The Analysis of Electric Differential Drive Technology and Characteristics on Overhead Crane

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ABSTRACT

Using electrical differential drive to reduce the weight of the trolley on bridge crane. The analysis of rotational speed of reel on both sides of the crane girder in different conditions show that when the trolley and the hook make joint motion rotational speed of reel is uniquely determined by the condition that the middle pulley of the hook does not rotate. Studying the forces of the rope under joint motion and the conditions that the middle pulley does not rotate in the view of mechanics, then, calculating the minimum of hoist that makes the trolley run normally. Studying the power of the reel drive motor under the joint motion, calculating minimum power required for a single motor.

INTRODUCTION

Overhead Crane is widely used in iron and steel, metallurgy, transportation, energy, chemicals, machinery, light industry, environmental protection, water conservancy and other industries of the national economy and played an important role in the national economy. With the rapid development of China's economy and the urbanization process, the market demand of large-scale machinery and equipment which make overhead crane as representative is huge. In recent years, our crane manufacturing industry have been doing a lot of useful work around environmental protection and lightweight, among which mechanical differential technology has been used in grab ship unloader\(^{1-2}\), by reducing weight of the trolley, which achieve lightweight; the key components to achieve mechanical differential
technology—mechanical differential gearbox is bulky and production costs is high, so in recent years researchers have proposed using the electric differential technology in grab ship instead of mechanical differential technology[3-5], and analyzes the requirements of electrical control of electrical differential and the main similarities and differences between electrical and mechanical differential. For the overhead crane, present research is focused on the optimization of the trolley, running mechanism, bridge structure and other aspects[6-8] to achieve lightweight.

This paper puts forward electric differential drive technology to achieve significant weight loss of overhead crane, and study driving speed, power distribution and other characteristics.

**PRINCIPLE OF ELECTRICAL DIFFERENTIAL DRIVE TECHNOLOGY ON OVERHEAD CRANE**

Overhead crane by electrical differential driving through removing lifting mechanism on the trolley and driving mechanism of self-driving trolley and placed them on both ends of the main beam, greatly reducing the weight of the trolley and the load on the beam, which can greatly reduce the weight of the beam and combining lifting and trolley drive to reduce the weight of the drive to achieve significant weight loss of overhead crane.

![Simplified model of Overhead crane by electrical differential driving.](image)

Overhead crane by electrical differential driving is shown in Figure 1, leading to a rope from one side of the reel, let it pass through the side of the fixed pulley group, the movable pulley group on the hook, and then through the fixed pulley group on the other side, finally twine on the reel on the other side. Electrical differential overhead crane works by controlling the speed and direction of the reel to achieve trolley, lifting and their joint motion. When both sides of the reel turn in the opposite direction and the speed is the same, the hook lifts; when both sides of the reel turn in the same direction and speed, the trolley moves; otherwise, the trolley and hook achieve joint motion.
MOTION ANALYSIS OF TROLLEY AND HOOK

As shown in figure 2, $V_1$ and $V_2$, respectively represent linear velocity of the drum on both sides, $V_x$, $V_y$ respectively represent walking speed of the trolley and lifting speed of the hook, $V_{y1}$, $V_{y2}$ respectively represent the linear velocity of wire rope between the fixed pulley group and movable pulley group. When the trolley and the hook move at a certain speed, by analysis of the change of the length of wire rope, the relationship between moving speed of the trolley as well as the hook and rotating speed of the drum on both sides is as follows:

\[
\begin{align*}
V_1 &= V_x + V_{y1} \\
V_2 &= -V_x + V_{y2} \\
V_{y1} + V_{y2} &= 2mV_y
\end{align*}
\]  

(1)

In formula: $m$ is the ratio of pulley group.

According to the formula (1), rotating speed of the drum on both sides is not certain when the trolley and the hook move at a certain speed. It is because lifting speed is certain by rotation of middle pulley to make the change of the length of wire rope same when rotating speed to make hook lift of the drum is different. In fact, rotating speed of the drum on both sides is decided by work speed of the trolley and the hook and it must be uniquely identified. Therefore, the middle pulley can not rotate.

Assuming the middle pulley does not turn, then $V_{y1}=V_{y2}$. According to the formula (1) the relationship between moving speed of the trolley as well as the hook and rotating speed of the drum on both sides is as follows:

\[
\begin{align*}
V_1 &= V_x + V_{y1} \\
V_2 &= -V_x + V_{y2}
\end{align*}
\]  

(2)

Figure 2. Motion model of trolley and hook.
According to the formula (2), when \( V_1=V_2 \), namely the drum collect or release rope, \( V_x=0, V_y=V_1/m=V_2/m \), namely the hook lift but the trolley does not move; when \( V_1=-V_2 \), namely one drum collect rope but another drum release rope, \( V_x=V_1=V_2, V_y=0 \), namely the trolley move but the hook does not lift.

