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Modeling and Simulation of the Tracked Pipe Duct Cleaning Robot Based on the Pro/Engingeer and RecurDyn

CAI Chang-liang

School of Mechanical Engineering, Inner Mongolia University of Technology, Hohhot,010051, P. R. China

Abstract: In order to solve the problem of the pipeline inspection and cleaning, combining the 3D modeling software Pro/Eningeer (Pro/E) and the dynamics analysis software RecurDyn, the main model, the track system model of the tracked pipe duct cleaning robot and the road model are built, and the entity assembly in RecurDyn is applied and the simulation model is obtained. The paper carries out the dynamic simulation with the software RecurDyn. The speed, the torque of driving wheel and the vibration-acceleration of gravity of the whole robot in the vertical direction are obtained and analyzed. Finally, the simulation and the calculation results are compared, the two results are basically the same, it has guiding significance for the further study and the potential applications of the tracked pipe duct cleaning robot.

Key words: tracked pipe duct cleaning robot; RecurDyn; dynamics; simulation model

1 Introduction

The pipeline is widely used in the production life of industry and agriculture. It will produce the pipe blockage and damage during the use of the pipeline, need for regular maintenance, inspection and cleaning, but the environment of the pipeline is often not easy to achieve and not allowed to enter, the inspection and cleaning are difficult, and the efficiency of the artificial inspection and cleaning is low. Therefore, one of the most effective ways is to use the pipe cleaning robot to realize the online-inspection and cleaning. In recent years, study on the pipe cleaning robot is becoming more and more attention in all societies. Based on the above-meationed, the tracked pipe cleaning robot was designed for inspecting and cleaning the pipeline.

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The RecurDyn is a new generation of simulation of multi-body dynamics optimization software which based on the recursive algorithm developed in South Korea. It uses a new theoretical equation of motion relative coordinate system and generalized recursive algorithm, it very suitable for solving multi-body dynamics problems of large-scale and complex contact. In this paper, based on the specialized low motor track packet ——RecurDyn/Track (LM) provided by industry application sub system of RecurDyn[1], regarding the tracked pipe duct cleaning robot as the research subject, driving the simulation tracked pipe cleaning robot in the hard road by the relevant parametric parts of low motor track packet, obtain and analyzes the speed curve, the torque curves of the left and the right driving wheels and the vibration-acceleration curve of gravity of the whole robot in the vertical direction[2], then evaluation the ride comfort, the stability and the reliability of the tracked pipe duct cleaning robot. At the same time, the outstanding performance of dynamics analysis software RecurDyn in multi tracked robot simulation performance [1-2] is verified.

2 Entity modeling

2.1 Establishment of the components model

The main components of the model include a fuselage shell, cradle head, scanner, mechanical arm, connecting road, the working device (brush) models. It is time-consuming that RecurDyn need to use the parameter modeling method to build the models, so these component models using CAD/CAM/CAE integrated 3D modeling software Pro/E to complete, the main body of combination model as shown in Figure 1.

Figure 1 The main body of combination model

2.2 Low speed track system model

The track system is mainly composed of five parts of the low track plate, driving wheel, idler wheel, roller, tensioning device, in order to build and simulate the models conveniently, the track system omits the establishment of the track roll, use the parametric modeling method establish the 3D entity model of the left driving wheel, idler wheel and tensioning device under the environment of RecurDyn sub system [3-4].

After using parametric method to finish building each component model of the left track wheel, utilize the Track (LM) function of low-speed tracked assembly module in the application of RecurDyn (Sub-System Toolkit) [5]. From the beginning of the driving wheel, according to counter clockwise order choice of each component, the left track system model is established. The tracked wheel is composed of 35 tracks plate, the left track and the right track are completely symmetrical relative to the body, so the entire system model can be finished by copying, pasting and moving, the left and the right tracks can be set their own parameters of pavement independently, the single track system model as shown in Figure 2.

