

Design and Analysis of the Pipe Handling Manipulator for Workover Rigs

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Abstract: Aiming at the problems of high labor intensity, low efficiency and poor safety of manual operation in oilfield well repairing operation, a new type of tubing grasping robotic arm of well repairing machine is designed, which aims at realizing the automation of tubing lifting and lowering operation. The arm is suitable for both straight and inclined well workover operations, and is capable of completing such actions as grabbing, moving, centering and discharging the tubing. The article elaborates the structural design of the robotic arm, including the key components such as bottom rotating hydraulic cylinder, big arm, small arm, gripping arm and gripper, and realizes the precise control of each part through the hydraulic system drive. In addition, the article carries out an in-depth analysis of the kinematics and dynamics of the robotic arm, establishes the forward and reverse kinematics model of the robotic arm by using the D-H parametric method, and verifies the workspace and kinematic performance of the robotic arm through MATLAB. The results show that the robotic arm can significantly improve the efficiency of well repair operations, reduce the labor intensity of workers, and enhance the safety of operations, providing technical support for the development of automation of oilfield well repair operations.

Keywords: Workover rig, Pipe handling manipulator, Hydraulic system, Kinematic analysis, Tubing transfer.

1. Introduction

At present, many oilfields have entered into the middle and later stages of development, the implementation of oil recovery operations has become more difficult, and the process of well condition has become more complex, in the process of oil recovery often occurs some of the wells internal or equipment failures, resulting in wells to reduce production, or even stop [1]. In order to ensure the normal production of oil wells, it is necessary to take corresponding measures to eliminate the faults, resulting in a continuous increase in the workload of well repair [2].

In the process of lifting and lowering the pipe column by the well dressing machine, it can only work while releasing the spray, and the labor intensity of the operator is high, time-consuming and inefficient. Moreover, the winch wire rope lifting, not to mention the downward pressure on the tubular column, the lifting and lowering operation process is easy to induce well surge, blowout and other accidents, low safety [3]. At the same time, the well repairing operation needs mutual cooperation and exchange between the staff in turn, which requires high technical level of the staff, and in the harsh working environment, the staff not only have to face high intensity labor, but also have to deal with high danger [4-6]. Therefore, the automated operation equipment for lifting and lowering pipe columns with high efficiency and fast transportation can reduce the number of actual operators, lower the labor intensity of workers, improve the efficiency of the overall operation, and safeguard the personal safety of the operators [7-9]. In order to reduce the labor intensity of workers, improve the safe operation level of well repairing operation, realize automatic control of lifting and lowering tubular column instead of manual wellhead operation, and realize a series of actions such as grasping and releasing tubular column and tubular column alignment. Therefore, in this paper, a new type of pipe grabbing mechanical arm for well dressing machine is designed, the motion simulation of

the mechanical arm under different working conditions is carried out, and the mechanism parameters or structure of the mechanical arm are optimized to realize the high efficiency and accuracy of lifting and lowering the pipe column.

2. Structural Design

2.1. Program Design

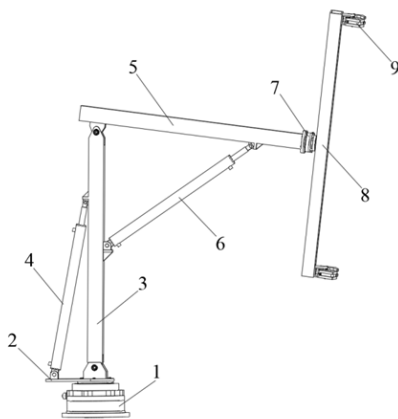
2.1.1. Overall Program Design

According to the workflow of the well dressing machine, combined with the analysis of the function of , according to the design requirements, the research and design of the final scheme of the work of the well dressing machine rotary arm type pipe grasping mechanical arm, and create a three-dimensional model of the whole machine. the well dressing machine pipe grasping mechanical arm. As shown in , it is the pipe grabbing mechanical arm of the well dressing machine Table 1 technical parameters of .

