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Machine Design of Robot for Detecting Oil Pipeline

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In order to study a new type of pipeline inspection robot, the overall structure of the pipeline climbing robot is designed for the actual environmental conditions and testing requirements. 3D modeling of the robot was carried out using Pro / E's 3D solid modeling function. This model is introduced into ADAMS, and its climbing process is simulated and analyzed. The speed of robot climbing and the output torque of each joint motor are determined when the motion is stable and reliable. The results show that the minimum turning torque required to ensure the stability of robot motion is400 N · mm. The minimum friction is 5N. Therefore, when the robot does not deviate from the direction, the trajectory of the robot is stable and reliable.

1. Introduction

With the development of the oil industry, more and more oil pipelines are erected at high altitudes. The pipeline is high temperature, high pressure or toxic gas, and the working environment is complex and harsh (Alborz et al., 2016), which is not suitable for manual operation. With the increase in the number of aerial work, accidents related to the artificial operation of the pipeline also continue to occur. It brings great hidden trouble to the safety of the factory and the enterprise (Jin-Hyuk et al., 2014). In this case, the study of pipeline climbing robots has received increasing attention (Penghui et al., 2015). Pipeline climbing robot is a kind of automatic climbing on the outer surface of pipeline, and has certain obstacle surmounting ability. A series of pipeline climbing operations can be carried out through the installation of relevant testing equipment by engineers and technicians (Lei and Shan, 2016). Especially in dangerous and complex working conditions, pipe climbing robots that install inspection equipment can replace workers with simple operations on pipelines, so workers are freed from dangerous operations (Mahmoud et al., 2013). This will ensure the safety of production, but also successfully completed the pipeline inspection work. It has great application value in actual production.

2. Structure design of petroleum pipeline inspection robot

The way section titles and other headings are displayed in these instructions, are meant to be followed in your manuscript. The ontology design of pipeline climbing robot mainly includes the mechanical structure design and solid modeling of each component. In this paper, the 3D modeling design method based on Pro/E is used to model the components of the robot ontology. Based on the symmetrical structure of the robot and combined with the modular design method, the body of the robot is divided into four parts: the hand module, the trunk module, the arm module and the connecting arm module (Mahmoud et al., 2015). It can greatly improve the design efficiency.

2.1 Gripper mechanism

The clamping mechanism consists mainly of motors, cams, springs, left gripping arms, right gripping arms and splints (including positive and negative plywood) (Daniel and Karsten, 2014). In this design, the lower portion of the left and right gripping arms is in contact with the cam in such a way that the hemisphere is in direct contact with the arcuate groove of the cam surface. To a certain extent, it reduces the friction of the clamping mechanism itself. The clamping and relaxation of the grips is smoother (Mahmoud et al., 2014). In addition, in order to make the robot move more stably in the climbing process, the inner wall of the left arm and the right arm of the gripper mechanism is changed into an arc. The contact area between the clamping end of the

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gripper and the pipe is enlarged, so that greater friction can be generated, and the stability of the motion gesture can be improved.

For the clamping of the pipe, the design of the gripper is very important. It is the core part of the whole robot design (Bahadur, 2016). The left and right gripping arms of the grips are symmetrical structures (Ana et al., 2015). The cam structure is axially symmetrical. The upper and lower surfaces are an oval face. When the cam is rotated from the long axis to the short axis, the angle of the gripper is maximum, and the pipe is released. When the cam rotates from the minor axis to the long axis, the angle of the grips is minimal, and the pipe is clamped (Haocai et al., 2016). In order to make the simulation results more realistic and reliable, in the structural design and solid modeling, the claws, gripping arm, cam and motor fixed and connected location is also designed. The upper and lower clamping plates are designed to fix the motor and hinge the left and right clamping arms. The size of the splint is strictly designed according to the size of the cam contour and the selected motor, which is more in line with the actual needs (Amit and Hamad, 2016).

Other major components

In addition to the gripping arms, cams and upper and lower plywood that need to be designed in the gripper structure described above, the torso, arm and connecting arm of the machine are also required to be modularized (Montero et al., 2015). This is essential for a complete robot design. Based on the symmetrical structure design, the robot's torso is also a module, the upper and lower torso is symmetrical. The two parts of the robot are connected in series through the articulation of a connecting arm. The main components also include the arm and the connecting arm of the climbing robot. The arm is used to connect the gripper mechanism and the trunk part. As an intermediate component, the connecting arm plays the role of the upper and lower parts of the serial robot.

