Mechanical Structure Design and Dynamic Simulation of Rail Car

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Abstract: Based on the analysis of the mechanical structure of the traditional rail car, a new type of rail car is proposed with the actual operation requirements. The mechanical structure design with the front wheel guiding mechanism ,body steering bearing mechanism and a new self-adaptive mechanism respectively，which could enable the car to run normally in the deformed rail and optimize turning performance of the car .The parameters of the self-adaptive mechanism and the required torque are analyzed from the kinetic view, and an accurate and reliable virtual prototype model was established through combining the virtual prototype technology with Pro/E and Adams modeling simulation. The simulation results show that the design of the virtual prototype model is consistent with the mathematical model along with the friction is reducing significantly when turning the car and the function that self-adaptive deformed rail is realized. This verifies the rationality and practical feasibility of the mechanical structure for this rail car which also provides a useful reference for the further development of the rail car prototype.

1 BACKGROUND

With the rapid expansion of the industrial scale of factory aquaculture, high precision, convenient and economical rail-type automatic feeding system has rapidly become a research hot spot. Now like Arvo-Tec 、 Strovik 、 TransFeed 、 Crystalvision etc. international companies had developed the rail car of the rail-type feeding machine with high precision, low noise, long service life and other characteristics. In contrast, China hasn't begun to do research on rail-type feeding machine until recent years. Due to the long distance of the guide rails, there are some problems with the car such as wheel suspended and wheel-slip as a result of manufacturing and installation errors, and the wheel on the rail bend would get stuck easily; In a way ,the car can't run on a rail with flexible deformation, which affects automatic feeding robot accurate positioning and bait throwing. The innovative structures of the self-adaptive rail car, which is a kind of automatic breeding equipment, not only solve the running problem of factory aquaculture rail car but also improve the automation level of factory aquaculture by mechanical design and virtual prototype platform[1-6]. Different from the traditional factory aquaculture rail car, the rail car proposed in this paper has the following two characteristics：①a new self-adaptive mechanism is used to enable rail car to run normally in the deformed rail. ②The turning angle of body steering bearing mechanism can be adjusted according to the turning radius of rail and optimizing its turning performance. In order to verify the rationality and practical feasibility of the design, the virtual simulation platform has been done by using virtual prototype technology, the parameters of each mechanism and the operation of each mechanism has been analyzed and determined. Then making a judgment and giving suggestions for optimization on rationality of mechanical structure design of rail car.[7-10]

2 STRUCTURAL DESIGN OF RAIL CAR

2.1 The Front Wheel Guiding Mechanism

The guiding wheel of the guiding mechanism contacts with the side surface of the rail when the car turns. The guide shaft, the guide plate and the connecting rod provide the force to make two front wheels turn synchronously. Compared with the conventional flange structure, this structure reduces the friction force when the car turning and increases the torque that the front wheels need in turning phase, which would be better for car turning. In order to accommodate different radius of bend, the variable angle between two guide plates could be adjusted according to the bend radius.

2.2 Body Steering Bearing Mechanism

The functions of steering bearing mechanism are as follows：When the car sensor detects the corner limit switch, The electric control device makes the electric push rod work to push the steering bearing rotating for a certain angle in the opposite direction of the rail bend, which could drive the rear wheels assembly to rotate for a certain angle in the opposite direction of the rail car；When the front wheels of the car leave the rail bend，the car sensor detects the limit switch of rail bend, the electric push rod pushes the body steering bearing mechanism to return to the original state. The body steering bearing mechanism cooperates with the front wheel guiding mechanism which could enable rail car turning in a smaller radius along with reducing the collision with friction between the flange of the rear wheels and the rail, transient turning radius and friction noise, so that the rail car could pass through the railbend smoothly.

