Application and Research of Air Cushion Transportation in Flexible Assembly for Spacecraft

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Abstract: With the development of spacecraft, the problem of flexible transfer between large weight and large size spacecraft stations needs to be solved urgently. Air-cushion transporter is a special transporting platform for heavy load. It can effectively solve the transfer problem of large spacecraft. This paper introduces a parallel air-cushion vehicle for large cargo transportation. In this way, there may be a certain height difference on the road surface where the air cushion vehicle moves, which will affect the transfer. The air volume adjustment of the air cushion vehicle is introduced to ensure the smooth transportation method. Through test, it summarizes the key indicators of air-cushion transporting, which can provide reference for the research of large spacecraft transporting methods.

1. Introduction

With the development of a series of super-large spacecraft, the spacecraft cabin and spare parts are very large and heavy. In order to meet the different transshipment requirements of large spacecraft in the assembly process, maneuverable and flexible posture adjustment needs to be solved urgently. Air cushion transporter is a special transporting platform applied to heavy load\(^1\) [2]. It is used in equipment manufacturing and heavy industry as well as special handling in special environment. Compared with omnidirectional\(^3\) transshipment and Mecanum\(^4\) transportation, air cushion transporter has the advantages of high load and small size. In recent years, AGV\(^5\) technology has also been applied in air cushion transporter based on the demand of accurate mobile positioning.

2. Principle introduction

The working process is shown in Figure 1. The air cushion module is the core component of the air cushion vehicle. It consists of an aluminium alloy flat disc and a special ring-shaped reinforced rubber airbag bonded to the flat disc. When the compressed air enters the gasbag from the upper intake pipe, the gasbag expands into a circular shape. At this time, gasbag joins the ground, and the air in the air chamber is sealed, the pressure rises, when the air pressure is enough to support the load on the aluminium alloy, the aluminium alloy plate will be lifted off the ground. Finally, the compressed air escapes from the air chamber at the bottom of the gasbag and lifts the load off the ground. At this time, the air entering and escaping the air chamber reaches balance, and the air pressure is stable, and the whole system is in balance. The air cushion suspension transportation system has flat-panel type, parallel type and AGV type. Different forms of air cushion vehicles can meet the needs of different industries. Figure 2 is a parallel type of air cushion vehicle and Figure 3 is an AGV guided air cushion vehicle.
Air is filled into the air cushion, and the air bag forms the air pressure chamber. The pressure of the air chamber rises and the flat disc is lifted off the ground. The compressed air overflows from the air bag, forms a film with the ground, and suspends the air cushion module from the ground.

Figure 1. Principle

Figure 2. Parallel mode

Figure 3. AGV mode

3. Composition of Air Cushion Transfer Vehicle

The number of air cushion vehicle used for transport goods should consider not only the load, but also the size of the object to be transported. The typical composition of a single vehicle is shown in Fig. 4, Fig. 5. In order to ensure the stability of transportation, the parallel transportation of large-sized spacecraft is usually carried by several vehicle. Take the case of spacecraft's packing container transportation as an example. Transportation weight: 60t, size: 13m×6m×6m (length×width×height). Two air cushion trucks are used to lift the packing box at the front and back positions, and the two air cushions are connected in parallel for spacecraft transportation. Parallel transportation is shown in Fig. 6 and mode of transportation is shown in Fig. 7.

Figure 4. Air cushion transfer vehicle(a)

Figure 5. Air cushion transfer vehicle(b)

Figure 6. Parallel air cushion vehicle

Figure 7. Parallel transportation

3.1. Main structure

The vehicle body is a rigid carrier. The loads and tools to be carried are placed on the vehicle body. The air cushion module is installed under the vehicle body. The balance module and the driving module are installed in the vehicle body. According to different uses and requirements, the size, shape and structure of the vehicle body are different. When in use, the load can be transported as long as the
vehicle body is driven under the object being carried.

3.2. Air cushion module
The air cushion module is the core component of the air cushion suspension transportation system. It consists of an aluminium alloy flat disc and a special ring reinforced rubber airbag attached to the flat disc.

3.3. Driving Walking Module
The electric drive device provides the power needed for the operation of the whole system, as shown in figs. 8 and 9. The electric driving device is mainly composed of driving wheel, walking motor, steering motor and down-pressure device. The drive has the function of slow start, that is, when the whole vehicle starts or stops, it will not overload the heavy objects due to suddenly acceleration or deceleration. Drive can complete the following three directions: downward pressure, walking, steering.

3.4. Balanced module
Balanced module can eliminate the bias effect during walking by changing the air pressure in each air cushion module. It has the function of automatic adjustment and balance for different pavement conditions and different loads of weight and center of gravity. Balancing module is composed of sensor, PLC, valve, buffer tank, pressure gauge, pipeline and so on. The sensor is used to detect the distance between each air cushion module and the PLC receives the feedback signal of the sensor to control the valve to adjust the air pressure in the gasbag. Buffer tank can balance the uniformity of compressed air flow.

