Method for Controlling Speed of Port Loading and Unloading Machinery Based on Real-time Information

Xiaomo Yu, Wenjing Li, Derong Wang, Ying Li, and Xinquan Liu

Department of Logistics Management and Engineering
Nanning Normal University
Nanning 530001, China

ABSTRACT


The steady state distortion of port loading and unloading machinery is easy to appear in the process of frequency conversion speed regulation, so it is necessary to carry out the design of mechanical speed control. The automatic control technology of frequency conversion speed regulation of port loading and unloading machinery based on real time information adaptive regulation is put forward. The constraint parameter model of frequency conversion speed regulation of port loading and unloading machinery is constructed by taking the parameters such as rotating inertia moment, load strength, steady state power, gain and equivalent load of the manipulator as the constraint indexes. The control objective function is constructed, Smith controller is used to adjust the frequency conversion speed of port loading and unloading machinery, combined with real-time information feedback adjustment compensation method to suppress the speed regulation error of port loading and unloading machinery, the output time delay compensation model of port loading and unloading machinery is established, and the automatic control optimization of frequency conversion speed regulation of port loading and unloading machinery is realized. The simulation results show that the steady-state output ability of frequency conversion speed regulation automatic control of port loading and unloading machinery is strong, and the load intensity and efficiency of port loading and unloading machinery are improved.

ADDITIONAL INDEX WORDS: Real-time information, port loading and unloading, machinery, speed control.

INTRODUCTION

The port loading and unloading machine has the advantages of high load strength and good stability, and is widely applied to the fields of port loading and unloading and the like. The port loading and unloading machine adopts an alternating-current electromagnetic coupling mode to realize the electromagnetic induction control, the power optimization output is realized through the frequency conversion and speed regulation, and the output frequency conversion torque control of the port loading and unloading machine is realized by adopting an electromagnetic coupler so as to achieve pressure-stabilizing output (Zhu and Ren, 2019). The influence of the torque differential output of the variable-frequency speed control causes the output voltage of the port handling machinery not to be good, and it is necessary to carry out the automatic control of the speed regulation of the port loading and unloading machine (Gharibreza, 2017; Hua et al., 2018; Kaushik, 2018; Moreno and Garcia-Alvarez, 2017).

Conventionally, the method for automatically controlling the frequency conversion speed of the port loading and unloading machinery mainly comprises a fuzzy PID control method and a torque error compensation control method and the like (Chen, 2017), and the error compensation and the feedback adjustment are carried out in combination with the gain of the output voltage, the power loss and the like. In order to improve the automatic control performance of the frequency conversion and speed regulation of the port loading and unloading machinery, the above method is disturbed by small disturbance in the control of the port loading and unloading machinery, and the steady state of the output is not good (Wang, 2018). In this paper, the automatic control technology of frequency control of port loading and unloading machinery based on the self-adaptive adjustment of real-time information is presented in this paper, and the model of automatic control of frequency-changing and speed-regulating port loading and unloading machinery is constructed, and the inertia moment and the load strength of the mechanical arm are calculated (Chen, Hassanzadeh-Aghdam, and Ansari, 2018; Jiang et al., 2017). The parameter of the steady-state power gain and the equivalent load is a constraint index, the control target function is constructed, a Smith controller is adopted to carry out the frequency conversion rotation speed regulation of the port loading and unloading machine, and the speed regulation error suppression of the port loading and unloading machine is carried out in combination with the real-time information.
feedback adjustment compensation method, the output time-delay compensation model of the port loading and unloading machine is established, and the automatic control and optimization of the frequency conversion and speed regulation of the port loading and unloading machinery are realized (Cao et al., 2019; Gao et al., 2017). Finally, the simulation experiment is carried out to show the superiority of the method in improving the control ability of the port loading and unloading machinery (Noël and Kerschen, 2017).

MATERIAL AND METHODS

Analysis of Control and Constraint Parameters of Port Loading and Unloading Machinery

In order to realize the automatic control of frequency conversion speed regulation of port loading and unloading machinery, the control objective function is constructed with the parameters such as rotating inertia moment, load strength, steady state power gain and load of port loading and unloading manipulator as constraint indexes, and the optimal design of control law is carried out (Cao, Li, and Liu, 2019). Firstly, the equivalent output circuit structure model of port loading and unloading machinery is established as shown in Figure 1.

