ESMA 2019  
IOP Conf. Series: Earth and Environmental Science 440 (2020) 052058  
doi:10.1088/1755-1315/440/5/052058

Structural Design and Mechanical Analysis of Horizontal Transport Device for Spacecraft Marine Transportation

Hailin Dai‡, Ruizhao Du*, Xu Jiang§ and Yushuang Li‡
Beijing Institute of Spacecraft Environment Engineering, Beijing 100094, China

*Corresponding author e-mail: bhdhl88@163.com, ‡374456848@qq.com, §876823230@qq.com, †875985190@qq.com

Abstract. As a large spacecraft used to transport up-going cargo and test load equipment to space, cargo spacecraft is an important means of space transportation for material transportation and replenishment of China's space station in the future. The cargo spacecraft is the first large-scale spacecraft to be transported by sea in China. In this paper, a cargo horizontal conveyor is designed. The mechanical structure of the device is introduced, and the finite element analysis is carried out. The results show that the structure of the horizontal conveyor is reasonable, and its mechanical properties meet the requirements of use.

1. Introduction
As a large spacecraft used to transport up-going cargo and test load equipment to space, cargo spacecraft is an important means of space transportation for material transportation and replenishment of China's space station in the future [1]. After the completion of the ground research and development of China's cargo spacecraft, the mode of transportation from the assembly test plant to the Hainan launch site is sea transportation, that is, large commercial ships are transported by sea to the launch site [2-4].

In order to meet the fast-paced loading requirement of large spacecraft, some ground test equipment needs to be transferred from the cabin to the designated area. In this paper, a device for horizontal transmission of spacecraft marine transport equipment is designed, and the components of the device are analyzed, calculated and optimized by finite element analysis software, so that it can meet the requirements of light structure and high stiffness and strength performance.

2. Structure Composition of Horizontal Conveyor
The equipment system designed in this paper can be divided into six parts: profiles, rollers, sprockets, X-direction sliders, X-guide rails and fixed platforms. The structure of the device is shown in Figure 1. The conveyor is mounted on a fixed platform, which is fixed together with the aluminum alloy frame of the hoist. The transmission function is realized by parallel cylindrical rollers, and the transmission mode is chain transmission [5]. In detail, there are flexible balustrade devices on the left and right sides to prevent the delivery of goods falling in the air, damage to the delivery of goods and other machines.
When not working, the conveyor can move along the x-axis direction, insert into the inside of the vertical hoist, reduce the space occupied, and avoid the deflection caused by gravity. This function is realized by a left-right adjustable mechanism consisting of two sets of slide blocks and a set of gears and racks at the lower part of the conveyor. Each set of slide blocks is composed of two slide blocks and one guide rail. Each set of two sliders is fixed on the fixed platform. Two guideways and two groups of racks are parallel installed on the lower surface of the transmission component. When the motor drives the gear to rotate, the rack matched with the gear moves along the x-axis direction, and the guide rail moves along the slider, thus driving the whole transmission device to move along the x-axis direction. It avoids interference with the guide, chain and tray of the vertical lifting parts when inserting. The layout and size of the above parts have been repeatedly designed and optimized, and the interference simulation has been carried out [6]. Finally, the structural parameters of each part have been determined, so that the whole tooling can meet the requirements of use.

When the conveyor is moved along the X direction and placed in the vertical lifting parts, the structural force is ensured to be stable, and the safety of the tooling is improved when it is not in use. The supporting structure is designed. It can be placed on the supporting structure.

3. Structure Design of Horizontal Conveyor

3.1. Selection of Aluminum Profiles

Based on saving tooling space and guaranteeing the strength of the structure, two aluminium profiles are selected as the support frame of the whole tooling, and the length of the frame is \( L = 2000\text{mm} \). When the overall load of the tooling is 80kg, the end of a single profile is loaded with \( F = 400\text{N} \), one end is fixed and supported, the other end is cantilever, APS-8-30150 aluminum profile is selected, which is suitable for frame combination structure with high stress and strength. Its shape adopts round corner transition, the surface is anodized, and the special bolt for rigid strength of M6*16 is used with elastic fastener [7]. Internal connection is one of the most widely used profiles in industrial frameworks. Its main performance parameters are shown in Table 1.