2.3 Self-adaptive Mechanism

The self-adaptive mechanism comprises the self-adaptive wheel and the clamping mechanism,when the rail car suffers from deformed rail or slipping, the front wheel sensor will send signal to PLC thought detecting the car is in a non-running state. Then PLC controls the electromagnet of the clamping mechanism to work, therefore, the slider is embedded with the groove of the ratchet, and the ratchet is screwed in so that the bevel supports wedge extending outwardly until the wedge is in good contact with the rail and the car resumes walking. PLC controls the electromagnet of the clamping mechanism pushes the slider to retract and stops the self-adaptive mechanism when the car sensor detects the car is in a running state. Finally, the rear wheels return to normal running. Through the cooperation of the PLC and the self-adaptive mechanism, the rail car could work normally in the deformed rail.

3KINEMATIC ANALYSIS

The rail car adopts the self-adaptive wheel as shown in the figure, the self-adaptive mechanism is control to be turned on and off by the cooperation of the PLC and the clamping mechanism. The self-adaptive wheel consists of a ratchet, a wheel hub and a wedge .with the requirement of practical task ,the car loads 90 kg, running velocity is 18 m / min.

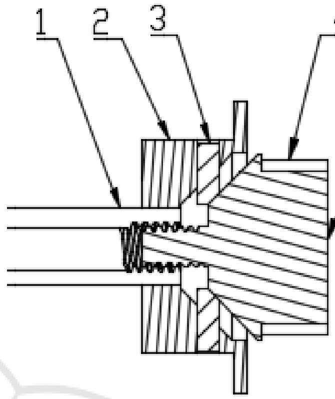


Figure 1:Partial structure of self-adaptive wheel 1.axle 2. Wheel hub 3.wedge 4.groove 5. Ratchet.

Force analysis：
To ratchet

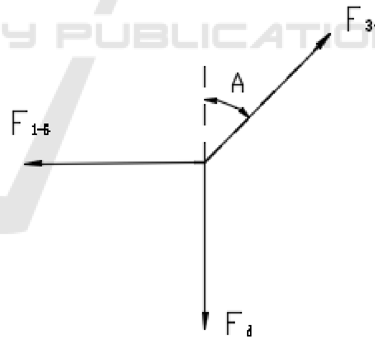


Figure 2: Force analysis of ratchet.

To wedge

$$F_N = G \quad (1\text{-}1)$$

$$F_{3-5} = F_{5-3} \quad (1\text{-}2)$$

$$F_{1-5} = F_{3-5} * \sin A \quad (1\text{-}3)$$

$$F_N = F_{5-3} * \cos A \quad (1\text{-}4)$$

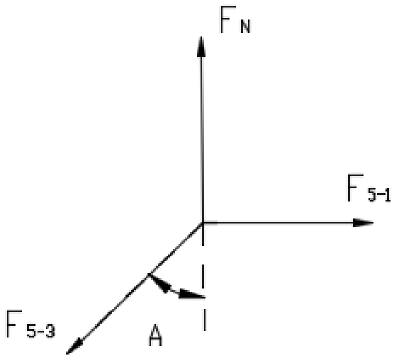


Figure 3:Force analysis of wedge .

Solution of equation：

$$F_{1-5} = \frac{G}{\tan A} \tag{1-5}$$

let $A = 45^{\circ}$ than $F_{1\text{-}5} = G$

Assume the rear wheel loading 1000N, the screw thread of the wheel axle adopts a left-handed rectangular screw thread, friction coefficient of thread friction joint[11] : u=0.1

$F_{1\text{-}5}$ is provided by the screwing force of the thread, the working principle of the screw transmission joint is as follows:

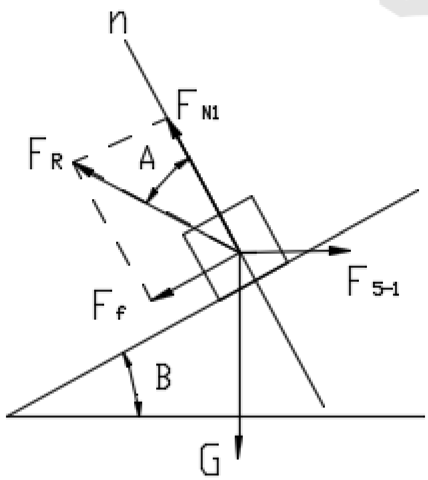


Figure 4:Principle of screw transmission joint.

