Proposal of "Manufacturing Technology for Design (MFD)" as a New Concept of Manufacturing Technology Management for New Value Creation

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Abstract--**One of the most important issues in technology management at manufacturing companies is to realize "process innovations" that will improve current activities and business processes in order to produce high-quality, low-cost products, systems, infrastructures and services with a short lead time by fully utilizing manufacturing technologies.**

Design for manufacturability (DFM) is one of the effective methodologies and concepts aiming at process innovations installing manufacturing knowledge and know-how into product design.

To strengthen the competitiveness of manufacturing companies, "value innovations" that create new value for customers and markets are as important as "process innovations". However, DFM often prevents realization of value innovations because it restricts the flexibility of product design. The restriction of product design flexibility disturbs the possibilities of the creation of innovative products, systems, infrastructures, and services. To realize both process innovations and value innovations, a different approach is required.

In this paper, "manufacturing technology for design (MFD)" is proposed as a new concept for increasing the flexibility of product design, and manufacturing technology management for MFD is discussed with references to actual applications.

I. INTRODUCTION

Japanese manufacturing companies have evolved by importing technologies from Europe and the U.S.A. and improving them by developing manufacturing technologies. However, Japanese manufacturing companies should find new ways to maintain their competitiveness and continue their growth, in light of the excellent companies of newly emerging countries such as Taiwan, Korea and China.

One of the ways to resolve this issue is to realize "process innovations [1]-[6]" that will improve current activities and business processes in order to produce high-quality, low-cost products, systems, infrastructures, and services with a short lead time by fully utilizing manufacturing technologies.

Concurrent engineering is a famous methodology aiming at process innovations. It improves product development processes by cooperation between product design engineers and manufacturing engineers. In research studies of concurrent engineering, concepts are mainly discussed from various viewpoints, including development processes, technologies for design and evaluation, information technologies (IT), communication, leadership, infrastructure, systems, tools, and organizations[7],[8]. However, concrete and practical management methods (from the viewpoint of manufacturing technology) are not fully discussed.

Design for manufacturability (DFM) is a practical method that is expected to accelerate promoting concurrent engineering. The essence of DFM is to design products by installing manufacturing knowledge and know-how into product design. Many research studies on DFM have been reported and proposed from many viewpoints, such as the necessity of guidelines for product design, the effectiveness of considering manufacturability at the product design phase, education methods, IT systems, and tools to support product design engineers[9]-[16]. Furthermore, technology management from the viewpoint of manufacturing (manufacturing technology management) for accelerating DFM has been proposed [17].

To strengthen the competitiveness of Japanese manufacturing companies, "value innovations [18]-[22]" that create new value for customers, markets, and businesses by producing new products, systems, and services with advanced technologies are as important as process innovations. Furthermore, realization of both process innovations and value innovations is required. New ideas of product design engineers in the product development phase are important for realizing value innovations by creating innovative new products. However, DFM often prevents new ideas of product design engineers, because it restricts the design abilities. To realize both process innovations and value innovations, the development of new technology management methods or concepts different from DFM is a serious issue that must be resolved.

Many manufacturing companies have introduced several methods and tools aiming at establishment of both process innovations and value innovations. "Technology roadmapping" and "quality function deployment (QFD) " are famous as the methods and tools for promoting cooperation and collaboration among the participants from different departments including research and development (R&D), product planning, product development and design, and manufacturing engineering, by encouraging discussions for creating new ideas[23]-[26]. However, the discussions by using these methods and tools do not always create practical and concrete ideas because of conventional and conservative knowledge and know-how of participants. For example, product design engineers tend to create the ideas of the new functions for new products based on their conventional knowledge of manufacturing technologies because it is

difficult for them to create innovative ideas of manufacturing technologies and processes. On the other hand, manufacturing engineers also tend to consider the manufacturing processes for realizing product design engineers' ideas based on their conventional knowledge of manufacturing technologies. .

