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The Structure Design and Performance Analysis of an Automated Guided Vehicle (AGV) Frame for Large Load

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Abstract. Aiming at the problem of the limited load of automated guided vehicle (AGV) used in logistics transportation, design a simple structure, safe and reliable AGV frame. The frame adopts seesaw structure to reduce the deviation of center of gravity, so that it can bear large load, and analyze its performance. The three-dimensional modeling of the AGV frame was created with SOLIDWORKS software and imported into HYPERWORKS for static analysis of full-load bending conditions, full-load bending and torsion conditions, emergency braking conditions, and emergency turning conditions to determine whether the strength and stiffness of the AGV frame meet the requirements, and according to the results of simulation for structural optimization. Then, the vibration characteristics of the frame structure were determined by free modal analysis through HYPERWORKS. The maximum stress and displacement of the AGV frame under four working conditions are obtained. Among which, the full-load bending and torsion condition is the most unfavorable. The maximum stress is 236.6MPa, which does not exceed the yield limit (343 MPa) of the material 16MnL. The maximum deformation is 1.413mm, which is within the allowable range. The natural frequency of the frame is between 10-46Hz, which belongs to the low-frequency range. The strength and stiffness of the AGV frame designed in this paper meet the requirements when the load is 3 tons, and there is no resonance phenomenon with the road surface. At the same time, it also provides certain ideas and reference value for designing other types of frames.

Keywords. Automated guided vehicle (AGV) frame, Structural design, Statics analysis, Free modal analysis

1. Introduction

Automated guided vehicle (AGV) is a product developed for automated logistics. It is an intelligent transportation device that can be automatically transported through a guidance system [1]. With the rapid development of China's manufacturing industry, the load capacity requirements for AGV are also constantly increasing. However, at present, most of the AGVs with light load below 2 tons [2] are on the market, and their load is limited, which hinders the rapid development of AGV in the logistics and transportation industry to some extent. For the loading problem of AGV, researchers mostly study the design of the mechanical mechanism and wheel train but ignore the study of the frame. For example, Guo Bao-xi et al. [3]. designed a special gear train to realize double-car linkage

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and heavy load, which improved the automation rate and adaptability of vehicles. Ma Yue et al. [4]. designed a new mechanical structure and gear train to achieve a high load in a small space. Wang Yunfei et al. [5] designed an electrically controlled hydraulic drive heavy-duty AGV to increase the load capacity of the AGV. Wu Di et al. [6] adopted the chassis layout of four steering wheels and four support wheels to improve the bearing capacity of AGV. The frame is an integral part of the AGV and a key load-bearing component that can withstand various forces and moments generated by the AGV during driving, as well as various assembly loads [7]. If the strength, stiffness, and vibration characteristics of the frame do not meet the requirements, significant vibration and noise may occur, and even fracture may occur under certain limiting conditions [8], this will lead to the failure of AGV product development. Therefore, this paper designs an AGV frame for logistics transportation with reference to some relevant requirements of the automobile frame. The maximum load of the frame is 3 tons as the design goal, and through statics analysis, the strength and stiffness of the frame are judged to meet the requirements under the four working conditions of full load bending, full load bending and torsion, emergency braking and emergency turning, and through free mode analysis, the natural frequency of the frame is determined, and whether the resonance phenomenon will occur on the road surface is judged. According to the simulation results, the structure is optimized until the frame meets the design requirements.

2. Materials and Methods

2.1 Method

2.1.1 Frame structure design

The AGV frame must have sufficient strength and stiffness and electronic equipment installation space to ensure that the AGV has sufficient carrying capacity and can occur a variety of working conditions without damage.[9]