According to the equivalent circuit model shown in Figure 1, the control constraint parameter analysis of the port loading and unloading machine is carried out, the parameters such as the rotational inertia moment (Xu et al., 2008), the load intensity, the steady-state power gain and load of the mechanical arm are taken as the constraint indexes to obtain the electromagnetic coupling pole logarithm \( P \) and the torque control coefficient \( \beta \), the thickness of the electromagnetic coil is \( l_p \), the output equivalent gain of the port loading and unloading machinery is \( G_i(s) \), the output torque of the controlled object is \( G_m(s) \), a Smith controller is adopted, the coupling parameter model for the frequency conversion and speed regulation of the port loading and unloading machinery is constructed, and the output torque of the port loading and unloading machine satisfies the \( e^{-\omega t} \) and \( G_m(s) = G_i(s) \). The frequency-variable speed-regulating feedback equation for the port loading and unloading machine is described as follows:

\[
H(s) + Y(s) = G_m(s)U(s) \tag{1}
\]

The above formula shows that in the speed regulation feedback control of the port loading and unloading machine (Cao, Li, and Liu, 2018), the output control transfer function of the port loading and unloading machine is obtained by taking the \( G_m(s) \) as the output time lag and considering the influence of the disturbance factors under the condition of small disturbance:

\[
\frac{Y(s)}{R(s)} = \frac{G_m(s)G_i(s)e^{-\omega t}}{1 + G_m(s)G_i(s)} \tag{2}
\]

The characteristic equation has no delay term. Under the condition of \( R \), constant stability, the constraint parameter model of the controller is described as follows:

\[
\frac{Y(s)}{R(s)} = \frac{G_m(s)G_i(s)e^{-\omega t}}{1 + G_m(s)G_i(s)} + G_m(s)(G_i(s)e^{-\omega t} - G_i(s)e^{-\omega t}) \tag{3}
\]

According to the analysis of the above control constraint parameters, the equivalent model of frequency conversion speed regulation of port loading and unloading machinery is constructed (Amirat and Munch, 2019).

Analysis of Control Object and Loading and Unloading Machinery Parameters

Under the condition of stable electric energy transmission, the automatic control object model for frequency conversion and speed regulation of port loading and unloading machinery is constructed, and the output torque of the port loading and unloading machine can be expressed as:

\[
T_m = \frac{\pi k_i k_m I_m B L_m l_m (2r_c + 2I_a + I_m)}{\text{ln}(r_c + I_m) - \text{ln}(r_c - I_m)} \tag{4}
\]

\[
k_i = 1 - \frac{1}{0.9[r_c / (\beta p(I_a + I_m))]} + 1 \tag{5}
\]

Feedback constraint control is carried out for coil sequence of port loading/unloading machinery (Jiang, Cui, and Wang, 2014). In the hysteresis link of armature reaction, calculate the power consumption \( P \) of port loading/unloading machinery and load \( I_c \) to calculate the effective current value \( R \) of port loading/unloading machine, the current value \( I_c \) at the output end and current value \( D \) of side induction coil are as follows:

\[
I_c = \frac{a_0 M_m I_c}{R_c + Z_c} \tag{6}
\]

\[
I_o = \frac{a_0 M_m I_c}{R_c + Z_c} \tag{7}
\]

\[
I_0 = \frac{M_m I_c}{I_{eq}} \tag{8}
\]

A full-wave rectification coupling control method is adopted to calculate the reflection impedance of the port loading and
unloading machine (Bao et al., 2013), which comprises the following steps:

\[
Z_\eta = \frac{M_\eta R_s}{L_s} - j \omega L_\eta
\]

(9)

The frequency conversion speed regulation of the port loading and unloading machine is carried out by using the Smith controller, and the speed regulation error suppression of the port loading and unloading machine is carried out in combination with the real-time information feedback adjustment compensation method (Chen et al., 2017), and the impedances $S$, $G$ and $H$ under the control of the variable-frequency speed-regulating output voltage-stabilizing control are respectively:

\[
Z_s = \frac{M_s R_s}{L_s}
\]

(10)

\[
Z_m = \frac{\omega L_m^2}{L_s + R_s}
\]

(11)

\[
Z_p = \frac{\omega L_p}{Z_p}
\]

(12)

According to the above analysis, the parameter calculation of the frequency conversion speed regulation of the port loading and unloading machinery is realized, and the original parameter foundation is input for the automatic control of the frequency conversion speed regulation (Ma, Zhang, and Ma, 2019).