2.2 Overall assembly

The overall assembly is a process of organizing and positioning the main parts of the product (Raziq et al., 2012). Using the assembly function of Pro/E, the above parts are assembled from top to bottom. The rationality of the size and shape of each part is also verified in the assembly process. The three-dimensional model of the completed pipeline climbing robot is shown in Figure 1.

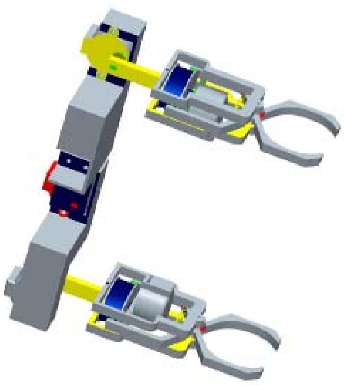

Figure 1: 3D model of pipe climbing robot

3. Simulation analysis of robot virtual prototype

In order to further analyze the advantages and disadvantages of the overall design of the pipeline climbing robot and obtain the relevant performance parameters, and analyze the mechanism of the mechanism in the process of motion, the 3D prototype software Pro / E and the dynamic simulation software ADAMS are used to carry out the virtual prototype simulation analysis.

3.1 Processing of robot solid model

Data exchange interface ADAMS/View is provided by Parasolid. First, the entity model of pipeline climbing robot established in Pro/E is exported to Parasolid format. Then, the formatted file is imported into ADAMS / View. In this way, the simulation analysis in ADAMS environment is closer to the physical object. It basically conforms to the virtual prototype simulation requirements. In the Pro/E modeling, each component of the robot does not add material, quality and other information. Therefore, in ADAMS, it is necessary to add the corresponding information to the parts to ensure that the physical characteristics of the various components of the robot meet the actual requirements (Christof et al., 2014).

Define model material and quality characteristics: The ADAMS/View part library contains the material's dynamic friction coefficient, static friction coefficient, density, Poisson's ratio and elastic modulus. The main material data used in this paper are shown in Table 1.

Table 1: Material data of pipe climbing robot model

material	E(N/mm^2)	μ	ρ(10^{-6}kg/mm^3)
Steel	2.07E+05	0.29	7.801
Stainless steel	1.90E+05	0.305	7.75
Rubber	7.84	0.47	1.5
Cast iron	1.00E+05	0.211	7.08
Aluminum	7.17E+04	0.33	2.74

Add constraints and drivers: First, a fixed pair is added between the climbing pipe and the earth (Ground). Then, the contact force attribute (Contact) is defined between the gripper and the pipe, and the gripper arm and the cam. The gripper and the arm, the turning motor 1 and the torso 1, the trunk 1 and the connecting arm, the turning motor 2 and the torso 2, the trunk 2 and the transfer motor 3, both of them are applied to the fixed connection constraint. Finally, a rotation pair (Revolute Joint) is added between the arm of the robot and the corresponding motor, between the connecting arm and the relay motor 3. For each movement, the corresponding rotary drive is applied. By ADAMS, the machine has 21 motion parts, 9 rotation pairs, 11 fixed pairs, 10 degrees of freedom, and 5 drives. There is no implied error (Dongwoo et al., 2012).
Define the drive function and contact force: As mentioned earlier, the pipeline climbing robot designed in this paper can use two gaits climbing. In this paper, one of the gaits, that is, flipped climbing gait, is simulated and analyzed. Therefore, in the parameter setting, the Velocity in the MOTION_3 drive for the relay motor is set to zero. Handle motor 1 (MOTION_5) in 0-1.5s, Angle increases from 0°C to 90°C and then remains stable until 7.5 s. In the subsequent 1.5s, it is reduced to 0 degrees at a constant speed. Flip motor 1 (MOTION_1) in 0-1.5s, Angle is kept at 0 ° C and then increases to 180°C in 1.5-4.5 s, and then it remains stable. Flip motor 2 (MOTION_2) in 0-4.5s, Angle is maintained at 0°C and then increases to 180°C in 4.5-7.5 s and then remains stable. The gripper motor 2 (MOTION_4) holds 0°C (Tadashi and Jun, 2013).

