Structure of Tunnel Digging and Loading Trolley and Calculation of Electronic Control System and Analysis of Common Faults of Electronic Control

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Abstract: The tunneling truck is mainly used for tunneling construction. It has the functions of digging, loading, anchoring, and wet spraying. This paper analyses the main structure and working principle of tunnel digging and loading trolley, the selection and calculation of main electrical components, the overall calculation of tunnel digging and loading trolley, and the common electrical faults and troubleshooting methods. It has certain reference value for domestic counterparts.

1. Introduction
Tunnels are mainly used for tunneling in tunnel construction and have the functions of digging, loading, anchoring, and wet spraying. It is suitable for large and medium-sized roadways with a section of $6 \times 6$ meters. “The whole machine has a compact structure, high power, many functions, and fast operation speed, humanized design and is easy to repair.”

The whole machine structure adopts high-strength alloy steel welding, hydraulic and electrical components and other key parts adopt internationally renowned brands, and the whole machine has reliable performance and high working efficiency. Using the motor as the power source to realize the zero emission of the entire machine, the use cost of the equipment is effectively reduced compared to the fuel equipment section. The tunnel excavates and installs the platform by digging and dredging with the left arm, and transports the slag to the tail of the machine through its own scraper conveyor and reprints it to other feed equipment. At the same time, milling operations can also be carried out, and the right arm is used instead of artificial spraying. [1]

The tunnel excavation platform is supported by the drilling of the catheter by the right arm. At the same time, milling operations can also be carried out. The right arm is used instead of the artificial spray. Tunnel excavation and loading trucks are safe, comfortable, efficient, and practical in function. They can replace manpower construction on a large scale, greatly reducing the labor intensity of workers and reducing the number of construction personnel. [2] The figure shows the exterior map of the tunnel excavation truck 1 of a domestic enterprise.
2. Main structure and working principle
The tunnel excavation platform consists of a left arm, a right arm, a feeding device, a crawler walking assembly, a frame assembly, a hydraulic operating system, and an electrical system.

2.1 Left arm
The left arm is mainly composed of rotary tanks, large arms, large arm tanks, middle arms, middle arm tanks, small arms, small arm tanks, telescopic joints, telescopic oil tanks, shovels, and bucket tanks. The whole use of multiple joints, retractable mechanism, easy in the tunnel small space flexible operation. The bucket adopts high strength wear resistant steel, and the bucket tooth adopts an assembly structure to facilitate the flexible replacement after wear. The diagram of the left arm is shown in Figure 2.

2.2 Right arm
The right arm is mainly composed of the lower triangle mechanism, the upper triangle mechanism, the expansion cylinder, the rotating cylinder, and the fast exchange mechanism. You can replace different machines, such as milling heads, plumbing machines and so on. The diagram of the right arm is shown in Figure 3.

2.3 Material delivery mechanism
The feeding mechanism mainly consists of a left push plate, a right push plate, a push plate cylinder, a transport tank, a main drive part, a scraper chain, an active Sprocket, and a conveying hydraulic motor.
The tank body is lined with imported wear resistant plates, scratch plates and active sprockets are made of high-strength wear resistant diamonds. Control push plate cylinder expansion can open or close the left and right push plate, push plate open can increase the width of the shovel, push plate closure can be easy to walk. Controlling the expansion of the lifting tank can make the transport tank rise and fall to meet the needs of work or walking. Activating the hydraulic motor drives the scraper chain to transport the feed stone from the feed port to the tail of the transport tank. A schematic diagram of the feeding mechanism is shown in Figure 4.

Figure 4: Diagram of the feeding mechanism

2.4 Track walking assembly
The crawler walking assembly is mainly composed of track frame body, drive Sprocket, guide wheel, support wheel, support board, chain rail joint, track board, Buffer spring, tension cylinder, walking speed reduction box and walking hydraulic motor. The function of this assembly is to walk the entire machine and to shovel the stone. The tray is used to support the weight of the upper track and does not allow it to droop too much to reduce the vibration of the upper track when the machine moves. Buffer Springs can reduce the impact on the track. The tensioning cylinder can make the track moderately tensioning, the track too tight will increase the propulsion resistance, accelerate wear, reduce the track service life, and the track is too loose and easy to fall off. The track walking assembly is shown in Figure 5.

