Simulation of assembling cargo-hold spaceship pallets

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ABSTRACT. The pallet is the load-carrying body between cargo and cargo-hold cabin. Due to the narrow space of cargo-hold cabin, it is difficult for workers to operate. During the installation process of the pallet, it can easily collide with cabin. Based on the installation technology of the pallet, the assembly process of pallet is simulated and analyzed in this paper. The main installation process includes the lifting of pallet, the process of pallet entering the cabin and the assembling of separating device. In the simulation, the practicability of tooling, the standing position of operators, visibility and accessibility of operations are analyzed to determine the risk points in the installation process of pallet. According to the simulation results, feasibility of pallet installation is verified, space requirements for installation are given, and position requirements and posture requirements of workers in the operation process can also be achieved.

1 Introduction

Pallet device is a load-carrying body between cargo and cargo-hold cabin [1], which can be controlled by manipulator arm to take out the pallet and cargo on the pallet, moving them to the designated place to complete the transport function of cargo. The installation of pallet has a very strict requirement [2], a number of tests are carried out to meet the installation requirement [3]. Therefore, simulation analysis of the pallet installation process is needed to verify its feasibility.

Based on the analysis of the pallet assembly process, three-dimensional models of the pallet and the corresponding tooling are established and then imported into the simulation software Jack. By defining digital humans, the installation process of the pallet is simulated. According to the simulation results, the risk points are determined in the installation process of pallet, and some requirements, including installation space, position and posture of workers are presented to give suggestions for further study.

2 Model of pallet and tooling

The three-dimensional model of pallet, cargo-hold cabin and tooling were established by the Creo software. Pallet mechanism consists of six parts, namely the pallet structural body, pressing and releasing device, repeating locking device, guiding mechanism, electric separation mechanism and a controller. The pallet structure body contour size is $2.4\text{m}\times1.7\text{m}\times0.3\text{m}$, as shown in Figure 1.
The rotating tooling is mainly used for horizontal parking of cargo-hold cabin, axial rotation along the X axis in the state of horizontal parking and static parking at any location. It consists of four parts, namely before-ring components, after-ring components, rotating frame car of cargo-hold cabin and flotation systems, as shown in Figure 2a.

Pallet uses separating device as pressing and releasing mechanism. The separating device consists of explosive power source and action execution mechanism, as shown in Figure 2b.

In the simulation software, the height of human is defined to be 167.8cm and the weight is 59kg, as shown in Figure 3 [4].

After the simulation models are established, they are imported into the Jack software [5]. The simulation environment is shown in Figure 4.
3 Simulation of pallet installation

The pallet simulation includes three parts, namely lifting of pallet, pallet installation and the installation of separating device.

3.1 The lifting of pallet

Humans open the pallet packing box and hang the pallet to an open position with spreader, as shown in Figure 5a. Then the pallet is lifted vertically with the spreader, as shown in Figure 5b.

3.2 Installation of pallet

After the pallet is lifted, it will be smoothly transported to the top of cargo-hold cabin opening by crane, then humans get into the cargo-hold cabin and lifting car respectively. The pallet is falling into the cabin slowly under the observation of human, as shown in Figure 6a [6].

3.3 Installation of separating device

After the pallet installed in place, the workers begin to install the separating device which is between the pallet and cargo-hold cabin. First, the screw barrel should be assembled and then the lock body should be assembled. The assembly of separating device is shown in Figure 6b.

4 Simulation results and analysis

4.1 Analysis on the standing position of staff
Because of too many facilities in the cabin and large radian of the cabin surface, the space in the cabin is very limited. Workers are required to install the separating device in both low and high position, and the motion of workers are restricted. Therefore, it’s suggested that auxiliary pedals should be installed in the cabin to provide the stand position of workers to observe the motion of pallet (Figure 7).

![Figure 7. Pedals installed in the cabin](image)

4.2 Visibility analysis of operators

Vision of workers is very important to the installation of the pallet, which directly affects the installation quality. In the dropping process of the pallet, the relative position of the pallet and cabin should be carefully inspected to make sure the alignment of guide rail and guide pulley. The visibility of the workers in the lift car can be analyzed by cone and obstacle area of the staff (Figure 8). The white transparent area is the visual area of the workers and green area is the visual-obstacle area under occlusion of the lift car. Consequently, the vision of the workers in the lift car can meet the requirements.

![Figure 8. Vision of the workers in the lift car](image)

The vision analysis of the workers both in and out of the cabin can be seen from Figure 9. The workers outside the cabin can observe the above area, while workers in the cabin can observe the underneath area to ensure that there is no interference.

![Figure 9. Vision of the workers (a) outside the cabin (b) inside the cabin](image)

In the assembly process of the separating device, vision is the key parameter of installation quality. When installing the separating device in the low position, the vision of workers is shown in Figure 10a. Although workers can observe the whole separating device, the vision will be sheltered by the
separating device during the assembly of the bolt near bulkhead, bringing much difficulty. While workers install the separating device in the high position, the vision of the workers is shown in Figure 10b, which is the same case with some difficulty in the assembly of the bolt near bulkhead.

![Figure 10](image1.png)

**Figure 10.** Vision analysis of separating device installation (a) In low position (b) In high position

4.3 Interference check and recognition of dangerous points

Interference check includes that whether the pallet intervenes with cabin and guide rail during the dropping process and whether the separating device can be installed properly.

The distance between the inner walls of the two guide rails is only a little larger than the maximum width of the pallet guide pulley. Hence, it is likely that guide pulley will collide with pallet. The maximum width of the two guide pulleys is larger than the distance of the two inner walls of a single guide rail with enough space. In the dropping process of the pallet, interference check of the pallet to guide rail and pallet to cabin can be conducted by collision-detect function. In the simulation process, the pallet is required to nearly no shake and drop slowly and steadily to avoid interference. In addition, the position of the pallet screw barrel used to assembly the separating device is very close to the position of the separating device installation, which is a dangerous point and easy to collide (Figure 11a). Therefore, much attention should be paid to the position during the dropping process of the pallet.

![Figure 11](image2.png)

**Figure 11.** (a) Dangerous point (b) Installation of separating device

4.4 Analysis of work postures

To ensure the health and safety of workers, work postures of workers are analysed in the simulation. Watchdog is used to monitor the work postures during the whole installation process [7]. It is found that the work posture will cause harmful levels of stress on the musculoskeletal system when workers squat to install the separating device (Figure 12). Since this operation is a short-time job and cannot be avoided, it can only be accepted. To further analyse the static strength of this posture, it is proved that 80% of people can complete the motion and the analysis results can be seen from Figure 13.
5 Conclusions
In this paper, the installation of cargo-hold spaceship pallet is simulated to verify the pallet-mounting process. The following results can be derived from this investigation.

1. The pallet installation plan is feasible, and workers can operate with good visibility and accessibility.

2. In the dropping process of the pallet, there is enough room between pallet and guide rail or cabin to avoid the collision. Whereas the distance between guide pulley and guide rail is relatively close, which is easily to collide. Consequently, the pallet is required to drop steadily to avoid shaking and inclining.

3. Workers operate under low stress during the installation, which would cause nearly no harm to health.

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