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Design and Development of a New Lightweight High-speed Stacker

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ARTICLE INFO	ABSTRACT
	A new lightweight high-speed stacker is designed and developed. Its technical parameters are leading the industry level, which can meet the current requirements for high efficiency of intelligent logistics system. Starting from the key structure of stacker, through the theoretical analysis of the new mechanism and the comparison of the new and old equipment, the advantages of the new mechanism in improving the efficiency and light-weight design of stacker are explained. Through ANSYS Workbench finite element software, the structural strength of the main bearing mechanism is analyzed, and the results show that the strength meets the requirements.

1. Introduction

With the increasing efficiency requirements of all walks of life, the logistics storage system needs to be improved in hardware system and software control. As the core equipment of the logistics storage system, the upgrading and technology upgrading of the stacker system is particularly important. The technical parameters of stacker, such as horizontal operation speed and acceleration, vertical operation speed and acceleration, fork storage and pick-up speed, play an important role in improving the operation efficiency of stacker and the efficiency of intelligent warehouse. However, the premise of improving these technical parameters is that the design and structural strength of the stacker should meet the requirements.

In this paper, the lightweight measures of lattice aluminum alloy column are selected to reduce the self weight of the stacker and play a fundamental role in the speed-up of the stacker. Through the design of the new driving mechanism, it is possible to improve the acceleration of the stacker. Through the design of the lifting mechanism driven by synchronous belt, it provides a guarantee for the improvement of the lifting acceleration of the stacker. The lightweight high-speed stacker designed by the above measures can meet the requirements in terms of running speed and warehousing efficiency.

2. Introduction of Lightweight High Speed Stacker

In the current intelligent logistics system, lane stacker is often used. According to the structure of the stacker, it can be divided into double column stacker and single column stacker. The lightweight high-speed stacker researched in this paper is one of the single column stacker, and its structure is shown in Figure 1. Working principle of the stacker: the clamping rail driving mechanism drives the

stacker to run horizontally along the rail of the three-dimensional warehouse, the synchronous belt lifting mechanism drives the pallet and the fork to rise and fall to the designated position along the column, and the goods are sent to the target location address or taken out through the expansion mechanism of the fork.
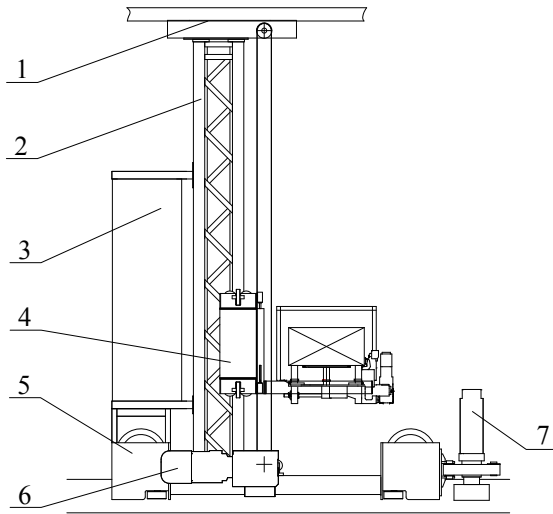

Figure 1. Schematic diagram of lightweight high-speed stacker: 1. Upper crossbeam 2. Lattice aluminum alloy column 3. Electrical components 4. Freight platform 5. Lower crossbeam 6. Synchronous belt lifting mechanism 7. Clamping rail driving mechanism

3. Key Structure Design of Lightweight High Speed Stacker

For the requirement of high speed, high acceleration and high efficiency, the conventional design of the traditional stacker can not meet the requirements, which requires new design methods such as changing the structural form and material of the column, adopting new driving mode and lifting mechanism. The specific implementation of the design is as follows.