3.2 Simulation and analysis of motion stability

The stability of the climbing robot mainly includes the stability of the motion and the stability of the trajectory. Through simulation analysis, the joint turning torque and gripper clamping force required for climbing robot are obtained. The stability of the motion attitude can be satisfied as long as the actual output torque of the robot joint drive motor and the gripper force provided by the manipulator are greater than the simulation results. When the displacement and velocity of the center of mass of the robot body can make the robot move smoothly along the pipe direction at a predetermined speed, the stability of the trajectory can be guaranteed (Bassem et, al., 2014). The output torque of turn motor 1 is shown in Figure 2. The output torque of turn motor 2 is shown in Figure 3. The output torque of gripper motor 2 is shown in Figure 4. The Friction force of gripper 1 in the direction of motion is shown in Figure 5.

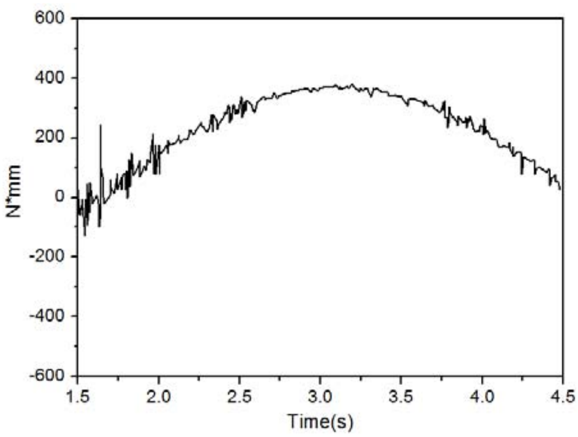

Figure 2: Output torque of turn motor 1

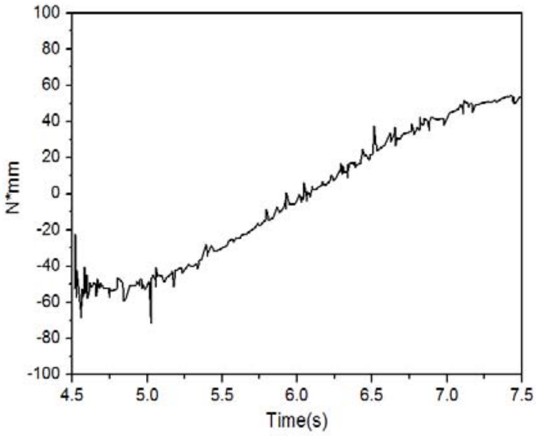

Figure 3: Output torque of turn motor 2

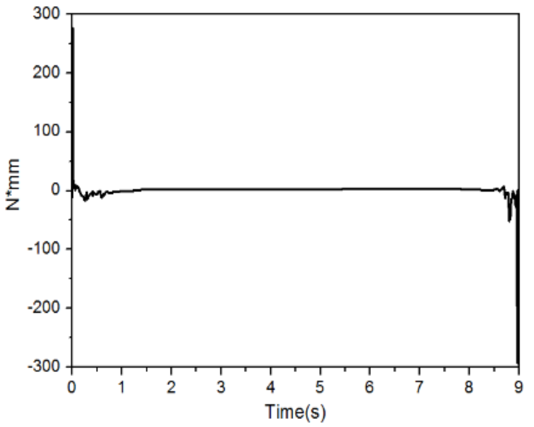

Figure 4: Output torque of gripper motor 2

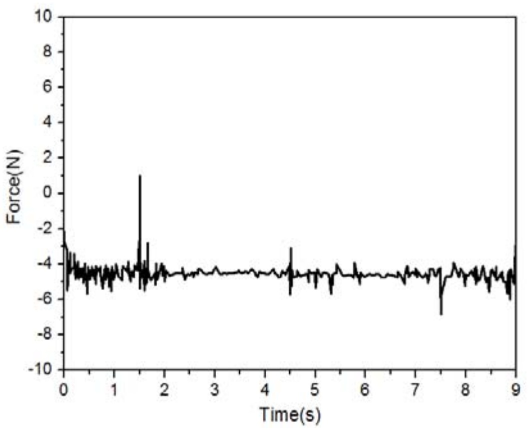

Figure 5: Friction force of gripper 1 in the direction of motion

It can be seen that the output torque of the turnover motor 1 changes continuously with the height of the trunk 2 during its running time (about 1.5~4.5s). The maximum value is about 400N·mm. The output torque of the flip motor 2 varies with the height of the gripper 2 during its running time (about 4.5~7.5 s). The maximum value is about 60N·mm. The gripper motor 2 is divided into two operating periods throughout the motion cycle. The first period is from the initial state (clamping pipe) to release the pipeline, the time period is about 0~1.5s.