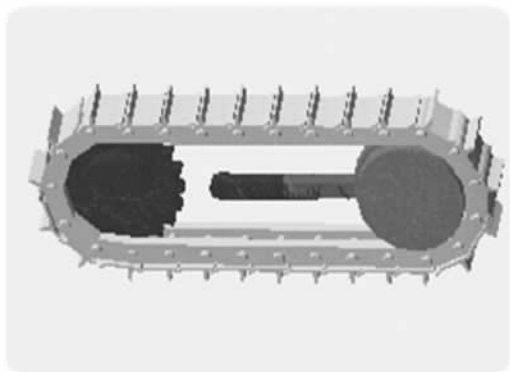

Figure 2 The single track system model

2.3 Whole assembly model

The simulation model of the robot is the main model (not include the track system) finished by Pro/E saved as $x-t$ format, according to the simulation requirement, setting the corresponding modeling environment in RecurDyn, open the $x-t$ file, the multistage system modeling and spatial multi-contact surface definition module are used, the whole pipeline cleaning robot model assembly is completed, the whole assembly model as shown in Figure 3.

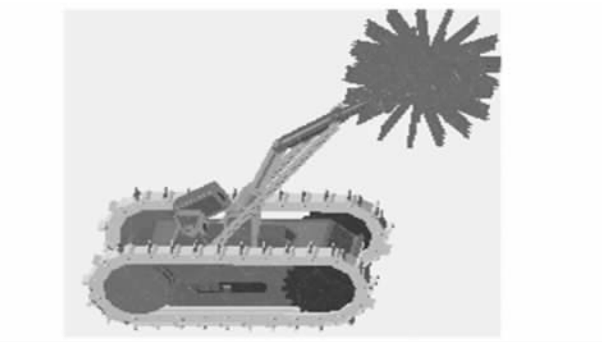

Figure 3 The whole assembly model

3 Establishment of the dynamic model

3.1 The establishment of constrains

Applying the corresponding constrains between the driving wheel, the tensile wheel, the body and other components, to insure that the robot can run smoothly. Constraints of the components as shown in Table 1.

Table 1 The constraints of components

Component No. 1	Component No. 2	Type of the constrained pair	Constrained pair number
Body	Ground	Fixed	1
Cradle head	Scanner	Fixed	1
Mechanical arm	Connecting rod	Fixed	2
Mechanical arm	Brush	Fixed	2
Driving wheel	Body	Revolute	2
Driving wheel	Ground	Revolute	2
Idler wheel	Ground	Revolute	2
Tensile wheel	Idler wheel	Translation	2

3.2 Applying speed drive

Both side tracked are driven by 2 independent wheels separately, apply motion on the Re-joint of both driving wheel and the body, select "velocity and time" option in the EI dialog box, input expression: STEP(TIME,0,0,1,0) + STEP(TIME,1,0,3, -200D). Using the step (TIME, t_0, y_0, t_1, y_1) driving function to definite the speed of the driving wheel. The meaning of the function is that the time increase to 3 s from 1 s, the rotating angular velocity of the track increased from 0 to -200D[5-7].

3.3 Define parameters of the pavement

The pipeline can be viewed as similar to rigid pavement, therefore, in order to analyze the kinematics and dynamic performance of the track in the hardness road, select the hard surface as the crawling media of the track, setting relevant parameters of the pavement. The cohesive soil deformation modulus is 5.173 7 Pa, the internal friction of the soil is 0.633 86 Pa, the exponential number is 0.13, the cohesion is 0.068 95 N, the shearing resistance angle is 34°, the shearing deformation modulus is 25 Pa, the sink age ratio is 0.05, complete the parameter setting of, the simulation model as shown in Figure 4.