3.1 Application of Lattice Aluminum Alloy Column

It is the first time to use a new lattice aluminum alloy column, whose density accounts for about one third of the density of steel, which is helpful for the lightweight design of stacker and plays a fundamental role in the realization of high-speed and high acceleration technical requirements. See Figure 2 for the structural diagram of lattice aluminum alloy column. Lattice aluminum alloy column is the main load-bearing component of lightweight stacker, in which the two legs are the main load-bearing structure of the column, and the battens (also divided into battens and battens) connect the two legs, so that the two

legs can be integrated for the overall work. Different from solid web members, the battens of lattice members will produce a certain amount of shear deformation due to the action of shear force, so compared with solid web columns, their bending stiffness is different [1], and the bending deformation is also different under the same load, so calculating the bending deformation of lattice aluminum alloy columns is very important for the design and development process.
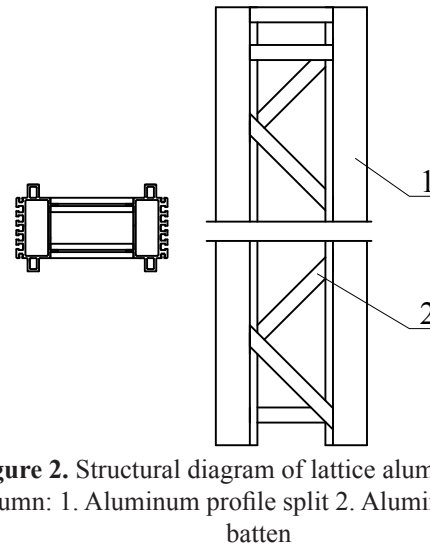

Figure 2. Structural diagram of lattice aluminum alloy column: 1. Aluminum profile split 2. Aluminum profile batten

3.1.1 Column Deflection Analysis

According to the superposition method calculation [2], the column deflection is composed of three parts, which are the deformation caused by the action of each mass unit on the column, the deformation caused by the loading platform and the acceleration of the cargo rise, and the deformation caused by the inertia force of each mass unit including the column itself. The deflection equation of the column can be obtained from reference [3], as shown in formula (1).

$$f = f_M + f_{a_v} + f_{a_H} = \frac{1}{EI_d}\left[\begin{array}{l} \sum_{i=1}^{5} M_i y_i (h-y_i) + \\ \sum_{i=1}^{2} m_i a_v x_i y_i (h-y_i) + \frac{1}{6}\sum_{i=1}^{5} m_i a_H y_i^2 (3h-y_i) + \frac{1}{8}qh^4 a_H \end{array}\right]$$

(1)

Formula (1): M_i is the moment of each mass unit to the column, n·m; $x_i y_i$ is the coordinate of each mass unit; h is the total height of the column, m; m_i is the mass of each mass unit, kg; av is the lifting acceleration, m·····s^{-2}; a_H is the horizontal running acceleration, m·····s^{-2}; E is the elastic modulus of the column; I_d is the equivalent moment of

inertia of the column section.

This formula is derived from the solid web column, but for the lattice aluminum alloy column, the equivalent moment of inertia is derived. Because this paper studies the double leg lattice aluminum alloy column, only the equivalent moment of inertia of the double leg lattice component is derived. There are two methods to deduce the equivalent moment of inertia [1,4]: one is to use the conversion slenderness ratio method, that is to use the method of equal critical force to obtain the conversion slenderness ratio. Compared with the definition formula of slenderness ratio $\lambda = \mu l / \sqrt{I / A}$, the equivalent moment of inertia can be obtained. The second is to use the displacement comparison method, that is, by comparing the expression of top lateral displacement of solid web members and lattice members under the action of horizontal load Q, the calculation formula of equivalent moment of inertia is derived. The equivalent moment of inertia derived from the conversion slenderness ratio method is only applicable to the mechanical analysis of a single member, and it is impossible to carry out the overall analysis and calculation of lattice members. Therefore, this paper adopts the displacement comparison method to derive the equivalent moment of inertia of lattice members, and the derivation process is as follows. The schematic diagram of the double leg lattice members corresponding to the new column is shown in Figure 3, and the dotted line in the figure represents the batten.
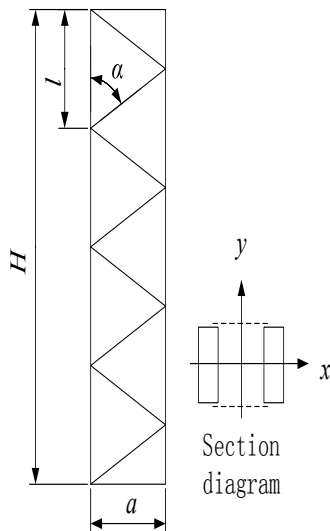