As Fig.1 shown in , the overall structure of the is schematic, and the device is composed of tubing grabbing robot arm of the well dressing machine robot arm system and tubing grabbing device. The gripping device is the core component of the tubing transfer system, and the tubing column also plays the role of supporting when the wellhead carries out the action of upper unloading buckle. The tubing gripping arm of the well dressing machine mainly includes the bottom rotating hydraulic cylinder, support base, big arm, big arm hydraulic cylinder, small arm, small arm hydraulic cylinder, gripping gripping arm gripping arm hydraulic cylinder, hand and other institutions, as well as fine-tuning device and locking device between . The functions of the fine adjustment device and the locking device are to ensure the precise positioning of the tubing delivery and delivery; at the same time, a positioning device is also set up to ensure the precise positioning of the tubing column during the workover operation. The connecting parts of each institution.

Table 1. Technical Parameters of Gripper Arm for Well Repair Machine

Technical name	Parameters
Lifting height	6300mm
Number of tubes transported per hour	>Forty
Maximum lifting weight	200kg
Tube O.D. range	Φ60~89mm
rating	15kW
Weight	<4T
rated pressure	10MPa
electric power source	15Kw380VAC
Arm length	3500mm
Length of small arm	3500mm
Grab arm length	4000mm
Tube length	9500mm



1-Bottom rotating hydraulic cylinder; 2-Support base; 3-Large arm; 4-Large arm hydraulic cylinder; 5-Small arm; 6-Small arm hydraulic cylinder; 7-Grabbing arm hydraulic cylinder; 8-Grabbing arm; 9-Gripping hand

Figure 1. Schematic diagram of the overall structure of the pipe-gripping arm of the well dressing machine

2.1.2. Operational Processes

The pipe grasping robot arm of the well dressing machine can work with the inclined well and straight well dressing machine, and the following is an example of the process of working with the straight well dressing machine, which is mainly divided into two work processes of starting and lowering the pipe:

(1) Pipe up operation

Before performing the tubing up operation, the unit needs to be centered with the wellhead. When the tubing comes out of the well, the swimming chuck chucks the tubing upward and lifts the column, stopping the upward movement when the tubing head joint hoop of the next tubing is exposed for a certain length. The pipe grabbing arm is rotated from horizontal to vertical, and then the big arm and small arm cooperate to drive the pipe grabbing system to rotate to the parallel position with the wellhead, check whether it can be centered, i.e., check whether the axes of the and the axes of the tubing are coaxial or not. If not, grabbing hand adjust the big the relative positions of and small arm to ensure that the center of the and the center of the tubing coincide gripper to ensure the accurate positioning of the tubing and increase the rigidity of the system to ensure safety.

After completing the above checking action, the relative

position of each part of the robotic arm and the control data of the hydraulic cylinder are recorded. According to the alignment data, when the oil pipe is lifted by the large hook of the tanker, the hydraulic cylinder of the gripping arm controls the gripping arm to turn from the horizontal state to the vertical state, the hydraulic cylinder of the large arm and the hydraulic cylinder of the small arm control the large arm and the small arm to transport the gripping arm to the vicinity of the oil pipe and the gripping arm is in the middle of the oil pipe, the hydraulic cylinder of the gripper controls the gripping hand to open, the hydraulic cylinder of the large arm and the hydraulic cylinder of the small arm control the large arm and the small arm to move the gripping arm to make the oil pipe axis and the Gripper axis coincides, the gripper hydraulic cylinder controls the gripper to tighten, the sensor accepts the gripper pipe completion signal, the bottom of the rotary hydraulic cylinder to adjust the direction of movement of the robot arm, the big arm hydraulic cylinder and small arm hydraulic cylinder controls the big arm and small arm to move the gripper arm to make the gripper arm close to the horizontal pipeline rack, at the same time gripping the arm hydraulic cylinder controls the gripper arm to turn the arm from the vertical state to the horizontal state, the oil pipe arrives at the pipeline rack on the oil pipe discharge position axis of the oil pipe The oil pipe reaches the upper part of the oil pipe discharge position axis on the pipe discharge rack, so that the oil pipe axis is parallel to the oil pipe discharge position axis, the mechanical arm cooperates with the pipe discharge rack, and the gripping arm loosens the oil pipe, and puts the oil pipe on the pipe discharge rack. The discharge pipe rack will slowly roll the oil pipe along the discharge rack to the outer row. By repeating this procedure, the operation of starting and discharging all the oil pipes can be completed. During the whole working process of the pipe column handling device, the center lines of the two hydraulic grippers are always parallel to the pipe grabbing arms to ensure that no collision occurs when the oil pipes are being grabbed and transported.