Fig. 5: Tracked walking assembly

2.5 Frame assembly
The frame assembly is mainly composed of the upper frame, the lower frame, the fuel tank assembly, and the motor oil pump assembly. The frame assembly connects the main parts of the entire machine and provides the mounting space for driving and various hydraulic control elements. The motor oil pump assembly consists of motors, working oil pumps, pilot oil pumps and couplers. It is the hydraulic power of the left arm, right arm, scraper chain and track walking.

2.6 Hydraulic operating system
The hydraulic operating system is mainly composed of walking hydraulic system, left arm hydraulic system, right arm hydraulic system, feed hydraulic system, pilot hydraulic system, oil filter, return oil filter, hydraulic oil cooling device and pressure measuring device. The high frequency of use is the liquid control pilot valve, and the low frequency is the electromagnetic liquid control switch valve. [3]

2.7 Electrical systems
The electrical system is suitable for three-phase five-wire AC power supply, and the voltage fluctuation range is 0.85 ~ 1.1 times the rated voltage. The power supply system of the TN-S grounding standard is
repeatedly grounded at each output. There is no load current on the PE line under normal operating conditions, and the device housing connected to it does not have a potential. Applicable to altitude ≤ 1000M; Environmental temperature -5 ~ 40 °C; The surrounding medium is free of corrosive metals and damaged insulation gas and conductive dust; A place where water and liquids shall be prevented from immersion; Phase sequence: Each time the power supply is connected, the phase sequence must be checked for correctness, and the power motor can be activated. If the motor does not rotate, then the power source phase sequence is reversed, the power source phase sequence is changed, and the motor can be clicked again.

3. Calculation of Main Electrical Components Selection

3.1 Motor capacity selection for driving hydraulic pumps
The following technical parameters are to be satisfied under the start-up and rated load of the hydraulic pump:
The maximum speed of the hydraulic pump is 2100r/min, the required start torque $T_{\text{start}} = 102\text{nm}$, and the maximum load torque $T = 548\text{nm}$.

3.1.1 Since the rated speed of the 4-stage three-phase asynchronous motor is close to the maximum speed of the hydraulic pump of 2100r/min, a 4-stage three-phase asynchronous motor with a rated speed of 1480r/min is selected;

3.1.2 The maximum power required to obtain the maximum load torque and rated speed is:
$$p = \frac{t \times n}{9550} = 1480 \times 9550 = 84.9\text{KW}.$$ Therefore, the motor should have a selection power of 90 KW;
1.3, 90kW motor rated torque $T = 9550P/n = 580\text{NM} & GT; T_{\text{maximum}} = 548\text{Nm}$, that is, can meet the maximum load torque requirements;
1.4, 90kW motor star start torque is 1/3 of the triangular start torque, IE $T_{\text{star}} = 1/3 \times 1.5 \times TN = 1/3 \times 580 = 290\text{ N.m.} & GT; T_{\text{start}} = 102\text{Nm}$, which can meet the start-up torque requirements;
In summary: The motor driving the hydraulic pump should be 4 poles, 1480r/min, and 90 kW.

3.2 Selection of total power cable specifications
The rated current of the driving hydraulic pump motor is 167A; The current of lighting and solenoid valve is 15A in total; Considering the construction environment and the ventilation and cooling conditions of the tunnel, the current load flow should have a surplus of 20 <UNK>; The total current required for the entire device is $(167 + 15) \times 1.2 = 218\text{A}$;
In summary: The power cable specification should be $YC3 \times 70 + 1 \times 25$.