Figure 3. Schematic diagram of double leg lattice members

Based on the theory of structural mechanics, it can be concluded that the displacement of the top of a double leg lattice member can be expressed as follows:

$$\Delta = Q\delta \tag{2}$$

δ is the lateral compliance coefficient of lattice member. According to the unit load method of structural mechanics, the lateral flexibility coefficient of double leg lattice members can be calculated as follows

$$\delta = \frac{2H^3}{3}\left(1 + \frac{1}{8n^2}\right)\lambda_1 + H\lambda_2 \tag{3}$$

where: $\lambda_1 = \dfrac{1}{EA_x a^2}$, $\lambda_2 = \dfrac{1}{EA_y \cos\alpha \sin^2\alpha}$; A_x, A_y is sectional area of legs and battens; n is Number of battens, $n = H / l$.

When the influence of battens on the deformation of lattice members is not considered, the moment of inertia of battens on the y-axis can be expressed as

$$I = aA_x\left(a/2\right)^2 \tag{4}$$

By substituting equation (3), (4) into equation (2), the displacement calculation formula of lattice members under horizontal load Q can be obtained

$$\Delta = Q\frac{H^3}{3EI}\left(1 + \frac{3\lambda_2}{2H^2\lambda_1}\right) \tag{5}$$

According to the mechanics of materials, the integral method is used to calculate the bending deformation of the web member, and the deformation of the top under the action of horizontal load Q can be obtained as

$$\Delta = Q\frac{H^3}{3EI} \tag{6}$$

The equivalent moment of inertia for calculating the top deflection of lattice column can be obtained by combining formula (5) and formula (6)

$$I_d = I \Big/ \left(1 + \frac{3\lambda_2}{2H^2\lambda_1}\right) \tag{7}$$

Combined formula (1), (7) can be used to deduce the deflection formula of lattice aluminum alloy column in operation.

3.1.2 Column Simulation Analysis

In the last section, the stiffness of the column is calculated theoretically. In order to reflect the deformation and stress-

strain of the column more intuitively, the finite element analysis software ANSYS Workbench is used to simulate the lattice aluminum alloy column.

The mechanical structure of the stacker is simplified. The pallet and the electrical control cabinet are equivalent to the mass unit and coupled to the corresponding position of the column. The simplified model is modeled by Solid-Works, imported into workbench, and meshed by the multizone module in mesh. The density of mesh is controlled by the sizing controller [5].

Boundary condition setting: set the fixed constraint at two walking wheels to constrain their degrees of freedom in X, y and Z directions respectively. Because the upper crossbeam moves in a circular straight line along the track direction according to the sky rail, the degree of freedom of the upper crossbeam in the z-axis direction is constrained. Apply the gravity acceleration and the running acceleration along the tunnel direction to the stacker as a whole, and apply the corresponding load at the synchronous pulley of the upper crossbeam [6].