The second period is from the release to the clamping pipe, the time period is about 7.5~9s. Its output torque with the gripper clamping and release and constantly changing. The maximum value is about 300N · mm.
It can be seen that there is a slight fluctuation in the output torque of the motors 1 and 2 during the inverting process. However, in general, in the flip gait, the robot movement is relatively stable and reliable. Therefore, in order to ensure the stability of the robot movement posture, the output torque of the selected inverting motor should be at least 400N·mm, and the output torque of the gripper motor should be at least 300N·mm. As shown in Figure 5, the friction force (i.e., contact force) generated between the gripper and the pipe in the direction of movement is about 5N. In the simulation model of the robot, the corresponding quality is set for each component, so that the measured data is more in line with the actual requirements. Under the action of gravity, the maximum mass of 5N friction can withstand about 500g, while the quality of the robot in the simulation model is about 460g. It can be seen that under this condition, the clamping force provided by the gripper can support the weight of the robot itself. Therefore, in order to make the robot climb up smoothly, the gripper must provide a large enough clamping force to ensure that the friction between the gripper and the pipeline is not less than 5N, and thus to ensure the stability of its sports posture.

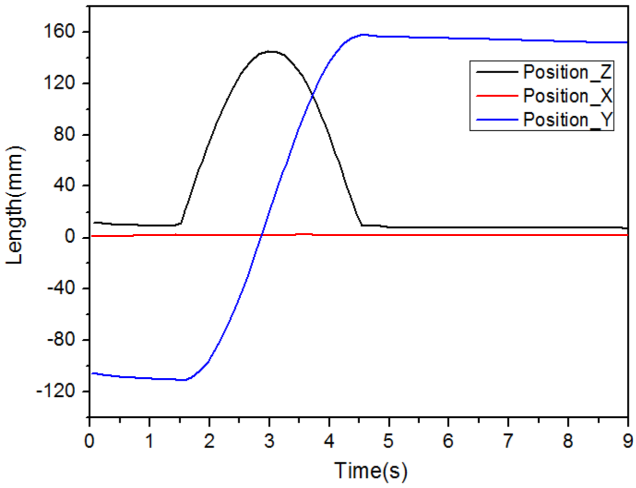

Figure 6: The displacement curve of the center of mass in X, Y and Z directions

The displacement curve of the torso 2 centroid in X, Y and Z directions measured by ADAMS / Postprocessing is shown in Figure 6.
It can be seen from Figure 6 that the displacement of the center of mass on the X axis is always 0, except that there is a displacement change on the Y and Z axes. It shows that the robot torso moves only in the plane of YOZ and does not deviate from the direction of movement. From the displacement curve on the Z-axis, it can be seen that the displacement reaches the maximum at about 3s. At this point, the robot's torso's posture has been moved from the parallel pipe to the vertical pipe, which is in line with the requirements of the actual movement. After calculation, the velocity of the center of mass in the Y direction is about 1.5-4.5 s, and the speed of the other time period is about zero. At about 3s, the speed reaches its maximum. The output torque of the overturning motor 1 is also maximized, which is consistent with the design requirements. Therefore, in a motion cycle, the Y direction is the main direction of motion of the robot. Both the displacement and the velocity change smoothly, which ensures the stability of the trajectory.

4. Conclusions

The structure design and solid modeling of pipe climbing robot are mainly carried out. The dynamic and kinematic simulation analysis of the virtual prototype of the robot is carried out. Finally, the modal analysis of the core parts of the gripper mechanism is carried out under prestressing. Through the simulation and analysis, the following conclusions can be obtained: Through the analysis of the contact force between the output motor and the contact force between the hand and the pipe, the minimum turning moment required to ensure the stability of the motion attitude is 400N · mm and the minimum friction force is 5N. This provides the basis for the structural design and physical prototyping of articulated creeping robots. By analyzing the change of the displacement and velocity of the trunk centroid with time, it is found that the displacement and velocity are stable, and the trajectory is stable.

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