(2) Down-pipe operation

Similarly, before carrying out the tubing lowering operation, the device needs to be centered with the wellhead. After the gripper clamps the tubing, the gripper arm is rotated from horizontal to vertical, and then the big arm and small arm drive the gripper system to rotate to a position parallel to the wellhead, to check whether it can be aligned, i.e., to check whether the axis of the tubing is coaxial with the center of the wellhead. If not, adjust the relative positions of the big arm and small arm to ensure that the center of the tubing is coincident with the center of the wellhead.

After completing the above checking action, the horizontal pipe rack transports the oil pipe to the position of grabbing pipe, the big arm and the small arm control the grabbing arm to reach the position of grabbing pipe, the hydraulic cylinder of grabbing arm rotates the grabbing arm to be parallel to the axis of the oil pipe, the grabbing arm is located directly above the oil pipe, and the grabbing arm is controlled to be open, and the position of the grabbing arm is fine-tuned so that the axis of the grabbing arm is overlapped with the axis of the oil pipe and the grabbing arm is tightened. Gripper tightened, the bottom of the rotary hydraulic cylinder to change the direction of movement of the mechanical arm, the mechanical arm to the wellhead position, the big arm, the small arm driven by the grasping arm to move, the grasping arm hydraulic cylinder to make the grasping arm rotated to the vertical state, to transport the tubing to reach the wellhead position, waiting

for the swimming kawa card to hold the head of the tubing, the hydraulic gripper for the action of the release, the oil pipeline downward centering by the hydraulic tongs on the buckles and tightened, the device is rotated to the horizontal position, ready for the next The device is rotated to horizontal position, ready for the next tubing to be lowered into the well. Repeat this to complete the lowering of all fuel lines.

In the whole process of lifting and lowering the oil pipe by the , all the mechanisms are driven by hydraulic pressure, which significantly improves the efficiency of the pipe column picking and dropping and the reliability of the device's performance in the process of operation pipe grabbing robotic arm

The whole structure of the machine is made of material Q355B steel.

2.2. Structural Design and Analysis

2.2.1. Overall Structural Design

As Fig.2 shown in, the three-dimensional structure schematic diagram of the pipe grabbing mechanical arm of the well dressing machine. The dimensions of the whole machine are: length 3500mm, width 375mm, height 3500mm.



Figure 2. Schematic structure of diagram of the three-dimensional the well dressing machine's pipe-grabbing robot arm

(1) Carrying capacity: each time the tube column is taken out about 9.5m, its weight is about 130kg, so the carrying capacity of the robotic arm is moderate.

(2) Scope of work: The well dressing machine pipe grabbing mechanical arm realizes the transportation of oil pipe from the pipe rack to the wellhead and from the wellhead to the pipe rack.

(3) Degrees of freedom: four degrees of freedom.

This includes the degrees of freedom to move in the direction of the right-angle coordinate axes and around x, y, and z the degrees of freedom to rotate the z-axis. The combination of these four degrees of freedom enables the object to realize the movement and attitude transformation that satisfies the movement of the tubing column between the wellhead and the row of tubing racks.

(4) Flexibility: high flexibility, fast discharge action and high efficiency.

Positional accuracy: When the pipe column is moved and transported to the wellhead, it needs to be aligned with the wellhead to be buckled, so the positional accuracy of this pipe-grabbing robotic arm is required to be high.

2.2.2. Base Design and Analysis

As Fig.3 shown in, the hydraulic base structure of the well dressing machine pipe grabbing robot arm is schematic. As

the carrier of the whole device, the base must be designed to ensure its stability, functionality and safety. The base of this device adopts a turntable type base, which is convenient for the movement of the device, making it easy to carry and install, and the overall structure of the base is material 2-3 composed of hydraulic cylinders, which makes the overall structure stable. As Table made of Q335 shown in, the basic dimensions of the hydraulic base. The base is installed with rotatable feet, in the complex terrain of the wellsite work can be supported feet, to ensure that the device can work smoothly; the base is also welded with the main beam hinge seat and lifting hinge seat, respectively, with the intermediate beam and lifting the hydraulic cylinder hinged; in the end of the base is installed with a buffer spring, which can buffer the intermediate beam in the lifting the hydraulic cylinder when the impact of the lowering to reduce the force on the base Table 2.