Set a path in the column height direction, and select the deformation and stress-strain curve on the path as shown in Figure 4 and figure 5. The maximum deflection of the column appears at the top of the column, the maximum deformation is 1.6mm, and the allowable deflection range of the column is $[f] = H\left(\dfrac{1}{2000} \sim \dfrac{1}{1000}\right) = 2 \sim 4$

mm. The comparison shows that the simulation results meet the requirements and the design is reasonable. From the stress-strain curve, the maximum stress appears near the top of the column, the maximum stress is 10.6mpa, far less than the yield strength. Because of the existence of battens in lattice column, the stress-strain curve along the column height direction is not a smooth curve, but a sudden change occurs at the junction of battens column, as shown in Figure 5.
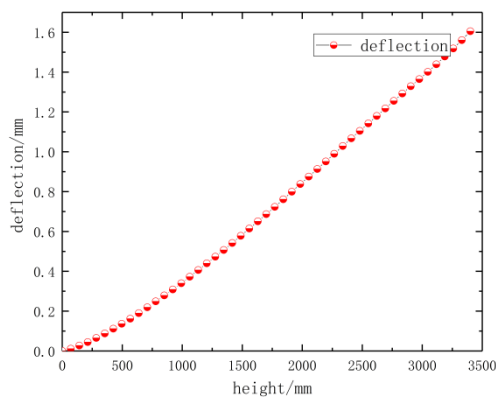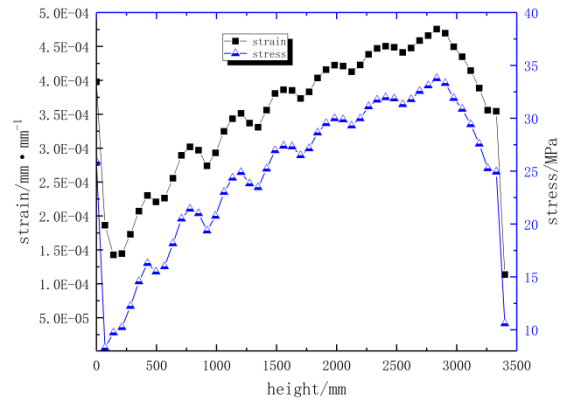

Figure 5. Stress strain curve in height direction

3.2 Design of Driving Mechanism with Clamping Rail

Compared with the traditional direct drive method, the rail clamping drive mechanism adopted in this paper can make the stacker achieve higher acceleration without sliding, so it is more suitable for the high-speed and high acceleration high-efficiency lightweight stacker.

Design of Driving Method of Clamping Rail

The driving mode of clamping rail refers to a group of driving wheels located on both sides of the track abdomen to provide traction. The reduction motor drives the clamping wheel, which generates the friction force through a set of positive pressure between the clamping device and the track, so as to realize the walking drive of the stacker on the track. The supporting wheels on both sides of the stacker are only used as driven wheels. The clamping device can be spring or disc spring assembly, and the clamping force can be adjusted. The schematic diagram of clamping rail drive is shown in Figure 6.
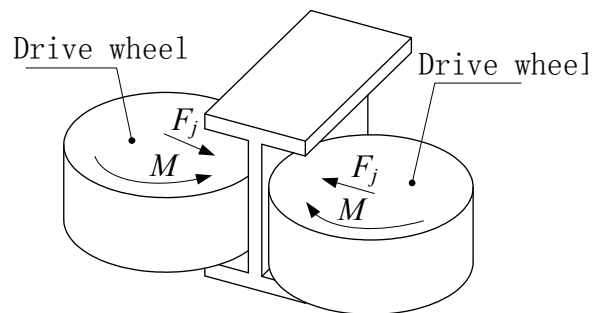

Figure 6. Schematic diagram of clamping rail drive

$$f_{1\max} = 2\mu_1 F_j > ma_H + \mu_2 mg + 2\mu_2 F_j = F \qquad (9)$$

Figure 4. Deflection curve in height direction

Where f_j is the clamping force between the driving wheel and the track. Sorting out formula (9) can get the value range of acceleration of rail clamping driving mode

$$a_H < \frac{2(\mu_1 - \mu_2)}{m} F_j - \mu_2 g \qquad (10)$$

According to the above formula, the horizontal running acceleration is directly proportional to the clamping force f_j and inversely proportional to the self weight m of the stacker. The acceleration can be increased by adjusting the clamping force, increasing the friction between the driving wheel and the track, and reducing the weight of the stacker itself. With this driving mode, the horizontal acceleration of the stacker can reach 3.5~5 m·s^{-2}, which greatly improves the running speed of the stacker and the efficiency of the warehouse.