Optimization of Variable Frequency Speed Controller for Port Loading and Unloading Machinery

On the basis of constructing the parameter model of variable frequency speed regulation and the description of the controlled object (Zhang et al., 2017), the optimal design of the controller is carried out. The self-adaptive adjustment model of pressure stabilization compensation for port loading and unloading machinery is expressed as follows:

\[
\begin{aligned}
\dot{x}_1 &= x_1 \\
\dot{x}_2 &= f_0(X,t) + g_0(X,t)u(t) + d_0(t) \\
\dot{x}_3 &= x_3 \\
\dot{x}_4 &= f_0(X,t) + g_0(X,t)u(t) + d_0(t)
\end{aligned}
\]

(13)

Combined with time delay error compensation, the automatic control state equation of frequency conversion speed regulation of port loading and unloading machinery under steady state regulation is obtained as follows:

\[
\begin{aligned}
\dot{u}_s' &= W_s' - \left( S_0 \cdot m_0 \cdot \cos(P_0 \cdot \theta) \right) \cdot j_\theta \\
\dot{u}_p' &= W_p' - \left( S_0 \cdot P_0 \cdot m_0 \cdot \cos(P_0 \cdot \theta) \cdot \frac{2\pi}{3} \right) \cdot j_\theta \\
\dot{\theta} &= \frac{\chi}{2} \\
x' &= \frac{1}{K} \left[ \frac{1}{2} m_0 \cdot P_0 \cdot j_\theta \cdot \cos(P_0 \cdot \theta) \right]
\end{aligned}
\]

(14)

In the formula, $W'$ is the weighted coefficient of port loading and unloading machinery speed regulation control, $G$ is the corresponding current value, $S_0$ is the load strength loss, $P_0$ is the transmission phase of port loading and unloading machinery, $\theta$ is the torque angular speed of port loading and unloading machinery (Xu et al., 2012), and $x$ is the load inertia of output loading and unloading machinery. Therefore, the Smith controller is used to adjust the frequency conversion speed of port loading and unloading machinery, and the real-time information feedback adjustment compensation method is combined to suppress the speed regulation error of port loading and unloading machinery. The optimal control law is obtained as follows:

\[
\begin{aligned}
\frac{dV}{dt} &= g_{so}m_s h(E_{so} - V) + g_{sn}n^4(E_k - V) + g_{sl}(E_l - V) + I_{so} \\
m_0 &= \alpha_s(V) / (\alpha_s(V) + \beta_s(V)) \\
\frac{dn}{dt} &= \alpha_s(V)(1 - n) - \beta_s(V)n \\
h &= \max(1 - 1.25n, 0)
\end{aligned}
\]

(15)

Under the optimal control model, the load strength of port loading and unloading machinery is expressed as follows:

\[
p_0 = \frac{\omega^4 L_p^2}{(\omega L_p + R_p L_p + R_p M_p)^2}
\]

(16)

The efficiency factor of frequency conversion and speed regulation of port loading and unloading machinery is expressed as follows:

\[
\eta = \frac{P_0}{T_p(Z_m + R_p)} = \frac{\omega^4 L_p^2}{(\omega L_p + R_p L_p + R_p M_p + h R_p)}
\]

(17)

In which: $h = \omega^4 L_p^2 / (R_p L_p + R_p M_p)$. According to the optimization design of the control law, under the condition that the load is $R_p$ and $R_s$, the power gain compensation and the voltage stabilizing regulation are realized, and the load strength and the voltage stabilizing performance are improved (Cao, Wang, and He, 2016).

Bearing Capacity Analysis of Load Transfer Mechanism of Port Handling Machinery

Based on the constraint parameter model of the pressure-bearing control of the port loading and unloading machinery, the carrying capacity study of the load transfer mechanism of the port loading and unloading machine is carried out, and the characteristic decomposition is carried out according to the finite element analysis model of the pressure-bearing control of the port loading and unloading machinery (Samarati, 2016), the bearing pressure and the stress yield response characteristic data acquisition of the port loading and unloading machine are carried out by using a 6-dimensional force sensor, and the characteristic matrix of the pressure-bearing control constraint control of the port loading and unloading machine of the underwater vehicle is defined as:

\[
R = X(n)X^T(n) = \begin{bmatrix}
x_1(n)x_1(n) & x_1(n)x_2(n) & \ldots & x_1(n)x_n(n) \\
x_2(n)x_1(n) & x_2(n)x_2(n) & \ldots & x_2(n)x_n(n) \\
\vdots & \vdots & \ddots & \vdots \\
x_n(n)x_1(n) & x_n(n)x_2(n) & \ldots & x_n(n)x_n(n)
\end{bmatrix}
\]

