
This is an obvious fact but is not well recognized by many people. We must remember that each drawing has its intended audience.

4.2 Purposes of drawings

Drawings have the functions of conveying, storing, searching and utilizing information, and offering a tool for thinking. They are very simple views but also a keen insight into the nature of drawings. If drawings are compared to language, they must have a function of thinking similar to that of language.
To give an unambiguous meaning to drawings, there are various rules established among those who prepare drawings and those who read and interpret them. However, the education on drawing in Japan is too centered on teaching drawing standards, the results of which are drawings that lack "heart", the most important thing in product manufacturing. We hope we can change this situation.
When manufacturing a product, we imagine its shape in our mind. A real product can be manufactured on the basis of the image alone if its shape is very simple; however, if the mechanism and structures are a little more complicated, the image alone is insufficient to manufacture the real product. We try to express the image in the forms of paintings, drawings, or clay models. These forms are convenient for revising and improving the design. In particular, drawings have universality and are ideal for the manufacturing of industrial products because dimensions must be specified for manufacturing them.
Drawings have the functions of conveying information and supporting thinking. Detailed consideration becomes possible when a design image is expressed in the form of drawings. Drawings help us to examine detailed issues such as whether it is possible to manufacture the product, to assemble the parts, and to satisfy the required functions and accuracy of the final product, which we tend to overlook if we are just thinking in our mind.

The authors of this paper always make a

rough sketch before preparing a drawing. A rough sketch is very effective for finding a total balance of the shape, which is then turned into a drawing. When turning a sketch into a drawing, it is necessary to calculate and determine the dimensions of a real product. This is an important process of design that requires the ability to analyze on the basis of principles and theories.

Each line and each number has its own meaning. Students who do not know the meaning of those lines and numbers may feel that preparing a drawing is a waste of time.

When someone becomes able to imagine the 3D shape of a product while viewing a drawing, then he/she can read and interpret drawings. One can create good products only when one becomes able to read and interpret drawings. Well-prepared drawings are necessary for creating good products. Well-prepared drawings even have artistic value.

5. IMAGE-TRAINING METTHOD

Recently, a growing number of young designers have sought our advice because they cannot read and interpret drawings or they are unskilled at drawing by hand. In response to their needs, we have devised and introduced an image-training method that uses drawing by hand in creative activities.

Our image-training method is a means of fostering design ability, namely, an effective way of learning how to make ambiguous decisions on the design (shape) and how to devise the shape. Below are an example of the image-training method and its achievements followed by a discussion on the improvement in the skills of mechanical designers.

5.1 Current trend of new employees

The results of the skills assessment test, which is conducted for new employees every year, fall far short of our expectations. The lack of a basic understanding of mechanical engineering may be the result of insufficient education provided by educational institutions.

For example, 1) a small (decreasing) number of courses related to design drawings, processing practices, and measurements, which are required for product manufacturing, are provided by educational institutions. New employees therefore tend to lack the qualities of design engineers. Also, 2) design engineers need the knowledge and ability to read and interpret drawings and to figure out what the products will be on the basis of the drawings; however, most new employees do not have sufficient knowledge or understanding.

These facts make us aware that it is the mission and responsibility of companies to explore any possibility of educating and fostering new employees so that they will become industry-ready design engineers.

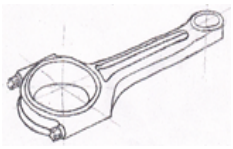
5.2 Introduction of image-training method and its achievements

Not only the ability to make drawings but also creativity and conceptual power are required in the design process. It is also important to consider the association with other departments in every process of manufacturing and to prepare for predictable events from the phase of design. Therefore, there is an increased need for education that enhances the comprehensive imagination required throughout the entire process of design. To provide such education, we have adopted the image-training method that uses drawing by hand in creative activities.

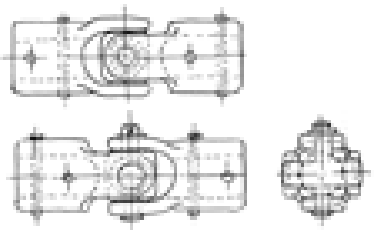
The training is given in the form of exercises written on an A4 sheet of paper, as shown in Fig. 1. New employees work on them every morning before they attend the conventional training program.

