Innovative Application of Digitized Design in Traditional Manufacturing: An Example in the Powder Metallurgy Industry

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Abstract. This research began with a series of in-depth interview with experts in the field of powder metallurgy, combined with literature review, a design process with a checklist of design quality for powder metallurgy cultural and creative products was established. We first verified this design process with the checklist by applying it to improve the design of an existing powder metallurgy cultural and creative product. Then we designed three cultural and creative products based on the established design process with the checklist of design quality and chose an icon of Hakka Lion among them to prepare a toolset and finished the test production of a sample, which all of our interviewed experts deemed as having excellent quality. Therefore, this research verified that the traditional technology of powder metallurgy could not only be utilized to produce mechanical parts, but it can also be applied in the cultural and creative industry to produce high value-added artifacts that are typically full of very complex curvature surfaces. In addition, the design process with the checklist of design quality for powder metallurgy cultural and creative products was also verified to be applicable. Besides, this research also introduced the technology of digitized design to the design and manufacturing process of an old powder metallurgy manufacturer successfully. Through which we enhanced the integrity and efficiency of this production process significantly. Hope that the result of this research will be helpful for the powder metallurgy industry in Miao-li County of Taiwan to find a way out.

1. Introduction

Powder metallurgy (the common abbreviation as PM will be utilized from now on) industry has developed in The Miao-li County for almost fifty years, there currently are more than thirty companies with a massive share of more than 70% among the total output of the PM industry in Taiwan[1][2]. In response to this massive trend, the Executive Yuan of Taiwan announced “Challenging 2008—A six-year plan of national key development” in 2002 [3]. In this planning, they vowed to take the development of cultural and creative industry as a key development policy of Taiwan government. Then a consecutive plan “Creative Taiwan—An action plan for the development of cultural and creative industry” was further announced in 2009 to deepen the result of this policy [4], which had created a boom of creative design in Taiwanese industries effectively. According to Newman’s argument, digital transformation is the dominant trend in industries all over the world currently [5]. This research intended to combine the
two leading trends in industries, i.e., the boom of cultural and creative artifacts as well as the proliferation of digitization on almost everything. We first interviewed some PM experts to acquire their specialized experience and knowledge; then we developed a design process with a checklist of design quality for cultural and creative PM products based on these interview results. Based on the design process and the checklist of design quality, we developed three cultural and creative PM product designs. Then we chose a Hakka Icon of Lion [6] among them to produce a test sample and our PM experts all rated this test sample as having good quality, which further verified the viability of our design process and checklist for design quality. The previous literature on applying PM technology in the field of cultural and creative artifacts can only barely found. As Chen [7] pointed out, the primary application of PM technology was in the field of mechanical parts, while the major developments of PM technology were in its material contents and micro phenomenon in the production process. Gummeson [8] also raised the issue of high-pressure water atomization in PM products. In the Taiwanese academia, there were only a few previous literatures on applying PM technology in the field of cultural and creative artifacts such as Cheng’s article [9].

2. Aim of Research

This research was set out to figure out a comprehensive checklist for design review, in order to establish a firm basis of introducing both cultural and creative products as well as the digitization technology to the PM industry. In pursuing this objective, we began with interviewing PM experts to acquire the knowledge on constraints and rules of traditional design for PM products, then applied digitization technology to integrate this knowledge into the design process and the checklist for design review of PM products. We especially envisaged the enhancement of efficiency in communications between design and manufacturing engineers in arranging this design process and the checklist for design review. In summary, the scope of this research are as follows: (1). Exploring the design constraints of PM products to maximize design quality, (2). Developing the design guideline of PM cultural and creative products following the design constraints that we identified earlier. Since cultural and creative products are usually small in size, our design guideline can only fit with the powder compression model machine of 3 tons and the maximum product range under 30mm x 30mm, (3). Focusing on the merit of enhancing communication efficiency by applying digitization technology.