(18)
Based on the load transfer mechanism model, the dynamic geometric characteristic parameters of port loading and unloading machinery are sorted, and the stress yield response distribution relationship of hoisting port loading and unloading machinery can be expressed as follows:

$$\lambda_i > \lambda_2 > ... > \lambda_{j-1} > \lambda_j > ... > \lambda_n$$  \hspace{1cm} (19)

According to the pressure-bearing capacity of the load transfer mechanism of the port loading and unloading machine, the control parameter model of the port loading and unloading machine is expressed as follows:

$$\sum_{i=1}^{n} [\theta_{\rho}(n+1) - \theta_{\rho}(n)]y_i =$$

$$\sum_{i=1}^{n} \eta_i \lambda_i - \delta_i^*(n) \varphi_{\rho}(n)q_i + \nu \sum_{i=1}^{n-1} \lambda_i \alpha_{\rho}(n)q_i$$  \hspace{1cm} (20)

According to the speed and acceleration of the hoisting port loading and unloading machinery in motion, combined with the flexible drive analysis method, the load distribution model between the connecting rods of the port loading and unloading machinery is constructed, and the load transfer mechanism bearing mechanics model of the port loading and unloading machinery is designed to improve the intelligent control ability of the port loading and unloading machinery.

**Optimal Design of the Control Law of Port Loading and Unloading Machinery**

Based on the analysis of the bearing capacity of the load transfer mechanism of the port loading and unloading machine, the control law optimization design of the port loading and unloading machine is carried out on the basis of the analysis of the bearing capacity of the load transfer mechanism of the port loading and unloading machine, the invention provides a port loading and unloading machinery intelligent control technology based on load transfer mechanism loading and end posture mechanical parameter adjustment (Alfaro and Villanueva, 2013), and the load transfer control capability of the port loading and unloading machinery is improved. The parameter identification of the load transfer mechanism model of the port loading and unloading machine is carried out, and the inverse Jacobian matrix of the loading moment is obtained as follows:

$$i^{-1} T = \begin{bmatrix}
    c \theta_i & -s \theta_i & 0 & a_{i,j-1} \\
    s \theta_i c \alpha_{j-1} & c \theta_i c \alpha_{j-1} - s \alpha_{j-1} - d \alpha_{j-1} & c \alpha_{j-1} & d \alpha_{j-1} \\
    s \theta_i s \alpha_{j-1} & c \theta_i s \alpha_{j-1} & c \alpha_{j-1} & 0 \\
    0 & 0 & 0 & 1
\end{bmatrix}$$  \hspace{1cm} (21)

In the formula, \(s\) denotes the sine of the load transfer mechanism at the angle \(\theta\), and \(c\) denotes the cosine of the angle \(\theta\). Under continuous driving, the disturbance torque of port loading and unloading machinery is \(\omega(k)\), in the 6-degree-of-freedom space model, and the axial pressure transformation matrix of port loading and unloading machinery is obtained as:

$$\delta^T = \begin{bmatrix}
    T_1^T & T_2^T & T_3^T & T_4^T & T_5^T & T_6^T
\end{bmatrix}$$  \hspace{1cm} (22)

The pressure-bearing control identification parameter of the port loading and unloading machine is analyzed as the parameter model of the port loading and unloading machinery is:

$$\varphi_{\rho}(n)q_i =$$

$$P(k) = \sum_{j} u_j(k)P^j(k) +$$

$$\sum_{j} \left\{ P(k) - x(k) \right\}$$  \hspace{1cm} (23)

The adaptive adjustment coefficient of loading force is introduced, and the driving equation of bearing capacity of port loading and unloading machinery is obtained as follows:

$$\dot{x}(k) = \sum_{j} x(k) u_j(k)$$  \hspace{1cm} (24)

$$P(k) = \sum_{j} u_j(k)(P^j(k) + \sum_{j} \left\{ x(k) - x(k) \right\})$$  \hspace{1cm} (25)

Neglecting the influence of the dynamics of the port loading and unloading machinery and the dynamic characteristics of the motion control system, the pressure-bearing mechanical control of the port loading and unloading machinery is carried out in combination with the feedback compensation method, and the mechanical space distribution function of the port loading and unloading machinery is obtained as follows:

$$\sum_{j} \left\{ x(k) - x(k) \right\} =$$

$$\sum_{j} \left\{ x(k) - x(k) \right\}$$  \hspace{1cm} (26)