According to the deformations of aluminium profiles under static loads:

\[
\delta = \frac{FL}{3EI} = \frac{400 \times 2000}{3 \times 70000 \times 265.83 \times 10^3} = 5.73\text{mm}
\]

Since the guide rail will also bear part of the load, the displacement of the end of the variable height transmission component will be less than this value.

| Table 1. Attribute parameters of aluminium profiles. |
|----------------------------------------------------|
| term          | parameter |
| Material Science          | 6063-T5          |
| weight          | 1.85kg/m          |
| Section Length          | 80mm          |
| Section width          | 20          |
3.2. Rollers
According to the load of 100kg, choose the roll of 38, and choose the center distance. The weight and smoothness of the conveyor must be considered. At least three rollers must contact the conveyor at any time, as shown in Figure 2.

![Figure 2](image)

**Figure 2.** Legend for Calculating Roll Spacing and Length (1-Goods 2-Rollers).

P=1/3L, among them, P--roller spacing, mm; L--Cargo delivery length, mm
The shortest delivery length L=360mm, then P=100mm. Considering the smoothness of transportation, the final distance between the rollers is 100mm. The length of the conveyor is 2000 mm, which requires about 20 rollers [8].

Selection of Roller Length:
Because the bottom of the goods is hard and flat, it can be calculated according to the following formula: B=(70%~80%) W

Among them, B is the length of the roll; W - Width of Cargo Delivery
The broadest W=570mm for the cargo is B=(70%~80%) W=(399~456)mm. Considering the size limitation of the cargo hold and the smoothness of the cargo delivery, B = 400mm is selected.

3.3. Selection of slider for guideway
The slider of the guide rail is installed on the lower surface of the horizontal conveyor component, and the slider plays a fixed role. At the same time, the high level conveyor component can move along the X axis. Therefore, the slider of the guideway needs higher strength and lower friction resistance.

1) Length Selection of Guideway:
The length of the guide rail is determined according to the length of the high level transmission component. \( L = 1800 \text{mm} \)

2) Type Selection of Guide Slider:
The friction coefficient of the guide rail system is \( \mu = 0.1 \) and the efficiency is \( \eta = 80\% \).

Fig. 3 is a schematic diagram of the force acting on the slider of the guide rail. The force acting on the guide rail is calculated.

Slider radial load:
\[
F_r = (800 + 1.9 \times 2 \times 10 + 800) / 2 = 819(\text{N})
\]

The pitching moment of profiles, rollers, guideways and cargo at 1.8m is
\[
M_A = (800 \times 1.8 + 800 / 2 \times 2^2 / 2) / 2 = 1120(\text{Nm})
\]

![Figure 3](image)

**Figure 3.** Force diagram of slide block of guide rail.
3.4. Transfer load
The transmission force is: $$F_{\text{tran}} = 800 \times 0.1 = 80\text{(N)}$$

The speed of roll transfer is determined according to productivity and process requirements. The speed of driving roller conveyor should not be greater than 1.5m/s. Excessive speed can cause noise and wear. The speed of chain driving roller conveyor should be less than 0.5m/s. In this project, chain drive roller transmission is adopted, and the transmission speed is 1m/s.

If the total transmission efficiency $$\eta = 90\%$$, the required power is: $$P_{\text{trans}} = \frac{F_{\text{tran}} \cdot v_{\text{tran}}}{\eta} = 44.5\text{(W)}$$

Because the motor and reducer are driven by a set of vertical lifting parts, the selection of driving parts is carried out by combining two kinds of loads.

3.5. Selection of Conveyor Belt Motor for Conveyor Parts
According to the calculation in 3.4, the motor torque is required to be:

$$T = 9550\frac{P_{\text{trans}}}{n} \approx 0.85\text{(N.m)}$$

Hybrid stepper motor with rated torque of 1.8Nm and rotary inertia of 460g.cm2 is selected.

3.6. X-Directional Moving Gear and Rack
The weight of rollers, guideways and profiles is about 100kg, and the friction coefficient of slider is set to 0.1, so the driving force of X-direction movement is as follows.

$$F_X = 1000 \times 0.1 = 100\text{(N)}$$

The indexing circle diameter is about 60 mm. For this reason, stainless steel racks with modulus of 3.18 mm and rack allowable transmission force of 1050 (tooth surface) / 4370 (bending) are selected.