3.3 Selection of three-phase AC contactor model
The rated current of the driving hydraulic pump motor is IN167A, and its current is linear current; In accordance with the principle of cost reduction, the three-phase AC contactor should be connected to the line flowing through the phase current, that is, phase $I = \frac{IN}{\sqrt{3}} = 167 / \sqrt{3} = 96\text{A}$. In summary: The three-phase AC contactor specification should be selected by Schneider brand LC1-D115.

3.4 Selection of leakage circuit breaker specifications
The rated current of the driving hydraulic pump motor is 167A; The current of lighting and solenoid valve is 15A in total; Considering the construction environment and the ventilation and cooling conditions of the tunnel, the current load flow should have a surplus of 20 <UNK>; The total current required for the entire device is $(167 + 15) \times 1.2 = 218\text{A}$;
In summary: The specification of the leakage circuit breaker should be 4 poles and the rated current is 250A.

4. General calculation of motor power of tunnel excavating truck
4.1 Basic parameters for tunneling and loading trucks
Vehicle quality: 25-27T
Drive wheel circle diameter: 0.63548 M
Motor: Main motor: 90kW- 1480 rpm
Hydraulic series pump: A11VLO 190 + A10VO 71 + AZPF-11 / 019
Walking motor reducer: TM40VD-A-92 / 169-1
Work Pressure of Multiway Valves for Walking and Picketing Devices: 28MPa
Working pressure of multiway valve for milling drill: 25 MPa
Driving speed: 1.5 m/h

4.2 Maximum traction calculation
Rolling resistance \( F_1 = (0.05 - 0.1) G = 0.075 \times 26 \text{T} = 19.5 \text{KN} \) (rolling resistance coefficient 0.075),
Soil deformation resistance \( F_2 = (0.05 - 0.1) G = 0.1 \times 26 \text{T} = 26 \text{KN} \),
turning resistance \( F_3 = 0.5 G = 0.5 \times 26 \text{T} = 130 \text{KN} \),
\[ F = F_1 + F_2 + F_3 = 19.5 + 26 + 130 = 176 \text{KN} \]

4.3 Calculation of Maximum Climbing Angle
The resistance to secretly digging a car to climb the slope is as follows:
Rolling resistance \( F_1 = fG \cos \alpha = 0.1G \cos \alpha \) (for rolling resistance coefficient)
Ramp resistance \( F_2 = G \sin \alpha \)
Internal resistance \( F_3 \approx 0.1G \)
Inertial resistance to unstable motion, wind resistance is small, ignored here. The maximum adhesion of a dark excavation truck on a bad ramp:
\[ F_f = \psi G \cos \alpha = 0.7G \cos \alpha \leq \text{Maximum traction } F \] (for adhesion coefficient)
When the sum of the resistance is equal to the maximum adhesion, the dark dig can climb the maximum slope, IE.
\[ F_f = F_1 + F_2 + F_3 = F_f \]
\[ 0.7G \cos \alpha + G \sin \alpha + 0.1G = 0.7G \cos \alpha \]
That is, \( \sin \alpha = 0.6 \cos \alpha + 0.1 = 0 \) when the attachment coefficient is 0.7
\[ 0.7G \cos \alpha = 0.7 \times 260 \times \cos \alpha = 163.5 \text{kN} < 192.7 \text{kN} \]
Therefore, the traction provided by the hydraulic system can ensure that the slope of 26° is climbed. When the ramp is greater than 26°, the adhesion is less than the resistance, less than the traction, and it can not climb up.