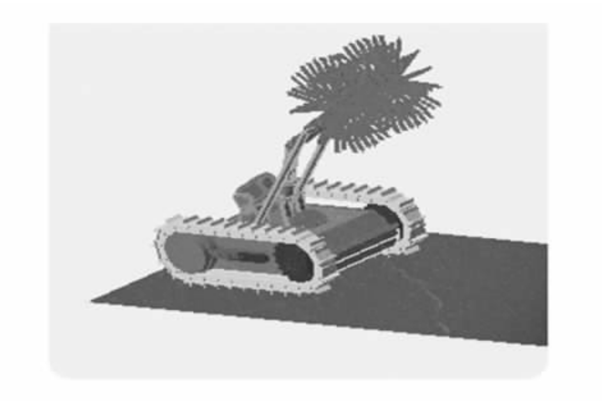

Figure 4 The simulation model

4 The calculation and simulation

4.1 The calculation

When the tracked robot driving straight in the hardness road, the theoretical velocity (v_p) is related to the rodent numbers of driving wheel (z), the center distance of track pin hole (l_o) and the speed of driving sprocket (n_k). The theoretical velocity (v_p) is:

$$v_p = \frac{z l_o n_k}{60} = 0.95 \text{ m/s} \tag{1}$$

4.2 The driving torque

When the tracked robot driving on the hard surface, the torque of a single driving wheel provided by the motor (T_o) is related to the total weight of the robot (mg), the coefficient of rolling friction (f) and the radius of driving wheel (r_q). The torque of a single driving wheel (T_o) is:

$$T_o = mgfr_q = 241.5 \text{ NM} \tag{2}$$

The output torque of motor (T_1) is related to the total transmission efficiency (i) and transmission efficiency (η):

$$T_1 = \frac{T_o}{2n\eta} = 12.88 \text{ NM} \tag{3}$$

$$i = i_g i_0 i_s = 0.6881 \tag{4}$$

Where i_g is the transmission ration of reducer; i_o is the transmission ration of main reducer; i_s is the transmission ration of reducer in the round edge; η is the transmission efficiency, $\eta = 0.851$.

4.3 The kinematics analysis

According to the design requirements, the driving function is converted the speed of the motor into angular velocity of the driving wheel, the velocity-time curve of hard road as shown in Figure 5.

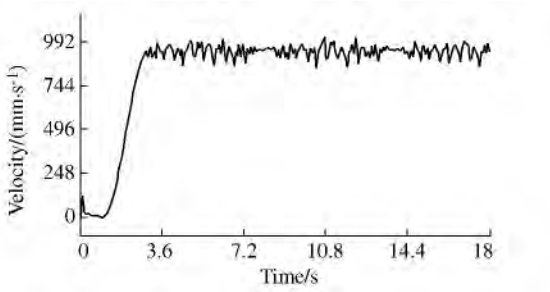

Figure 5 The velocity-time curve of hard road

The simulation step number in unit time inversely proportional with the step during kinematics simulation, and the step time size is longer, the more realistic simulation results, but the corresponding simulation time is also longer [2,6]. The simulation time is 18 s, the simulation step is 250. By the simulation velocity-time curve can be obtained: the cleaning robot is accelerating from 0 seconds to 2.8 s, the track acceleration from standstill to 0.977 m/s, in this stage, the acceleration can be regarded as a constant acceleration. Thereafter, the robot running at a constant speed 0.98 m/s from 2.8 s to 18 s in the stage, the speed of cleaning robot is approximately 0.97 m/s in the stable stage, the error is 2.3% compared with the theoretical calculation, the date in the range of allowable error, satisfies the design request. By the chat can be obtained [1]: cleaning robot has a range of velocity fluctuation in the stable stage, and there is a certain cycle, the cycle is about 5.7 s, all these date show that the cleaning robot running on hard pavement is relative stable, smooth, reliable.

4.4 Simulation and analysis the torque of the driving wheel

The left and the right tracked wheels are driven separately, the torque curve of the driving wheels as shown in Figure 6 and Figure 7.

