Research On Computer Load Simulation Algorithm Using Dynamic Damping Compensation of Bench

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Abstract. According to the load simulation algorithm structure of hardware-in-the-loop test, this paper proposes a dynamic damping compensation inverse model control algorithm based on the system transfer model of two classic load simulation algorithms. The dynamic damping compensation algorithm and the classical load simulation algorithms are compared and analyzed in online HIL testing to show the control effect. The experimental results show that the proposed compensation algorithm can achieve the dynamic response of the bench test well, and improve the accuracy and robustness of the bench test.

Keywords: Load simulation algorithm, HIL test, parameter identification.

1. Introduction

The semi-physical simulation test bench aims to carry out the research on the dynamic performance of the automobile while ensuring the economy and efficiency of the research work [1]. In order to present the working performance of the test-bench control algorithm, and at the same time, meet the real-time and robust demand of the hardware-in-the-loop experiment, the load simulation accuracy of the test-bench must be guaranteed. The load simulation algorithm is the key to realize the HIL test under dynamic driving conditions [3]. The classic load simulation algorithms include PI algorithm (PIA), torque feedforward algorithm (FFA), inverse model algorithm (IMA) and so on [3], as shown in Figure 1, Figure 2. and Figure 3.

In Figure1., $G_{t, eq}(s)$ is the PI controller just like speed follower. Under this algorithm, the dynamometer works in speed mode, and the drive motor works in torque mode. This PI control method can simulate vehicle’s wheel load to a certain extent. Because of fewer control parameters it involved,
it is less affected by experimental disturbance and delay, and has better robustness. But its dynamic response performance is not so good, and cannot meet the requirements of the high-frequency speed changes [4].

Feedforward torque algorithm, shown in Figure 2, can improve the dynamic performance better than PI algorithm by adding a torque feedforward signal. In FFA, both the drive motor and the dynamometer are all working in torque mode. The system actual output torque is fed forward, and the disturbance term in the system will be reduced, and the dynamic performance of the system will be improved accordingly [5].

![Figure 3. Inverse model algorithm](image)

The inverse model algorithm, shown in Figure 3, needs to substitute the torque value that is measured by the torque sensor into the algorithm control link. That is, the compensation function $G_C(s)$ is obtained from experiment. Here, the estimated value $\tilde{G}_{\text{est}}^1(s)$ is defined, which determines the dynamic response capability of the IMA. IMA simulation accuracy became better because of the improvement of modeling accuracy. The IMA compensates for test-bench damping and inertia moment to make it have better dynamic performance [6].

In this paper, the load simulation will be calculated in part 2. Then, the IMA and its algorithm improvement method is researched, and the dynamic damping compensation algorithm will be put forward in part 3. Finally, part 4 will draw a conclusion about the control effect of the DC-IMA by experiment comparing.

Load simulation

In this paper, the output shaft of the vehicle drive motor is selected as load simulation point. In the load simulation test-bench, its coupling stiffness, rotation resistance, damping and other interference factors are considered. And then, the torque output is controlled to make it consistent with the theoretical road load of the vehicle under established dynamic conditions.

\[
T_{out} = T_{dy} + J_{dy} \frac{dw}{dt} + B_{dy}n
\]  
(1)

Among them, $T_{out}$ is the output torque of the test-bench; $T_{dy}$ is the output torque of the dynamometer; $J_{dy}$ is the inertia moment of the dynamometer; $B_{dy}$ is the damping coefficient of the dynamometer.

The driving resistance of a vehicle mainly is divided into acceleration resistance, gradient resistance, air resistance, friction resistance and braking resistance. Without considering the road slope, we can get the follow equation.

\[
F_t = F_b + F_w + F_f + F_j
\]  
(2)

Where, $F_t$ is the total resistance of the vehicle; $F_b$ is the braking resistance; $F_w$ is the air resistance; $F_f$ is the friction resistance; $F_j$ is the acceleration resistance, the specific expressions are:
\[ F_j = m\delta \frac{1}{3.6} \frac{dv}{dt} \]  
\[ F_w = \frac{C_p A}{21.15} V^2 \]  
\[ F_f = mgf \]

Where, \( m \) is the body mass; rotation mass conversion factor \( \delta = 1.05 \); \( C_p \) is the air resistance coefficient; \( A \) is the windward area of the frontal; \( V \) is the vehicle speed.