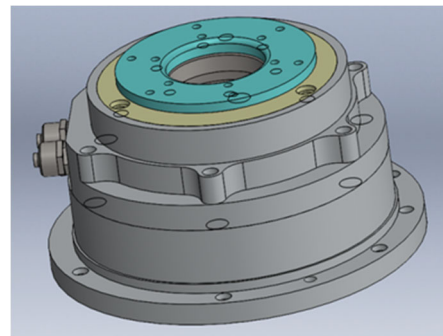


Figure 3. Schematic structure of diagram of the three-dimensional the hydraulic base

Table 2. Basic Dimensions for Hydraulic Bases

Size Type	Size
maximum diameter	900mm
high degree	479.5mm
Oil chamber volume	63153439mm ³

2.2.3. Arm Design and Analysis

The arm structure consists of a large arm and a small arm, the large arm supporting the large arm hydraulic cylinder, the small arm supporting the small arm hydraulic cylinder, the large arm and the small arm in the mechanical structure of the two crank-slider mechanism, to ensure that the arm part of the stability of the operation process. As Figure shown in, for the well dressing machine grab pipe mechanical arm mechanism movement sketch Fig.4 .

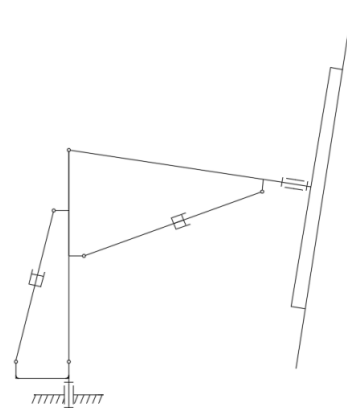


Figure 4. Sketch of the movement of the mechanism well dressing machine's pipe grasping robot arm

(1) Calculation of the limit position of the boom hydraulic cylinder

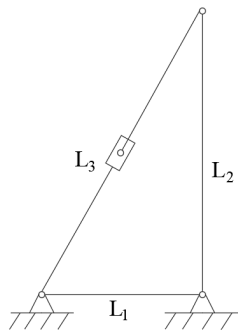


Figure 5. Schematic diagram of the position of the hydraulic cylinder of the big arm

In , Fig.5 $L_1 = 794\text{mm}$, $L_2 = 2475\text{mm}$, and according to the triangle principle $1681\text{mm} < L_3 < 3267\text{mm}$.

The length of the jib hydraulic cylinder is $1930\text{mm} \sim 3930\text{mm}$, then $1930\text{mm} < L_3 < 3267\text{mm}$.

(2) Calculation of the limit position of the hydraulic cylinder of the small arm

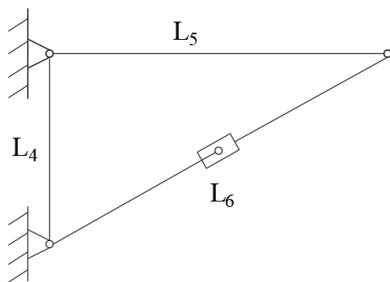


Figure 6. Schematic diagram of the position of the hydraulic cylinder of the small arm

In , Fig.6 $L_4 = 1461\text{mm}$ and $L_5 = 2237\text{mm}$, according to the triangle principle $776\text{mm} < L_6 < 3698\text{mm}$.

The length of the small arm hydraulic cylinder is $1930\text{mm} \sim 3930\text{mm}$, then $1930\text{mm} < L_6 < 3698\text{mm}$.

2.2.4. End-effector Design and Analysis

The end-effector of the pipe-grabbing mechanical arm of the well dressing machine consists of a pipe-grabbing arm and two hydraulic grippers, which ensures the stability of the pipe column running in the air and prevents the bending of the column. As Figs.7 shown in, a three-dimensional structural schematic diagram of the gripper structure of the pipe grabbing mechanical arm of the well dressing machine.

