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Research and Design of Automatic Laying and Quilting Equipment for Multi-layer Insulation of Spacecraft

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***Abstract*—In view of the low efficiency and unstable quality of the laying and quilting process of the multi-layer insulation of spacecraft, this paper designs an automatic laying and quilting integrated equipment, which adopts fixed base type. Laying and quilting share one platform and Y-direction drive. A buffer structure and a three-layer feeding structure were designed for the high flexibility of the polyester mesh and the complex combination of multi-layer insulation. In order to overcome the problem of fixed frame structure without fixed platform, the support belt system was designed, and the control system was adjusted to perform stepping quilting, in response to the special needs of multi-layer insulation for large stitching. The test results show that the spacecraft multi-layer insulation automatic laying and quilting equipment realizes high-speed and stable operation. The structure is reasonable and the design goal is achieved.**

Keywords—multi-layer insulation; paving and sewing; framed; step quilting.

I. INTRODUCTION

The spacecraft multi-layer insulation (MLI) is composed of reflective screens and spacer layers [1-3]. For the low-temperature MLI, reflective screen is an aluminized polyester film, and the spacer layer is a polyester mesh. Since the aluminized polyester film and the polyester mesh are separately produced, it is necessary to lay them at intervals before the MLI is produced. This process is currently done manually, so the efficiency is low. In order to prevent the change of the shape of MLI and the thermal insulation performance, it is necessary to sew the MLI. For the sewing of complex shapes MLI, it is currently done manually too, so the efficiency is low and the sewing quality is unstable.

At present, there is no laying and sewing equipment in the market, however, the existing spreader cannot meet the demand of large stretch ratio polyester mesh laying and variable material combinations. The literature [4] proposed the heavy hammer tension control system. However, when adjusting the tension, it is necessary to replace the hammer of different quality. The process is cumbersome, and the overall structure is large. In literature [5], the method of controlling the tension by the motor's reverse torque and the dynamic balance of the oscillating roller is proposed, but it is only suitable for materials with certain rigidity and cannot be applied to the tension control of the polyester mesh. The small stitch length of the single needle quilting machine is also inconsistent with the thermal insulation performance of MLI.

In this paper, according to the special requirements for the laying and sewing of MLI, an integrated equipment for automatically laying and quilting of MLI was designed, which can solves the problems of low efficiency and unstable quality of manual operations. The equipment has the following characteristics: the fixed frame design [6], the automatic laying and quilting share a platform and Y-direction drive, and a buffer structure and a three-layer feeding structure were designed for the high flexibility of the polyester mesh and the complex combination of multi-layer insulation[7]. In order to overcome the problem of fixed frame structure without fixed platform, the sling belt system was designed, and the control system was adjusted to perform stepping quilting, in response to the special needs of multi-layer insulation for large stitching [8]. The laying unit has functions of automatic setting of the number of layers, material selection, setting of the spreading length and cutting.

II. DESIGN BASIS

A. Design Parameters

According to the current raw material size and MLI production requirements, the design parameters of the equipment can be proposed. The effective laying dimensions are required: horizontal 1800mm, longitudinal 1000mm~4000mm adjustable. The effective sewing size: horizontal 1300mm, longitudinal 3920mm, and machine size: ≤ 2800mm × 8600mm.

The laying unit can complete the automatic laying of any combination of MLI. The overlap precision of each side of the reflective screen is ±5mm, the front and rear coincidence precision is ±8mm. Any side of the spacer layers cannot be shorter than the reflective screens, and the laying speed ≥ 100mm / s.

The quilting unit has a stitch length of 0.5~25.5mm. The sewing precision is better than 1mm, and the quilting thickness range is 5~30 units.

B. Design Principles

The production of MLI has the following characteristics. First, the MLI is laid and quilted for continuous operation. Second, the number of units of MLI is not fixed, and the commonly used units are 10 units, 15 units and 20 units. Third, the composition of MLI is not uniform. The thickness of the outermost two-layer reflection screen has two specifications.

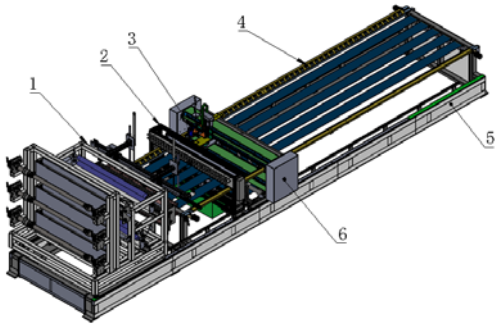
Last, the low-temperature MLI consists of 6~18μm thick aluminized polyester films and polyester meshes. The material is light and thin, and the polyester mesh has a large deformation after being subjected to tension [9].