4.4 Calculation of transport capacity
Transport chain pitch 78.1 mm; Chain wheel partition circle diameter 180mm; The rock density is about 1800 kg/m³. The inflation factor is 1.3. Transmission Belt Transmission Capacity 120 m³/h, The transport quality per meter on the transport chain is:
\[ q_1 = \frac{120}{1.3 \times 3600 \times 0.6} \times 1 \times 1800 = 76.92 (kg/m) \]
Welding scraper conveyor chain per meter quality
\[ q_2 = 13.46 + \frac{31}{12.1} \times 1.6 = 17.5 (kg/m) \]
Welding scraper conveyor chain per meter quality
Transport quality per meter on the transport chain is:
\[ n_1 = \frac{V}{\pi D} = \frac{0.6 \times 60}{\pi x 0.18} = 63.7 (r/min) \]
The basic operating resistance of the welded scraper transport chain with carrying branches is:
WZK = (q₁w₁ + q₂w₂) L₁gcos α + (Q₁ + Q₂) L₂gsin α = 9604.6(N)
The basic operating resistance of the empty branch of the welded scraper transport chain is:
WK = (W₂ Cos α - sin α) Q₂ L₁g = 109.2(N)
When calculating traction, the running resistance of the curve segment is about 10 % of the running resistance of the straight segment, then the traction of the welding scraper transport chain is about:
F = 1.1(WZK + WK) = 1.1 × (9604.6 + 109.2) = 10685.2(N)
For the resistance coefficient of the soil and the chain when moving in the chute, 0.6 and 0.4 are taken respectively; The driving power required to weld the scraper transport chain for the welding scraper transport chain inclination angle (maximum tilt angle 19 °) is:
Pₘ = \frac{FV}{\eta} = \frac{10685.2 \times 0.6}{0.95} = 6.75(KW)
\( \eta = 0.95 \) (Transmission efficiency for chain drive)

The output torque of the deceleration motor is:
T = \frac{Fr}{\eta} = \frac{10685.2 \times 0.18}{2 \times 0.95} = 1012.3(Nm)
\( \eta = 0.95 \) (Transmission efficiency for chain drive)

The selected reduction motor parameters are: the motor power is 11KW; The output torque of the deceleration motor is 1630; The output speed of the motor is 1440 rpm, and the speed reducer transmission ratio is 22.41. Therefore, the output speed of the deceleration motor is 1440 rpm / 22.41 = 64.26 rpm. The welding scraper transport chain speed is:

\[ v = \frac{n \pi D}{60} = 0.61(m/s) \]

Output torque of the reducer motor:
T = 1012.3 Nm < 1630 Nm;
It is calculated that the welded scraper transport chain can meet the demand of conveying energy by 120 m³ / h.

4.5 Entire power matching calculation

4.5.1 Power during walking
Since the A11VLO variable pump is a constant power pump, the maximum power is set by the spring on the variable pump, and the working process is basically unchanged. The power setting value of the variable pump is determined by the working pressure and flow rate.

4.5.1.1 Computation of Working Pressure for Flat Walking
The rolling resistance and internal resistance must be overcome when the hydraulic undercover digging trolley is running on the flat ground. Rolling resistance:

\[ F₁ = fG = 0.1 \times 16 \times 10^4 \times 9.8 = 15.68(kN) \]
Internal resistance:

\[ F₂ = 0.1G = 0.1 \times 16 \times 10^4 \times 9.8 = 15.68(kN) \]
The traction force is:

\[ F = F₁ + F₂ = 15.68 + 15.68 = 31.35 \text{ (kN)} \]

Driving wheel resistance moment:

\[ T₂ = \frac{F \times D}{2} = \frac{31.35 \times 0.63548}{2} = 9.96(kNm) \]
The resistance moment of the motor to be overcome:
At low gear: \( P = 4.5 \) Mpa

4.5.1.2 Maximum Flow for Flat Walking

The maximum output flow of the pump is:

\[
Q_p = nV_p = \frac{1480 \times 190 \times 0.95}{1000} = 267 \text{L/min}
\]

At this time, the pressure \( P \) of the high gear is 10.56, so the power is:

\[ N = PQ = \frac{10.56 \times 267 \times 13}{60} = 45 \text{kW} \]

The pressure \( P = 5.71 \) Mpa and the power is:

\[ N = PQ = \frac{5.71 \times 267 \times 13}{60} = 24.3 \text{kW} \]

4.5.1.3 Maximum Power of Right Arm Working Device

The average pressure of the working device is 20 MPa.

\[ Q_p = nV_p = \frac{1480 \times 190 \times 0.95}{1000} = 267 \text{L/min} \]