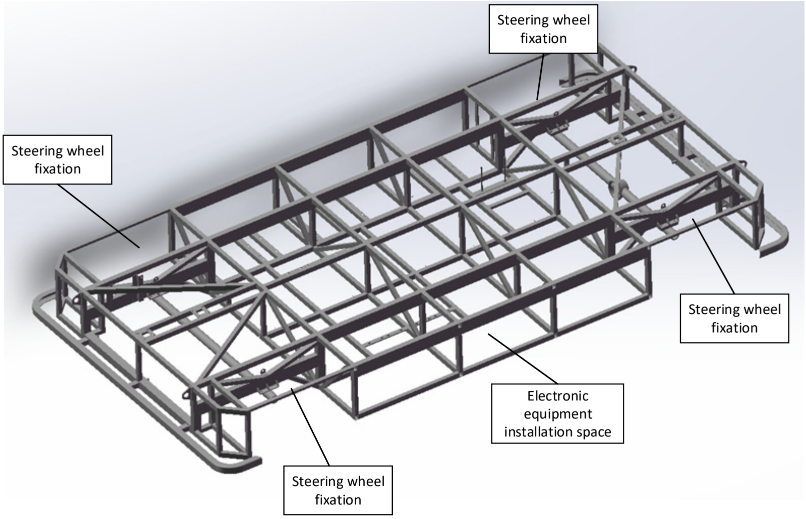


Figure 1. SOLIDWORKS model

In order to improve the bearing capacity and compressive capacity of AGV frame, this paper uses the box girder with good bending and torsional performance to design [10]. A reasonable total height of box section can improve the torsion rigidity of box section beam [11]. In this paper, a box section beam with a thickness of 2mm is used to build the main frame and the sub-frame for the arrangement of each device. In order to improve the bearing capacity of the frame, the seesaw structure is set above the 4 longitudinal beams, which aims to share the impact of the load on the frame, reduce the shift of the center of gravity of the frame, and make it more suitable for carrying heavy goods or bearing large loads. The overall frame size is 4800×2300×460mm. The SOLIDWORKS model is shown in Figure 1.

2.1.2 Materials

The selection of frame material should be based on the yield limit, elastic modulus, density, and other parameters of the material [12]. The material used in this paper is the frame material of a commercial vehicle, namely 16MnL. Its mechanical properties are shown in Table 1.

Table 1. Mechanical properties of 16MnL

Performance	Parameter	Unit
Yield limit	343	Mpa
Elastic modulus	2.12	Gpa
Density	7.87	$kg\cdot m^{-3}$
Poisson's ratio	0.31	

2.2 Determination of load and operating conditions

In AGV driving, the frame will be affected by its quality, the loading equipment quality, and the cargo's quality to produce bending, torsion, and combined deformation, which requires the AGV frame to have better stiffness and strength. The base loads carried by the frame are shown in Table 2.

Table 2. Basic load on the frame

Type	Load /kg
Frame Quality	300
Equipment Quality	700
Bear Quality	3000

The actual driving conditions of AGV are very complex. Still, as long as the frame can show excellent performance under the four typical working conditions of full-load bending conditions, full-load bending and torsion conditions.

3. Results

3.1 Static analysis

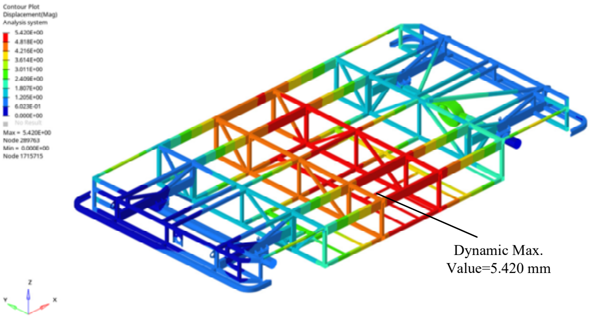
To better explain the constraints of each working condition, this paper takes the X axis to represent the longitudinal of the frame, the Y axis to represent the transverse of the frame, the Z axis as the vertical direction of the frame and establishes a coordinate system.

It should be noted that the constraints applied in this paper represent only translational degrees of freedom in the X, Y, and Z directions.

3.1.1 Full-load bending conditions

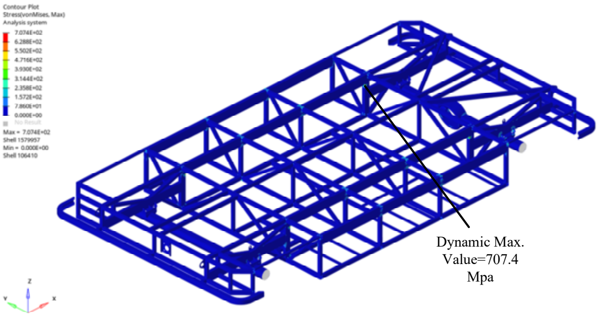
According to the movement condition and stress characteristics of AGV under full-load bending conditions, constraints are added to the connection position between the frame and the driving wheel. The X and Z directions of the left front wheel position, the X, Y, and Z directions of the right front wheel position, the Z direction of the left rear wheel position, and the Y and Z directions of the right rear wheel position are fixed constraints, and the constraints of the other directions are released.

