Random Vibration Analysis of L-type Electric Luggage Conveyor Vehicle Frame

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Abstract—In order to verify the rationality of the designed L-type electric luggage conveyor vehicle frame structure, this paper imports the frame structure of the designed L-type conveyor vehicle into ANSYS Workbench software, conducts modal analysis, and evaluates the performance of the frame by analyzing the inherent frequency and vibration pattern, then uses Matlab to build the simulation model of the airfield pavement, calculates the power spectrum density, and the dynamic response and stress solution of the conveyor vehicle under specific operating conditions, and conducts random vibration The dynamic response and stress solution of the frame under the specific operating conditions are obtained. The results show that the frame of the L-type electric luggage conveyor is less excited by the road surface during the driving process, which will not cause large damage to the structure and is reasonably designed in terms of vibration characteristics.

1. Introduction

Many airports have completed the electrification of special equipment with the promotion of the "oil-to-electric" project, but the frame structure has not been improved according to the load change before the modification of the conveyor vehicle. The unevenness of the road surface will affect the vibration of the vehicle, and the vehicle will be excited by the random displacement generated by the road surface, leading to structural fatigue damage, and may even cause resonance[1], in the driving process of some newly produced electric equipment and "oil-to-electric" equipment, there have been different degrees of vibration, leading to driver discomfort, so After the modal analysis of the structure, a random vibration analysis is necessary. In the design and analysis of airport conveyor belt vehicles, there are relatively few random vibration analyses for the vehicle body and important structures. In this paper, based on a new type of airport conveyor belt vehicle, ANSYS Workbench analysis software is used to analyze the modal analysis and random vibration analysis of the frame structure, to obtain the equivalent force cloud diagram and dynamic response of the frame, to analyze the rationality of the structural design, and to provide reference for the design of the frame and the whole vehicle.

2. Random Vibration Analysis Method

Luggage conveyor vehicles in the airport driving process, will be caused by the unevenness of the road surface vehicle vibration, this excitation for a kind of random vibration load. The structure will have a variety of failures that may occur when it receives a random load state. In order to verify the reliability of the frame structure, random vibration analysis of the structure is required, and the process is as that:

1) To build 3D modeling of the frame, and pre-stress modal analysis using ANSYS Workbench
software.

2) To build an airport road surface model using Matlab and calculate the power spectral density.

3) Based on the pre-stress modal analysis, input the power spectral density to solve the response and maximum stress of the frame under random vibration.

The power spectral density (PSD) is a probability statistic of the structure for random excitation of a random pavement and is used to describe the relationship between power spectrum and frequency. Due to the strict requirements of airports, there are fewer opportunities to perform pavement unevenness measurements in airports, so the power spectral density of the airfield pavement can be obtained by calculation.

The spatial power spectral density of the road surface $G_d(n)$ can be expressed by the following equation:

$$G_d(n) = G_d(n_0)(\frac{n}{n_0})^{-w}$$  \hspace{1cm} (1)

$n_0$ is reference spatial frequency; $G_d(n_0)$ is the pavement spectrum value; $n$ is spatial frequency.

In addition to the unevenness of the road surface, the input of the random vibration analysis of the frame is also the travel speed of the conveyor car. The relationship between the two is as follows:

$$G_d(f) = G_d(n)/v$$  \hspace{1cm} (2)

If $w=2$, Substituting equation (1) into equation (2):

$$G_d(f) = G_d(n_0)G_d(n_0)n_0^2\frac{v}{f^2}$$  \hspace{1cm} (3)

$$G_d(\omega) = G_d(f)/(2\pi) = 2\pi G_d(n_0)n_0^2\frac{v}{\omega^2}$$  \hspace{1cm} (4)

3. Complete vehicle structure modeling

As shown in Fig.1(a), the design of the frame is sketched, the battery pack is placed separately in the middle of the frame on both sides, which not only provides power for the conveyor car but also plays a counterweight effect; the middle part of the frame holds the electronic control equipment and other auxiliary equipment, which is convenient for installation and later maintenance. The three-dimensional model of the frame is shown in Fig.1(b), which consists of longitudinal beam, crossbeam and other parts. The longitudinal beam is changed from the previous I-beam to C-channel steel, with small support rods welded inside to increase the structural strength, and the crossbeam is changed from round tubes to square tubes with different specifications to increase the bearing area and facilitate installation and maintenance. The total mass of the improved frame is 426.25 kg, and the connection between the components is welded.

The main difference between the L-type electric luggage conveyor and the traditional conveyor is the innovation of the conveyor frame, which combines the telescopic conveyor mechanism with the linear conveyor mechanism to realize the luggage transportation inside the cargo compartment of the aircraft.

From Fig.2, it can be seen that the conveyor mechanism, lifting mechanism, battery and electric control equipment are carried by the frame, and the loads generated by these parts are distributed in different positions. The second and fourth crossbeams of the frame are hinged with the lower end of the lifting mechanism, the battery box is installed in the middle of the left and right side beams of the
frame, and the electric control equipment is installed in the middle of the third and fourth crossbeams.