The maximum flow rate is 0.45 times of the total displacement of the pump.

\[ N = PQ = \frac{267 \times 0.45 \times 25.3}{60} = 40.1 \text{kW} \]

The working pressure of the pilot pump is \( P = 15 \) Mpa, the displacement \( V = 19 \text{cc/r} \), the speed \( n = 1480 \text{r/min} \), the efficiency \( \eta = 0.90 \) and the maximum flow rate are:

\[ Q = nV\eta = 25.3 \text{L/min} \]

The maximum input power is:

\[ N = \frac{15 \times 25.3}{60} = 7 \text{kW} \]

According to the above calculation results, since it is impossible for the left and right arms to work at the same time, the parameters which consume more power are selected to calculate. When the motor works in the tunnel, the maximum total power is:

\[ N = 24.3 + 50.1 + 7 = 81.4 \text{kW} \]

Therefore, the motor power 110 kW completely meets the design requirements.

5. Electrical Common Fault and Removal Method

5.1 Common Faults and Clearance Methods for Whole Machine to see “Table 1”

| Therefore | Can be caused by | Exclusion method |
|-----------|-----------------|------------------|
| The motor doesn’t start or doesn’t work properly | 1. Lack of phase of power supply; Or the sequence is incorrect; 2. Insufficient voltage; 3. Contactor damage or electrical line failure. 4. Hydraulic system compression | 1. Check the power supply to ensure that the three-phase voltage is normal; Phase sequence is normal; 2. Measurement of voltage and adjustment of voltage to normal; 3. Repair, replace contactors and troubleshoot lines. 4. Check whether the handle and knob return to the middle position. |
| No movement or slow motion | 1. Inversion of the motor; 2. The coupling is damaged and the oil pump does not turn; 3. Damage to the pumps; | 1. Correct the steering and turn counterclockwise from the fan side; 2. Replacement of the coupling; 3. Repair or replacement of pumps; |
4. Low pressure of hydraulic pilot systems;  
5. Inhalation of air;  
6. The oil surface is too low;  
7. Obstruction of oil absorption or return filter;  
8. There is air in the tank;  
9. Hydraulic fluids are inadequate or too viscous.  
10. Hydraulic cylinder leakage.

4. Correct the pressure adjustment of the pilot system;  
5. Inspection of oil suction lines, replacement of seals, elimination of leakage;  
6. Refueling to the middle of the oil standard;  
7. Cleaning or replacing oil absorption or oil recovery filters;  
8. Unscrew the hose at the cylinder joint and move the exhaust back and forth;  
9. Replacement of hydraulic fluids as required.  
10. Replacement of service hydraulic cylinders.

1. The scraper chain or Sprocket is stuck with a hard object;  
2. Chain adjustment is too tight.

1. Manipulating the scraper chain to quickly reverse the positive to squeeze out hard objects and manually remove obstacles when necessary;  
2. Loosen the chain properly.

1. The pressure of the walking safety valve or the passing valve is low;  
2. Damage to the walking oil motor;  
3. Damage to the bearing or gear of the walking gearbox.

1. Observe the walking pressure, if the pressure is too low, adjust the overload valve on the motor; Check the brake valve over Gaoze or whether it is stuck.  
2. Repair or replace walking oil Motors;  
3. Inspection of walking gearboxes and repair or replacement of damaged parts.