In Exercise 1, the new employees are asked to bring to mind a mechanical drawing and to draw a single-view drawing of a shape. This is for training to always retain interest in and observe an object and incorporate the shape into their idea. This training is important

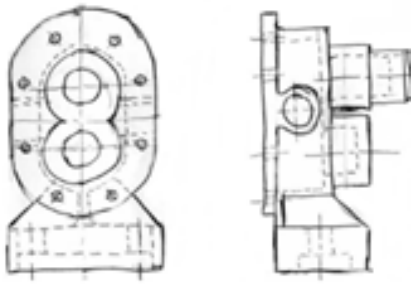
because the new employees must bring to mind some known shapes when they design something from scratch on blank paper.
In Exercise 2, they are asked to develop a three-axis orthographic view from a single-view drawing.
In Exercise 3, which is aimed at improving the ability of drawing by hand, they are asked to create a single-view drawing from a 2D drawing.
In Exercise 4, they are asked to prepare a production drawing of a part on the basis of a 2D assembly drawing. This training seems difficult but is very effective for new employees who have little experience in design.



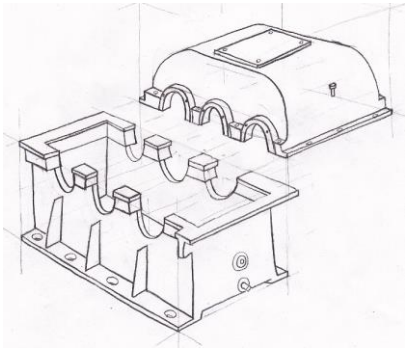
Exercise 1
Connecting rod



Exercise 2 Univrsal joint



Exercise 3 Gear pump



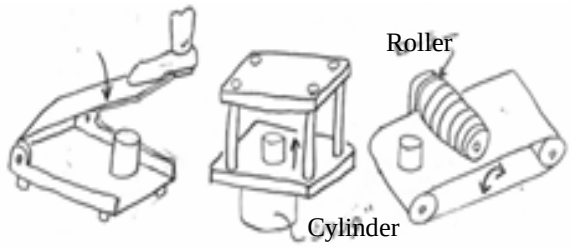
Exercise 4 Reduction gear:Body

Figure 1: The training A4 sheet of paper

A chart called a skill map is used in our company to assess the skills of engineers. This chart consists of five grades from E1 for new employees to E5 for those who have 20 or more years of experience. Approximately twelve items are prepared in each grade. Among the 12 items at E1, the following three items of mechanical drawing assess the improvement in the skills related to rough sketching and drawing by hand.

- Preparation of drawings: Ability to make simple single-view drawings and sketches.
- Skill: Ability to read and interpret basic mechanical drawings (ability to understand structures).
- Design knowledge: Understanding of mechanical drawing techniques.

The results of assessments well demonstrate that the new employees feel their skills are improved after the training, although the results cannot be taken as absolute because the assessments are based on self-reports and are subjective. The results show that the image training, namely, the training involving observing an object with their eyes, creating an idea, and drawing it with their hands, can make these procedures second nature. We recommend the image-training method for young designers because it is easy and costs nothing to sketch something in their mind onto a sheet of paper.



Device to smash a can, and to destroy

Figure 2: Generate ideas of conceptual plans

The extra time is used for training to generate ideas of conceptual plans, as shown in Fig. 2. In this training, new employees are not given a task but are asked to think of a theme they want to design, to create multiple plans and to

make a rough sketch. Then they self-assess their plans and develop them into assembly drawings and production drawings. By creating approximately three conceptual plans, they are trained to avoid limited thinking and can develop a free and multidimensional way of thinking.

The sense of the shape and size of products and devices can be acquired through the repeated process of drawing and redrawing, while the knowledge about design, materials and manufacturing can be acquired directly from engineers when the new employees visit factories and hear from the engineers about their actual work. On the basis of this acquired knowledge and sense, they can naturally expand and improve their design ability.