3.5. Integrated Control System
The integrated control system is mainly composed of three parts: power supply system, motion control system and human-computer interaction system. The power supply system is the power supply for the whole vehicle, which provides the power for the vehicle electrical equipment, mainly including the storage battery group and the power conversion management module. Motion control system is the core of electrical integrated control system, which mainly completes the functions of vehicle motion.
control, safety monitoring and self-diagnosis of running state. Human-computer interaction system provides the main control interface for user operation, including vehicle status display system and remote control system. For parallel air cushion truck transportation, its motion control processing system works by changing the conduction relationship of the driving steering control valve group to change the air flow direction of the steering cylinder, thus completing the lateral/vertical switching of the driving wheel. The working mode of the motion control and processing system is as follows: by changing the conduction relationship of the drive steering control valve group, the direction of air flow in the steering cylinder is changed to complete the lateral/vertical switching of the driving wheel. The driving wheel moving control device includes a driving wheel moving direction control valve group and a driving wheel moving speed control device. The driving wheel moving direction control valve group is used to change the direction of air intake of the walking air motor, realize the positive and negative rotation of the air motor, and change the moving direction of the air cushion vehicle. The driving wheel moving speed control driver is used to change the opening of the driving wheel moving speed control valve group and adjust the air intake of the air motor, so as to realize the control of the driving wheel moving speed.

3.6. Pneumatic control system
The pneumatic control system consists of air cushion control valve, air cushion, external air pipe reel, air source treatment valve group, driving down pressure gasbag control valve and air pipe. Pneumatic control system is mainly used for driving and steering control, tracheal recovery control and air cushion control. The air cushion vehicle can monitor the total air pressure in real time. When the air supply pressure can not meet the requirements of the air cushion vehicle, the system gives a pressure alarm. The air cushion vehicle is equipped with air source processing device to ensure the working environment of the pneumatic system.

4. Transportation Index test
In order to verify the transshipment capability of the developed parallel air cushion vehicle, the test load is 80t, and the two air cushion vehicles are transported in parallel.

(1) Walking test. The functions of translation, in-situ rotation, acceleration and deceleration were tested to observe whether the moving process was smooth and to measure the parking acceleration.

(2) Travel acceleration: When parking at maximum speed (8m/min), measure its acceleration.

(3) Measure the braking distance when parking. The braking test is carried out during the moving process of the mobile platform, and the braking distance is measured.

(4) Point test. Measure the minimum displacement of the air cushion transfer platform under one control command, that is, the pointing accuracy.

(5) Cooperative performance. Whether parallel two vehicles can be transported smoothly in the process of transshipment.

The load test is shown in Fig. 10. The results of load test of mobile platform are shown in Table 1. Load test results show that it can meet the transshipment requirements of spacecraft from the test results.
Figure 10. Load test

Table 1. Test result

| No. | Item                              | data   | Average value | Result     |
|-----|-----------------------------------|--------|---------------|------------|
| 1   | In-situ rotation migration        | 0.2    | 0.3           | 0.7        | 0.37       | <5mm       |
| 2   | Parking acceleration             | 1.06   | 1.12          | 1.11       | 1.08       | <1.3g      |
| 3   | Stopping distance (8m/min)        | 82     | 91            | 87         | 77.5       | <100mm     |
| 4   | Point distance                    | 5      | 2             | 3          | 5          | 3          | <5mm       |
| 5   | Stationarity (Parallel connection)| √      | √             | √          | √          | √          | stable     |

5. Typical application

Air cushion vehicle has been used in aerospace field. Fig. 11 is an air cushion truck for transshipment spacecraft packing container used in domestic space transportation field. Fig. 12 is for transporting large spacecraft and brackets. Fig. 13 shows the application of air cushion transfer platform in docking of foreign aircraft cabins. Fig. 14 shows that in the engine assembly building of the French Guiana Space Center, the solid rocket engine section is transported by air cushion vehicle with a load of 220 tons.

Figure 11. Heavy packing container transportation Figure 12. Spacecraft and Bracket Transportation
In production practice, such as Airbus, Nokia, ABB, Siemens, Toshiba, Bombardier, General Electric, ALSTOM, BMW, MERCEDES BENZ, Volvo, etc. use air cushion suspension transport equipment to solve the transportation problems of equipment on their production lines. Fig. 15 is the application of Air cushion vehicle in locomotive manufacturing industry. Fig. 16 shows the application of generators in transportation.

6. Concluding remarks

Through the cooperative operation of two or more hovercraft, the large-scale and heavy product handling and moving of spacecraft can be accomplished[6]. Air cushion vehicle transshipment has the advantages of small size and heavy load. It has no advantage in lean control compared with electronic control transshipment truck. It can provide reference for aerospace transshipment logistics field.

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