Dynamic and Static Analysis of a AGV Forklift

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Abstract. In this paper, a dynamic counterweight device is designed to avoid the offset of AGV forklift in the actual vehicle operation; the strength of the working device under dangerous working conditions is verified by finite element static analysis; based on the multi-body dynamics theory, the dynamic analysis of the forklift truck shows that the reason for the deviation is the eccentric load of the forklift after lifting. The function of the dynamic counterweight device is verified by the dynamic analysis of whether there is a dynamic counterweight device or not. The results show that the dynamic counterweight device can significantly improve the running deviation of AGV forklift when the eccentric load meets the design requirements, and improves the motion accuracy.

1. Introduction
AGV forklift is one of the main logistics tools in an intelligent factory[1]. It has a high load capacity, a high degree of standardization, and wide application. It is the development direction of factory automation logistics in the future[2][3]. With the economic and social development and infrastructure construction needs in China, the demand for unmanned forklifts for intelligent storage systems will increase, and its precision, efficiency, driverless and energy-saving characteristics will be more widely used.[4][5] The Omni-directional mobile AGV forklift based on the mecanum wheel can realize the straight-line walking, left-right translation, rotation around its center, etc. The best choice in limited space and particular application[6]. However, in actual operation, the AGV forklift will have an unbalanced load, which will lead to unstable operation of the forklift and affect the accuracy of forklift movement.

2. AGV forklift dynamic counterweight device
The dynamic counterweight device should meet two functional requirements in the process of AGV forklift operation: firstly, when the AGV forklift forks the goods, the dynamic counterweight should move to the corresponding working position and keep it so that the tires on both sides are evenly loaded; when the forklift forks the goods at the far left end, the dynamic counterweight device should ensure that the whole vehicle does not overturn. According to the use conditions and requirements, the dynamic counterweight device designed in this paper, as shown in Figure 1 below, uses a motor to drive a driving wheel directly under the dynamic counterweight, in which there is a driven roller at each corner of the dynamic counterweight. The scheme has a simple and reliable structure, low cost, and meets the accuracy requirements.
3. Static analysis of AGV forklift truck

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3.1. Static analysis of inner portal frame

Finite element static Analysis is based on the finite element analysis to investigate the structure's response under static load[7][8]. Its main feature is that the gear is fixed and does not consider the influence of inertia and damping[9][10]. When the distance between the inner gantry rollers is equal to that of the forklift, the inner gantry is dangerous. Therefore, the static analysis is carried out to verify whether the strength and stiffness meet the design requirements. Figure 2 shows the nephogram of the equivalent force of the inner gantry. It can be seen from the figure that the maximum value is 209.88mpa, which is located at the position where the lifting cylinder acts. For 16Mn steel, it is 230MPa[11], so the strength of the inner gantry meets the design requirements.
Figure 2 shows the stress nephogram of the outer portal frame. It can be seen from the figure that the maximum stress is 179.61 Mpa, which acts on the transverse beam of the outer portal frame. For 16Mn steel, it is $\sigma_s = 230$ MPa, so the strength of the outer portal frame meets the design requirements.

Figure 3 shows the displacement nephogram of the outer gantry. According to the figure, the maximum displacement of the outer door is 6.2 mm, and Allowable horizontal forward movement $[f] = 30$ mm, so the stiffness of the outer portal frame meets the design requirements.

4. Dynamic analysis

4.1. Analysis of simulation results without dynamic counterweight device

The weight of AGV forklift without dynamic counterweight device is 3039.6 kg, and its centroid position is (-1266, -713.28, 851.8). Set the analysis condition as straight line along X direction.
Figure 4. Forklift center of mass Vel_TX

According to figure 4, the stable speed of the AGV forklift truck in X direction is about 954.85mm/s, while the theoretical $V_x$ in X-direction is 972.22mm/s, the error is small and acceptable.
From the analysis of the displacement curve, it can be seen that its displacement in the positive direction of the X-axis shows a linear increase, with a linear displacement of 8497.82mm. Figure 5 (b) is the displacement curve of the AGV forklift in the positive direction of X when it moves in the positive direction of Y. It can be seen from the figure that its displacement along the Y-direction is about 32.3mm, and the running time is 10s. Figure 6 shows the angular displacement of the forklift’s center of mass around the Z-axis. It can be seen that the forklift’s deviation in the Y-direction is caused by the forklift's rotation around the Z-axis.