As a result, it often becomes difficult to create innovative product functions with low cost and short lead time. To realize both value innovations and process innovations, it should be necessary to propose new practical technology management concepts that increase the flexibilities of creating new ideas utilized with conventional useful methods and tools including technology roadmapping and QFD.

In this paper, "manufacturing technology for design (MFD)" is proposed as a new practical method of manufacturing technology management that is focused on the new product development for increasing the flexibility of the new ideas creation by product design engineers.

First, the main factors preventing the flexibility of product design are considered in terms of the problems of cooperation between product design and manufacturing engineers. Second, approaches for promoting MFD are discussed by considering methods for eliminating the main prevention factors of the flexibility of product design. Finally, the effectiveness of each approach is indicated with reference to actual applications, and the manufacturing technology management methods for successful MFD are proposed to strengthen the competitiveness of manufacturing companies in Japan.

II. ISSUES OF PRODUCT DESIGN FLEXIBILITY

In this section, the main factors that prevent the flexibilities of product design are considered by investigating actual issues in the product development phase in manufacturing companies, such as the lack of cooperation between product design and manufacturing engineers.

Actual issues were investigated by conducting interviews of managers who are familiar with the issues concerning product development and manufacturing. Six managers were selected from different business fields, including digital products, electric devices, optical appliances, office equipment, high precision instruments, films and digital media, and materials were selected as interviewees as shown in Table 1.

Table 2 shows common issues at the product development phase identified from the results of interviews. Each issue is caused mainly by a lack of cooperation between the product design and manufacturing engineers.

TABLE 1: INTERVIEWEES

No	Business Field	Main Products
1	Digital products & electric devices	- Personal Computer/Mobile phone and terminal
		- Home appliances (refrigerator, laundry, air-conditioner)
		- Semiconductor / Liquid Crystal Display
2	Optical appliances	- Digital and analog camera/voice recorder
		- Medical Endoscope/micro scope
3	Office equipment	- Digital multifunction Device/Digital copy machine/laser printer
		- Inkjet printer/digital color scanner
4	High precision instrument	- Data communication card/IC Dictionary
5	Films & digital media	- Consumer film for analog camera/optical media motion picture film for video tape
6	Materials	- Petrochemical / Ceramics/ Carbon/ Aluminum

TABLE 2: ISSUES AT THE PRODUCT DEVELOPMENT PHASE

Issues	F	Q	C	L
Insufficient quality products have been manufactured in mass production because the risk of new product functions and functions on manufacturing quality cannot be estimated in the product design phase.	●	●		●
Despite proposals of design improvement of products from manufacturing engineers to product design engineers, the product design engineers cannot identify the cause of defects because their knowledge concerning manufacturing is insufficient.	●	●		●
A target cost cannot be established because of increasing production cost and defects caused by insufficient consideration of the effect of product design on manufacturability.	●		●	●
Proposal for the improvement of cost reduction from the manufacturing engineers cannot be accepted because the product design engineers cannot alter the structure or materials that have already succeeded in establishing the good functions of products.	●		●	●
High accuracy parts are required from the product design engineers to the manufacturing engineers because the effects of parts accuracy on the function of products are not clarified.	●		●	●
Influence of product design on manufacturing cannot be understood or identified by product design engineers since functions are taken as top priority over other indicators	●	●	●	●

F: function, Q:quality, C:cost, L: lead time

From the actual issues caused by the lack of cooperation between product design engineers and manufacturing engineers shown in Table 2, the following factors that prevent product design flexibility can be extracted.

1) Obscurity of effect of accuracies of parts

Product design engineers do not grasp the effects of the accuracies of parts and assembly on the product function and manufacturing cost because of their lack of their manufacturing knowledge. Therefore, the product design engineers tend to stop considering new ideas, and carry out design parts and assembly accuracy previously adopted in conventional products.

2) Shortage data on new materials and parts

To realize new innovative products that have new functions, it is effective to adopt new materials and parts. However, the quality and reliability of new materials or parts are not usually well known. Therefore, product design engineers tend to abandon the adoption of unknown materials and parts with uncorroborated quality or reliability. As a result, innovative functions are not realized because only materials and parts utilized in conventional products are adopted.