1. Loose connectors;  
2. Failure of the gasket or sealing ring;  
3. Weld leakage.

1. Tighten the connector;  
2. Replacement of gaskets;  
3. Rewelding.

5.2 Common Faults of Walking and Transmission Hydraulic Motor and Methods of Removal to see “Table2”

| Therefore | Can be caused by | Exclusion method |
|-----------|-----------------|-----------------|
| The motor does not turn or rotates very slowly | 1. Large load, insufficient pump pressure;  
2. The shaft connected to the motor is too long or different from the motor.  
3. Lead handle output pressure is too low | 1. Reduce the load, increase the pressure of the safety valve and the overload valve, and increase the pump oil supply pressure;  
2. Adjust the length of the connection shaft and the concentric degree with the motor.  
3. Adjust the output pressure of lead handle. |
| Impact sound | 1. Not enough oil pressure (that is, insufficient back pressure);  
2. There is air in the oil;  
3. The oil supply of the oil pump is not continuous or the change valve frequently changes direction;  
4. Hydraulic motor parts are damaged. | 1. To increase the pressure of oil replenishment, one-way valves or throttle valves can be added to the return road;  
2. Check the oil path, find the intake point, and discharge the air;  
3. Inspection and elimination of pump and change valve faults;  
4. Repair hydraulic motor. |
| Liquid motor shell temperature is not normal. | 1. The oil temperature is too high;  
2. Oil discharge joint thread is too long, the rotor is firmly supported  
3. The shaft connected to the motor is too long or different from the motor;  
4. Hydraulic motors are inefficient. | 1. Check all components of the system without any normal failure. If all components are normal, oil cooling should be strengthened;  
2. Reduce the slip length of the oil discharge joint;  
3. Adjust the length of the connection shaft and the concentric degree with the motor;  
4. Repair or replace hydraulic Motors. |
Large oil discharge and weak motor rotation

1. Damage to piston rings of hydraulic Motors;
2. The damage of the interface between the motor fuel shaft and the rotor body is mainly due to the impurity embedded in the oil fluid between the fuel shaft and the rotor body, which bites each other.

1. Replacement of piston rings;
2. Repair or replace damaged parts and then clean pipes and fuel tanks

There's a leak in the motor.

1. Damage to the sealing ring;
2. The oil discharge joints are threaded too long to hold the rotor and the shaft connected to the motor too long or the motor is not centered so that the pressure of the motor shell cavity is too high and breaks through the sealing ring.

1. Replacement of sealing rings;
2. Replace the sealing ring after reducing the length of the oil discharge joint into the shaft or adjusting the length of the connection shaft and the degree of consistency with the motor.

The hydraulic motor inlet pressure gauge has a very abnormal vibration.

1. There is air in the oil;
2. Hydraulic motors are abnormal

1. Eliminate the factors that produce air in the oil until there are no bubbles in the fuel tank;
2. Repair hydraulic Motors.

Fault analysis of rotating speed change

When debugging a hydraulic transmission system containing a hydraulic motor, if the hydraulic motor does not turn or rotate slowly or unsteadily, this is related to the system mechanism. The reasons are not the same. In hydraulic transmission systems, this situation is encountered, in addition to checking the overflow valve problems but also to check whether the pilot valve output pressure is normal.

6. conclusion
The structure and working principle of the tunneling truck are introduced in this paper. It plays an important role in the development and use of the same kind of machinery for the calculation of major electrical components and the analysis of common faults and troubleshooting methods.

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References
[1] Hongpeng, Zhaosheng, An Sancha. Discussion on the applicability of double-arm dark digging trolley in the construction of earth subway tunnel[ J] .. Tunnel Construction(Chinese and English), 2018, 38(04): 699-708.
[2] Liuyuchuan, Li Yangzengjie. Study on the construction method of excavation arm construction of underground tunnel excavation truck[ J] .. Well Construction Technology, 2017, 38(05): 51-55.
[3] Xu Gong first set of dark digging table hydraulic cylinder to fill the domestic blank[ J] .. Nonferrous equipment, 2015(06): 52.
[4] Lu Qi. Development analysis of shallow buried tunnel construction technology[ J] .. Construction and Design, 2019(02): 183-184.

[5] Qin Jin. Application of shallow buried tunnel construction technique[ J] .. Jushe, 2019(01): 55.

[6] Zhang Junrong. Sand and Pebble strata secretly dig tunnels to penetrate the existing cable construction technology at close range[ J] .. Science, Technology and Innovation, 2019(01): 48-51.

[7] Liucailiang, Li Liuchengyu.qian buried and dug subway tunnel excavation method comparative analysis[ J/OL] .. Railway survey.