ATLANTIS PRESS
Advances in Engineering Research, volume 184
2nd International Conference on Sustainable Energy, Environment and Information Engineering (SEEIE 2019)

Research on the Production Mode of Improving Production Efficiency of Spacecraft Multi-layer Insulation

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***Abstract*—The production of multi-layer insulation for spacecraft has formed a specialized unit production mode, which has made great progress in terms of production technology and methods.But because there are many types of products and low repetition rates, the production belongs to the production of single-piece small-volume products. Therefore, for a long time, The production of multi-layer insulation has problems such as long production cycle, high human resource consumption, and low production efficiency. Starting from the production mode, this paper studies how to further improve the multi-layer production efficiency by reducing the variation of multi-layer insulation and improving the flexibility of the production operation system. Finally, multi-variety small batch unit production model was used for simulation verification.**

Keywords—multi-layer insulation; group technology; equipment flexibility

I. INTRODUCTION

The country's extensive attention to the aerospace industry and its continued investment have created a rare opportunity for its development, which has enabled many aerospace technologies to enter a new stage of leaping development. At the same time, aerospace industry is also facing tremendous pressures and challenges such as the rapid increase of tasks and the constantly tightening development progress. In order to adapt to the needs of the model tasks in the new stage, In the field of production of spacecraft multi-layer insulation (referred to as MLI), through the specialized production, the MLI production can be completed by a fixed team using specialized techniques.

However, due to the variety of MLI and low repetition rate, it belongs to a single-piece small-volume product, so it also has the common problem of single-piece small-volume production such as long cycle, high labor consumption, low production efficiency[1-3]. Literature [4] proposed intelligent production methods of dynamic perception, real-time analysis, independent decision-making, and precise execution. However, it is difficult to apply to the production of MLI with more manual work. The literature [5] integrates the device clustering and unit layout problems to construct the manufacturing unit framework model and the objective function. But it only considers the system flexibility, and the optimization of the product is not involved.

In order to fully exploit the potential and advantages of specialized production and further improve production efficiency, this paper starts with the improvement of production methods, studies how to reduce the change of MLI and improve the flexibility of production operation system. The simulation proves that the overall efficiency and stability are better than the previous production mode.

II. STATUS AND PROBLEM ANALYSIS

The MLI consists of reflective screens and layers of spacer, which is then processed into the desired shape and coated with a specified mask on the outer layer to form the final product[6-8]. The production process still belongs to the production of single-piece small-volume products, and there are many problems such as various types, complicated production links, poor equipment flexibility, and weak planning guidance.

A. MLI Type

The reason for the wide variety of MLI is that the types of materials, the combination of materials, and the shape of the MLI are not uniform.

1) There are many types of MLI materials, and there are various combinations depending on the coating position and application environment. The materials constituting the MLI include reflective screen, spacer layer, mask, grounding component, tape, suture, etc., and each material is classified into different types according to thickness, material, and the like. Since the MLI of different spacecrafts need to face different space environments, the materials used by each spacecraft are different. The MLI used in the same spacecraft is divided into high-temperature, medium-temperature and low-temperature, and the material composition is also different. The low temperature MLI in the same model may also differ in material used depending on the coating position, especially the selection of the mask, so that there may be dozens of different classifications depending on the type of raw materials.

2) The thickness of MLI also varies with coating position. The superposition of a layer of spacers and a layer of reflective screen is called a unit,and the number of common MLI units includes 5, 9, 10, 11, 15, 20and 30.

3) The shape and size of MLI vary widely. For the same spacecraft, since the shape and size of the MLI coated objects are different, the shape of the MLI is rarely the same, and the size spans from a few centimeters to several meters. For the spacecraft of the same platform, only a small number of MLIs have the same shape, and the MLIs of different platforms are different.

B. MLI Production

There are many production processes involving more than ten different types of operations. Taking low-temperature MLI production as an example, Figure 1 is the main production process.

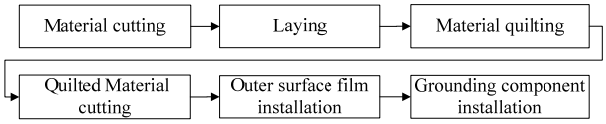

FIGURE I. LOW-TEMPERATURE MLI PRODUCTION FLOW CHART

C. Equipment Flexibility

Fewer steps of MLI production can be processed using automated equipment, and the equipment is not flexible enough to adapt to different working conditions. Taking multi-needle quilting equipment as an example, it is mainly used for quilting MLI to prevent it from opening. Due to the single quilting pattern and large stitch length, it is impossible to fix MLI of the elongated shape and the small size, so that about 1/3 of the MLI needs to be manually sewn, which reduces the production efficiency.

