Research on Control Algorithm of Electric Linear Loading System

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Abstract. In the design and application of Electric Linear Loading System (ELLS), a high-precision torque control is a major challenge. Existing solutions like direct inverse control, adaptive control and fuzzy control can achieve certain control performance, but the high cost of high-precision control sometimes cannot meet practical requirements.

This paper mainly focused on the problems of low loading accuracy in electric linear loading system, which mainly includes the servo position disturbance and flow nonlinearity. Wang[4] show that the proposed control algorithm is feasible, which has a certain engineering reference value.

1 Introduction

As shown in Fig.1, the host computer PC sends a sine protocol to control the output torque of the motor. The current loop proportional control is introduced, which improves the response speed of the load motor; In order to improve the loading accuracy and reduce the extra force, a parallel algorithm based on fuzzy PID and repetitive controller is designed in the force loop. The fuzzy controller improves the dynamic performance and anti-interference ability of the system, but nearly eliminates the load dependence of the system. R Ghazali[6] adopts a robust controller based on sliding mode control, and a high-performance ELLS system can be designed using discrete-time controller, sensor, multi-degree-of-freedom (DOF) is used to turn the DSMC, which mainly consists of load motor, motor driver, encoder, sensor, and computer, as shown in Fig.2.

2 System structure

The successful development of ELLS can not only test device used to test the performance of linear servo, but also improve test efficiency and accuracy significantly. At present, domestic and foreign scholars have proposed a large number of control methods to improve the performance of ELLS. Ni[2] proposed a method based on feedforward feedback and neural network to suppress the extra disturbance and flow nonlinearity. Wang[4] proposed a feedback linearization method which reduces the extra torque and improve the stability of the closed control loop. The repetitive controller periodically adjusts the deviation, which reduces the system response and tracking error.

The simulation results show that the composite control algorithm is feasible, which has a certain engineering reference value. The combination of the two controller results in good dynamic and static characteristics. The simulation results show that the composite control algorithm is feasible, which has a certain engineering reference value. The combination of the two controller results in good dynamic and static characteristics.
3 System mathematical model

3.1 Load motor model

\[ i_q = R_i i_q + L_s i_q \frac{dt}{dt} + P \varphi W_m \]
\[ J_l \frac{d \varphi}{dt} = T_e = T_r \]

where:
- \( i_q \): motor current
- \( R_i \): motor resistance
- \( L_s \): motor inductance
- \( \varphi \): motor angular displacement
- \( W_m \): motor back EMF
- \( J_l \): motor's moment of inertia
- \( T_e \): motor's back EMF coefficient
- \( T_r \): mechanical angular displacement

3.2 Intermediate transformation model

\[ T_e = K_{em} \varphi \]

where:
- \( K_{em} \): motor's back EMF coefficient

3.3 Torque and force relationship of ball screw

\[ F = \frac{T_s}{r} \]

where:
- \( F \): linear load force
- \( T_s \): torque of ball screw
- \( r \): ball screw radius

4 Composite controller designer

4.1 Current loop design

Figure 1. System control open loop control block diagram

Figure 2. Motor simplified model
Figure 3.

\[ G_{iq}(s) = \frac{i_q}{L_s R_i + G_{iq}} \]

Figure 5.

4.2 Force controller design

For input and output linear scale transformation, the corresponding universe of discourse range. In the actual application, the quantization factor \((Q)\) and the universe of output variable \(U\) is defined as follows:

\[ (Q) = \{\text{NB, NM, NS, ZO, PS, PM, PB}\} \]

\[ U = \{0, 1, 2, 3\} \]

4.2.1 Fuzzy PID Controller Design

According to the experience of many people, fuzzy rules are summarized after a lot of people's experiments and work experience. The fuzzy rules of the system are:

- \(IF \text{ error} = 0 \text{ and error rate} = 0 \rightarrow \text{Fuzzy output} = 0\)
- \(IF \text{ error} = 0 \text{ and error rate} = 1 \rightarrow \text{Fuzzy output} = 1\)
- \(IF \text{ error} = 1 \text{ and error rate} = 1 \rightarrow \text{Fuzzy output} = 2\)

The gain adjusts its fuzzy control rules according to the universe of discourse. The corresponding universe of discourse range. In the actual application, the quantization factor \((Q)\) and the universe of output variable \(U\) is defined as follows:

For the fuzzy controller input error \(e\), error rate of change \(ec\) and output \(U\) are divided into seven fuzzy subsets: NB, NM, NS, ZO, PS, PM, PB. The block diagram of the concrete structure is shown in Fig. 5.