In view of the above characteristics, the following principles should be observed in the design of automatic laying and quilting equipment. Quilting can be carried out immediately after the laying is completed. The two works are continuous and share the same operating platform, saving the space. The equipment should meet the laying requirements of any number of units and combinations. The equipment also should overcome the material characteristics and ensure the laying quality.

III. SCHEME DESIGN

A. Overall Design

The equipment laying adopts the pulling type [10]. That is, the material rollers do not move, and the manipulator pulls the material out to the appropriate length and cuts it. After the laying is completed, the raw materials are fixed and the needle is moved for quilting. The laying unit and the quilting unit share the belt support, and the structure has good strength and necessary rigidity. The fixtures' width on both sides of the equipment is 35mm each, which satisfies the simultaneous clamping of the 1800mm wide material of the reflective screens and the spacer layers. The main components of the equipment are shown in Figure 1.

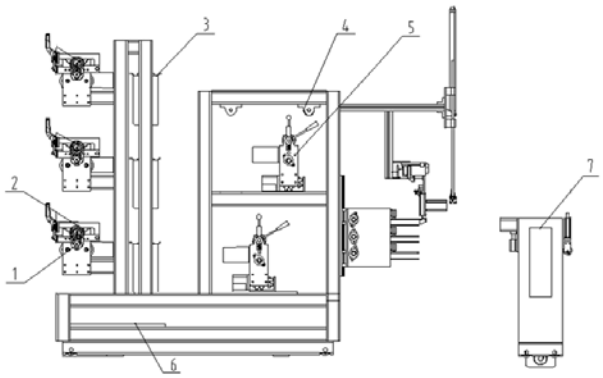


1. Laying unit; 2. Pulling mechanism; 3. Quilting head; 4. Flip type fixture; 5. Equipment base; 6. Quilting saddle

FIGURE I. THE MAIN COMPONENTS OF THE EQUIPMENT

B. Laying Unit

The laying unit mainly comprises a material parking mechanism, a feeding mechanism and a pulling mechanism, and the structure is as shown in Figure 2. The material parking mechanism can meet the placement of two kinds of 1500mm wide-width reflective screens and 1800mm wide-width spacer material. The mechanism and the bed are aligned to ensure that the material laying process is not twisted, and the structure mainly includes 1, 2 in Figure 2. The feeding mechanism can complete the alternating feeding of the two reflective screens and the spacer layer, and eliminate the tension of the material [11]. The structure mainly includes 3, 4, and 5 in Figure 2. The pulling mechanism can cooperate with the feeding mechanism to meet the alternating drawing of the two reflective screens and the spacer layer.

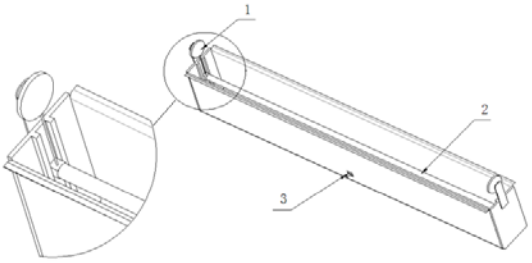


1. Feeding motor 1; 2. Material placement frame; 3. Buffer mechanism; 4. Loose cloth device; 5. Feeding motor 2;
6. Propulsion cylinder; 7. Pulling mechanism

FIGURE II. SCHEMATIC DIAGRAM OF THE LAYING UNIT

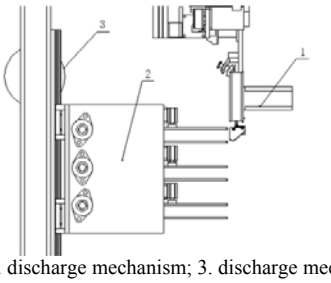
In addition, the parking mechanism and the feeding mechanism can realize two positions of standby and work through the propulsion cylinder at the bottom of the rack, and its main function is to give up the working space when the quilting head is working.

The buffer structure is composed of a spring balancer device and a pressure bar. The pressure of the pressure bar can be adjusted by the spring balancer to pre-spin the cloth [12], and the internal stress of the cloth generated during the winding process can be removed as much as possible. There are remaining cloth detection sensors in the buffer tank as shown in Figure 3.



1. spring balancer; 2. pressure bar; 3. detection sensor

FIGURE III. BUFFER MECHANISM



1. cutter motor; 2. discharge mechanism; 3. discharge mechanism lifting motor

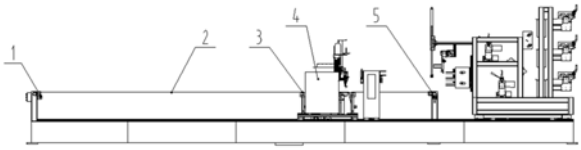
FIGURE IV. FEEDING MECHANISM

The feeding mechanism shown in Figure 4 adopts a three-layer feeding mode, which can be lifted and lowered as a whole, and each layer can send a material.