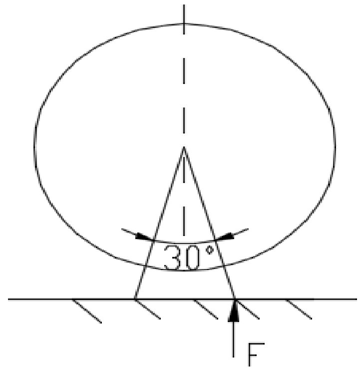


Figure 5: Resistance.

According to mechanical principles[12]

$$\mathrm{F} = \mathrm{G} * \tan(\mathrm{A}+\mathrm{B}) = 1000 \times \tan 20.7 \approx 400\mathrm{N}$$
(1-6)

$$\mathrm{M} = \mathrm{F} * \frac{d}{2} = 100 \times \frac{20}{2} = 4000 N.mm \tag{1-7}$$

Because $B > A$ not self-locking, the ratchet will return to the original position, when the clamping mechanism is closed.

Because the adaptive wheel will generate a torque resistance when it extends out of the wedge

$$T_1 = \sin\left(\frac{360/12}{2}\right) \times 90 \times 1000 \approx 25000 N.mm \tag{1-8}$$

$$\mathrm{T} = T_1 + M \approx 30000 N.mm \tag{1-9}$$

4 RAIL CAR MODEL

Adams software has a strong dynamic simulation function ,and Pro/E has powerful modeling capabilities which can build a variety of complex models, this paper combines the advantages of both, Pro/E is used for modelling and the dynamic simulation analysis is carried out in ADAMS. Creating a model with Pro/E and Adams is a process of continuous improvement, 3D solid modeling includes two steps: part modeling and the car model assembling, according to the structure characteristics and functional requirements of the rail car to complete the modeling and assembly along with obtaining the 3D solid model. Rigid bodies and constraints are defined by the interface program Mechanism/Pro between Pro/E and ADAMS, then the 3D solid assembly model established by Pro/E is converted into ADAMS which could further perfect

ADAMS dynamic model. The specific modeling steps are shown in figure 6.

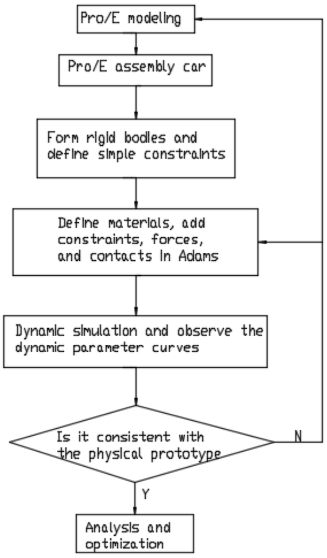


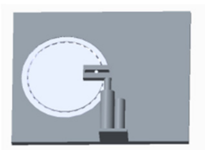
Figure 6:Modeland simulation block flow sheet

4.1 Pro/E Model

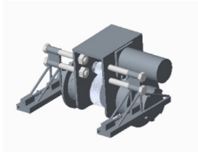
The mechanical structure of the self-adaptive rail car is modeled by Pro/E software . Figure 7 is a part model of the rail car. Figure 8 is Pro/E model.

a. Rail car assembly

b. The Front wheel assembly



c. Body steering bearing mechanism



d.Self-adaptive mechanism

Figure 7: The mechanism of each part and the general assembly model of the car

4.2 Adams Virtual Prototype Modeling

Simplifying the Pro/E model and importing it into ADAMS. Generating the ADAMS model by the interface software mechpro2005 between ADAMS and Pro/E. Then combining the parts without relative motion in ADAMS with Boolean sum, defining material properties, constraints, forces, contacts, and motions.