![Standby vehicle model](image1)

![Model of vehicle in transmission](image2)

Fig.2 3D model of the whole vehicle

4. Modal Analysis
The model is imported into Workbench, coordinates, materials and constraints are set, and then the meshing and boundary conditions are set[3]. The load distribution of the frame is shown in Tab.1.

| name                  | load/N | name                  | load/N |
|-----------------------|--------|-----------------------|--------|
| motor                 | 2000   | conveyor rack         | 8800   |
| battery               | 15000  | front Lifting Frame   | 1250   |
| electric control equipment | 3000  | rear Lifting Frame    | 850    |
| vehicle Shell         | 1674   | cab and driver        | 1200   |

After completing the above settings, the modal solution of the frame model can be performed, and the results obtained are shown in Tab.2. The range of the first 6 orders of intrinsic frequencies is between 43 and 71 Hz.

| modal order | frequency/Hz | vibration characteristics                        |
|-------------|--------------|--------------------------------------------------|
| 1           | 43.044       | longitudinal beam cross-swing                    |
| 2           | 49.413       | vertical bending of longitudinal beam            |
| 3           | 52.819       | front crossmember swing + longitudinal beam second-order swing |
| 4           | 57.746       | mid-transverse beam vertical bend + longitudinal beam second-order vertical bend |
| 5           | 64.272       | rear crossmember swing + longitudinal beam third-order swing |
| 6           | 70.446       | longitudinal beam twisting + vertical bending of middle and rear cross members |

5. Random Vibration Analysis
According to GB/T 7031-2005[2], the excitation frequency caused by the unevenness of the road surface is related to the speed. According to the requirements of the airport on the road surface, the road surface of L-type electric luggage conveyor belt vehicle driving in the airport can be regarded as B-class road surface, and according to MH/T 6030-2014[4], the driving speed of electric conveyor belt vehicle is 0~40 km/h, which is generally 25 km/h.

In equation (5), when \( w \to 0 \), \( G_d(w) \to \infty \). Thus the PSD is:

\[
G_d(\omega) = 2\pi G_d(n_0) \frac{n_0^2 \omega^2}{\omega^2 + \omega_0^2}
\]

(5)

\( \omega_0 \) is minimum cutoff angle frequency; Equation (5) can be regarded as the response of white noise excitation.

\[
G_d(\omega) = |H(\omega)|^2 S_w
\]

(6)

\( H(w) \) is frequency response function; \( S_w \) is PSD of white noise, \( S_w = 1 \).

\[
H(\omega) = \frac{n_0^2 \sqrt{2\pi G_d(n_0) \nu}}{\omega_0 + j\omega}
\]

(7)

The differential equation of pavement unevenness can be introduced from equation (7).

\[
q(t) + 2\pi n_3 \nu q(t) = n_0 \sqrt{2\pi G_d(n_0) \nu} W(t)
\]

(8)
$q(t)$ is unevenness function; $W(t)$ is gaussian white noise; $n_1$ is spatial cut-off frequency of the airport road surface.

According to equation (8), the simulation model of airport road surface unevenness is built in Matlab as shown in Fig.3, the time domain excitation signal is shown in Fig.4, and the calculated power spectral density is shown in Fig.5.

![Fig.3 Road roughness model in time-domain](image)

![Fig.4 Roadway Incentives and PSD](image)

![Fig.5 Equivalent stress contour](image)

The calculated PSD values are imported into the analysis module, and the frame is analyzed for random vibration, and the equivalent force cloud map is obtained. As shown in Fig.5, the maximum stress of the frame1 is 11.302 MPa, and the location of the occurrence is near the right longitudinal beam near the front cross member of the frame, and the node number is 303605.

The fatigue strength design is one of the items to be considered in the structural design, and the fatigue strength limit of Q345 steel is 294.6 MPa, and the maximum stress is much less than this value in the analysis results, so the improved frame structure meets the fatigue strength requirements\(^5\).

The displacement response at node number 303605 is shown in Fig.6. When the frequency is 49.323Hz, the resonance phenomenon occurs in the frame, and the displacement changes greatly, and the maximum displacement occurs at 70.317Hz. Therefore, when designing the electric luggage conveyor car, the vibration frequency of the structure and electric control equipment should be avoided to be close to this frequency\(^6\).
6. Conclusion
Based on the results and discussions presented above, the conclusions are obtained as below:

1) Improvements are made to the frame, and the load distribution is re-planned to make the load situation on the frame more reasonable, which can provide reference for the future design of electric equipment.

2) In the modal analysis, the first 6th order inherent frequency of the frame structure ranges from 43 to 71 Hz, and its vibration pattern is mainly bending, and the average deformation is less than 2.5 mm/m. The structural design of the frame is reasonable and safe in terms of vibration characteristics.

3) In the random vibration analysis, the PSD at 25km/h is calculated, and the 1 stress solution and the maximum stress location of the frame are obtained through simulation, which shows that the frame structure meets the fatigue strength requirements and provides a basis for the design of the frame and the whole vehicle structure.

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