As shown in Figure 2, the maximum displacement is 5.420mm, which occurs at the middle longitudinal beam of the sub-frame, which conforms to the concept of AGV load, but exceeds the deformation allowed by the design requirements and does not meet the stiffness requirements. As shown in Figure 3, the maximum stress is 707.4Mpa, which occurs at the welding place between the longitudinal beam of the main frame and the vertical beam of the subframe. The reason for the excessive stress here is that the center of gravity of the seesaw structure shifts to one side, so that the stress here is concentrated, exceeding the yield limit of the material, which does not meet the design requirements.



Dynamic Max.
Value=5.420 mm

Figure 2. Displacement cloud image under full-load bending condition



Dynamic Max.
Value=707.4
Mpa

Figure 3. Stress nephogram under full-load bending condition

3.1.1.1 Optimization scheme

In response to the above stress concentration problem, the support frame is welded at the corner of the frame to help disperse the stress and strength, thereby reducing the stress concentration at the corner. To solve the problem of excessive deformation in the middle of the frame, the support is welded in the rectangular area in the middle of the frame along the diagonal direction to increase the contact area between the bearing goods and the frame, so as to disperse the load and stress and reduce the deformation. As shown in Figure 4, The maximum displacement is 1.143mm, which is within the allowable deformation range and meets the stiffness requirements. As shown in Figure 5, the maximum stress is 195.3Mpa and the safety factor is 1.76, which does not exceed the yield limit of the material 16MnL and meets the strength requirements.

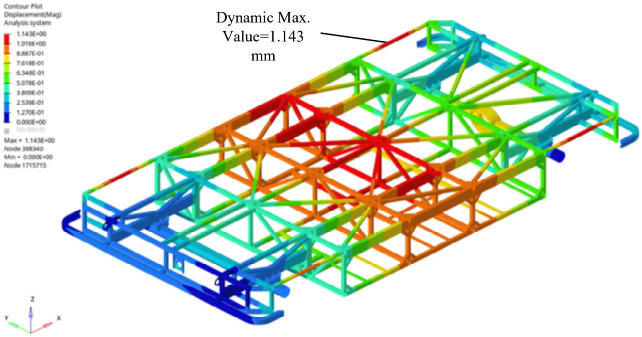


Figure 4. Displacement cloud image under optimized full-load bending condition

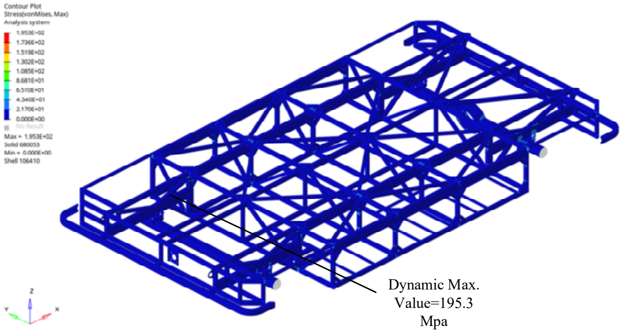


Figure 5. Stress nephogram under optimized full-load bending condition

3.1.2 Full-load bending and torsion conditions

Constrain the right front wheel position in the X, Y, and Z directions, the left rear wheel position in the Z direction, and the right rear wheel position in the Y direction, and apply a 1.5 mm displacement upward in the left front wheel position in the Z direction and the right rear wheel position in the Z direction. At the same time release constraints in the other directions.

As shown in Figure 6, the maximum displacement is 1.433mm, which occurs at the longitudinal beam on both sides of the frame. However, relative to the overall size of the AGV, the deformation is almost negligible, which meets the rigidity requirements of the frame. As shown in Figure 7, The maximum stress value is 236.6Mpa, which is far less than the yield limit of the selected materials and the safety factor is 1.45, meeting the strength requirements of the frame.