Table 1: The image-training sheet for machine elements.

With the drawing	Assembling drawing			
	A	B	C	
Contents				*Remarks*
Drawing frame	28	7	0	
Central mark	27	7	1	
Cutting mark	12	9	14	
Revised number	28	4	3	

Table 1 shows a part of the image-training sheet for machine elements. The questions are as follows (35 respondents; implemented on 30 March 2013).

A: Put a circle around the items you can imagine the shape of.

B: Put a triangle around the items which you know the name of.

C: Put an x-mark beside the items for which you have no idea of either the shape or name.

After checking the results of the image-training method, we tested the respondents' understanding of 55 items including drawing frames, break lines and finish marks, using the assembly drawing and detailed drawing of a turning mechanism of a liquid crystal exposure device as a sample.

Table 2 is a part of the answer sheet on which the respondents put a circle in the boxes that apply to their understanding. For example, the results regarding finish marks (indicated by the old style) were as follows: 19 respondents checked "Understand," 12 checked "Partly understand" and 4 checked "Do not understand." The results regarding geometrical tolerance were as follows: 10 respondents checked "Understand," 20 checked "Partly understand" and 5 checked "Do not understand." The overall evaluation of the results reveals a remarkable lack of understanding of drawings.

Table 2 : Is a part of the answer sheet

Machine element for the conclusion	○	△	×
Trapezoid screw	23	12	0
Screw for the pipe	17	15	3
Regular eyes screw	26	7	2
Rather thin screw	26	6	3
Hexagon bolt	35	0	0
Bolt with the hexagon hole	31	3	1
Axis coupling			
Flange coupling	10	12	3
Orr dam coupling	1	3	31
Buffering element			
Compression coil spring	18	11	6
Pulling coil spring	18	11	6
Leaf spring	6	23	6
Torsion bar	3	7	25

By providing young designers with training in areas in which they have difficulties, we are making efforts to help them understand ambiguous parts of design drawings, "pictures", and "drawings". Also, it is sometimes necessary to find a compromise between conflicting conditions for a shape, namely, to make an ambiguous decision to achieve a balanced design on the basis of the visual sense.

In the current subdivided process of design, designers need to recognize the relationship of one step with the previous or next step in the design process and to develop a multidimensional way of thinking. To

develop such abilities, we will continuously develop various materials for image training.

6. CONCLUSION

A rough sketch does not require the same clearness as that required in 3D CAD. Because conceptual design is an image, only a sketch that shows the kind of part needed is appropriate. Drawing an unnecessarily precise sketch is a waste of time. The chamfered shape and the devised procedures for processing can be expressed in the detailed design using CAD.

A rough sketch that is used for verifying the functions and structures of a product is a real technical concept drawing. It is also used as the means of knowledge management and will be referred to when the concept for the next-generation model of the product is developed.

Are there any means available for expressing a shape in the designers' mind other than drawing by hand? The advantage of drawing by hand is its unlimited potential, while creative activities will converge to a stack of numerical values as soon as the tool, CAD, is used. Drawing by hand requires experience. An idea is created by designers and their intention is shared through the use of CAD.

Young designers are assessed as having problems such as 1) a lack of a clear design concept, 2) a remarkable lack of recognition of machine elements and 3) a lack of understanding of drawings. To improve their design techniques and abilities, our company provides training on the basis of the originally developed method, utilizing a rough sketch and the drawing-by-hand method, which is directly related to manufacturing. The content of the training and its results have revealed that this training is helpful.

Education on drawing provided by educational institutions will be meaningful if it focuses on the principles of drawings and trains students to draw with their hands. Employees do not have a chance to learn the principles of drawing when they start working at companies.

An average fresh graduate who starts working at our company has shallow knowledge over a wide range of engineering, is good with computers but unfamiliar with actual phenomena, and is attached to only what he/she is interested in. The training provided in companies should also change to accept these new employees with changing average profiles and nurture them to become better engineers.

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