Taking the motor speed \( w_{mt} \) as the system output and torque \( T_{mt} \) as the input, the vehicle drive transfer function can be obtained as:

\[ G_{mt}(s) = \frac{w_{mt}(s)}{T_{mt}(s)} \]  

In the HIL test bench, the modeling error of the vehicle dynamics model is ignored. If the load simulation algorithm is accurate, the motor output torque of the actual vehicle \( T_{mt}(s) \) should be equal to the output torque on the test-bench \( T_{tb}(s) \). That means, the product of the theoretical motor speed \( w_{dm}(s) \) and the vehicle inverse model should be equal to the product of the test-bench rotation speed \( w_{tb}(s) \) and the test-bench inverse model, namely, the goal of load simulation is:

\[ G_{vh}(s) = \frac{w_{tb}(s)}{T_{tb}(s)} = \frac{w_{dm}(s)}{T_{mt}(s)} \]  

2. Test bench control algorithm

(1) Bench damping Identification

Giving a step speed input to the drive motor, the corresponding torque response of test-bench is obtained, as shown in Figure 4. Under the conditions of zero input torque of the dynamometer, when the motor speed is stable, the test-bench torque response will be equal to the test-bench damping at this moment.

Test-bench torque response is shown in the Figure 5. By averaging each processed speed segment, the “torque-speed” lattice is obtained, and quadratic fitting method is used to finish the curve fitting. Before the torque response averaging, the jump torque under each speed segment of the corresponding torque response is removed because these parts will interfere the fitting result. The result is shown in Figure 6.
So, the expression of the damping-speed fitting curve is:

\[
f(x) = -3.374 \times 10^{-9} x^2 + 0.0001178x + 1.799
\]  \hspace{1cm} (8)

(2) Inertia moment Identification

The dynamic equation of motor rotation is listed as followed:

\[
J_{tb} \frac{dw}{dt} = T_{drive} - T_{load} - Bw
\]  \hspace{1cm} (9)

where, \( J_{tb} \) is the inertia moment of the test-bench; \( w \) is the angular velocity of the shaft rotation; \( T_{drive} \) is the motor input torque; \( T_{load} \) is the motor load torque; \( Bw \) is the resistance moment.

Both the drive motor and the dynamometer are worked in torque mode. A small constant input torque \( T_{drive} \) is given to the drive motor; dynamometer input torque is controlled to be 0Nm, that means, \( T_{load} \) is zero. The test-bench shaft speed is imported into the damping-speed fitting curve for interpolation calculation to obtain the real-time damping value of the test-bench. This value will make a compensation to the input torque of the drive motor. The equation (9) becomes:

\[
J_{tb} \frac{dw}{dt} = T_{drive}
\]  \hspace{1cm} (10)

The damping torque fitting curve is shown in Figure 7(a). The test-bench speed curve is shown in Figure 7(b).
According to Figure 7(b) and equation (10), the rotational inertia of the test-bench $J_{tb}$ is 0.072kg·m². By adding the dynamic damping compensation and the test-bench inertia compensation in the IMA, the dynamic compensation inverse model algorithm (DC-IMA) is put forward.

3. Experimental verification
The test-bench is a dual PMSM towing bench, which is controlled by an independent inverter. The real-time system and the test-bench are communicating and exchanging data via CAN bus. The host computer is a portable computer, which compiles the model and exchanges data with the target computer (industrial computer) through the Ethernet. After receiving the experimental model, the real-time system in the target computer completes torque closed-loop control with the test-bench, and the host computer performs the sorting and analysis of the experimental data.

![Image](test-bench.png)

**Figure 8.** test-bench

![Image](ECE+EUDC driving condition.png)

**Figure 9.** ECE+EUDC driving condition

The DC-IMA is compared with FFA in the ECE+EUDC driving cycle shown in Figure 9. The torque fluctuation and speed error are selected as indicators. The overall control effects are shown in figure 10.

![Image](Control effect comparison.png)

**Figure 10.** Control effect comparison

As can be seen from figure 10, in some time, the error control and dynamic response capabilities of the DC-IMA are better than FFA and PIA.

Now, a typical time period of the driving condition is selected to do further research. During the acceleration switching period, which is between 15.5s and 21s period, the three algorithms’ torque fluctuations and speed error are shown in Figure 11.
In the above figuration, the vehicle is decelerated from 21km/h to 15km/h and then accelerated, which is called the state switching period. In the acceleration switching period, it is obvious that the DC-IMA has better control performance in torque fluctuations. The torque fluctuations converge faster, and the speed error fluctuations are also smaller. It indicates that the DC-IMA has better dynamic control and robustness performance.

4. Conclusion

In this paper, the dynamic compensation inverse model algorithm has a better effect on the torque fluctuation control, and the dynamic compensation of the torque is realized. In the state of switching period, IMA will slightly amplify the speed error when the positive and negative acceleration changes due to the differential link. However, as for the torque control ability, due to the existence of dynamic damping compensation, DC-IMA is better than the FFA and PIA.

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