The function of the pulling mechanism is to clamp the cloth sent out by the feeding mechanism, and then move to the required position on the frame. The clamping part of the pulling mechanism is composed of pressing plates, pressing cylinders and movable pressing plates, and the pressing plates are attached with non-slip material. A static elimination device is added at the discharge port to eliminate the influence of static electricity on the paving.

C. Quilting Unit

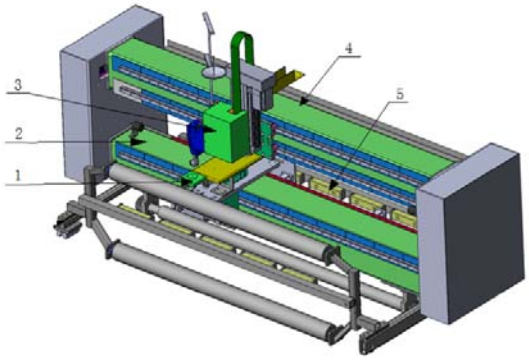
The software control system drives the servo motor and controls the movement of the head through the timing belt. At the same time, the quilting unit performs the needle and hook movement to complete the quilting of any pattern. The structure is shown in Figure 5.



1. locking assembly; 2. support belts; 3. support rollers; 4. saddle; 5. tensioning mechanism

FIGURE V. SCHEMATIC DIAGRAM OF THE QUILTING UNIT STRUCTURE

The saddle frame adopts a saddle structure and a welded box. The structure is stable and reliable through practical application, and the structure is shown in Figure 6.



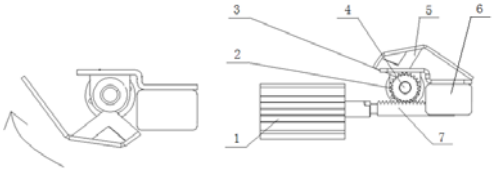
1. Lower head assembly; 2. Lower saddle tube; 3. Upper head assembly; 4. Upper saddle tube; 5. Support belt guide assembly

FIGURE VI. SCHEMATIC DIAGRAM OF THE SADDLE FRAME

The fixture system is pneumatic. The upper splint has a flip type, and the upper splint is hidden below the working plane after being turned over, so that the material can be moved from the quilting area to the cutting area. The structure is shown in Figure 7.

The support belt system is used to support the MLI to prevent sagging, thereby improving the quilting precision. The support belt system includes a support assembly, a locking assembly, and a tensioning mechanism.

One end of the support belt is fixed to the front frame of the machine, and the other end is connected to the rear frame of the machine by a support roller mounted on the saddle. During work, the saddle moves, driving the support roller to roll on the struts, thereby completing the movement of the saddle on the struts.



1. Upper clamping plate driving cylinder; 2. gear ; 3. lower clamping plate ; 4. fixture rotating shaft; 5. upper clamping plate ; 6. fixture beam; 7. rack

FIGURE VII. SCHEMATIC DIAGRAM OF THE FIXTURE

IV. PERFORMANCE TEST

A. Test Materials

After the equipment was completed, the laying test was carried out. The test materials are shown in Table 1, and the test site is shown in Figure 8.

TABLE I. TEST MATERIALS

Serial number	Name	Specification
1	Polyester mesh	20d~30d
2	Double-sided aluminized polyester film	6μm
3	Double-sided aluminized polyester film	18μm

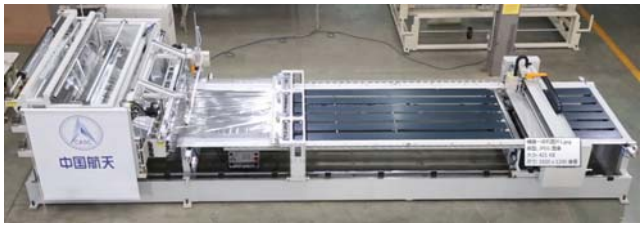


FIGURE VIII. THE TEST SITE

B. Results and Analysis

Test 1: The laying length is 2m, the number of units is 15, and the stitch length is 25mm. The quilting pattern is shown in Figure 9, and the processing effect is shown in Figure 10.