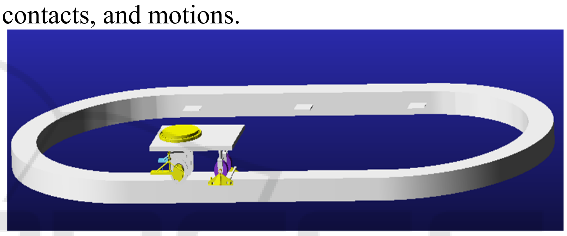


Figure 8:Adams model

5ADAMS DYNAMIC SIMULATION AND ANALYSIS

5.1 Bend Running Simulation

The simulation conditions assume that the rail car that loads 900N running on an annular rail which the straight line is 1.5 m and the bend radius is 0.8m. The car velocity curve and the car friction curve are shown in Figure 9-12.

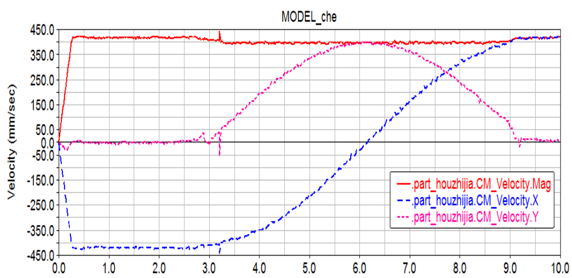


Figure 9: Relationship between car velocity and time

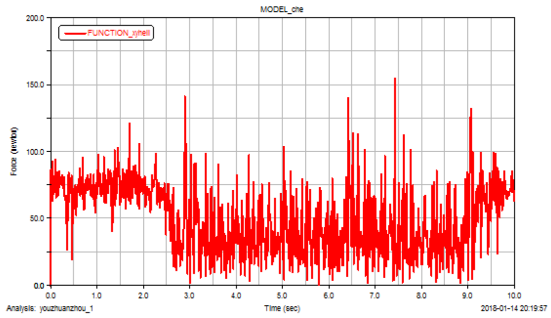


Figure 10: Friction of rear wheels in bend with body steering bearing mechanism

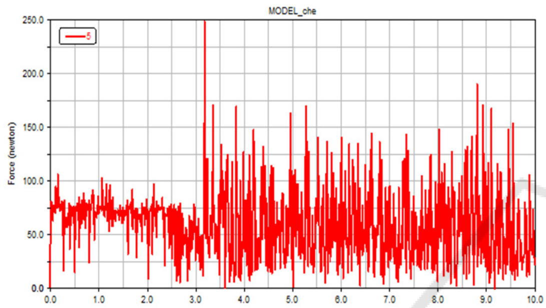


Figure 11: Friction of rear wheels in bend without body steering bearing mechanism

During the turning phase, the friction of the rear wheels with body steering bearing mechanism is about 35N, and the friction force of the rear wheels without body steering bearing mechanism is about 65N.

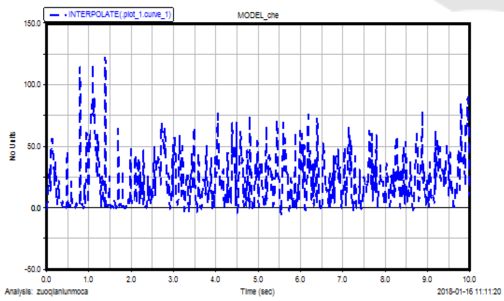


Figure 12: Relationship between front wheels friction and time

5.2 Self-adaptive Running Simulation

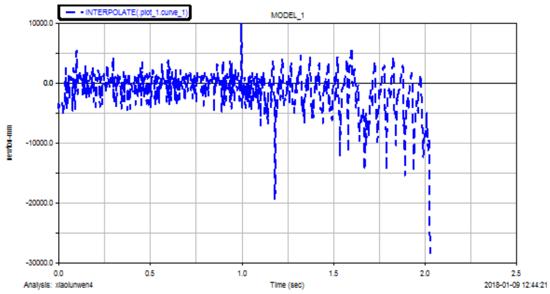


Figure 13: After the self-adaptive mechanism working, the required torque of rear wheels

