Application of the modular manufacturing technology of mechanized equipment in tea garden management machine

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Abstract. Modular technology of mechanical equipment is an efficient product manufacturing strategy; it could meet the diversified and personalized needs of users. At the same time, it could shorten the manufacturing cycle and reduce the production cost, so as to enhance the competitiveness of products. Based on the concept and method of modular manufacturing, the general steps of modular manufacturing of mechanical products was pointed out, and the modular division and manufacturing strategy aiming at realizing special functions were expounded when the tea garden management machine was taken as an example. By changing general and alternative modules, the transformation of different functions of the tea garden management machine is realized. It achieved the purpose of one machine with multiple uses, and has certain reference significance for the modular manufacturing of small agricultural machinery.

1. Introduction
Modular design and manufacturing is a modern design method[1]. The manufacturer can build product series through the division, design, selection and combination of modules by using this technology. By adopting product-based systematization and modular design, not only the product performance is more stable and reliable, but also the processing and assembly process is reasonable and the development and manufacturing cycle can be shortened[2]. It could quickly configure corresponding products according to the different needs of users, which is very conducive to the marketing promotion of products. Nowadays, the modularization is the advanced manufacturing technology that can meet the needs of economic development, the independent, innovative and standard way of information communication of modules make it occupies a very important position in both advanced production and modern manufacturing, and it is one of the key technologies to ensure obtaining success in international competition[3-4].

China is a tea production and trading power, and the tea industry has played an important role in the national economy and international trade. The expenditure of field management in tea production is very large, the cost of field management in tea farm accounts for about 50% of the total cost of tea production. In large-scale tea production, the harvesting workers account for more than 40% of the total cost, while the cultivation of tea garden accounts for about 30%. Higher production costs have become an important factor restricting the growth of tea benefits[5-6]. Over 60% of tea plantations in China are on steep slopes with a slope greater than 30 degrees. Because of the late start of tea garden management machinery in our country, the development of tea garden management machinery is not comprehensive.
enough. In recent years, under the implementation of the national urban integration strategy, a large number of young and middle-aged rural labor force has been transferred, labor resources are scarce, and labor costs have risen sharply. So, there is a great demand for tea garden machines with miniaturization, light weight, modularity, high efficiency and low consumption. Therefore, according to the requirements of tea plantation management and the performance of agricultural equipment, the modularization manufacturing technology of tea plantation management equipment is studied, the working equipment such as cultivation, fertilization, weeding, pest control, pruning and tea picking in tea plantation management are assembled, and the modular multifunctional machine for tea plantation was developed.

2. Principle of the modular manufacturing technology
Module is the basic unit of modular design and manufacturing. It is a standard component with independent functions, input and output interfaces[7-8]. Modular design and manufacture of mechanical equipment mainly includes three aspects: (1) module division (2) module series design; (3) module integration.

2.1. Module division

2.1.1. Module division principle. In modular mechanical product design, the target product should be divided into several modules first, and then the module is used as the basic unit to design and manufacture. The rationality of module division directly affects the function, performance and cost of modular system[7, 9-10].

The principles to be followed in module division are: minimize the total number of modules contained in the product and simplify the complexity of the module itself, so as to avoid confusion in module combination; more practical combinations should be got as possible to meet the needs of users with the limited number of modules; the certain functional independence and structural integrity of module should be guaranteed; interface elements between the modules should be paid enough attention, so as to facilitate the combination and separation of modules; the effect of module division on product accuracy and stiffness should be considered and the economic considerations should also be considered.

The lower level of module, the structure of module is simpler, the easier to improve the degree of generalization, but the more complex the management of product manufacturing and assembly. The division of modules should separate the same or similar functional units after overall consideration of products. The unification, simplification and classification of modules are carried out with the principle of standardization, then the modules exist independently in the form of universal units. Each module can be selected by different combinations and exchanges to form different products. At present, components or assembly are usually used as modules. For products with higher serialization degree, assembly should be used as modules, which is conducive to expanding the general scope of modules; for products with less serialization or non-serialization degree, components should be used as modules.