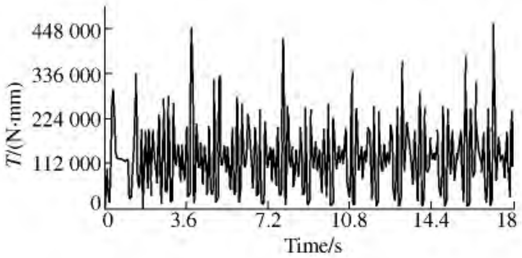

Figure 6 The torque curve of the left driving wheel

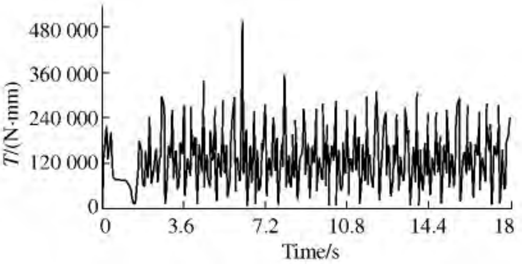

Figure 7 The torque curve of the right driving wheel

From diagrams of the left and the right driving wheels can be concluded [4]: when the tracked robot driving on the hard surface, the maximum torque occurred at 4.7 s after the starting of the motor, the torque is 49.54 NM which produced on the driving wheel of the right track. As can be seen from the simulation animation, the tracked wheel began to accelerate, the torque instantaneous increase. After stable operation, average driving torque of the right tracked wheel is 121.6 NM, average driving torque of the left tracked wheel is 120.7 NM, compared with the theoretical values, and the error is within the allowed range. The track system from the stationary start to speed up to 0.97 m/s and stable operation, In order to analyze the ride comfort of the cleaning robot, obtaining the vibration-acceleration curve of gravity of the whole robot in the vertical direction by using the software RecurDyn, as shown in Figure 8.

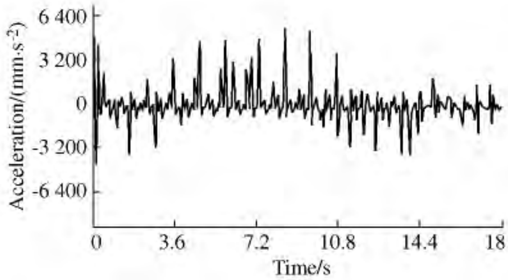

Figure 8 The vibration-acceleration curve of gravity of the whole robot in the vertical direction

By the vibration-acceleration curve of gravity of the whole robot in the vertical direction can be included [4]: cleaning robot from the start to the stable operation, the range of the vibration-acceleration of gravity of the whole robot in the vertical direction is from -4.5 m/s^2 to 4.23 m/s^2, the average acceleration is 0.04 m/s^2, it can be seen from the figure, in the whole process of simulation, the range of the acceleration fluctuate is large at the beginning of the start, this is because the instantaneous torque is large when the motor is started, the characteristics of the robot caused by unstable operation, the vibration-acceleration decreased significantly can tend to be stable after 14 s.

5 Conclusions

In this paper, using 3D modeling software Pro/E and the dynamics analysis software RecurDyn, complete the simulation model of the tracked pipe duct cleaning robot. The speed of the tracked wheel and the torque of the driving wheel are simply calculated, analysis kinematics and dynamics of the robot driving on the hardness road, obtaining the speed, the torque of driving wheel and the vibration-acceleration curve of gravity of the whole robot in the vertical direction. The simulation curve are analyzed and compared with the calculated results. On one hand, the results show RecurDyn has advantage in flexible simulation, on the other hand, verify the movement of the robot is reliable and steady on the hardness road. But it can be seen from the figure, the vibration-acceleration of the track system is relatively large at the beginning of operation, indicating that the real-time control, structure of the robot and the motor need further improvement.

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Brief Biographyies

CAI Chang-liang is now a master in the College of Mechanical Engineering, Inner Mongolia University of Technology. His research interests include control and structure design of the robot. 1025012430@qq.com