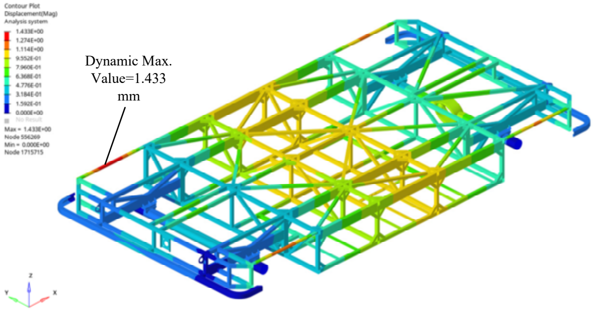


Figure 6. Displacement cloud image under full-load bending and torsion condition

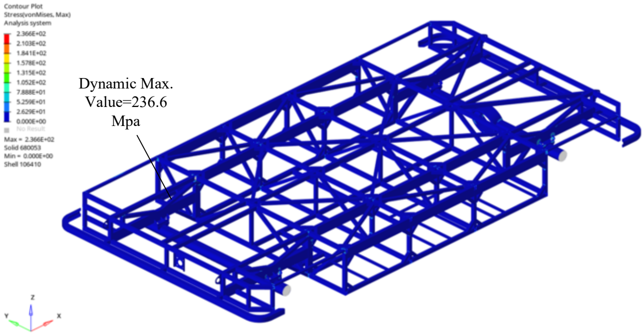


Figure 7. Stress nephogram under full load bending and torsional condition

3.1.3 Emergency braking conditions

The left front wheel position of the frame will be constrained in X and Z directions, the right front wheel position will be constrained in X, Y, and Z directions, the left rear wheel position will be constrained in Z direction, and the right rear wheel position will be constrained in Y and Z directions. At the same time release constraints in the other directions. The braking acceleration in X direction of the AGV under the maximum braking state is 0.3g [13].

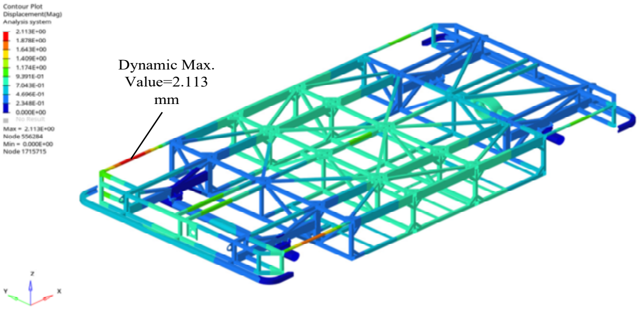


Figure 8. Displacement cloud image under emergency braking condition

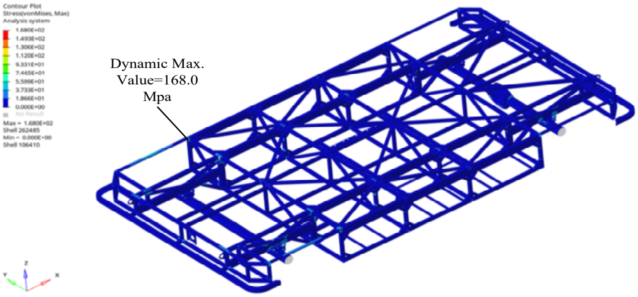


Figure 9. Stress nephogram of emergency braking condition

As shown in Figure 8, the maximum displacement is 2.113mm, which is less than the deformation allowed by the design requirements and meets the stiffness requirements. As shown in Figure 9, the maximum stress value is 168.0Mpa and the safety factor is 2.04, which is far less than the yield limit of the selected materials and meets the strength requirements.

3.1.4 Emergency turning conditions

Constrain the X and Z directions of the left front wheel position of the frame, the X, Y, and Z directions of the right front wheel position, the Z direction of the left rear wheel position, the Z direction of the right rear wheel position, and the constraints of the other directions are released. A transverse centrifugal acceleration of 0.2g and a longitudinal deceleration of 0.2g are applied [13].