2.1.2. Module division method. There are two main methods of module division: functional analysis and component analysis. Modules are divided according to the sub-functions of products and their interrelationships or the parts and their interdependencies of products. Functional analysis emphasizes the functional independence of modules, and is generally used in the conceptual design stage. Component analysis takes into account the geometric and physical correlation between components, on the premise that the structural design has been determined, and is generally used in the design of specific products.

2.2. Module series design
Modular series design includes horizontal series design, vertical series design, cross series design and full series modular design[9, 11-12].
2.2.1. *Horizontal series design*. On the basis of a certain product, a variant product is formed by changing, adding or reducing certain interchangeable specific modules. It is characterized by not changing the main parameters of the base products. This method is the simplest and easiest to implement, so this application is the most common. The key point is to take necessary measures in structure, such as designing reasonable interfaces, pre-processing the positioning surface and hole for connection, so that various modules can be added or replaced smoothly.

2.2.2. *Vertical series design*. Different types of base products are designed in the same type. It is characterized by changing the main parameters of the base product. The dynamic parameters of products with different main parameters are often different, which means that the structure and size of products will change. This design is more difficult than a series of modular design.

2.2.3. *Cross series design*. It is generally used in cross class products with a little difference in overall structure. Its characteristic is that different modules are selected to form cross-series products on the same basic component structure, or on cross-series products with different basic component structure, the same module is selected for units with the same function. The characteristics of cross series products are that their main foundation parts are of the same structure.

2.2.4. *Full series design*. The full series includes vertical series and horizontal series. It refers to the modular design of all horizontal and vertical series of a certain kind of product. Its complexity and difficulty are very great, and the types of modules required are abundant.

2.3. *Module integration*

The success of modular design depends on the integration of modules. Obviously, in order to ensure the combination of different functional modules and the interchange of the same functional modules, modules should have two characteristics: composability and interchangeability[13]. These two characteristics are mainly embodied in the interface of modules. For example, for assembly, units with the same function and different performance must have the same installation base and the same installation size to ensure the combination of modules. Module integration refers to the evaluation of the possibility, rationality and practicability of functional integration and structural overlap by selecting modules with different functions, and then aggregating them into products with specific functions. It can be seen that the integration of modules not only refers to the superposition of modules in structure, but also refers to the organic integration of modules in function. Firstly, according to the user's requirements, functional analysis is carried out to determine the functional modules, and then check whether there are ready-made modules that can be directly used in the module library. The ready-made modules that meet the required functions are integrated to see if they can meet the general functional requirements. If it cannot be satisfied, the relevant modules need to be re-selected; if there are individual modules that cannot be found off-the-shelf, they need to be redesigned and integrated until they are satisfied.

3. *Modular design and manufacture of tea garden management machine*

3.1. *Modular design criteria for tea garden management machine*

The modular design of tea garden management machine is to introduce the concept of product optimization design in modern mechanical design theory into the production method of product design and manufacture. That is to say, within a certain range, considering the structural characteristics of the designed products, we can locate the positioning of different functions, performances, specifications of working machines or their specific subsystems, and divide a series of functional modules. Through the selection and combination of modules, we can encapsulate and form a model tea garden working machines or their functional subsystems.
According to the classification, structure characteristics and usage requirements of tea garden working equipment, the method of functional division was adopted for module division, and each type of modules are designed according to horizontal series modularization. Finally, all kinds of modules are integrated.

3.2. Modular design of tea garden management machine
The total function of tea garden management machine can be divided into four sub functions: operation, walking, assistance and working. The function of operation, walking and working is the basic function of the operation machine. Auxiliary functions complement and improve basic functions, and can be configured according to specific circumstances. According to the similarity of the main structure of the machine tool, it can be divided into power module, speed change module, transmission module, operation module, rack module, walking module and working module. In the product family, the working functions of various operating machines are different, but their operation, walking and assistant functions are basically the same. Therefore, the working functions are divided into variation modules, and the operation, walking and assistant functions are divided into sharing modules. Sharing module is a function module shared by the whole product family. Variation module is a special function module for different operation functions.