The control law of port loading and unloading machinery is constructed by finite element dynamic analysis method. The joint load force/torque control term is the characteristic quantity of \(\{W_{j=1}\}\), controller parameters is:

$$\sum_{j} \left\{ x(k) - x(k) \right\}$$  \hspace{1cm} (27)

The Lyapunov function for the construction of port loading and unloading machinery is expressed as follows:

$$V_2 = V_1 + \frac{1}{2} \dot{e}_2^2$$  \hspace{1cm} (28)

Derivation of the Lyapunov function is:

$$\dot{V}_2 = \dot{V}_1 + e_1 \dot{e}_2$$  \hspace{1cm} (29)

According to the principle of Lyapunov stability, the stability of the control law designed in this paper is obtained. By introducing the loading force vector of port loading and unloading machinery, the steady state error compensation term of port loading and unloading machinery is obtained as follows:

$$\delta_2 = -\hat{\delta}(\alpha V^2 + mg \sin \theta + V \omega_1) + m \cos \theta \omega_1 +$$

$$c \dot{e}_1 + \lambda \dot{e}_1 - c \dot{e}_2 - c \dot{e}_1 \dot{e}_2 - \dot{\theta}$$  \hspace{1cm} (30)
Thus, the output time delay compensation model of port loading and unloading machinery is established, and the automatic control optimization of frequency conversion speed regulation of port loading and unloading machinery is realized (Xia et al., 2013).

RESULTS
In order to test the performance of the method in the automatic control of the frequency conversion of the port loading and unloading machinery, the simulation experiment is carried out, port handling machinery is shown in Figure 2.

The LSM303DLH port loading and unloading machine is used as the research object, the maximum power output is set to 2400 KW, and the torque inertia parameter of the port loading and unloading machine is set to 12 rad/ s. The sampling period for the output voltage of the port loading and unloading machine is 0.25 s, and the other variable parameters are set in Table 1.

Table 1. Design of control parameters for port loading and unloading machinery.

<table>
<thead>
<tr>
<th>Design Variable</th>
<th>Parameter Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Np, Nc</td>
<td>15</td>
</tr>
<tr>
<td>f /kHz</td>
<td>16</td>
</tr>
<tr>
<td>Cfc /F</td>
<td>0.42</td>
</tr>
<tr>
<td>Vc /V</td>
<td>23</td>
</tr>
<tr>
<td>Vs /V</td>
<td>24</td>
</tr>
<tr>
<td>Rps, Rs</td>
<td>0.0562</td>
</tr>
</tbody>
</table>

According to the above-mentioned parameter setting, the automatic control simulation of frequency conversion and speed regulation of the port loading and unloading machinery is carried out, the load intensity gain of the port loading and unloading machine and the variable frequency speed regulation control characteristic are tested, and the control performance curve is obtained as shown in Figure 3 and Figure 4.

DISCUSSION
Figure 3 shows that the frequency conversion speed regulation automatic control of port loading and unloading machinery is carried out by using this method, and the output power gain is large. Figure 4 shows that through the frequency conversion speed regulation control of port loading and unloading machinery, the output stability of port loading and unloading machinery is better, and the tracking accuracy of speed regulation torque is high, which improves the steady state control efficiency of port loading and unloading machinery.

CONCLUSION
In the process of power generation of port loading and unloading machinery, due to the influence of torque difference output of frequency conversion speed regulation, the output voltage stability of port loading and unloading machinery is not good, so it is necessary to carry out automatic control of speed regulation. In this paper, the automatic control technology of frequency conversion speed regulation of port loading and unloading machinery based on real time information adaptive regulation is proposed, and the constraint parameter model of frequency conversion speed regulation of port loading and unloading machinery is constructed. The control objective function is constructed with the parameters such as rotating inertia moment, load strength, steady state power gain and load of the manipulator. Combined with the real time information feedback adjustment compensation method, the speed regulation error of port loading and unloading machinery is suppressed. The output time delay compensation model of port loading and unloading machinery.
machinery is established, and the automatic control optimization of frequency conversion speed regulation of port loading and unloading machinery is realized. It is found that the performance of frequency conversion speed regulation control of port loading and unloading machinery is better, the output stability and speed regulation torque tracking performance are strong, and the voltage stabilization characteristics and load strength gain of port loading and unloading machinery are improved.

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