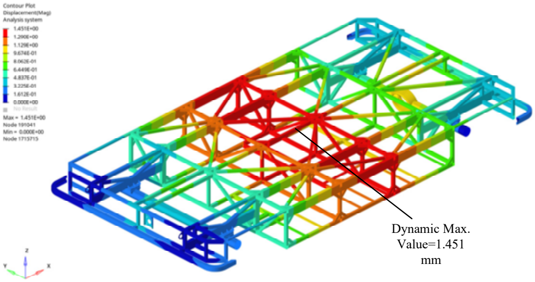


Figure 10. Displacement cloud image under emergency turning condition

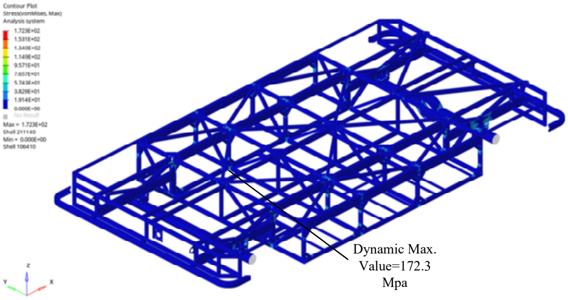


Figure 11. Stress cloud diagram of emergency turning condition

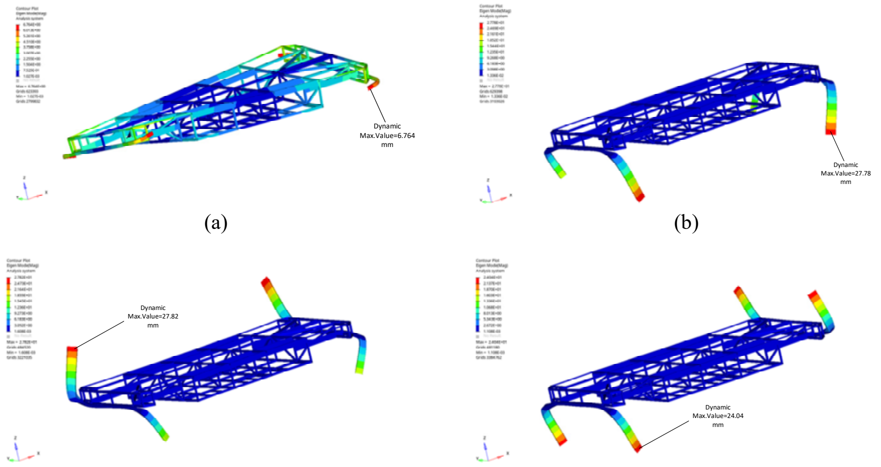
As shown in Figure 10, the maximum displacement is 1.451mm, which still occurs in the middle area of the main frame, which is smaller than the deformation allowed by the design requirements and meets the stiffness requirements. As shown in Figure 11, the maximum stress value is 172.3Mpa and the safety factor is 1.99, which is far less than the yield limit of the selected material and meets the strength requirements.

3.2 Discussion of the results of the statics analysis

Through the analysis of the simulation results of the displacement program and stress program of the four working conditions of the AGV frame, it can be seen that the maximum stress and maximum displacement in each working condition meet the requirements of strength and stiffness, and the stress and displacement of other parts of the frame are also in a balanced state, meeting the design requirements.