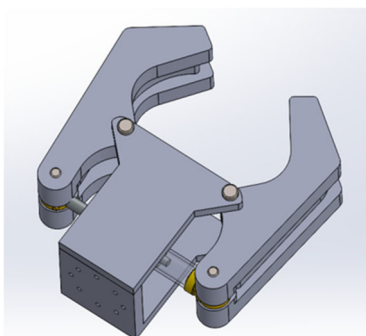


Figure 7. Schematic diagram of the three-dimensional structure of the gripper structure

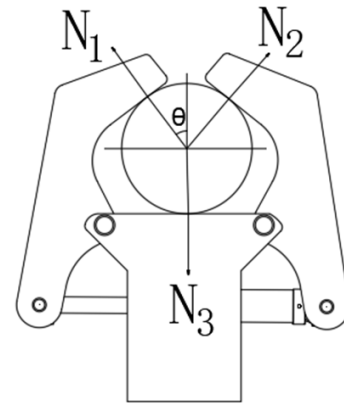


Figure 8. Schematic diagram of oil pipe force analysis

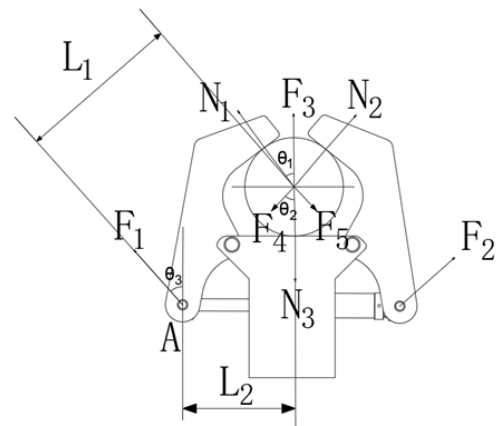


Figure 9. Schematic diagram of force analysis of gripper structure

This device is suitable for transporting oil pipe diameter range of $62 \sim 89\text{mm}$, the mechanical gripper was symmetrically distributed, the mechanical gripper hydraulic cylinder piston rod expansion and contraction pushes the gripper on both sides, which drives the mechanical claw around the center of rotation, so as to achieve the opening and closing of the mechanical gripper.

After the mechanical gripper grasps the oil pipe, as Figure shown in , the oil pipe and gripper force analysis schematic diagram of the well dressing machine gripping mechanical arm. In the mechanical gripper to grab Fig.8 and Fig.9 89mm of oil pipe, the claw to open to the claw's fingertips can avoid the oil pipe, this time the mechanical gripper hydraulic cylinder piston rod elongation is the largest, for 72mm . in the mechanical gripper clamped the pumping rod, due to the small diameter of the pumping rod so that the piston rod should be income in the hydraulic cylinder, this time the piston rod elongation of 10mm , so the mechanical gripper hydraulic cylinder stroke is 62mm .

From Fig.8 of the mechanical gripper in the clamping of the oil pipe when the oil pipe force analysis diagram can be seen, in the mechanical gripper clamping the oil pipe by the two sides of the mechanical claw together to clamp the oil pipe, in order to prevent the oil pipe sliding under the action of gravity, the need for mechanical gripper hydraulic cylinder thrust design.

As a fuel pipe has two mechanical grippers to grasp, so a single mechanical gripper only need to grasp up to one-half of the weight of the fuel pipe, by Newton's third law, the fuel pipe column balance equation:

$$\mu(N_1 + N_2 + N_3) = \frac{mg}{2} \quad (1)$$

As can be seen analysis in , due to the symmetrical arrangement of the mechanical gripper structure, from the Fig.8 , the balance equation is again made for it:

$$(N_1 + N_2) \cos \theta_1 = N_3 \quad (2)$$

Requirements for the maximum thrust of the hydraulic cylinder, it is necessary to mechanical gripper force analysis, force analysis shown in Figure 8. at point The balance equation of the moment is listed :A

$$F_1 L_1 = N_3 L_2 \quad (3)$$

$$F_1 \approx 185 N$$

The magnitude of the thrust in the direction of the hydraulic cylinder is:

$$F = \frac{F_1}{\sin \theta_3} = 276.5 N \quad (4)$$

Considering the possible inertia force of the oil pipe in the process of gripping and moving, the vibration generated and mechanical efficiency and other factors affecting the mechanical gripper hydraulic cylinders, then the actual size of the thrust produced by the mechanical gripper hydraulic cylinders:

$$F' = F \frac{K_1 K_2}{\eta} = 1048 N \quad (5)$$

3. Hydraulic System Design

3.1. Hydraulic System Design Requirements

The overall requirements of the hydraulic system design is to make the hydraulic system can complete the established work content, according to the analysis of the second chapter of the pipeline process, the hydraulic system puts forward the following requirements:

(1) It is capable of smoothly completing the pipe column discharge action, including hand gripping, base rotation, and movement of the robotic arm, etc., and is able to realize the pipe discharge action in accordance with the established process flow;

(2) Ensure the reliability of hand clamping to avoid slippage due to unstable clamping caused by the influence of oil on the surface of the pipe column;

(3) Ensure the stability of the whole machine during the rotation of the base;

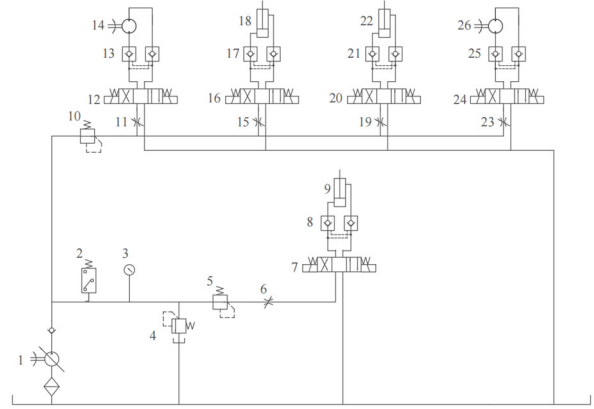
(4) Since this device is an auxiliary working part for the vehicle-mounted well dressing machine, its hydraulic system should be designed to match the whole machine;

(5) Design the rotation of the system to avoid large vibration noise;

(6) The selection of hydraulic devices should give full consideration to the economy.

3.2. Hydraulic system design analysis

Connect the previously designed components in the hydraulic pipeline, and configure the relevant instrumentation to draw the working principle diagram of the hydraulic system of the well dressing machine pipe grabbing mechanical arm, as Fig.10 shown in.



1-system hydraulic pump; 2-pressure relay; 3-pressure gauge; 4-relief valve; 5-pressure reducing valve; 6-gripper liquid line throttle valve; 7- gripper liquid line electro-hydraulic proportional reversing valve ; 8- gripper liquid line bi-directional unlocking ; 9-gripper hydraulic cylinder; 10-reducing valve; 11-bottom rotary hydraulic cylinder liquid line throttle valve; 12-bottom rotary hydraulic cylinder liquid line electro-hydraulic proportional reversing valve; 13-bottom rotary hydraulic cylinder liquid line two-way hydraulic lock; 14-bottom rotary hydraulic motor; 15- big arm liquid line throttle valve; 16-large arm liquid line electro-hydraulic proportional reversing valve; 17-large arm liquid line two-way hydraulic lock; 18-large arm hydraulic cylinder ; 19-small arm liquid line throttle valve; 20-small arm liquid line electro-hydraulic proportional reversing valve; 21-small arm liquid line two-way hydraulic lock; 22-small arm hydraulic cylinder; 23-gripping arm hydraulic cylinder liquid line Throttle valve; 24-Gripping arm liquid line electro-hydraulic proportional reversing valve; 25-Gripping arm hydraulic cylinder liquid line two-way hydraulic lock; 26-Gripping arm rotary hydraulic motor
Figure 10. Hydraulic circuit schematic diagram of well dressing machine pipe grabbing robot arm

This hydraulic system is a single hydraulic pump system, the pipeline oil are by the hydraulic pump supplied, in the inlet of the oil pump is equipped with suction filter to protect the hydraulic oil pump. Gripper hydraulic end of the liquid pressure and the pressure required by the rest of the components are different, so it will be configured in two separate liquid circuit, and respectively set up a pressure reducing valve. The of this pipe gripping robotic arm 1five behavioral actions by the gripper hydraulic cylinder are driven. In these actions, due to the clamping end of the hydraulic cylinder in the opening and closing, the piston rod are in the limit position, so its work only two working forms, so this to the liquid circuit, the flow requirements are not high, so in addition to the clamping end is not set throttle valve, the rest of the operating cylinder are set with a throttle valve member. Pressure relay 9, the bottom slewing hydraulic motor 14, the big arm hydraulic cylinder 18, the small arm hydraulic cylinder 22, and the gripper arm slewing hydraulic motor 26 is used for overload protection of the liquid circuit system,

when the pressure in the liquid circuit is too high, an electric signal will be sent to drive the relief valve 4, so that the hydraulic pump 1 for unloading.