D. Production Plan

The MLI belongs to the order-type production. Therefore, at the beginning of the development of the spacecraft, a MLI production plan can be formulated, but the plan is often insufficiently guided and needs to be continuously revised as the spacecraft development process proceeds. Therefore, the MLI production plan usually begins when the spacecraft development is about to enter the final assembly stage. The plan at this time is relatively accurate, but there are still many special circumstances that lead to adjustment of the demand time, which makes the plan insufficiency.

III. PRODUCTION MODE OPTIMIZATION

With the increasing popularity of single-piece small-batch production models, research on how to improve the efficiency of single-piece small-volume production has become the focus of attention in all walks of life. According to the research results, there are two main methods for rapidly improving the production efficiency of single-piece small batches: 1) reducing product changes; 2) improving the flexibility of the production operation system, and the two complement each other.

A. Reduce Product Changes

There are three main ways to reduce product changes: 1) serialization of the entire product and standardization and generalization of individual parts; 2) group technology, mass production using product similarity [9]; 3) change reduction scheme (VRP), reduce product types and processing techniques from three levels of parameters, entities and systems [10].

For MLI production, according to the current production status,analyze how to use the above three ways to optimize the production process. First of all, the MLI serialization is mainly reflected in two aspects, one is thespacecraft platform, and the other is the division of low, medium and high temperature. This article will break the limitation of spacecraft platform on the basis of the group technology, and create a new series from the dimension of covering position, that is the shape. In terms of material, this paper will analyze the unification (standardization) and de-modeling (generalization) of material specifications.

Then use the group technology, combined with the product serialization idea, explore MLI similarity from multiple angles.Analyze the task quantity of each stage through the work plan, and carry out similar MLI batch production ahead of the stage when the task is not tight. Improve production efficiency while reducing work stress during peak tasks.

Among the three levels of change reduction schemes, MLI production has experienced system-level changes (organizational structure changes) and physical layer changes (production process changes), establishing stable specialized production teams and fixed production process. In the following, it is necessary to combine the grouping techniques to make corresponding changes in the parameter layer change (process, step change).

At present, the commonly used group classification methods are visual inspection method, production process analysis method and coding classification method. The visual inspection method is mainly used in the occasions where the process characteristics are relatively simple. The production process analysis method is no longer used when the current MLI production process is relatively mature. The coding classification rule is more suitable for the classification of products with many features such as MLI. The coding classification method is divided into VUOSO system, OPITZ system and other classification methods. In the following, this paper will make adaptive changes based on the commonly used QTJLBM-1 classification methodfor MLI classification, establish a new series, and combine production. Then combine production plans to take advantage of group processing and analyze how to standardize material specifications [11].

TABLE I. STRUCTURE DIAGRAM OF MLI CLASSIFICATION CODING SYSTEM

I	II	III	IV	V	VI	VII	VIII	IX	X
MLI category code	Shape code				Material code				Unit code
MLI category	Covering position	External shape	Length dimension	Width size	Reflective screen material	Spacer material	Mask material	Grounding component type	Number of units

MLI category code I:1 low-temperature MLI positive sample, 2 low-temperature MLI process sample, 3 medium-temperature sample positive sample, 4 medium-temperature MLI process sample, 5 high-temperature MLI.

Cover position code II: 1 tank and gas cylinder, 2 engine brackets, 3 pipes, 4 decks, 5 equipment.

External shape code III: 1 rectangle, 2 circles, 3 profile.

Length size code IV: 1 100mm~150mm, 2 150mm~200mm, 3 200mm~300mm, 4 300mm~500mm, 5 500mm~700mm, 6 700mm~1000mm, 7 1000mm~1500mm, 8 1500mm~2000mm, 9 2000mm~2500mm, 10 2500mm~3000mm, 11 3000mm~4000mm.

Width size code V: 1 100mm~150mm, 2 150mm~200mm, 3 200mm~300mm, 4 300mm~500mm, 5 500mm~700mm, 6 700mm~1000mm, 7 1000mm~1500mm, 8 1500mm~2000mm, 9 2000mm~2500mm, 10 2500mm~3000mm.

Reflective screen material code VI: 1 6μm aluminized film, 2 18μm aluminized film, 3 20μm aluminized film, 4 aluminum foil, 5 nickel foil.

Spacer material code VII: 1 polyester mesh, 2 glass cloth.

Mask material code VIII: 1 single-sided aluminized film, 2 double-sided aluminized film, 3 other.

Grounding component type code IX:1 No grounding component, 2 pin 0.15m, 3 tape 0.5m, 4 tape 1.5m, 5 soldering piece 0.8m.

Unit number X: 1 3 units, 2 5 units, 3 9 units, 4 10 units, 5 11 units, 6 15 units, 7 20 units, 8 30 units.