3.7. Selection of X-direction mobile motor
Assuming the moving speed is 0.5m/s, if the total transmission efficiency $$\eta_x = 90\%$$, the required power and motor torque are:

$$P_x = \frac{F_x \cdot v_x}{\eta} = 55\text{(W)}$$

$$T = 9550\frac{P_x}{n} = 3.3\text{(N.m)}$$

A hybrid stepper motor with rated torque of 4.6Nm and rotary inertia of 1400g.cm2 is selected.

4. Mechanical analysis
In order to study the strength of the whole horizontal transmission component, the finite element simulation of the whole transmission component is carried out, and the maximum stress and the maximum displacement of the end are checked. Among them, the simulation has included the gravity of rollers, guideways, profiles and other components, as well as the load on the end of the package [9, 10]. The simulation results (deformation and stress) are shown in the following figures.

1) The terminal load of the high level transmission unit is 100kg.

By analyzing the displacement of the cantilever profile, the maximum displacement of the front end of the profile is 3.7mm, which is within the acceptable range as shown in Figure 4. Similarly, several points are selected on the profile in turn (from left to right of the fixed end) to check the stress situation. As shown in Fig. 5 and 36, it is found that the more close to the fixed end, the greater the stress change, reaching the maximum of 47MPa, and the smaller the stress change at the point far away from the fixed end. It should be noted here that the amount of deformation is enlarged for easy observation.
Figure 4. Deformation.

Figure 5. Stress.

Figure 6. Section Stress.
2) Horizontal conveyor end bearing 50kg
The maximum weight of the bags transported at the front hatch is 40kg, and the static analysis of the loaded bags is 50kg. The following results can be obtained. Through the displacement analysis of the cantilever profile, the maximum displacement of the front end of the profile is 1.7mm, which can meet the requirements of the use as shown in Figure 7. Similarly, as shown in Fig. 8, it is found that the greater the stress change near the fixed end, the maximum is 19MPa, and the smaller the stress change at the point far from the fixed end. The maximum stress is far less than the yield limit of the material, so the high level transporting parts can meet the load-bearing requirements of 50kg.

![Deformation](image1)

**Figure 7. Deformation.**

![Stress](image2)

**Figure 8. Stress.**

5. Conclusion
1) A device for horizontal transmission of spacecraft marine transport equipment is designed, which realizes the horizontal transmission of cargo: the horizontal transmission function is realized by power rollers, with high transmission efficiency and high automation level.
2) On the basis of completing the function of transporting cargo horizontally, the hoist has lighter weight and compact structure, which can better meet the cargo transporting in the process of transporting cargo spacecraft by sea.

3) The finite element simulation results show that the strength and stiffness of the horizontal transmission device can meet the requirements of operation.

References

[1] Y HU. Discussion about Dimension Analysis and its Application [J]. JCJEVC, (2006), 23(2):52-54.
[2] Y Y SHAO. Comprehension and Application for Dimensional Analysis and Rule π [J]. JDIT, (2010), 17(3):106-109.
[3] Z, J F. The Aircraft Cargo Carrier and The Method of Transporting Cargo into and out of the cargo hold: China, US 2002/0159869 A1 [P]. Nov.12, 2008.
[4] Du R Z, He Y, Xing S, et al. A device applicable to the entrance of a cargo ship's front hatch:China, 20151 0007340. 1 [P]. Jun. 17, 2015.
[5] Wang X, Zhang R, Guo X X. Overview of Foreign Cargo Spacecraft [J]. Space International, 2017(420): 24-32 (in Chinese).
[6] Kong X X, Xing J X, Wen B C. Analysis of Motion of the Part on the Linear Vibratory Conveyor [J]. Journal of Northeastern University (Natural Science), 2015, 36(6):827-831 (in Chinese).
[7] Yugo F, Minato-Ku, Toru T. AIR CARGO TRANSPORT SYSTEM: United States, US 2002/0159869 A1 [P]. Oct. 31, 2002.
[8] Y S DAI, L YANG. Applications of dimensional analysis and the rule π in chemical engineering-process improvement of teaching in the course of Principle of Chemical Engineering [J]. JNIT, (2010), 9(1):11-16.
[9] L ZHANG, M CAO, H G PENG, S L ZHOU. Application of therbligs analysis in assembly line balancing [J]. JZJUSE, (2010), 22(2):89-94.
[10] T GU, B H ZHOU. Application of action analysis method in improvement of cylinder block line balance [J]. MM, (2009), 47:54-57.