The bottom rotary hydraulic cylinder the bottom rotary hydraulic motor carries out the rotary action under the drive of, and its maximum angle of rotation is 14 of 360°, and when the rotation is in place, the positioning of its angle is by the two-way hydraulic lock ensured. The big arm swings big arm hydraulic cylinder 13 around the base under the drive of the, with a maximum swing angle of 18 of 90° and a maximum stroke of 1337mm, and when swung into place, its angular positioning is ensured by the two-way hydraulic lock 17. The small arm small arm hydraulic cylinder swings around the big arm under the drive of the, with a maximum swing angle of 22 of 90° and a maximum stroke of 1768mm, and its angular positioning is ensured by the bidirectional hydraulic lock when it swings into place 21. The hydraulic cylinder of the gripping arm rotates hydraulic motor the gripping arm slewing the drive of the, and its maximum angle of rotation is 26 of 360°, and when it rotates in place, the positioning of its angle is ensured by the two-way hydraulic lock 25. Each of the above actuating elements has a throttle valve member, these throttle valves can be controlled by electromagnetic control, in order to achieve remote control of the size of the flow rate, so as to make the action of the drive fluid cylinder is controlled.

4. Kinematics and Dynamics Analysis

4.1. Kinematic Analysis

4.1.1. Forward Kinematics

In order to establish the forward kinematic equations of the four-degree-of-freedom well dressing machine robotic arm, the improved is used D-H parametric method, and the robotic arm consists of four rotary joints, and the structure includes the base rotation, shoulder, elbow and wrist joints. Fig.11 shows the schematic diagram of the coordinate system for the motion analysis of the mechanical arm.

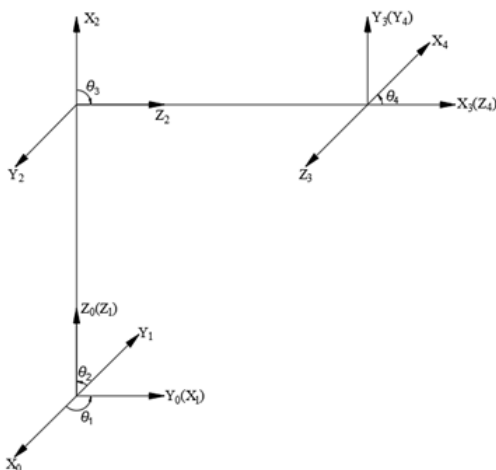


Figure 11. Schematic diagram of the coordinate system for robotic arm motion analysis

Total transformation matrix and end position:

$$\begin{cases} x = \cos \theta_1 [L_1 \cos \theta_2 + L_2 \cos(\theta_2 + \theta_3) + L_3 \cos(\theta_2 + \theta_3 + \theta_4)] \\ y = \sin \theta_1 [L_1 \cos \theta_2 + L_2 \cos(\theta_2 + \theta_3) + L_3 \cos(\theta_2 + \theta_3 + \theta_4)] \\ z = d_1 + L_1 \sin \theta_2 + L_2 \sin(\theta_2 + \theta_3) + L_3 \sin(\theta_2 + \theta_3 + \theta_4) \end{cases} \quad (6)$$

Using MATLAB to solve, the as Fig.12 is obtained working space schematic of the robotic arm shown in, and the limit position of the robotic arm working is located at x=0mm, y=0mm, z=7000mm.

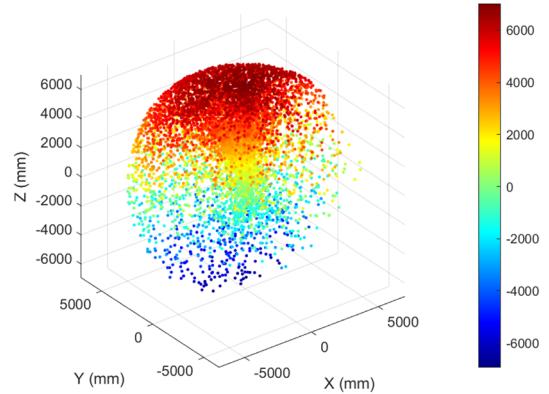


Figure 12. Schematic diagram of robotic arm workspace

4.1.2. Reverse Kinematics

Reverse kinematics equations:

$$\begin{cases} \theta_1 = \arctan 2(y, x) \\ \theta_2 = \phi - \arctan \left(\frac{L_2 \sin \theta_3}{L_1 + L_2 \cos \theta_2} \right) \\ \theta_3 = \arccos \left(\frac{D^2 - L_1^2 - L_2^2}{2L_1 L_2} \right) \\ \theta_4 = \arctan \frac{z'}{R} - (\theta_2 - \theta_3) \end{cases} \quad (7)$$

Using MATLAB to solve the problem, with the robotic arm working at the limit positions x=0mm, y=0mm, and z=7000mm with the joint angles $\theta_1 = 0^\circ$, $\theta_2 = 0^\circ$, $\theta_3 = 0^\circ$, and $\theta_4 = 0^\circ$.