3. Research Method and Results

The traditional applications of MP were concentrated in the production of precision and simple geometrical form of mechanical parts mostly. The whole industry was generally in lack of the experience around any consumer commodities or any complicated curvature product forms. Under such an endangered situation of the PM industry in Taiwan, especially in Miao-li County, we saw it would be worthwhile if we could offer them with some help with our research. The logical structure of the methods utilized in this research is as depicted in Figure 1:
(1) Design and manufacturing guidelines of OEM mechanical parts: In this stage, we collected engineer drawings of the OEM parts that were fabricated previously in the PM manufacturer which was collaborated in our research. Five types of PM parts that typically had some difficulties in forming or other fabrication processes were selected in this survey. We invited three PM experts from the PM manufacturer to develop a questionnaire to investigate the characteristics of these parts collaboratively. For instance, the questionnaire and the result of the first part of question b was shown in Figure 2:

![Figure 1. Logical Structure of Research Methods](image)

**Figure 2. Categorization of Characteristics of OEM PM Parts**

| Picture of PM parts | Description of Characteristics |
|--------------------|--------------------------------|
| ![PM part 1](image) | Expert A: A, B, C, E. |
| ![PM part 2](image) | Expert B: D, E. |
| ![PM part 3](image) | Expert C: C, E. |
| ![PM part 4](image) | Expert A: A, B, C, D, E. |
| ![PM part 5](image) | Expert B: B, C, D. |
| ![PM part 6](image) | Expert C: D, E. |
| ![PM part 7](image) | Expert A: A, E. |
| ![PM part 8](image) | Expert B: A, E. |
| ![PM part 9](image) | Expert C: C. |
| ![PM part 10](image) | Expert A: A, E. |
| ![PM part 11](image) | Expert B: A, B, E. |
| ![PM part 12](image) | Expert C: A, B. |
| ![PM part 13](image) | Expert A: A, E. |
| ![PM part 14](image) | Expert B: B, C, E. |
| ![PM part 15](image) | Expert C: A, E. |

Please select the descriptions that fit the PM parts in the pictures above.
A: too much run length  B: continuous run  C: thin edge
D: insufficient thickness  E: difficulty in density adjustment
The result of this questionnaire survey had concluded into six design guidelines of OEM PM mechanical parts as follows: (a). Step height on the parts cannot be higher than one-third of the thickness of the next layer, (b). The factor of easy adjustment on density must be taken into account on the form design, (c). Avoid the design of long and thin shapes, (d). It is essential to keep the same thickness when there are continuous steps or curvature surfaces, (e). It is preferable to make all edges in round shape, (f). All draft angles must be 3 to 5 degrees if there are any raised ribs, columns, or surfaces.

(2) Design characteristics of cultural and creative artifacts: There were only a tiny number of previous literature concerning the application of PM technology in the field of cultural and creative artifacts in Taiwan. It was only Cheng [13] who had pioneered the application of technologies including image processing and CAD/CAM in the cultural and creative artifact. It was an elephant keychain as shown in Figure 3. However, it was a straightforward design with slight variations on the surface only. Therefore, we took reference from cultural and creative artifacts manufactured in other ways and materials and concluded that these products are prone to have more complicated surface designs such as variations curvature, steps, and thickness, which may be challenging in PM manufacturing and thus require appropriate design modifications.

Figure 3. Cheng’s [6] PM Product – An Elephant Keychain

(3) Interviews of PM experts: As described above, we invited three PM experts from the PM manufacturer that was participated in our research to develop a questionnaire to investigate the characteristics of PM parts collaboratively. These three PM experts had also played the role of PM technical consultant for our research in the following stages.

(4) Manufacturing guidelines of PM: Additionally, the result of the questionnaire survey described earlier had also concluded into three manufacturing guidelines of OEM PM products as follows: (a). The process of forming had better take more gradual steps, (b). The adjustment of upward and downward forces of the press must be very careful, (c). Avoid having too much discrepancy on density in the product.