THE CONDITION TO MAKE THE SPEED OF TROLLEY AND HOOK CERTAIN

As shown in figure 2, \( S_1, S_2 \) respectively represent tension of rope on both sides, \( G \) is weight of the trolley, \( F \) is running resistance of the trolley, \( Q \) is weight of hoisting.

\[
F = (Q + G) \omega
\]  
(3)

In formula: \( \omega \) is running resistance coefficient.

\[
\Delta F = 0.33 \left( \frac{d_1}{D} \right)^{1.25} S + 0.00465 d_1^2
\]  
(4)

In formula: \( \Delta F \) is stiff resistance of rope; \( d_1 \) is diameter of rope; \( D \) is diameter of pulley.

\[
\Delta f = \frac{Q}{m} \frac{d_2}{D} \mu
\]  
(5)

In formula: \( \Delta f \) is rolling resistance of pulley; \( d_2 \) is inner diameter of pulley bearing; \( \mu \) is rolling friction coefficient.
When the trolley and hook make joint motion, according to load balance the relationship is as follows:

\[
S_1 - S_2 = F
\]

\[
S_1 \eta \frac{1 - \eta^{m-1}}{1 - \eta} + \frac{S_2}{\eta_d \eta} \frac{\eta^{m-1} - 1}{\eta^{m-1} - \eta^{m-2}} = Q
\]  \hspace{1cm} (6)

In formula: \(\eta_d\) is efficiency of guiding pulley; \(\eta\) is efficiency of pulley group.

Known from the analysis of the above, when work speed of the trolley and the hook is certain, to make rotating speed of the drum on both sides uniquely identified the middle pulley can not rotate. According to load analysis, tension difference of rope on both sides of middle pulley is less than rolling resistance of pulley.

\[
S_1 \eta \eta^{m-1} - \frac{S_2}{\eta_d \eta^{m-1}} \leq \Delta F + \Delta f
\]  \hspace{1cm} (7)

By solving formula (6) and (7), the minimum of hoisting to make rotating speed of the drum on both sides uniquely identified is acquired.

**CHARACTERISTIC ANALYSIS OF DRIVING MOTOR POWER**

When the hoisting rises, it makes negative work for motor on both sides. When the hoisting drops, it makes positive work for motor on both sides. When the trolley runs, motor consumes energy to overcome running resistance. When work speed of the trolley and the hook is certain, the power that these three work condition need is constant. When the trolley and the hook make joint motion, formula (6) is simplified as follow:

\[
S_1 = \frac{1}{2} \left( \frac{Q}{m} + F \right)
\]

\[
S_2 = \frac{1}{2} \left( \frac{Q}{m} - F \right)
\]  \hspace{1cm} (8)

Setting the power of the motor on both sides to \(P_1\) and \(P_2\), one side that collects rope makes negative work for motor, another side that releases rope makes positive work for motor.

\[
P_1 = \frac{1}{2} \left( \frac{Q}{m} + F \right)(V_x + mV_y)
\]

\[
P_2 = \frac{1}{2} \left( \frac{Q}{m} - F \right)(-V_x + mV_y)
\]  \hspace{1cm} (9)

The installed capacity of motor for electrical differential driving mechanism is decided by one side whose power is much than other. According to formula (9), \(P_1\) is much than \(P_2\), so the analysis for \(P_1\) is more important to select the rated power of motor.
\[ P_I = \frac{1}{2} \left( \frac{Q}{m} + F \right) (V_x + mV_y) = \frac{1}{2} \left( \frac{Q}{m} V_x + QV_y + FV_x + mV_y F \right) \quad (10) \]

From formula (10), \( Q \) and \( m \) have much influence on the rated power of motor because \( F \) is little. The greater the weight of hoisting, the much power that the motor need; the smaller \( m \), the much power that the motor need. When the weight of hoisting is constant, according to average inequality, the minimum of \( P_I \) is as follow:

\[ P_{min} = \frac{1}{2} (QV_y + FV_x + 2\sqrt{QV_y V_x F}) \quad (11) \]

CONCLUSION

The structure of electrical differential driving mechanism is simple and manufacturing is easy. Applying it to overhead crane accords with present development tendency of crane.

This page according to the theory of electrical differential driving, analyze the relationship between moving speed of the trolley as well as the hook and rotating speed of the drum on both sides. It has practical significance on the control of electrical differential driving. By analysis of work condition that the trolley and the hook make joint motion, calculating the power that the motor need on both sides. It has guiding significance on choice of motor.

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REFERENCES

1. Su Chao, Sun Jingyong.3200t/h mechanical differential bridge-type grab ship unloader [J]. Hoisting and Conveying Machinery, 2011, (S1): 34-36.
2. Liu Chaojue, Huang Xulin. Analysis of planet differential mechanism of overhead grab ship-unloader [J]. Hoisting and Conveying Machinery, 2014, (7): 73-76.
3. Peng Chuansheng. Development and application of four-drum rope trolley [J]. Hoisting and Conveying Machinery, 2000, (10): 6-8.
4. Yang Zhenli. An Electrical Differential Driving Bridge Grab Bucket Ship Unloader [J]. Port Loading and Unloading, 2014, (5): 7-10.
5. Wang Junhua. The power and load research of four-drum rope trolley [J]. Hoisting and Conveying Machinery, 2008, (4): 74-78.
6. Xu Xifeng. Coupling mechanism of bridge gantry crane box girder structure and stiffener [D]. Southwest Jiaotong University, 2013.
7. Shi Xiaofei. Study of particle swarm optimization method and development of software for overhead travelling crane girders [D]. Taiyuan University of Science and Technology, 2012.
8. Gao Fei, Liu Jinliang. The optimization of crane girder based on the improved genetic algorithm [J]. Hoisting and Conveying Machinery, 2012, (8): 41-45.