Among them, part of the code has a clear correspondence, such as 1 tank cylinder in the cover position code II, 2 engine bracket must correspond to the 3 shape in the outer shape code III, and the pipeline in the 3 cover position code II is inevitable corresponding to the 1 rectangle in the outer shape code III.Tens of thousands of MLIs can be divided into 26 groups, and the number of groups will change according to the design requirements of the spacecraft in the future.

The purpose of grouping is to concentrate production in the same group and to provide a basis for the development of production plans and targeted improvement of equipment flexibility. Therefore, the classification of the 26 groups is still many. Figure 2 is a relationship diagram among classification code, process and equipment. Since theCNC cutting equipment has high flexibility, it can meet the processing requirements of different sizes.Therefore, according to the influence of size on the quilting, the size can be simplified to the length size code IV: 1 100mm ~200mm, 2 200mm~4000mm and width size code V:1 100mm~200mm, 2 200mm~3000mm.The MLI with length 200mm~4000mm, width 200mm~3000mm can be quilted with multi-needle quilting machine, and the rest need manual quilting.By this 26 groups can be reduced to 15 groups or 15 series.

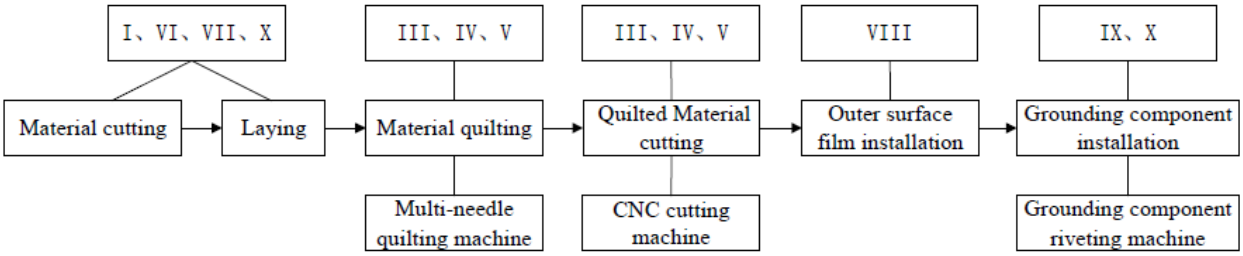

FIGURE II. RELATIONSHIP DIAGRAM OF CLASSIFICATION CODE, PROCESS AND DEVICE

After the grouping is completed, when different types of tasks overlap, the task can be arranged according to the grouping.The model boundary can be broken, and similar MLIs are produced in the same batch.So that the same resources are utilized, the preparation time is reduced, and the production efficiency is improved [12].

In the 15 groups, some of the layers have the same dimensions, specific shapes, and number of elements.Such as the switch heat shield multi-layer (classification code: 2531132112), the sensor multi-layer (classification) Code 1532211124) and so on. Therefore, such MLIs can be produced in advance when the amount of tasks is small, balancing the amount of tasks throughout the year. As shown in the example of the annual task volume in Figure 3, the task volume peak appears in March~April and June~July, and multiple tasks are performed at the same time.Sothe MLIs such as switch heat shield MLI can be arranged to January~February to play the role of cutting the peak and filling the valley.

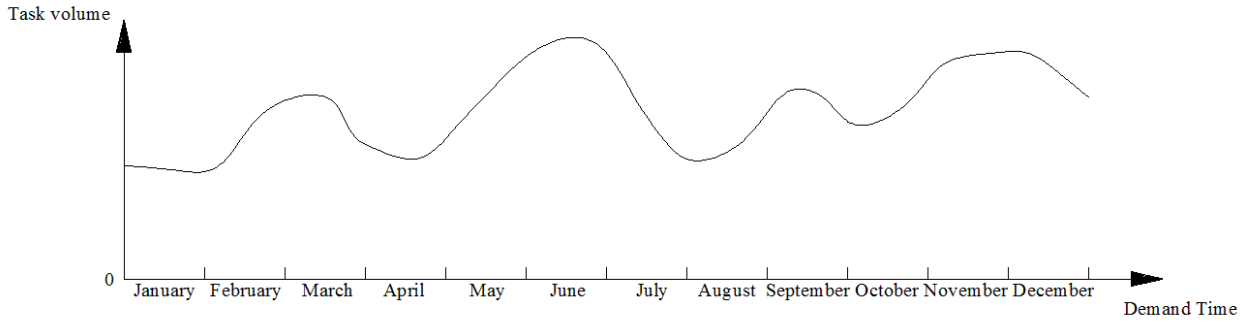

FIGURE III. EXAMPLE OF DISTRIBUTION OF MLI PRODUCTION TASK VOLUME THROUGHOUT THE YEAR

According to the classification and coding system, reducing the types of each classification code can further reduce the number of groups. There are two ways to achieve this goal. One is to uniformly make requirements from the design side andreduce the types of materials and units.The second is to increase the equipment flexibility, reducing the accuracy of certain classification codes or directly eliminating the impact of the classification code on the production process.