3.3 Design of Synchronous Belt Lifting Mechanism

The hoisting mechanism of traditional stacker is composed of drum, steel wire rope or chain wheel. In the long-term use, it is found that the above two mechanisms have defects that can not be optimized. For example, when higher lifting speed and acceleration are required, the chain drive has polygon effect and the chain vibration is obvious, which leads to the vibration and noise of stacker. After long-term use, the wear is serious When the width of the roadway is small, it can not meet the requirements of the height direction of the three-dimensional warehouse, and the ratio of the lifting pulley block is generally changed. When the drum is large and the wire rope is long, the wire rope is seriously worn and easy to cause the phenomenon of winding and rope disorder, resulting in the risk of falling.

Compared with the traditional hoisting mechanism, synchronous belt drive is a kind of meshing transmission body. The circular arc or trapezoid synchronous belt is used to mesh with the belt wheel, and the driving wheel drives the synchronous belt and carries the goods. Although the synchronous belt is a kind of elastomer, it can ensure that it does not stretch under the allowable working tension due to the function of internal steel rope or other reinforced structure. The pitch of the synchronous belt does not change, and it is correctly meshed with the belt pulley to realize no sliding transmission and ensure accurate transmission ratio.

Calculation of the best lifting speed of the synchronous belt. Refer to GB / t11362-2008 for the accurate formula of rated power pt of synchronous belt drive: when the number of teeth engaged by the small pulley of synchro-

nous belt drive is, the width is

$$Pt = \left(K_z K_w T_a - \frac{b_s m_0 v^2}{b_{so}} \right) \times v \times 10^{-3} \qquad (11)$$

Where b_{so} is the reference bandwidth; v is the transmission speed; m_0 is the unit mass of the belt; Kz is the coefficient of meshing teeth, when $Z_m \geq 6$, the value is 1, when $Z_m \leq 6$, the value is $K_z = 1 - 0.2$ (6- Z_m), 888 is the width coefficient, and 999 is the allowable working tension of the reference bandwidth.

By calculating the first derivative of equation (11) and returning to zero, the optimal velocity[7] is obtained

$$v_o = \sqrt{\frac{K_z K_w T_a b_{so}}{3 b_s m}} \qquad (12)$$

The parameters of the synchronous belt mechanism used in this paper are shown in Table 1.

Table 1. Parameters of synchronous belt mechanism

Z_m	b_s /mm	b_{so} /mm	m_0 / kg·m^{-1}	T_a /N
17	100	10	0.69	2928

By substituting the parameters into formula (12), the optimal operation speed of the designed synchronous belt lifting mechanism is 44.19 m·s^{-2}, which is consistent with the technical parameters of the stacker, and the design scheme is reasonable.

4. Conclusion

(1) Through the selection of lattice aluminum alloy components as columns, it plays a fundamental role in the lightweight design of high-speed stacker. By using the equivalent moment of inertia method of transforming lattice members into solid web members, the calculation formula of deflection deformation of lattice columns is derived, which lays a good foundation for the later application of lattice members in stacker.

(2) Through the design of the new type of clamping rail driving and the comparative analysis with the direct driving, the advantages of the clamping rail driving mode are clarified, and the acceleration range that the clamping rail driving mode can achieve is deduced through theoretical calculation, which provides a theoretical basis for the later engineering application.

(3) Through the design of the lifting mechanism driven by synchronous belt, it provides a guarantee for the improvement of the lifting acceleration of the stacker. Using the formula of the best speed of synchronous belt, the best

speed is 159 m S^{-2}, which proves the design is reasonable.

The lightweight high-speed stacker designed by the above measures can meet the requirements in terms of running speed and warehousing efficiency.

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