Modify the target position for sensitivity analysis, input when, we get the as Fig.13 at x=10mm, y=10mm, z=6990mm reverse kinematics sensitivity analysis schematic of the robotic arm shown in, with the joint angles of respectively $\theta_1 = 45^\circ$, $\theta_2 = 79.9^\circ$, $\theta_3 = 4.4^\circ$, $\theta_4 = 9.9^\circ$.

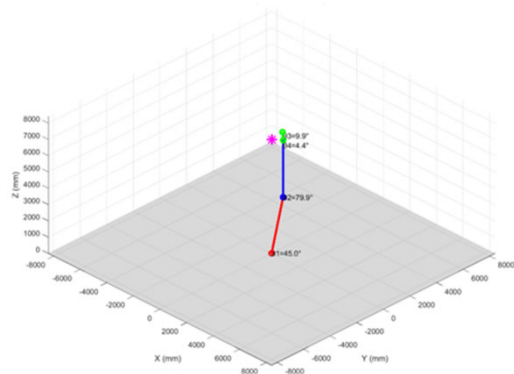


Figure 13. Schematic diagram of reverse kinematics sensitivity analysis of the robotic arm

4.2. Dynamics Analysis

Establishing the kinetic equations of a well dressing machine's robotic arm requires describing the relationship

between the joint moments and the motion (position, velocity, acceleration) of the robotic arm, which is usually done by using either the Joseph-Louis Lagrange method or the Newton-Euler method. The following detailed derivation procedure is based on the Joseph-Louis Lagrange method:

For the robotic arm, the equation takes the form:

$$\begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \\ M_{41} & M_{42} & M_{43} & M_{44} \end{bmatrix} \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \\ \ddot{\theta}_3 \\ \ddot{\theta}_4 \end{bmatrix} + \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix} + \begin{bmatrix} G_1 \\ G_2 \\ G_3 \\ G_4 \end{bmatrix} \quad (8)$$

The complete dynamic equations of the mechanical arm of the well dressing machine were established by the Joseph-Louis Lagrange method, revealing the nonlinear relationship between the joint moments and the state of motion.

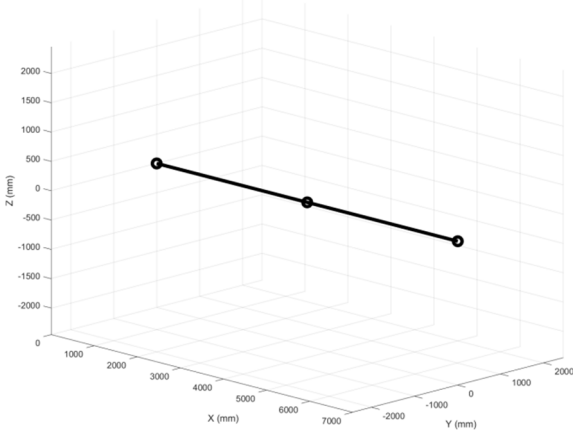


Figure 14. Schematic diagram of robotic arm dynamics moment analysis

5. Conclusion

(1) The well trimmer tubing grabber arm meets the structural feature requirements of a vehicle-mounted well trimmer and is mounted as an assembly on the well trimmer derrick.

(2) The well dressing machine gripping mechanical arm cooperates with the automated pipe rack, which improves the

efficiency of the well dressing operation, reduces the labor intensity of the workers, and improves the safety of the field operation;

(3) The device is driven by a hydraulic system, directly connected to the hydraulic station of the well dressing machine, and with the hydraulic sensor, the centering is accurate, fast and stable during operation;

(4) The design of the tubing grasping mechanical arm of the well dressing machine provides technical support for the design and application of the automated and intelligent well dressing machine.

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