In terms of uniform production requirements, research and promotion can be carried out for three aspects: 1) reducing the types of reflective screen materials, such as uniform specification of 18μm aluminized film and 20μm aluminized film; 2) reducing the number of grounding components, such as uniform pin type ; 3) Reduce the number of units, such as unify 9 units and 11 units into 10 units. At the same time, the model division of materials is eliminated in management and changed to uniform use.

A. *Improve the Flexibility of the Production Operation System*

There are two main implications for improving the flexibility of the production operation system: 1) production systems or equipment can produce as many types of products as possible; 2) production systems or equipment processing different products need to be transformed as short as possible [13].

At present, only the quilting, cutting and grounding components of the MLI production process are completed by equipment. The rest of the work is hand-made. Only the CNC cutting equipment can meet the requirements of most specifications in terms of equipment flexibility. The grounding component riveting equipment needs to be adjusted to adapt to the changes in specifications. The quilting equipment can not be changed according to the needs, so only about 2 / 3 of the MLI quilting task can be completed. Therefore, there will be a lot of work in improving the flexibility of equipment, mainly focusing on two directions: 1) developing highly flexible equipment instead of manual work; 2) integrating equipment, merging devices used in adjacent steps of the production process, reducing product transit time between the links.

It can be seen from the above analysis that improving the flexibility of the device can further reduce the number of groups, and even eliminate the influence of a certain classification code on the production process, thereby removing the classification code [14].Currently there are few devices used in the MLI production process, and new equipment development is urgently neededto replace manual work.

It can be seen from Fig. 2 that MLI production of domestic spacecraft lacks automation equipment support in 3 steps of material cutting, laying and outer surface film installation.The multi-needle quilting machine cannot meet all working conditions, and grounding component riveting machine needs to be adjusted according to the number of units. Therefore, the short-term goal is to develop automatic laying machine, develop single-needle quilting machine, develop outer surface filminstallation equipment and improve the adjustment efficiency of grounding component riveting machine. When the automaticlaying machine can automatically complete the laying of any number of units by simple setting, the influence of the unit on the laying part can be eliminated, and the division precision of the unit can be reduced [15]. The medium-term goal is to combine adjacent steps to form a machining center, such as a laying and quilting machine, which combines the material cutting, laying and quilting steps to form a continuous operation. The long-term goal is to form two sets of highly flexible production lines for high-temperature, low-temperature and medium-temperature MLI, namely low and medium-temperature MLI production line and mediumand high-temperature MLI production line, which can reduce the 15 groups to 2groups by highly flexible design.

B. *Simulation Verification*

The improved production efficiency was evaluated using a multi-variety small-volume production unit simulation evaluation method [16]. After improvement, there are 3 flexible processing equipment (numbered Ml-M3) and 10 production personnel (numbered Pl-P10). Among them, scheme A represents the original production mode, and scheme B represents the optimized production mode. The simulation period is 2 months. The simulation model was run 10 times, and the production efficiency fluctuation results are shown in Figure 4.

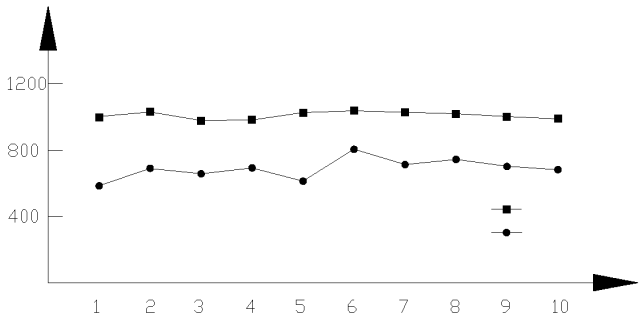

FIGURE IV. PRODUCTION EFFICIENCY FLUCTUATION CHART

It can be seen from Figure 4 that the overall efficiency of the scheme B is better than that of the scheme A, and as the scheme changes, the overall efficiency change of the scheme B is smaller than that of the scheme A, that is, the stability is enhanced.

IV. CONCLUSION

By analyzing the current status and existing problems of MLI production of domestic spacecraft, the MLI grouping and division method are proposed to form a group-processing production mode, starting from the improvement of single-piece small-scale production efficiency. In order to reduce the number of groups, it is proposed to standardize the design requirements of raw materials and develop highly flexible production equipment.

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