3) Lack of new manufacturing methods and processes

Product design engineers produce typical designs of products because of the adoption of conventional manufacturing methods and processes. In other words, the product design engineers cannot but design new products that are restricted by the conventional manufacturing methods and processes. On the other hand, manufacturing engineers have developed many type of manufacturing methods and processes in order to realize the new products by designed the product design engineers . However, it cannot be said that manufacturing engineers create innovative manufacturing methods and processes that lead to new product designs. This situation is one of the factors preventing product design flexibility

III. MANUFACTURING TECHNOLOGY FOR INCREASING PRODUCT DESIGN FLEXIBILITIES

It is difficult for the above factors of preventing design flexibility to be removed only by product design engineers, because those factors are related to manufacturing technologies.In this section, MFD is proposed as one of the effective manufacturing technology management concepts for increasing the flexibilities of product design by removing above prevention factors. MFD is not a concept only for creating new manufacturing methods and processes. The essence of MFD is the elimination of the factors preventing product design flexibility in order to increase the possibility of realizing both value innovations and process innovations. MFD includes the following approaches

A. Clarification of the effect of accuracy on product functions and cost

In the product design process, the main purpose is the realization of new functions. However, the effects of the accuracies of parts and components, and the assembly accuracies of products on the product functions are not sufficiently evaluated. Furthermore, the product design engineers should also satisfy the cost target that was determined at the product planning phase to gain profit. However, it is difficult for product design engineers to estimate the effect of the parts and components, and assembly accuracies on manufacturing cost in a short lead time because they do not have adequate manufacturing knowledge. To realize both increased flexibility of product design and the cost target, the clarification of the effect of various accuracies on product functions and cost is proposed as one of the approaches of MFD.

B. Clarification of the quality and reliability of new materials and parts

To realize new innovative products that have new functions, it is effective to adopt new materials and parts. However, the quality and reliability of new materials and parts are not usually well known. Many manufacturing companies of materials and parts usually have basic characteristic and physical properties data. However, they do not have sufficient data on the quality and reliability of materials and parts because it is difficult for them to grasp all the situations and conditions of use of their materials or parts. To increase the flexibility of product design, the clarification of the quality and reliability of new materials and parts is proposed as another approach of MFD.

C. Creation of new manufacturing methods and processes

Product design engineers tend to design new products considering conventional manufacturing methods and processes because the conventional manufacturing methods and processes present few risks to manufacturing quality. On the other hand, manufacturing engineers have made efforts to create new manufacturing methods and processes. However, the new manufacturing methods and processes have not been adopted in the new product designs because the effectiveness of these new methods and processes has not been understood by product design engineers. The creation of new manufacturing methods and processes by considering the benefits to product design is proposed as one of the key approaches of MFD.

IV. APPLICATIONS AND MANUFACTURING TECHNOLOGY MANAGEMENT OF MFD

In this section, examples of the actual application of each approach of MFD are demonstrated, and manufacturing technology management of MFD is proposed. The practical technology management methods for applying the approaches

examined in Section Ⅲ are demonstrated, and technology management from the viewpoint of manufacturing technology management is proposed.

A. Clarification of the effect of accuracy on product functions and cost

In a product consisting of mechanical parts, the shapes and surface accuracies of parts change depending on the processing method, and the contact state and relative positions between parts also change depending on the assembly method. The accuracies of parts shapes and surfaces, and the contact state and relative positions between parts affect the product functions. Moreover, the processing and assembly methods affect the manufacturing cost. For example, the cost of numerical computers (NC) machining is lower than that of gliding machining because NC machining can be executed automatically, not manually by skilled workers, but the accuracy of gliding machining is higher than that of NC machining.

It is difficult for product design engineers to create new and innovative products in a short lead time without understanding these complicated relationships among accuracy of parts and assembly accuracy, and product functions and cost. A method for clarifying the effects of accuracy on product functions and cost has been developed.

The method includes the following technologies.