(5) 3D digitization design expertise: The expertise of 3D digitization design is the major strength of our research team, through which we intended to help the PM industry by combining it with the PM knowledge that we acquired in this research. Now that we had learned the experiences regarding traditional PM design and manufacturing from our experts, it should be our turn to combine our expertise with their contribution at this stage.

(6) Summarization of new design process with checklist of design quality for cultural and creative PM products: In summarization of the former stages, our research had come to the point where the resulted new design process with checklist of design quality for cultural and creative PM products can be coming to the fore. At this stage, we integrated the design process and the checklist of design quality together to become a comprehensive flowchart as shown in Figure 4 on the next page:
(7) Real case verification: Based on the new design process with the checklist of design quality for cultural and creative PM products that we proposed above, we took Cheng’s elephant keychain as a real case to verify its viability. We showed the pictures of Cheng’s elephant keychain to our PM experts and consulted their opinions of required improvements, then an improved 3D design was finished, and our three PM experts had all took this design as having good design quality. Therefore, this real case has verified that the new design process with the checklist of design quality for cultural and creative PM products that we proposed is viable.

Figure 5 3D Model of the Redesigned Result of Cheng’s Elephant Keychain

(8) Applications in cultural and creative PM products: After the above initial verification of our new design process with the checklist of design quality for cultural and creative PM products, we have to further verify its applicability by the design and production of a real cultural and creative PM product. As the majority of the population in Miao-li County is Hakka, thus we aimed to choose icons of Hakka culture to develop our cultural and creative product. For this purpose, we chose three icons of Hakka culture for our initial design, i.e., tong tree flower, fire dragon, and Hakka
lion. Among these three initial designs, we chose the Hakka lion to produce a test sample shows the 3D digitized model in Figure 6 below.

![3D Digitized Design of the Hakka Lion](image1)

Figure 6. 3D Digitized Design of the Hakka Lion

Since cultural and creative products are usually small in size, we developed our design to fit with the powder compression model machine of 3 tons and the maximum product range under 30mm x 30mm. We pioneered the introduction of 3D printing to the PM industry by producing a plastic model using PLA, which is a convenient vehicle for enhancing the efficiency in communications in this stage. Following the plastic model, we established a CAD model of 2.5D of the embossed copper electrode, then use this CAD model to produce the CNC program with CAM software and produce it by five-axis engraving machine. The finished upper, lower and middle molds are shown in Figure 7 below.

![Upper, Lower and Middle Molds of the Hakka Lion](image2)

Figure 7. Upper, Lower and Middle Molds of the Hakka Lion

The toolset finished above was then used to produce green compacts as shown in Figure 8 below.

![Cooper and Iron Green Compacts of the Hakka Lion](image3)

Figure 8. Cooper and Iron Green Compacts of the Hakka Lion

4. Results and Discussions:

Finally, the results of this research had hit the aims that we set initially. They are as follows:
(1). Established a design process with the checklist for design quality of PM products, for which the viability had been verified in this research also.
(2). Introduced the technologies of 3D CAD/CAM and 3D printing in the design process of PM products and enhanced the communication efficiency significantly.
(3). Introduced the cultural and creative artifacts to the PM industry to help them secure better business opportunities and thus improved their economic value.
These research results had been proven to be effective in the PM manufacturer that collaborated with this research. It is hopeful that other PM manufacturers will be influenced to adopt these changes proposed by this research gradually.

5. Conclusions
This research adopted research methods of in-depth interviews and literature review, combined theories and practical experiences of PM and introduced new technologies including digitized design, CAD/CAM and 3D printing and new product of cultural and creative artifacts to the PM industry successfully. With the contributions made by this research, the PM manufacturer that collaborated with the researchers had found great prospect to prosper again in the future. We are sure that other PM manufacturers will found the hope in these changes proposed by this research and follow up to change together gradually.

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