The input \(dt_0\) and the output of the system \(q_a\) should be greater. To avoid the effect of the output of the system becoming small.

The closed-loop transfer function consists of a first-order lag and phase lag. Considering the problems of large load steady-state error, large load steady-state error, etc., the input \(dt_0\) and the output of the system \(q_a\) should be zero. From (9), the proportional gain is far greater than the gain is, the smaller the static deviation is. From (9), the static deviation of the control system commonly uses the method of self-tuning.

The initial parameters of PID uses zero method of tuning.

Based on the proportional control, and the control block diagram is shown in Fig. 3. The input of the system is \(e\), error rate of change \(ec\) and output \(U\), \(U\) are divided into seven fuzzy subsets: NB, NM, NS, ZO, PS, PM, PB. The membership functions adopt triangular functions with the corresponding universe of discourse range.

When the ELLS is in normal operation, the error \(e\) is relatively small. The current loop controller can be designed and the transfer function is:

\[ G(S) = G(S)(L(S)) \]

When the ELLS is abnormal, the error \(e\) is large. The current loop controller can be designed and the transfer function is:

\[ G(S) = G(S)(L(S)) \]

For current loop controller, it can be seen from the bode diagram of the system, the initial parameters of PID uses zero method of tuning. The closed-loop gain to evaluate the dynamic characteristics. The closed-loop feedback of output force and proposes the repetitive control. The block diagram of parallel fuzzy PID and repetitive control. The input \(dt_0\) and the output of the system \(q_a\) should be zero. From (9), the proportional gain is far greater than the gain is, the smaller the static deviation is. From (9), the static deviation of the control system commonly uses the method of self-tuning.

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The selection of the membership function of the fuzzy principle and can be used to get the actual control volume.

Consider the repetitive control system. The error $e(S)$ of the system is close to zero. From Euler's equation (13), we can see that $|1+C(S)P(S)| \leq 1$.

From (14), we get the system's characteristic equation:

$$G(S) = \frac{Q(S)}{1 + C(S)P(S)}$$

The (13) can be transformed into:

$$e(S) = -[1 - G(S)]Q(S)e_0$$

where $e(S)$ is the error of the system and $Q(S)e_0$ is the interference signal. Therefore,

$$Q(S)e_0 = 1 - G(S)$$

and the interference signal is:

$$e(S) = \frac{Q(S)}{1 + C(S)P(S)}e_0$$

$$\Delta = \frac{\sum_{i=1}^{n} \mu_i}{\sum_{j=1}^{m} \mu_j}$$

4.2.2 Repetitive controller design

The design of the repetitive controller is based on the disturbance of the load [10]. Figure 6 shows the repetitive amplitude attenuation and phase compensation relationship between the repetitive control system error $e$ and the input signal $x$.

Figure 6. $\Delta \frac{\Delta}{\Delta} \Delta \frac{\Delta}{\Delta}$, the repetitive control system error

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Figure 8. The control system structure diagram

5 System simulation

Table 1. System parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$K_c$</td>
<td>V/Krpm</td>
</tr>
<tr>
<td>$J_s$</td>
<td>kgm</td>
</tr>
<tr>
<td>$B_m$</td>
<td>Nm/rod</td>
</tr>
<tr>
<td>$J_e$</td>
<td>Kgm</td>
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</tr>
<tr>
<td>$P$</td>
<td>nm</td>
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</tbody>
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5.1 Linear load force tracking performance

Figure 9. Two kinds of control load force error curve

Figure 10. Fig 8 is a composite control tracking curve, and phase, PID control, there is a large deviation both in amplitude and phase, so EEQ

Figure 11. Excess force suppression ability
The actuator follows the specified sinusoidal path acted as the disturbance input. In order to compare the control effects under different controllers, traditional PID control and redundant force suppression simulation under compound control are carried out. Fig. 12 shows that when the steering gear moves at 1mm/Hz, the compound control compared with traditional PID extra force reduces from 150N to 60N. Fig. 13 shows that when the steering gear moves at 1mm/3Hz, the compound control reduces 380N to 110N compared with the traditional PID, and as time goes by, the effect of restrain force is getting better and better.

6 Conclusion

ELS is a key part in the design of electric load simulator. Compared with the torque servo system, ELS has strong coupling and many nonlinear factors. In this paper, propose a two-loop control structure of current loop and force loop closed-loop feedback. Current loop is controlled by Proportional control, which improves the current response and steady-state error. The force loop uses the parallel method of fuzzy PID and repetitive control, which not only improves the accuracy of the loading force, but also reduces the steady-state error. The simulation shows that the control method is very good at tracking servo capability and suppressing excess force in low frequency.

References