1) Analysis of the final product accuracy on the basis of parts and assembly accuracies
2) Analysis of the relationship between the accuracies of a product and its functions
3) Estimation of the manufacturing cost by clarifying the relationship between accuracies and cost
4) Clarification of the correlations between parts and assembly accuracies and product functions and manufacturing cost.

Figure 1 shows the method for the clarification of the effect of product and parts accuracy on product functions and cost.

This method has been successfully applied in the development of the key mechanical component for refrigerators and air-conditioning equipment as shown in Figure 2. A tolerance analysis method that can predict the final product accuracy using data of accuracy of parts and assembly has been developed. Furthermore, this tolerance analysis method can predict the effects of the final product accuracy on product function using experimental data obtained by product design engineers from the evaluation of product functions. Manufacturing cost was estimated by analyzing machining and assembly processes. Finally, the product engineers were able to grasp the key factors of product function, and establish a direction for realizing good function and reasonable manufacturing cost.

In this application, data of the effects of accuracies and functions have been accumulated by the product design engineers. However, this approach can be applied more effectively when the theories behind the function are clarified. As this application indicated, this approach is effective for not only clarifying the correlation between the accuracies and product functions but also aiding the product design engineers to focus on the key factors for creating new ideas. Furthermore, this approach makes product design engineers create new ideas in a short lead time. The key manufacturing technology management of this approach is not only the development of analysis methods but also enabling manufacturing engineers to understand the product design.

B. Clarification of the quality and reliability of new materials and parts

Technologies for clarifying the quality and reliability of new materials and parts in consideration of manufacturing are effective for increasing the flexibility of product design. However, it is difficult for product design engineers to evaluate the qualities and reliabilities of new materials and parts because product design engineers do not have sufficient know-how, methods, and equipment for evaluating them. It is necessary for manufacturing engineers to develop the technology for clarification of quality and reliability of new materials and parts.

This approach has been successfully applied in the development of coating methods for digital product parts. In the development of mainly digital products, the appearance of products is one of the key differentiation factors rather than the basic function because the basic function has been standardized. One of the key manufacturing technologies is coating technology using new coating materials. However,

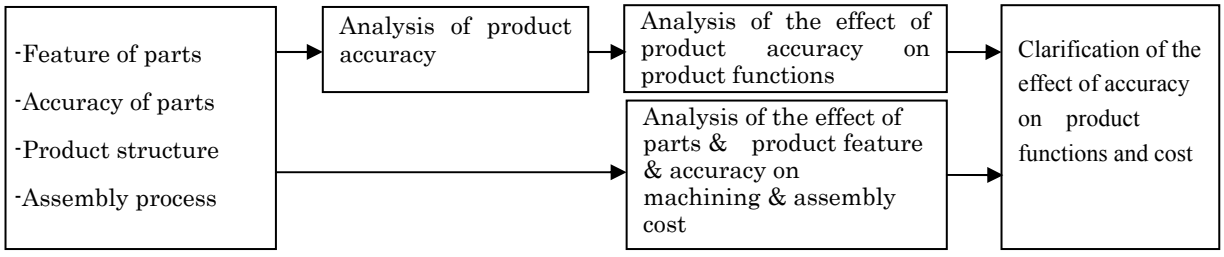

Figure 1: The method for the clarification of the effect of product and parts accuracy on product functions and cost