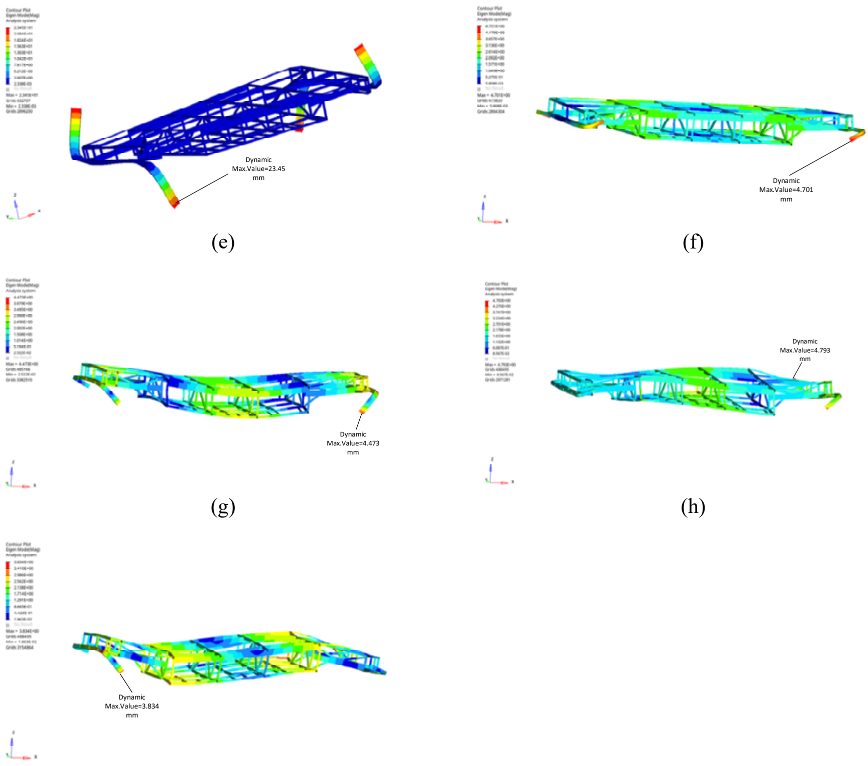
3.3 Free modal analysis

Considering that AGV may be stimulated by many complex conditions when driving outdoors [14]. To avoid the damage of resonance phenomenon to the vehicle structure and internal and external components, as well as the impact on operation performance, it is necessary to carry out modal analysis on the designed frame. When conducting free modal analysis, it is required to understand the vibration characteristics of the frame itself and the external source and avoid the resonance phenomenon caused by the consistent vibration frequency [15].Since modal analysis is the inherent property of the frame and has nothing to do with external forces, it is unnecessary to add any form of load to the frame [14]. The free modal analysis of the AGV frame was carried out, and the threshold of HYPERWORKS was set to 1. According to the research on the vehicle's dynamic performance, mainly in the low and medium frequency range, the vibration modes in the modal analysis were concentrated in the first 15 orders. Since the natural frequency of the analysis results of the first 6 modes is close to 0, which belongs to the rigid body mode and has no practical significance, the first 6 modes are not considered. [16] Table 3 shows the modal analysis results of the frame under the mode modes of order 7-15. Enlarge the deformation result by 50 times, as shown in Figure 12.



(a) (b)

(c) (d)



(e) (f)

(g) (h)

(i)

(a) Seventh model shape; (b) Eighth model shape; (c) Ninth model shape; (d) Tenth model shape; (e) Eleventh model shape; (f) Twelfth model shape; (g) Thirteenth model shape; (h) Fourteenth model shape; (i) Fifteenth mode model shape;

Figure 12. Vibration pattern of frame free modal analysis.

Table 3. Frame modal analysis results

Rank	Natural frequency /Hz	Mode of vibration	Maximum displacement value /mm
7	10.246	Integral torsion	6.764
8	20.961	The anti-collision beam is bent	27.78
9	21.040	The anti-collision beam is bent	27.82
10	21.230	The anti-collision beam is bent	24.04
11	22.288	The anti-collision beam is bent	23.45
12	31.374	Vertical bending	4.701
13	42.294	Bending plus torsion	4.473
14	43.303	Bending plus torsion	4.793
15	45.211	Bending plus torsion	3.834

3.4 Discussion of the results of free modal analysis

As can be seen from Table 3, the natural frequency of the AGV frame designed in this paper is between 10-46Hz, which belongs to the low-frequency range. In addition, the vibration modes of the frame are bending, torsional, and bent-torsional combinations, and the bent-torsional combination is mainly concentrated in high-order vibration modes, which conforms to the actual research situation of vehicle dynamic performance. It should be noted that the reason for the larger maximum displacement value of the mode 8-11 analysis is the deformation of the anti-collision beam. The anti-collision beam structure is used to reduce the AGV collision damage but has no impact on the strength and stiffness of the AGV frame, which will not be described in this paper. The main external vibration excitation source of the frame is the road surface, and the excitation frequency of the road surface is usually below 3Hz [17], which does not coincide with the natural frequency of the frame.

4. Conclusions

The AGV frame designed in this paper uses SOLIDWORKS software for three-dimensional modeling and HYPERWORKS software for static analysis and free modal analysis. It meets the stiffness and strength requirements under four basic working conditions under a load of 3 tons and determines the vibration frequency of the frame. It can be concluded that the frame will not resonate with the road surface. The large load makes AGV improve the efficiency of logistics transportation, promotes the development of AGV in the logistics industry to a certain extent, and provides a reference for the research and development of other frame products.

Acknowledgement

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