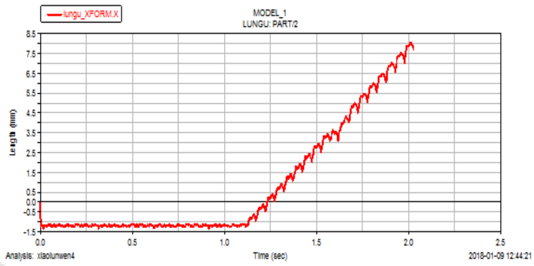


Figure 14: The displacement of CM of the rear wheels in the vertical direction

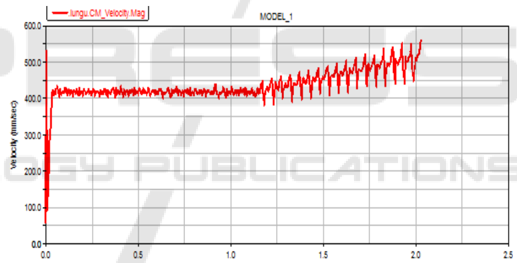


Figure 15: The car velocity with the self-adaptive mechanism working

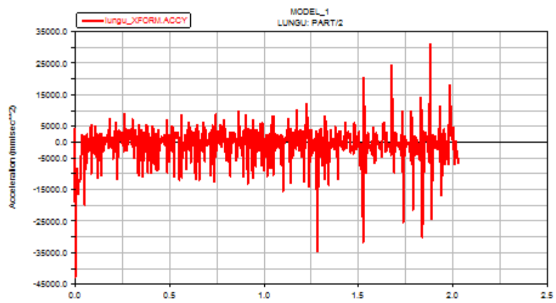


Figure 16: The car accelerated velocity with the self-adaptive mechanism working

6 RESULT

Figure 9 reflects the straight running and bend running of rail car with the stable velocity, which shows that the front wheel guiding mechanism and the steering bearing mechanism meet the design target. Figure 10-12 reflects that the friction is relatively stable whether the rear wheels or the front wheels, the friction of the rear wheels is obviously reducing with the improvement of using steering bearing mechanism. Figure 13 shows the driving torque of the rear wheels is accelerating after the self-adaptive mechanism working. According to the analysis, it can be seen that，the problem is due to the torque resistance that generated by the extension of the wedges and the increase of the car acceleration, the data curve shows that the simulation results within a reasonable range are consistent with the kinematic calculation results. Figure 14 show the CM of the car, with 0.5mm fluctuations, gradually rises after the self-adaptive mechanism working. This phenomenon is due to the discontinuity between wedge and wedge of the self-adaptive mechanism.Because the sampled fluctuation peaks are relatively small for the entire system. Therefore, there is little effect to the system. Through analysis, a spring pad can be added to the end of the wedges that contact with the rail to reduce the degree of fluctuation, So that the system is more stable.

According to the dynamic simulation results in ADAMS, it can be analyzed that the front wheel guiding mechanism and body steering bearing mechanism can make the car running smoothly all the way,and obviously reduce the friction of the rear wheels when the car runs in the bend. There is slight fluctuation of the CM of the car after the self-adaptive mechanism working , improving the contact surface of the wedge with the rail and add a spring pad can reduce the degree of fluctuation. From the perspective of dynamic mathematical model, Adams simulation results are consistent with the dynamic mathematical model, when the input is the same, the dynamic simulation results are consistent with the mathematical model results, which shows that the new structure can meet the design and the actual operation requirements.

7 CONCLUSIONS

In this paper, a new type of self-adaptive rail car is proposed, the front wheel guiding mechanism, body steering bearing mechanism and self-adaptive mechanism are simulated and analyzed by using virtual prototype technology, the relevant simulation results show that Adams simulation results are consistent with the dynamic mathematical model, when the input is the same, the dynamic simulation results are consistent with the mathematical model results, showing that the new structure meets the design and the actual operation requirements, which provides a theoretical basis for the next step of physical manufacture.

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