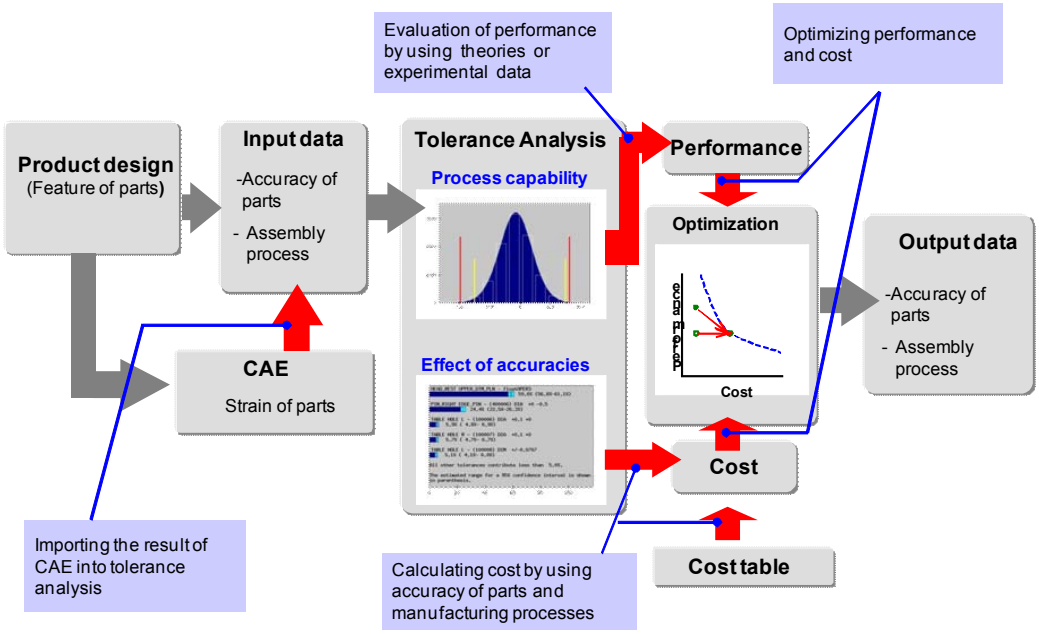

Figure 2: Application of the method for the clarification of the effect of product and parts accuracy on product performance and cost to in the development of the key mechanical component for refrigerators and air-conditioning equipment.

product design engineers tend to hesitate to use new coating materials for new products because their quality and reliability are unknown. To overcome this issue, manufacturing engineers have evaluated the quality and reliability of new coating materials that are useful for both environment and product design. Through the supply of such data from manufacturing engineers to product design engineers, the design of new product incorporating new coating materials is performed.

In this application, the quality and reliability were evaluated before the product design. However, it is usually difficult to evaluate the quality and reliability before product design. The key manufacturing technology management of this approach is to establish the technologies for evaluating the quality and reliability in a short time to accommodate sudden changes in product design.

C. Creation of new manufacturing methods and processes

The creation of new manufacturing methods and processes is the most effective approach of MFD. This approach has been successfully applied and demonstrated in the development of the key components of digital products as shown in Figure 3. One of the key factors for strengthening the competitiveness of digital products is the realization of smaller and lighter designs. To realize smaller and lighter designs, smaller and thinner parts have been adopted. However, the conventional wiring methods with harnesses and electric wires are preventing the realization of such smaller and lighter designs. To overcome this issue, manufacturing engineers have developed a manufacturing technology for printing wiring directly on the bodies of products. Conductive paste with low resistance, which solidifies at a low temperature, has been developed for use on the plastic material for cases. Furthermore, a new printing method for printing wiring directly on cases with curved surfaces has also been developed. As a result, it has become possible for product design engineers to consider new ideas for smaller and lighter products.

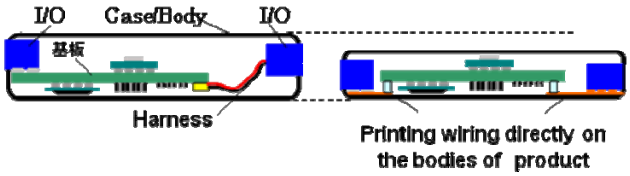

Figure3: Application of the creation of new manufacturing methods and processes in the development of the key components of digital products

In this approach of MFD, one of the key technology management methods is to shorten the development lead time, because the development of new manufacturing technology usually required a long time. Not only in-company development, but also the introduction of technologies from other companies would be a key management method. A necessary technology management method for shortening the development lead time is to search and conclude partnerships with companies that have the required technologies. Furthermore, another key technology management method is to integrate product development. Before developing new manufacturing technologies, it is necessary to share the product development plans and manufacturing technology development plans among product design engineers and manufacturing engineers.