TABLE II. TEST 1 RESULTS STATISTICS

Group	Item						
	Laying wrinkles	Repeatability in length direction	Repeatability in width direction	Length dimension accuracy	Quilting precision	Overall fold	Laying time
1	No wrinkles	±5mm	±1mm	1mm	1mm	Tiny folds	256s
2	No wrinkles	±3mm	±2mm	1mm	1mm	Tiny folds	256s
3	No wrinkles	±3mm	±2mm	1mm	1mm	Tiny folds	256s
4	No wrinkles	±5mm	±3mm	1mm	1mm	Tiny folds	256s
5	No wrinkles	±4mm	±1mm	1mm	1mm	Tiny folds	256s

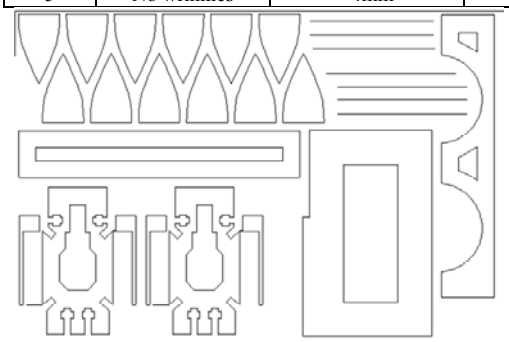


FIGURE IX. TEST 1 QUILTING PATTERN

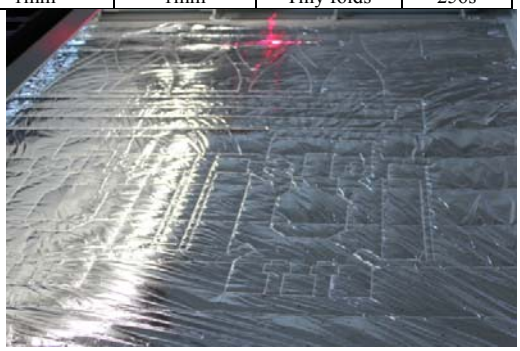


FIGURE X. TEST 1 PROCESSING EFFECT

Test 2: Laying length 4m, unit number 20, stitch length 25mm. Quilting pattern is shown in Figure 11, and the processing effect is shown in Figure 12.

TABLE III. TEST 2 RESULTS STATISTICS

Group	Item						
	Laying wrinkles	Repeatability in length direction	Repeatability in width direction	Length dimension accuracy	Quilting precision	Overall fold	Laying time
1	Tiny folds	±5mm	±2mm	1mm	1mm	Tiny folds	661s
2	Tiny folds	±5mm	±3mm	1mm	1mm	Tiny folds	661s
3	Tiny folds	±4mm	±2mm	1mm	1mm	Tiny folds	661s
4	Tiny folds	±6mm	±3mm	1mm	1mm	Tiny folds	661s
5	Tiny folds	±5mm	±3mm	1mm	1mm	Tiny folds	661s

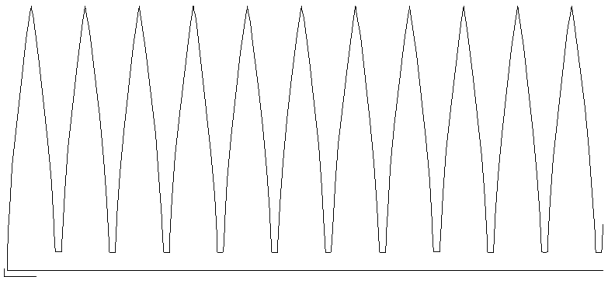


FIGURE XI. TEST 2 QUILTING PATTERN

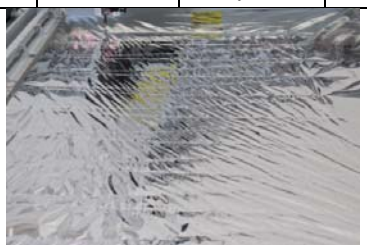


FIGURE XII. TEST 2 PROCESSING EFFECT

The test results show that the equipment can complete the automatic laying of any combination of MLI, and the number of units is adjustable. The coincidence accuracy of each side of the reflective screen meets the requirements of ±5mm and the front and rear coincidence accuracy meets the requirements of ±8mm. The laying speed of 10 units and 2 meters long MLI is about 117mm/s, 20 units and 4 meters long MLI is about 212mm/s, both are more than 100mm/s. The quilting precision is better than 1mm.

In summary, the equipment is reasonable in structure and achieves the expected results.

V. CONCLUSION

This paper designs an automatic laying and quilting equipment with a fixed base. Laying and quilting share one platform and Y-direction drive. A buffer structure and a three-layer feeding structure were designed for the high flexibility of the polyester mesh and the complex combination of MLI. In order to overcome the problem of fixed frame structure without fixed platform, the support belt system was designed, and the control system was adjusted to perform stepping quilting, in response to the special needs of MLI for large stitching. The test results show that the spacecraft MLI automatic laying and quilting equipment realizes high-speed and stable operation, and achieves design goals.

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