Figure 5 (a) is the displacement curve of the AGV forklift when it moves in the positive X direction. From the analysis of the displacement curve, it can be seen that its displacement in the positive direction of the X-axis shows a linear increase, with a linear displacement of 8497.82mm. Figure 5 (b) is the displacement curve of the AGV forklift in the positive direction of X when it moves in the positive direction of Y. It can be seen from the figure that its displacement along the Y-direction is about 32.3mm, and the running time is 10s. Figure 6 shows the angular displacement of the forklift’s center of mass around the Z-axis. It can be seen that the forklift’s deviation in the Y-direction is caused by the forklift's rotation around the Z-axis.
Figure 8. Four-wheel angular velocity curve

Figure 7 is the curve of the angular velocity and angular acceleration of the geometric center. The figure shows that the geometric center has an angular acceleration around the Z-axis and causes the Z-axis’s angular momentum to fluctuate. From its dynamic characteristics, the Y-direction deviation is the unbalance of the left wheel caused by the AGV forklift after the forklift picks up the goods. From Figure 8 we can see the force on both sides of the wheel is uneven, and the drive torque required on the left side increases. The speeds are equal, so the two wheels on the left slip and the forklift deflects when starting, causing the forklift to deviate[13][14].

4.2. Analysis of simulation results with dynamic counterweight

The group weight of AGV forklift with dynamic counterweight device is 3512.34kg, and its centroid position is (-1266, -795,801.14). Set the analysis condition as straight line along X direction.

Figure 9. Forklift center of mass VX

Figure 9, the stable speed of the AGV forklift's center of mass in the X direction is about 949.9mm/s, while the theoretical Vx in the X direction is 972.22mm/s. The error mainly comes from the modeling error, but the error is small.
Figure 10. Center of mass displacement curve with dynamic counterweight

Figure 10 (a) is the displacement curve of the AGV forklift when it moves in the positive X direction. From the analysis of the displacement curve, it can be seen that its displacement in the positive direction of the X-axis shows a linear increase. The linear displacement is 8468.7mm, which is less than none. The counterweight is caused by the rise in the AGV forklift’s weight, increasing by driving resistance.[15] The counterweight is caused by the increase in the AGV forklift weight, increasing by driving resistance. Figure 10 (b) is the displacement curve of the AGV forklift in X’s positive direction when it moves in Y’s positive direction. The figure shows that the displacement of the center of mass in the Y direction is 0.10mm, which is small and negligible, so the dynamic-counterweight device can prevent the forklift from deviating effectively.
To further verify the counterweight device's function, the working conditions of the forklift rotating around the Z-axis in situ were analyzed. From the Figure 11 and Figure 12, it can be seen that the AGV forklift with the counterweight device rotates faster and can be earlier reach the predetermined position; that is, the steering is more stable.

5. Summary

Based on the principle of finite element static analysis and multi-body dynamics, the strength and stiffness of forklift working device are checked, and the rationality of structure design is verified. Firstly, dynamics analysis of AGV forklift with or without dynamic counterweight device is carried out by using multi-body dynamics software RecurDyn. The dynamic analysis of the non dynamic counterweight device is carried out. Through the angular acceleration curve around the z-axis, it is concluded that the unbalanced load is the cause of vehicle running deviation. By analyzing the dynamic model of AGV forklift with dynamic counterweight device, it is verified that the counterweight device can solve the problem of AGV forklift running deviation. The results of dynamic analysis verify the rationality of the design of counterweight device

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