Figure 4 shows the approaches of MFD as a new concept of manufacturing technology management.

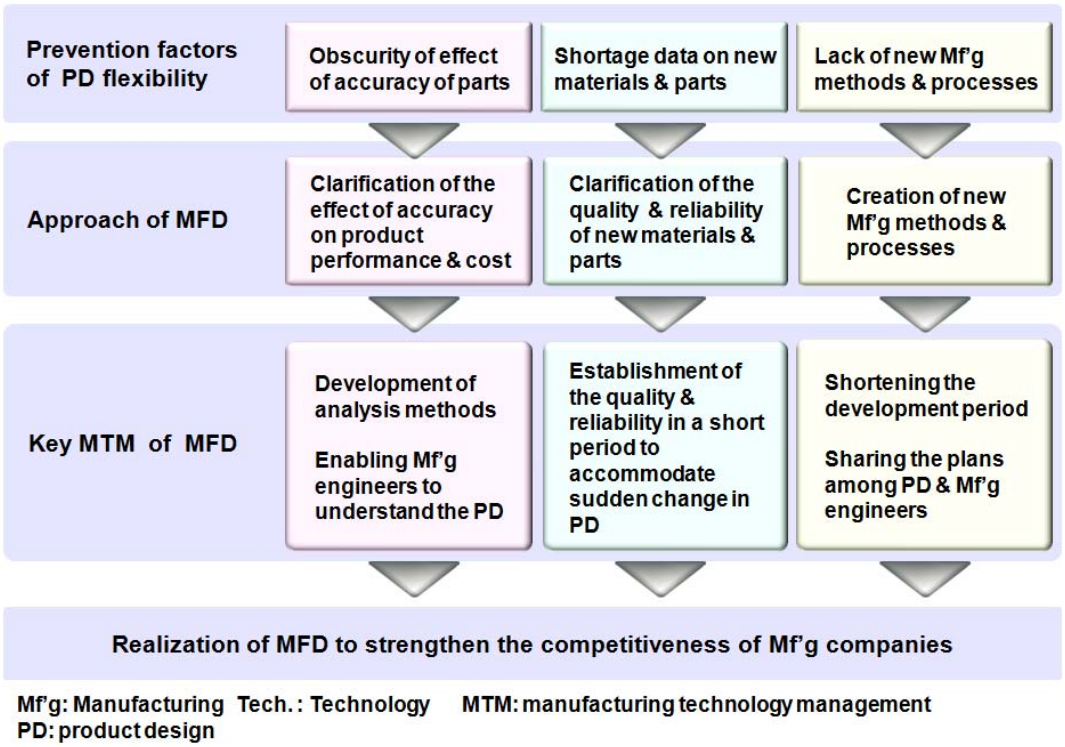

Figure 4: Approaches of MFD as a new concept of manufacturing technology management

V. SUMMARY AND CONCLUSION

In this paper, "manufacturing technology for design (MFD)" was proposed as one of the new concepts of manufacturing technology management for increasing the flexibility of product design, and promoting the creation of new ideas by product design engineers.

First, three factors preventing the flexibility in the creation of new product designs —obscurity of the influences of accuracy, shortage of data on new materials and parts, and lack of new manufacturing methods and processes— were identified by investigating actual issues of cooperation between product design engineers and manufacturing engineers in product development.

Second, MFD was proposed as an effective new concept for increasing the flexibility of product design through three approaches —the clarification of the effect of accuracy on product functions and cost, the clarification of the quality and reliability of new material or parts, and the creation of new manufacturing methods and processes — by considering methods and approaches for eliminating the three factors preventing flexibility in the creation of new product designs.

Finally, the effectiveness of each approach was evaluated with reference to actual applications, and manufacturing technology management methods for successful MFD were discussed to strengthen the competitiveness of manufacturing companies.

The manufacturing technology management approaches proposed in this paper will be effective for strengthening Japanese manufacturing companies, because these management approaches are based on the cooperation between product design and manufacturing engineers which many Japanese manufacturing companies are strongly promoting.

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