![Diagram of modular division of tea garden management machine](image)

**Figure 1.** The modular division of the tea garden management machine.

Horizontal series modularization refers to a variant machine derived from replacing, adding or deleting certain specific modules on the basis of the same specification. Its characteristics are that the main parameters, especially the dynamic parameters, are the same, and the differences are mainly reflected in some functions, structures, layouts or working modes. On the premise of not changing the sharing module, different mutation modules are changed to form different functional working machines, such as cultivation, fertilization, weeding, insect trapping (negative pressure), pruning or harvesting. The modular division of the tea garden management machine is shown in Figure 1.
Whether sharing module or variation module, there are several sub-modules. Each sub-module corresponds to a number of mutation sub-modules with different structure, layout or working mode, but they can be interchanged with each other. When different mutation sub-modules are configured, they constitute the same function but different performance working machine. For example, there are two alternative modules in the shared module: wheeled walking module and tracked walking module, which are reflected in the adaptability of working environment. What’s more, when the variation module adopts the middle tillage module, there are two alternative modules in the lower module: rotary tillage module and spiral tillage module, whose performance is different in the adaptability of different soils.

Through flexible connection and compatible combination of operation modules, the free configuration of all kinds of tea garden management machine has been realized. That is to say, according to different seasons and needs, the corresponding operating machines are allocated to realize multi-use of one machine and reduce the purchase cost.

4. Conclusion

(1) Modular design and manufacture of mechanical equipment mainly includes three aspects: module division, module series design and module integration. For the tea garden management machine, the method of functional division was suitable for module division, and each type of modules is ideally designed by horizontal series modularization.

(2) Through flexible connection and compatible combination of working modules, the free configuration of all kinds of tea garden management machine has been realized. And the corresponding operating machines are allocated to achieve the purpose of one machine with multiple uses and reduce the purchase cost.

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References

[1] Xiaozhong R., Jianxin S. and Xiaozhong D., Modularization structure of CNC gear form grinding machine based on modularization design theory, Machinery Design & Manufacture. 12 (2007) 98-100.

[2] Hong W., Tiansheng H, Yuping O.Y. and Zhen L., Development of mountainous orchard portable earth auger, Journal of Guangdong Agricultural Sciences. 14 (2014) 159-162.

[3] Lifeng Z., Weixing Y. and Jun Z., Equivalent multi-case optimization architecture for modular aircraft structures, Acta Aerinautica Et Aeronautica Sinica. 36 (2015) 834-839.

[4] Xuan L., Minglu Z., Wei L., and Xiaoling L., Research on modular design for special robots, High Technology Letters. 20 (2010) 175-179.

[5] Yu H., Hongru X., Guangming Q. and Zhiyu S., Latest research situations and trends about tea garden machinery during 2012 in China, Journal of Chinese Agricultural Mechanization. 34 (2013) 13-16.

[6] Yu H., Hongru X., Zhiyu S. and Wenqing D., Research on mechanization technology mode of tea plantation and management, Journal of Agricultural Science and Technology. 18 (2016) 74-81.

[7] Haining Y., Lihua Y. and Jian Y., Design and research on multi-functional module small farm machinery, Journal of Chinese Agricultural Mechanization. 34 (2013) 134-138.

[8] Hongxing L., Lulu F., Ru J. and Lifeng G., Partition method for module clustering of soybean seeding equipment pedigree, Transactions of the Chinese Society of Agricultural Engineering. 32 (2016) 43-50.

[9] Libing Z., Yongwei Y., Jiandong J., Shiming J. and Xian Z., Scheme design of small agricultural machinery based on reconfigurable module method, Transactions of the Chinese Society for
Agricultural Machinery. 36 (2005) 78-81.

[10] Mingpei Y. and Xiongqing Y., Aircraft family design using modular product platform methodology—an exploratory study, Aircraft design. 4 (2006) 30-37.

[11] Xiaozhong R., Chunmei L., Jianxin S. and Xinsheng D. Modularization design of aggregate machine tool based on UG, Tractor & Farm Transporter. 34 (2007) 28-30.

[12] Yan Z., Hongliang Z., Xiaozhong R. and Rongzhi W., Research on modular design of the flaw detector for wire ropes, Machinetool & Hydraulics. 38 (2010) 73-75.

[13] Jie S., Zhaowei S. and Yang Z., Key technologies of modular design of micro-spacecraft facing micro-spacecraft family, Journal of HARBIN Institute of Technology. 39 (2007) 1908-1911.